Low Loss and Compact Power Supply for Superconducting Magnet Using MERS Soft-Switching Converter

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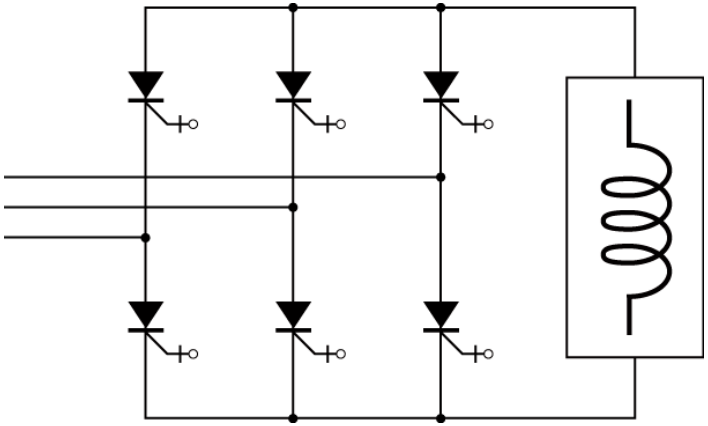
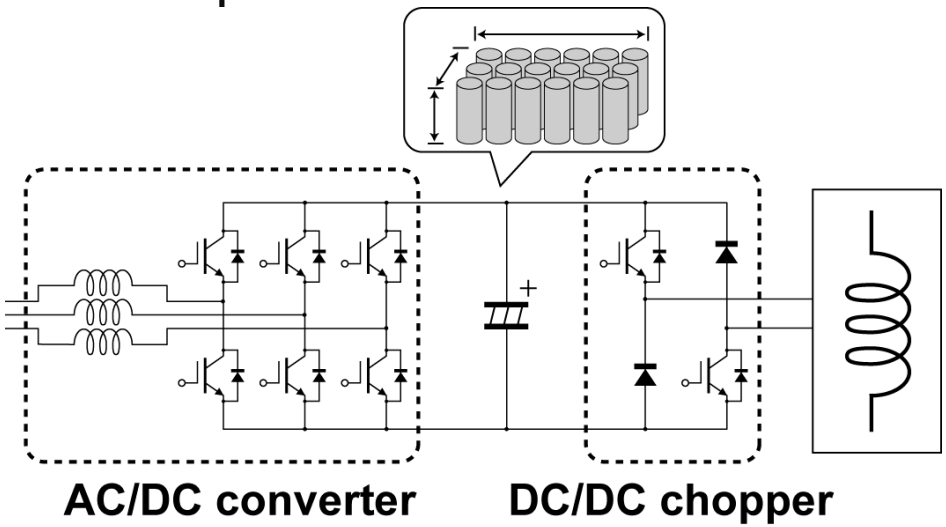
Background

- **Current Source Converter** widely used for magnet power supply.
  - ✓Good for large scale system construction
  - ✓Suitable for magnet load (Bi-directional voltage in DC side)
- **Voltage Source Converter** is widely used in industries.
  - ✓Much progress in development of IGBT, IEGT…
  - ✓Good controllability, reactive power profile (unity power factor)
  - ✗Two stage conversion needed. (AC/DC+DC/DC chopper)
  - ✗Bulky smoothing capacitor, lifetime problem



(a) Current source type



(b) Voltage source type

Proposal in this Paper

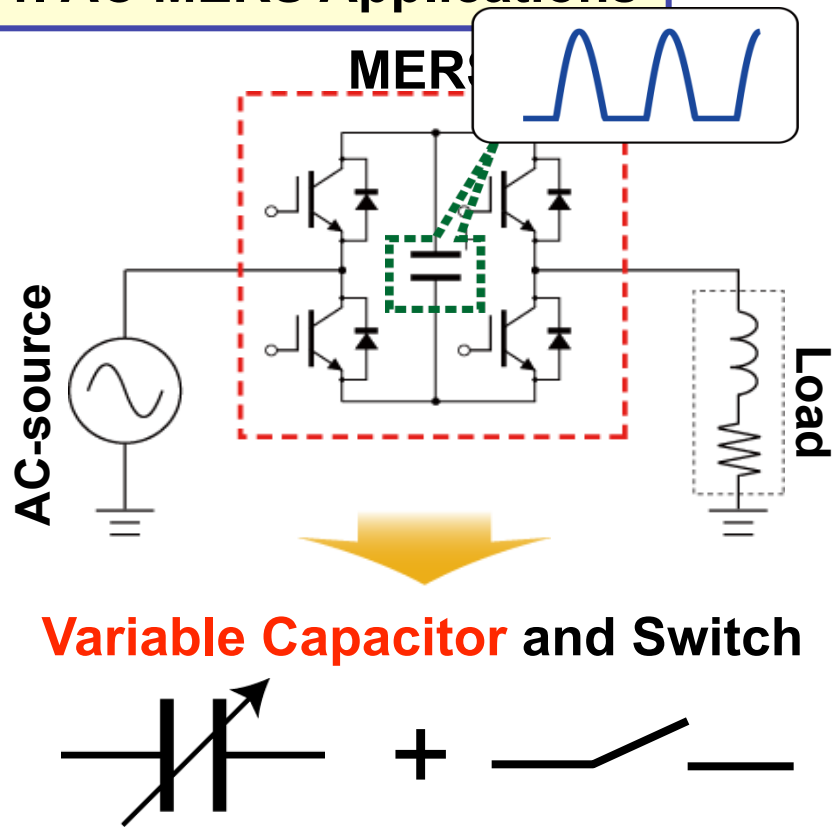
Propose a low loss and compact magnet power supply circuit with reverse conductive switches (IGBT, IEGT, MOSFET…)

Advantages:

- Direct conversion of 3-phase AC to DC current source (Magnet) without smoothing capacitor.
- Soft-switching in all semi-conductor switches,
  - ✓Low semi-conductor loss due to reduced switching losses
  - ✓High power rating device can be used with high switching frequency
- Bi-directional power flow, expected application is superconducting magnet including SMES.

