Constant DC Current Control of Unidirectional High-Frequency Isolated Medium-Voltage AC-DC Modular Matrix Converter

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Research Background

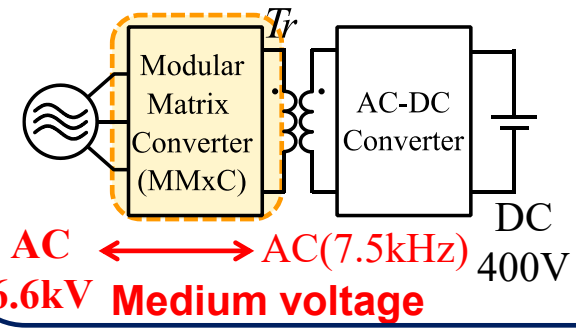
Electrical vehicles (EVs) are increasing toward carbon neutrality

Quick battery charger for high output power is being developed to reduce battery charge time for EVs

In quick battery charger,
Isolated AC-DC converter for high-power applications is used

Authors have proposed **isolated medium-voltage AC-DC converter using Modular Matrix Converter(MMxC)**

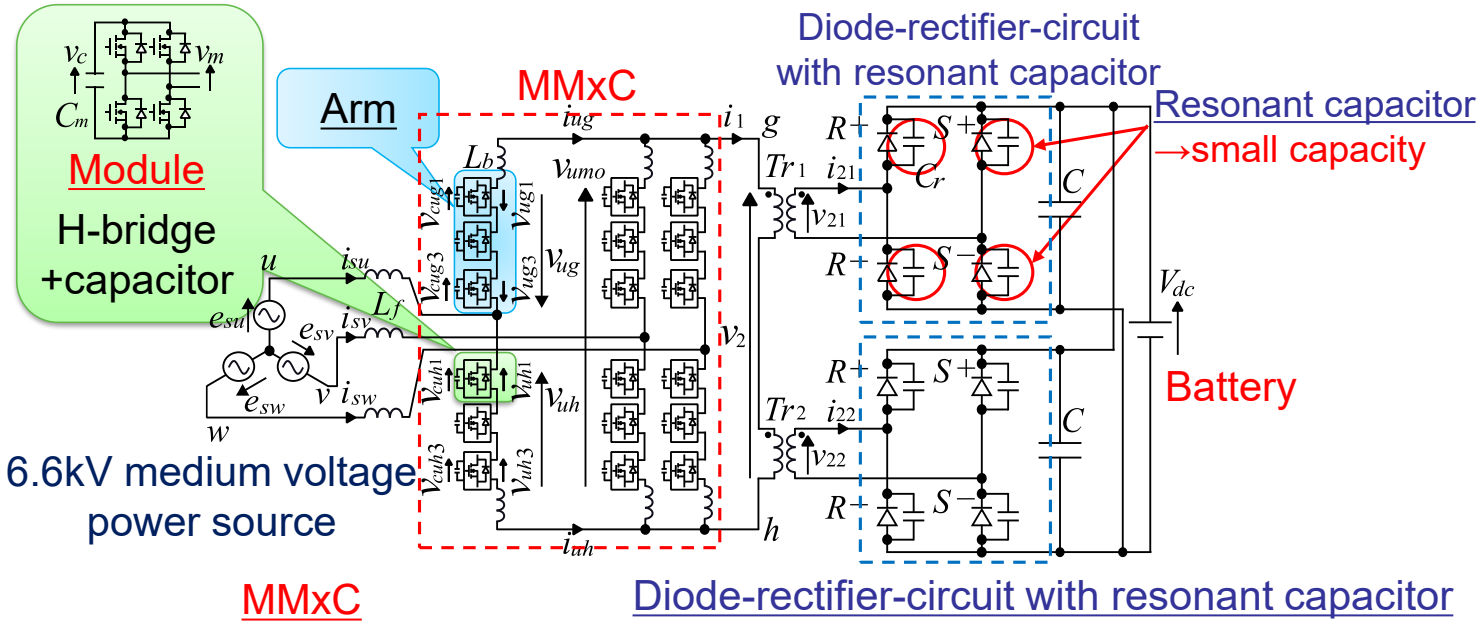
Proposed circuit



Feature

- Directly convert medium voltage power source by MMxC
- Achieve topology for high-power applications by input medium voltage
- Primary side composed by only MMxC
  →Downsized and high-efficient circuit