MERS (Magnetic Energy Recovery Switch)

1. AC MERS Applications



Characteristics

- Small sized dc-capacitor
- **Line frequency switching**
- Transformerless
- Simple control

Advantages

- Simple design principles
- **Low losses**
- **Compact size**
- **Low EMI**
- High Robustness

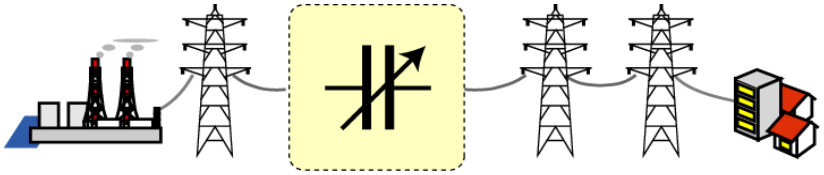
2. Soft-switching Power Conversion by MERS

Extended MERS concept for high frequency power conversion.

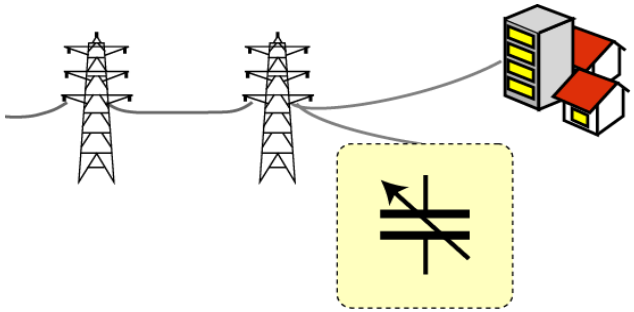
Applying “Simple” Reactive Compensation

Power Systems

Improved Transfer Capacity

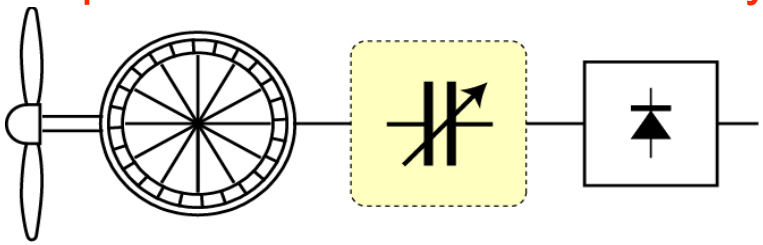


Voltage Quality Improvements



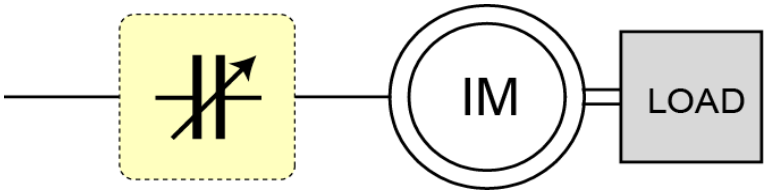
Power Generation

Improved Conversion Efficiency

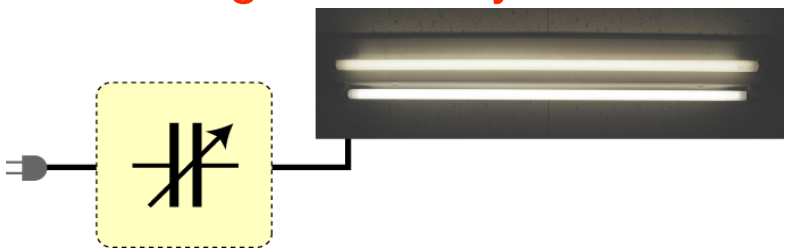


Intelligent Load Control

Voltage and Reactive Power Control

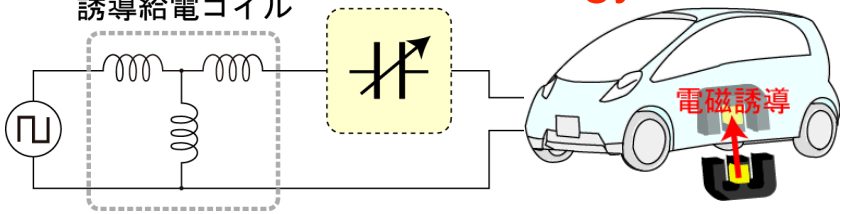


Light Intensity Control



Special Applications

Non-contact energy transfer



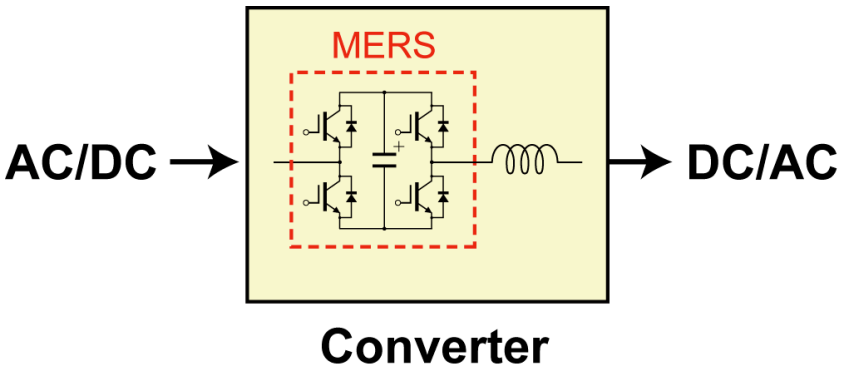
Soft-switching by MERS

1. AC MERS Applications

Series compensation as an adjustable capacitor

2. Soft-switching Power Conversion by MERS

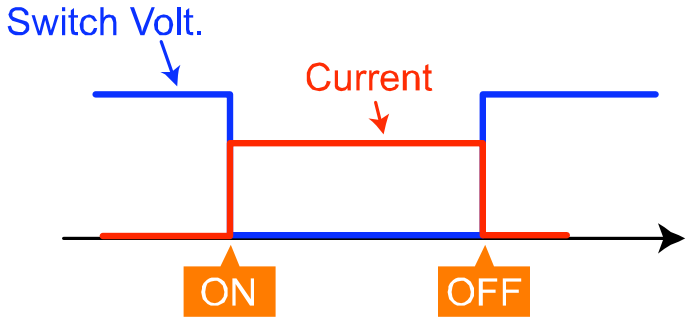
- MERS itself is used as 'Full converter'.
- Rich controllability
  - AC/DC, DC/AC, AC/AC…
  - Variable frequency



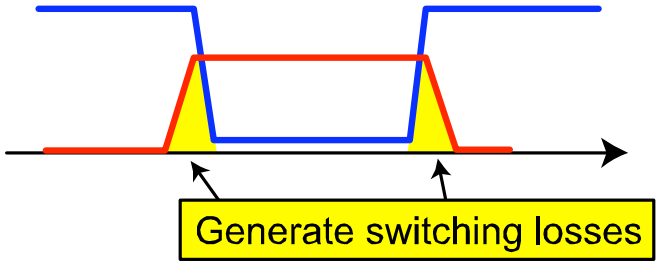
- Soft-switching and small passive components result in less heat and compact converter.

What is Soft-Switching?

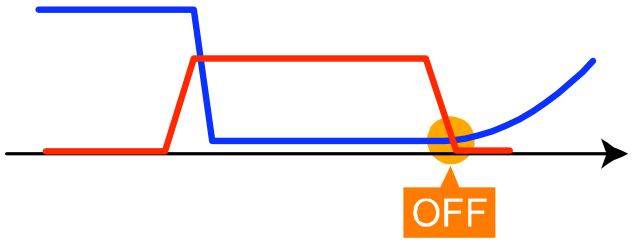
Ideal Switching



Actual Switching (Hard)

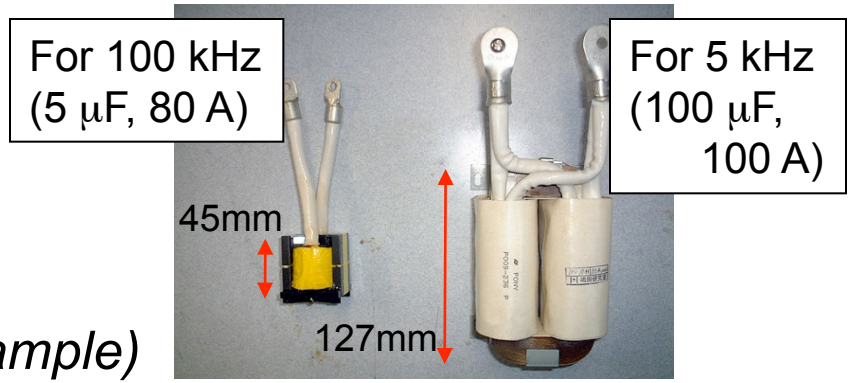


Soft-Switching (Zero-Volt)



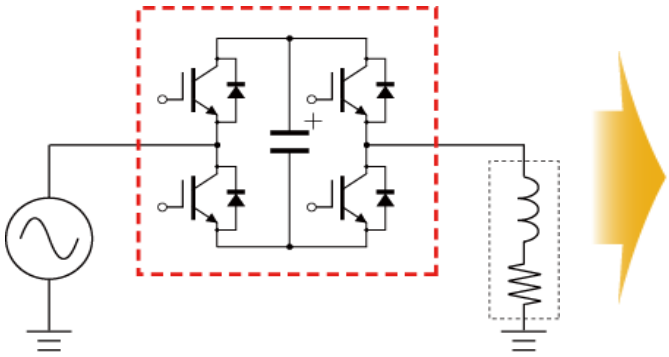
- Soft-switching can reduce switching losses, and electromagnetic emission.
- Can reduce size of passive components (inductors, filter) by increasing sw uency.