Circuit Configuration of Proposed Circuit



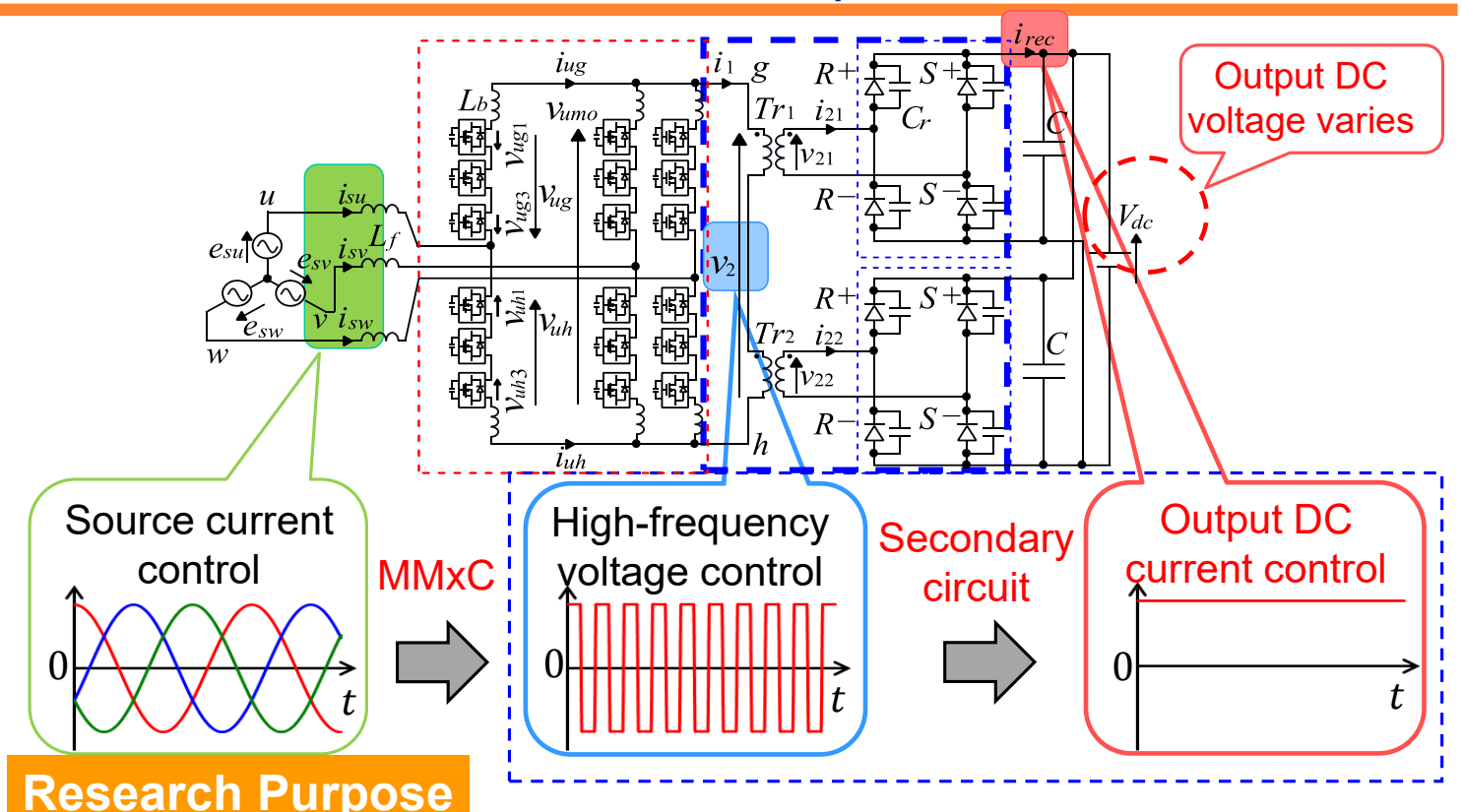
■ **Series connection of module**
Proposed circuit can achieve converter for high-power applications by input medium voltage.