High efficiency, high power density

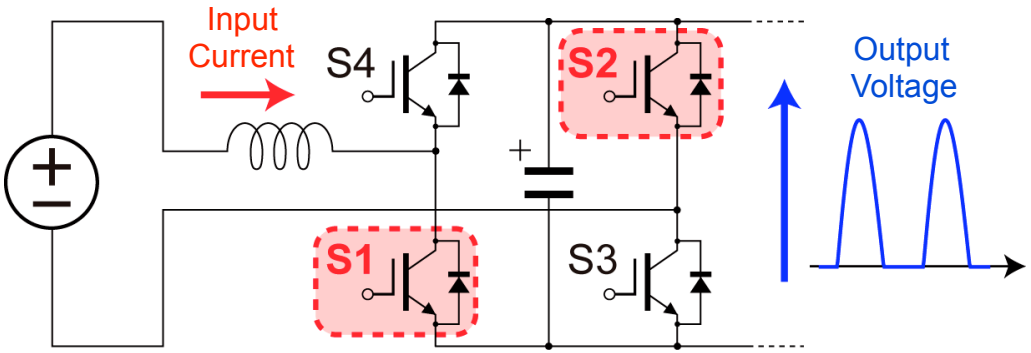


Inductor size difference (example)

Multi-Pulse Operation for More General Applications

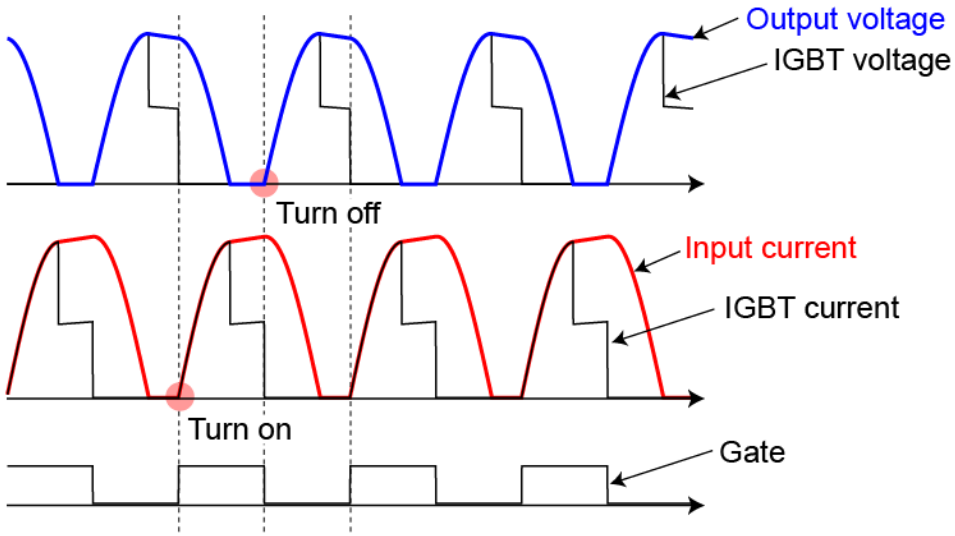


AC-MERS concept

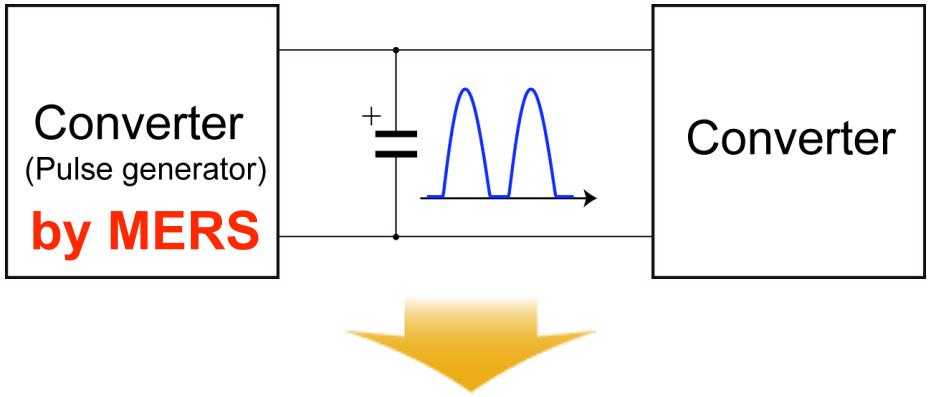


Step-up pulse voltage generator by MERS

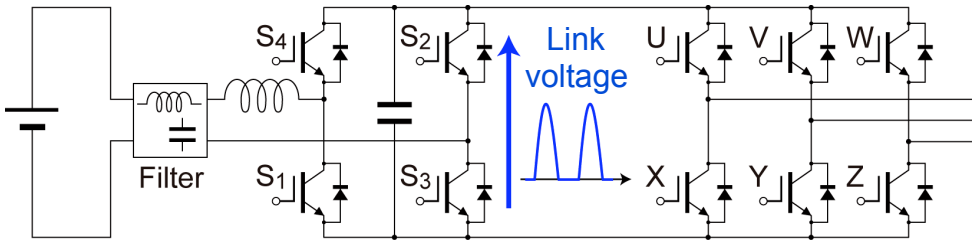
- Two switches(S1 and S2) are controlled with high frequency.
- Select small L and C to obtain discontinuous pulse input current and output voltage.
- All switches are controlled with zero voltage condition, soft-switching achieved.



MERS Pulse Link Concept

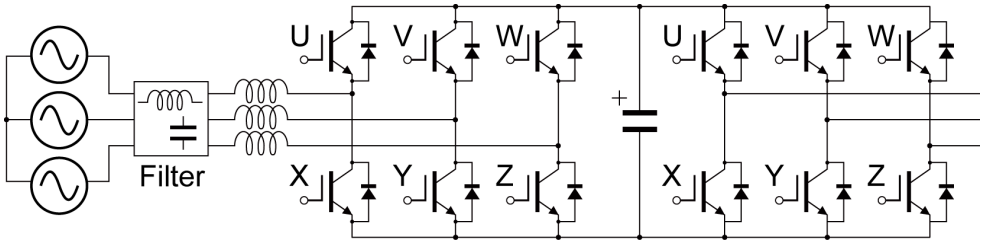


- Two converters are connected via pulse DC voltage.
- First stage generates the pulse.
- Both converters operate with soft-switching.
- No large smoothing capacitor



DC/DC step-up + DC/AC

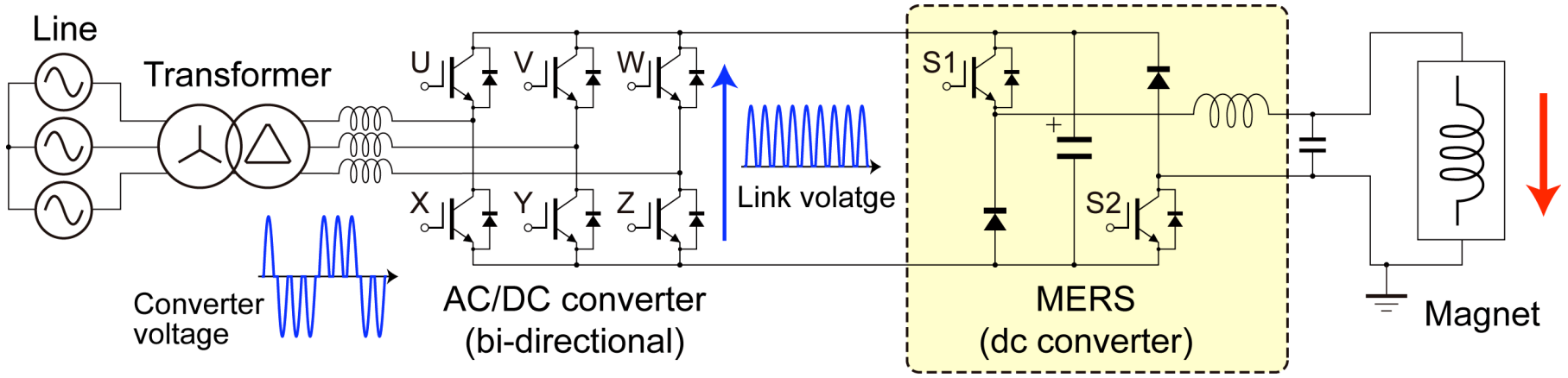
- Motor drive by DC source
  (c.f. Electric vehicle …)
- Grid connecting inverter
  (c.f. PV and fuel cell …)



AC/DC + DC/AC = direct AC/AC

- General motor drive
- Grid connecting of generator
- Improved P.F. and harmonics

MERS Pulse-Link for Magnet Power Supply

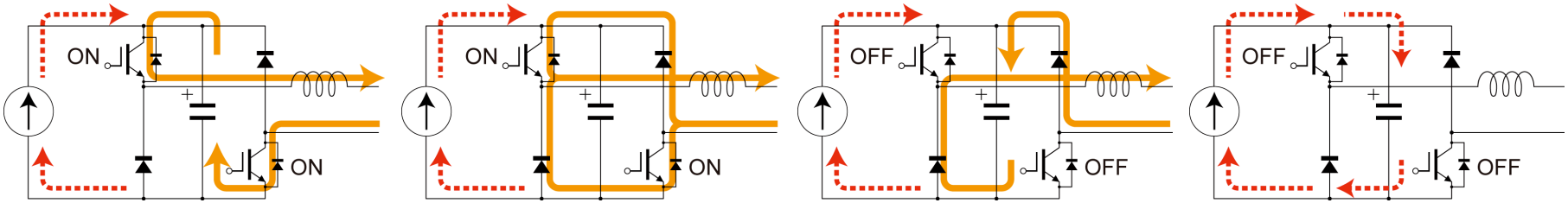


- AC/DC converter and DC voltage/current converter are connected directly.
- The DC converter based on MERS generates pulse voltage in capacitor.
- Bi-directional power flow, bipolar DC voltage output. Can be applied to superconducting magnet.