■ **High total-power-factor of transformer**
by resonant capacitors
→Downsized high-frequency transformer

■ Parallel connection diode-rectifier-circuit

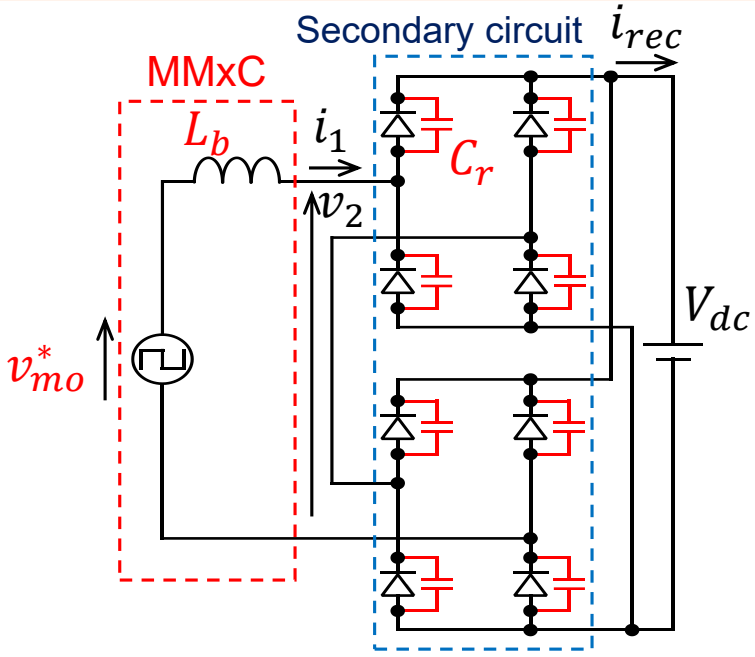
To achieve downsized and high-efficient circuit for high-power-applications

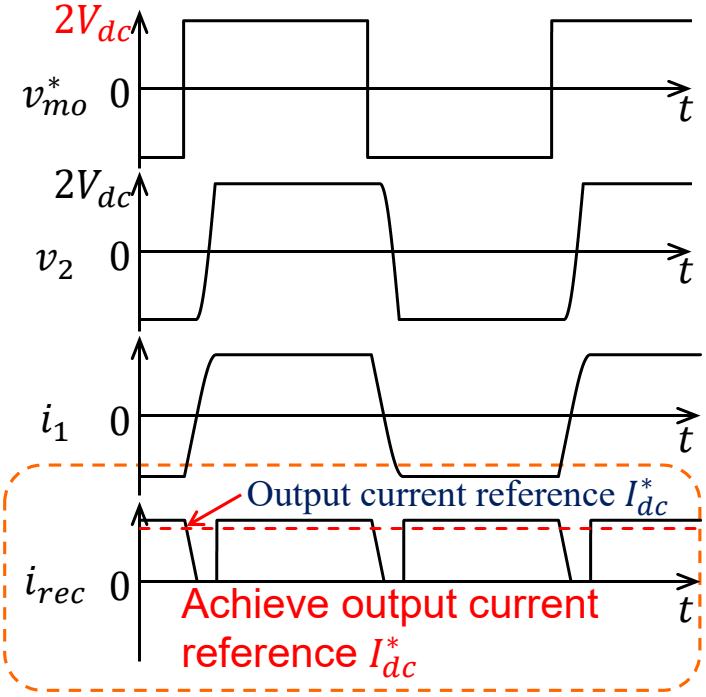
Control Method of Proposed Circuit and Research Purpose



Present output DC current control at any output DC voltage using high-frequency voltage generated by MMxC