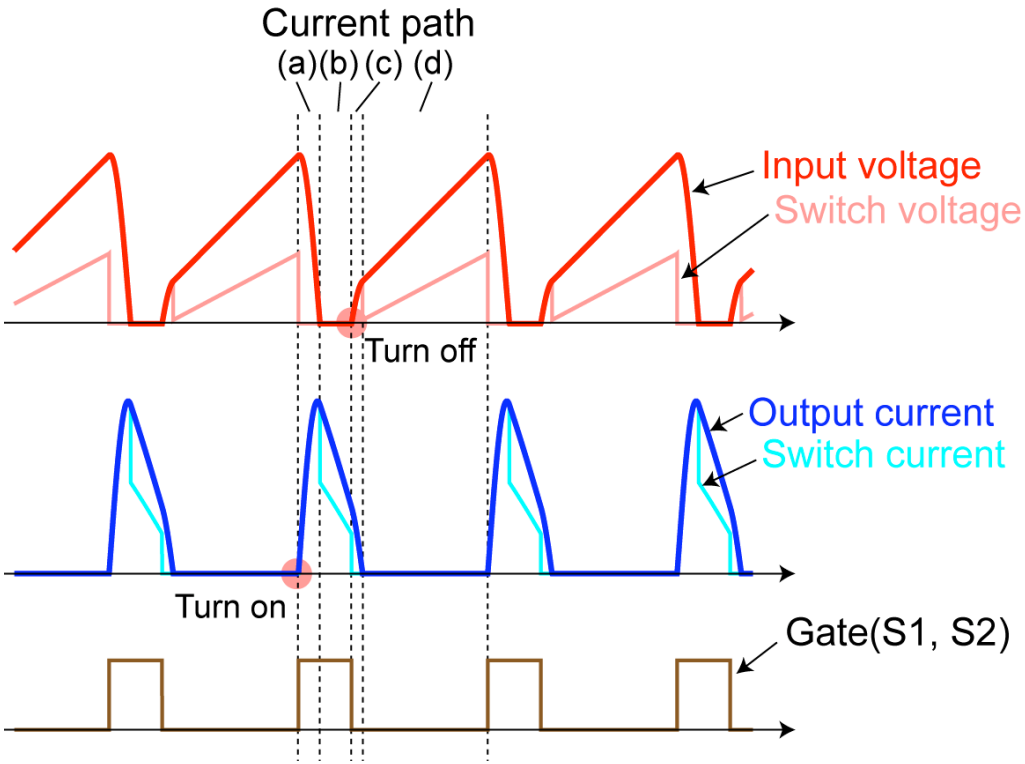
Advantages:

- No bulky smoothing capacitor (Good for power density)
- Both converter operates with soft-switching (High efficiency), higher switching frequency can be used.(Good for power density.)