High-Frequency Waveform at Rated Condition

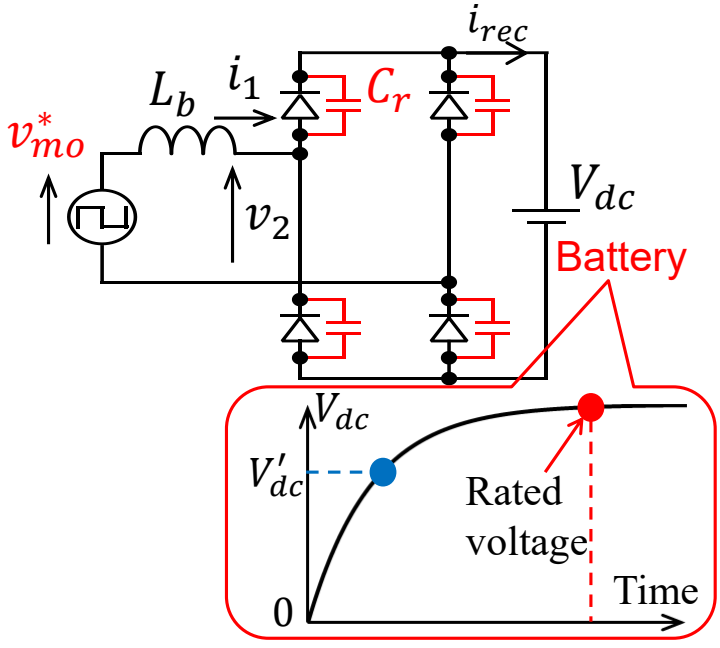




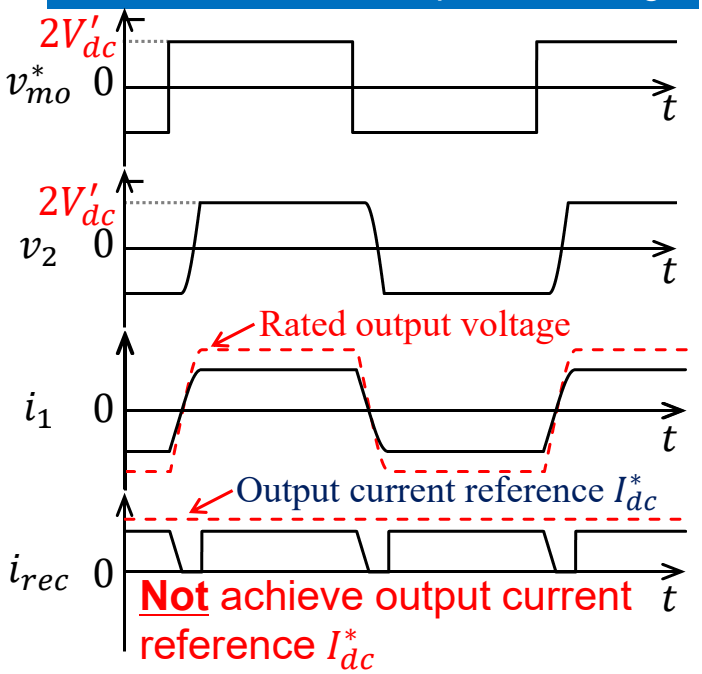
Control method and Feature

- Control amplitude of voltage v^*_{mo} equal to twice output DC voltage $2V_{dc}$
- DC current i_{rec} corresponding to DC current reference I^*_{dc} is acquired by design of resonant capacitor C_r
- High-frequency transformer is downsized by power factor correction

Research Purpose



Waveform at lower output DC voltage

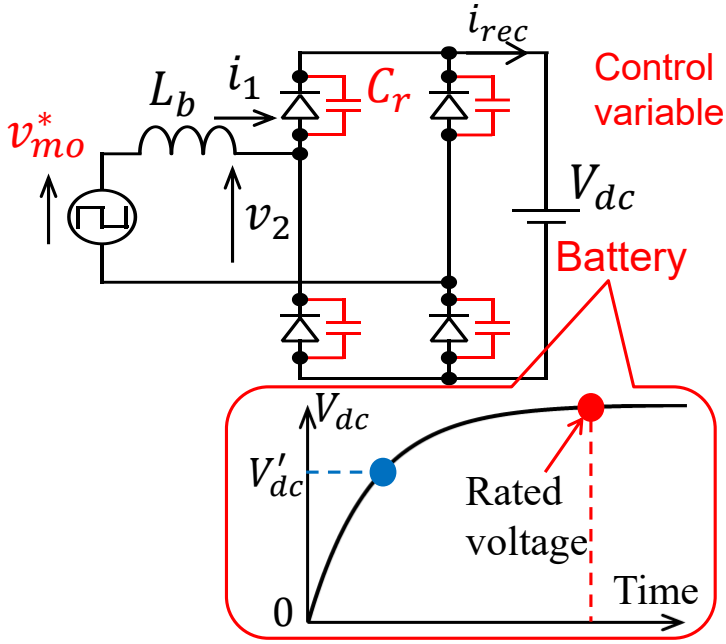


Research purpose

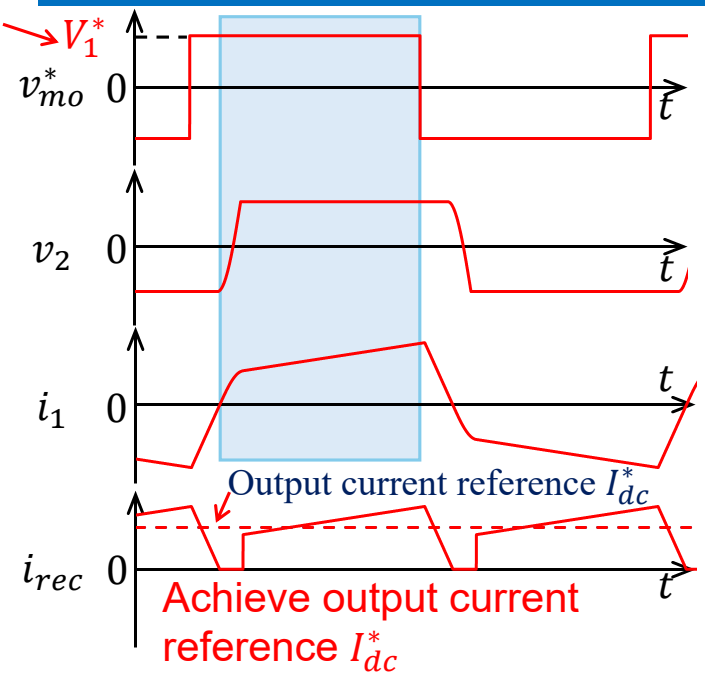
DC voltage V_{dc} varies by state of charge for battery
→Output current decreases due to low MMxC output voltage

Present output DC current control at any output DC voltage using amplitude of MMxC output voltage