Operation Principle of MERS DC converter

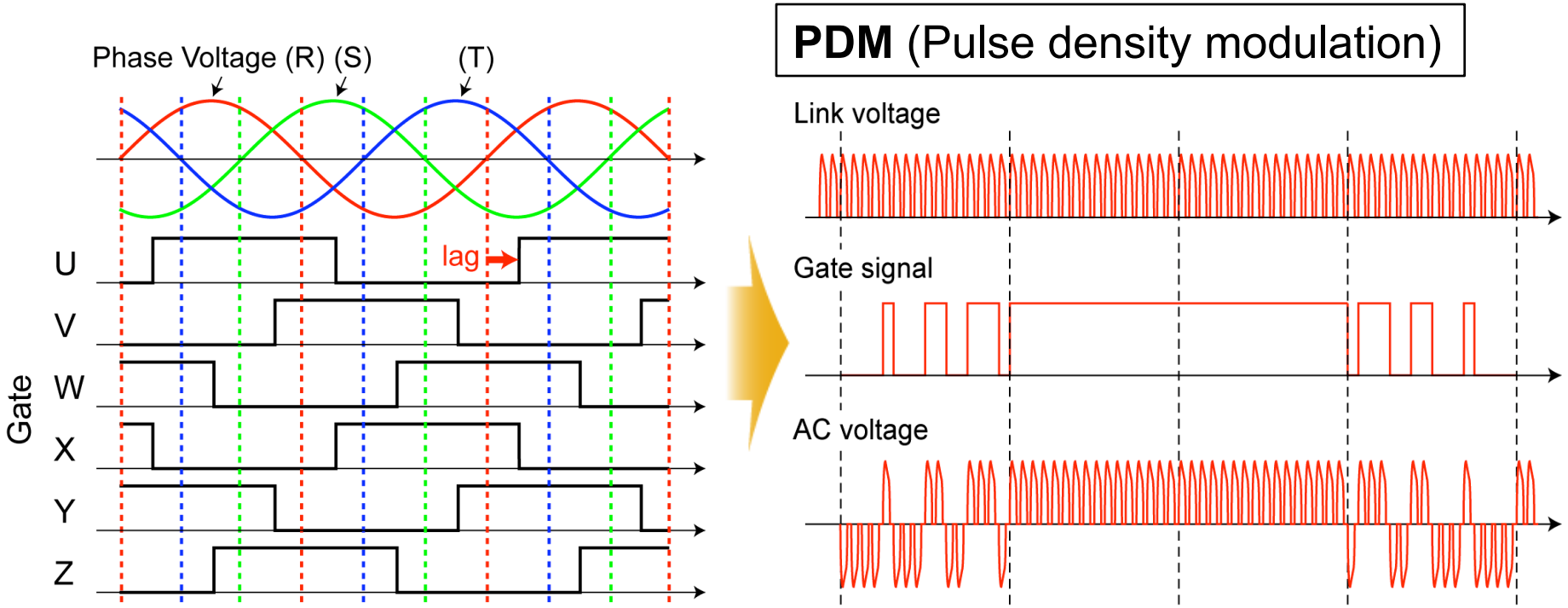


(a) Discharge (b) Parallel (c) Charge (d) Charge



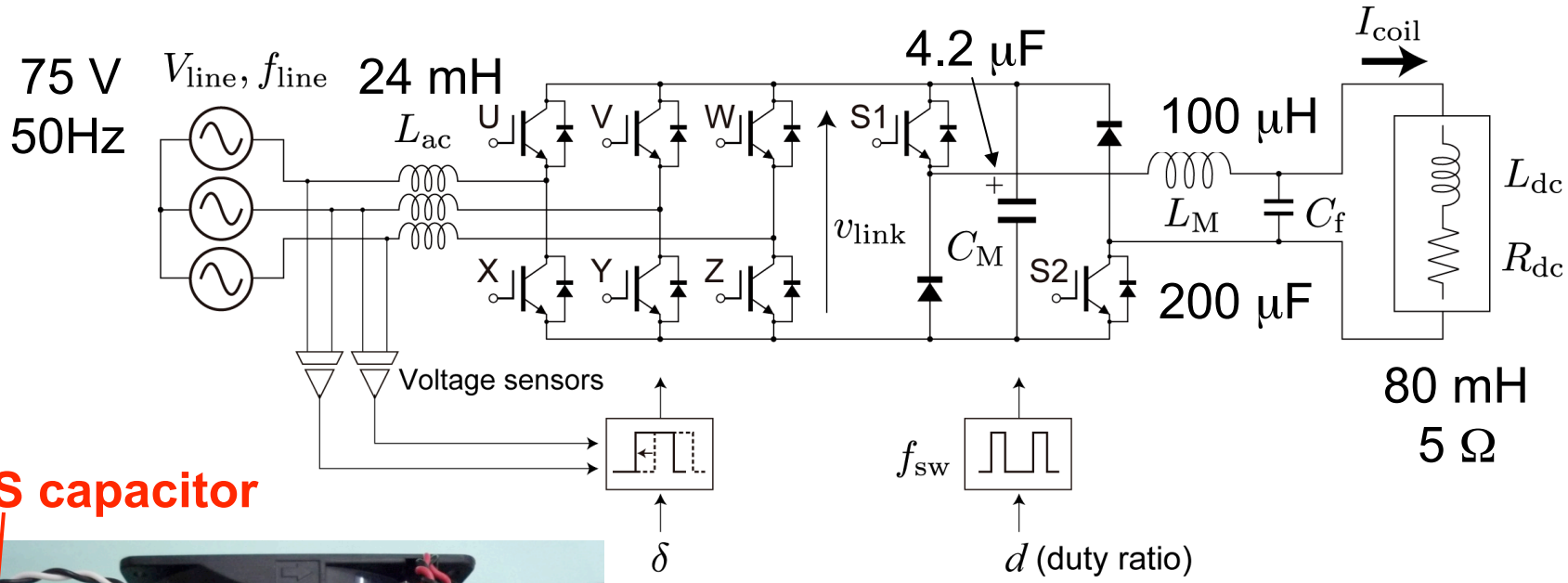
- Works as two quadrant DC chopper. (Bipolar voltage)
- Two switches are controlled simultaneously.
- Duty ratio determines power flow.
- Discontinuous input voltage and output current results in soft-switching.

Operation Principle of AC/DC converter

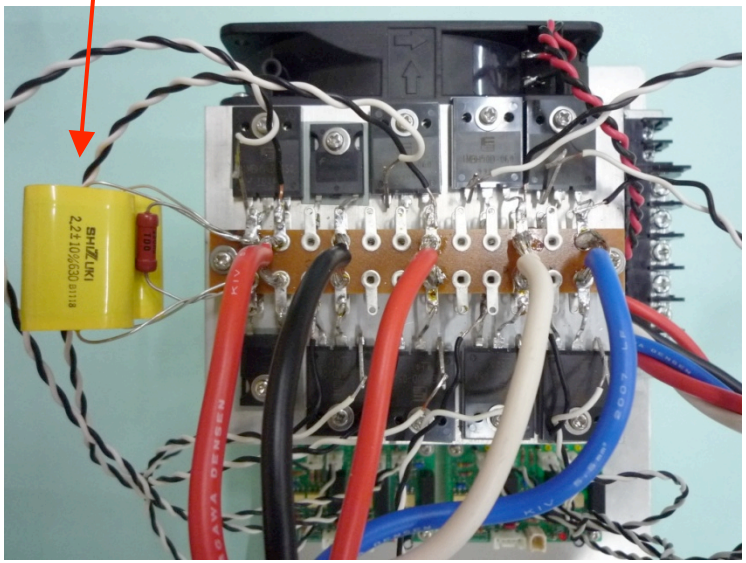


- Phase angle control based on AC grid voltage.
  - Lag gate signals results in AC to DC (Increasing magnet current)
  - Lead gate signals results in DC to AC (Decreasing magnet current)
- Both of active and reactive power can be controlled.
- Modulation can be applied to improve input current distortion.