Overview of Proposed Control Method



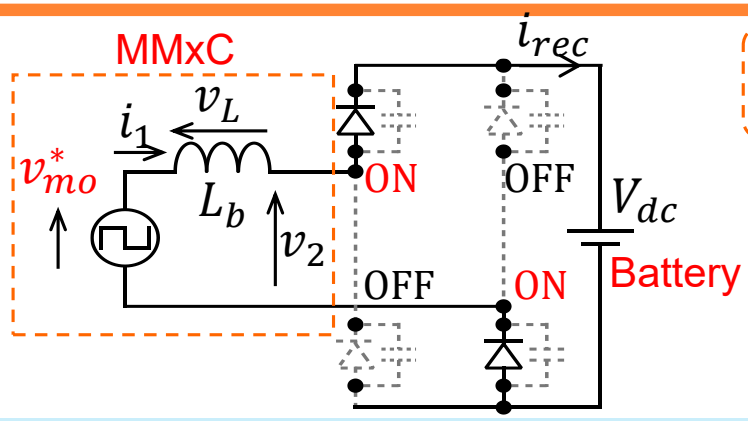
Waveform using proposed method



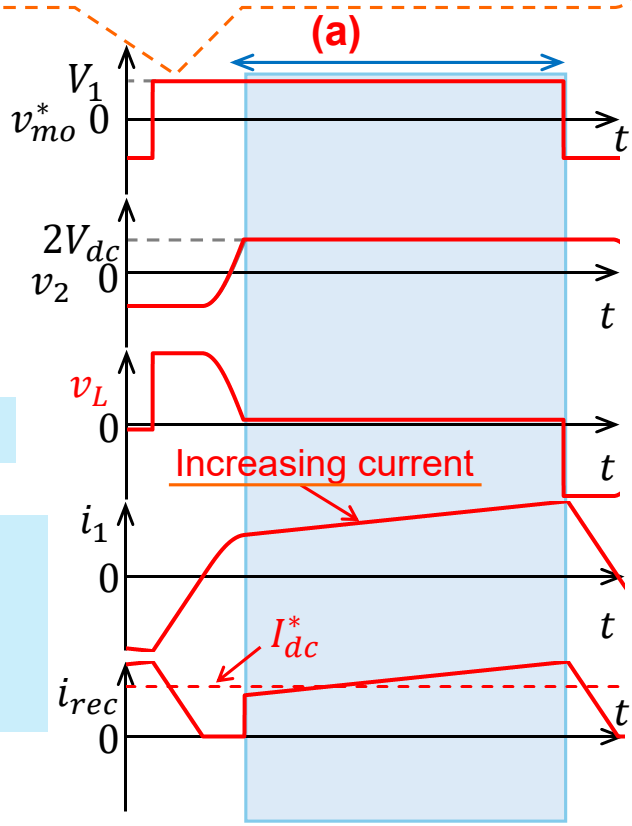
Feature of proposed method

- Realize **output DC current reference at any output DC voltage by using amplitude of MMxC output voltage v_{mo}**
- Using amplitude of MMxC output high-frequency voltage
  →Achieve stable operation of proposed circuit

Operating Principle of Proposed Method



Proposal
Higher amplitude than DC voltage $2V_{dc}$



Inductor voltage v_L is positive at (a) part

↓

Transformer current i_1 increases at (a) part

↓

Output current i_{rec} increases and is equivalently equal to current reference I_{dc}^*
→Control increasing amount of current i_1 by amplitude V_1 of MMxC output voltage

Calculate amplitude V_1 by PI controller to achieve output DC current reference

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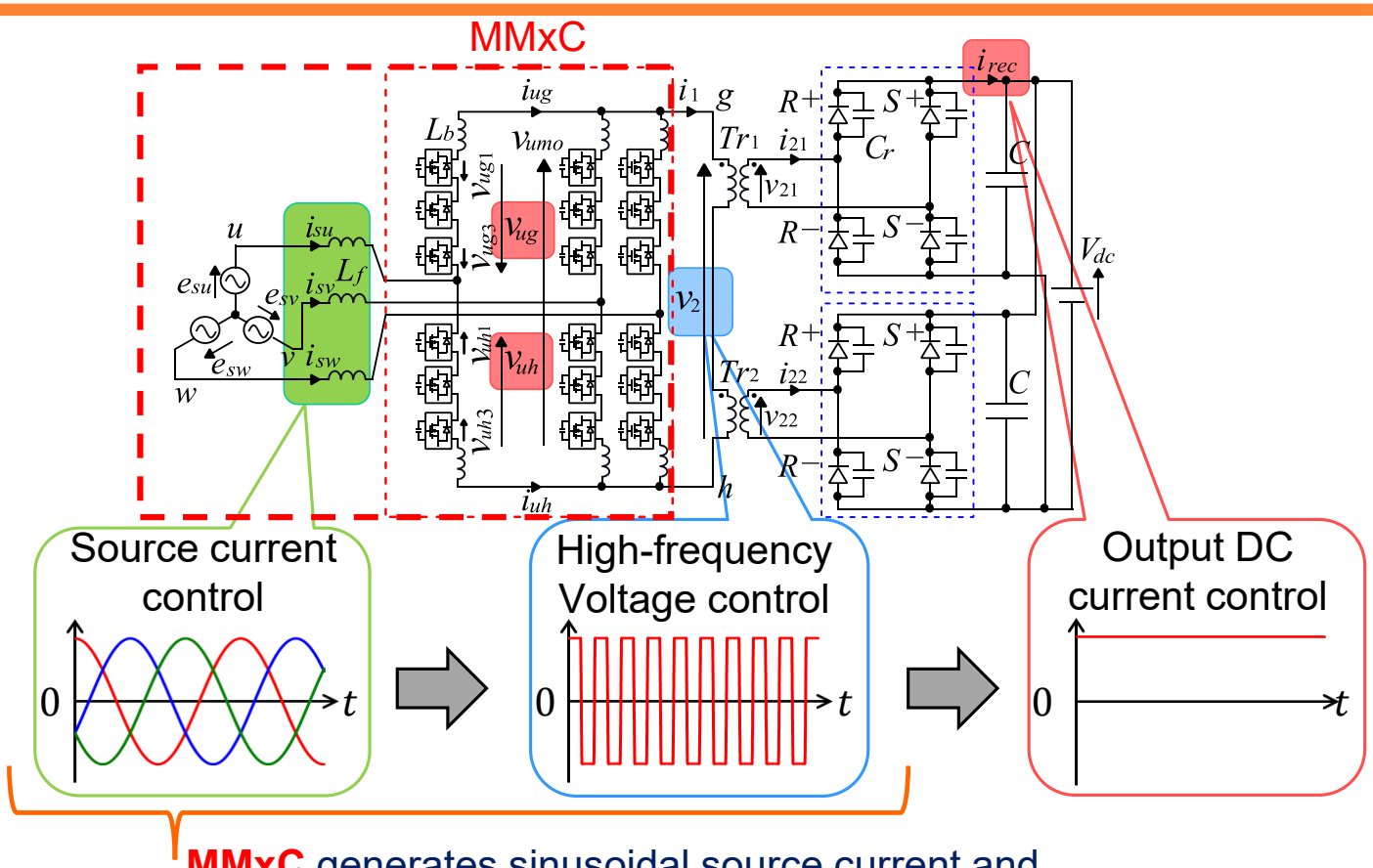
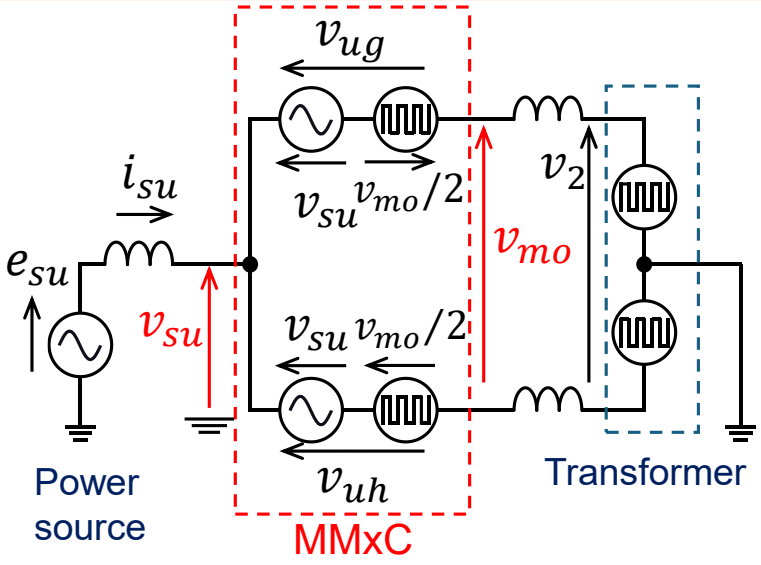
Generation Method of MMxC Output Voltage