Small Scale Experiment



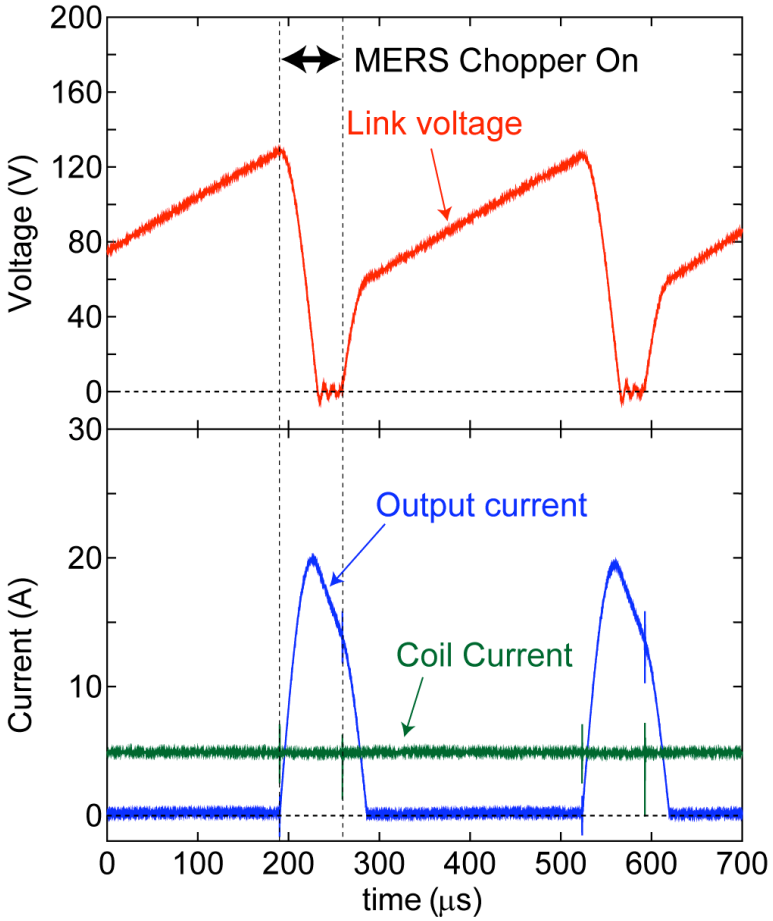
MERS capacitor



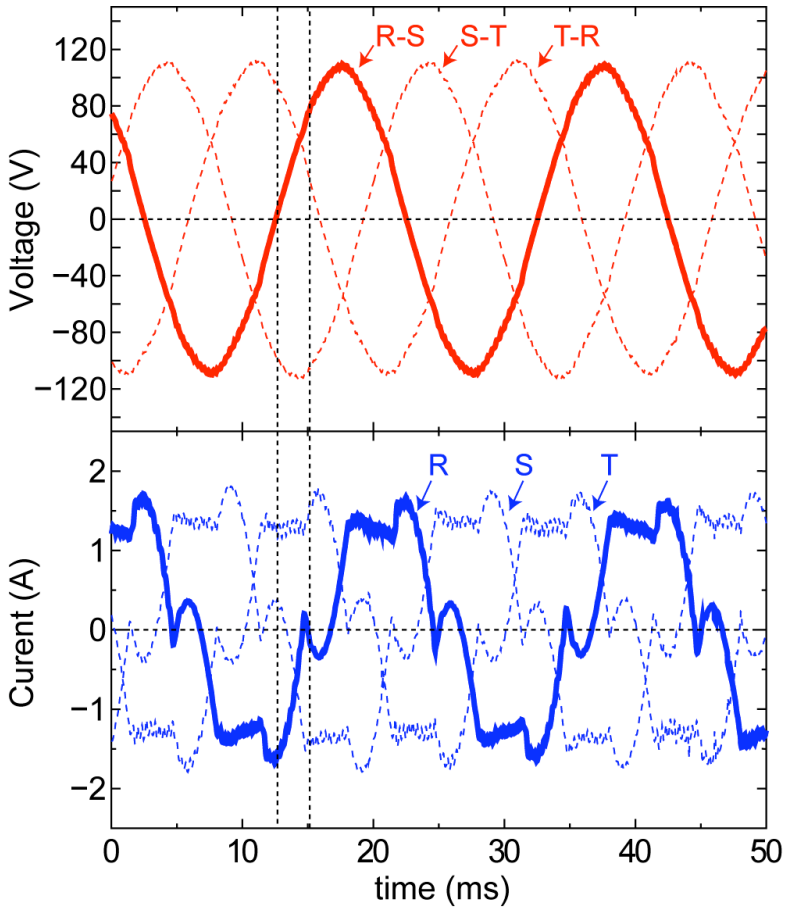
- Phase angle δ and duty ratio d were manually controlled.
- Magnet was modeled as L and R.
- Current in magnet was maintained at 5 A.
- No modulation applied in AC/DC

Experimental Waveforms

Link voltage and output current



AC line voltage and current



- Link voltage and output current were almost same as expected.
- Input current was distorted, but can be improved by further control.

Conclusions

- A new power supply circuit topology for superconducting magnet was proposed.
- Small scale experiments demonstrates the concept.
- Control principle should be established.
  - Eliminating energy storage results in link voltage fluctuation.
  - Poor voltage utilization of semi-conductors will cause low efficiency.
- Design principle should be shown.
  - At the rated operation, voltage and current rating utilization of semi-conductor switches should be maximum.
  - Design procedure to select circuit parameters for given specifications (rated magnet current, power…)

Laboratory Members with Prof. Shimada