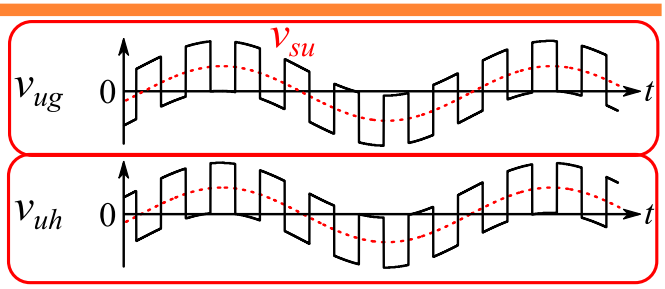


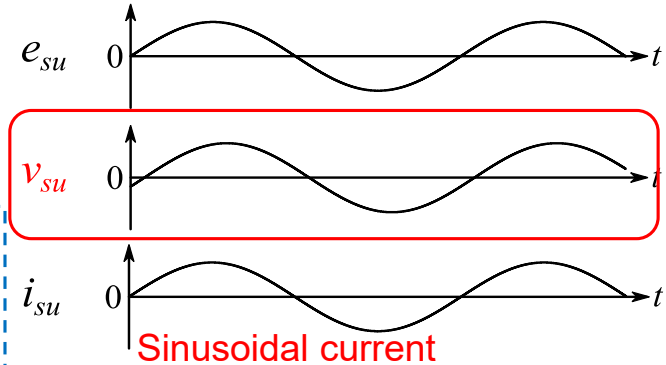
MMxC generates sinusoidal source current and high-frequency voltage at the same time using arm voltage v_{ug}, v_{uh}

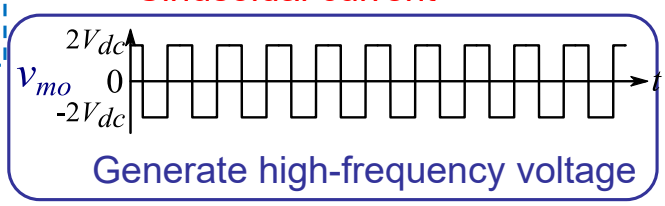
[9]

Operating Theory of MMxC





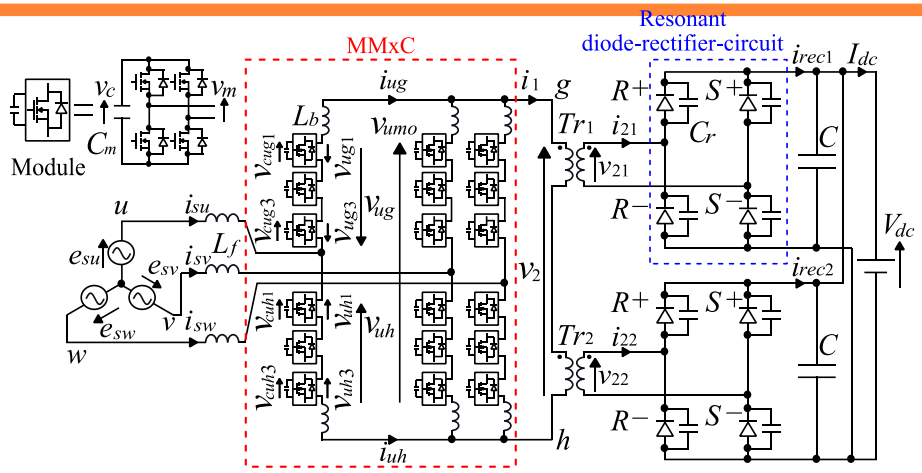




- Source current i_{su} is controlled by voltage $v_{su} = (v_{ug} + v_{uh})/2$
- High-frequency voltage v_{mo} is generated by voltage-difference $(v_{uh} - v_{ug})/2$

Achieve stable operation and output DC current reference by proposed method

Experimental Condition



Source voltage E, ω	200 V, $2\pi \times 60$ rad/s	Module capacitor voltage $V_C{}^*$	145 V
Rated power P_r	6 kW	Turn ratio of transformer a	1
Inductance L_f , L_b	1.0 mH ,0.4 mH	Frequency of transformer $1/T_s$	7.5 kHz
Number of series modules n	3	Resonant capacitor C_r	150 nF
Number of transformers m	2	Output DC voltage V_{dc}	200 V
Module capacitors C_m	1200μF	**Output current reference I_{dc}^***	**25A**

Aim of experiments

To achieve output DC current reference $I_{dc}^* = 25\text{A}$ using proposed control method in condition of output DC voltage $V_{dc} = 100,125,150,175,200\text{V}$.

Experimental Results at Output DC Voltage $V_{dc} = 100\text{V}$

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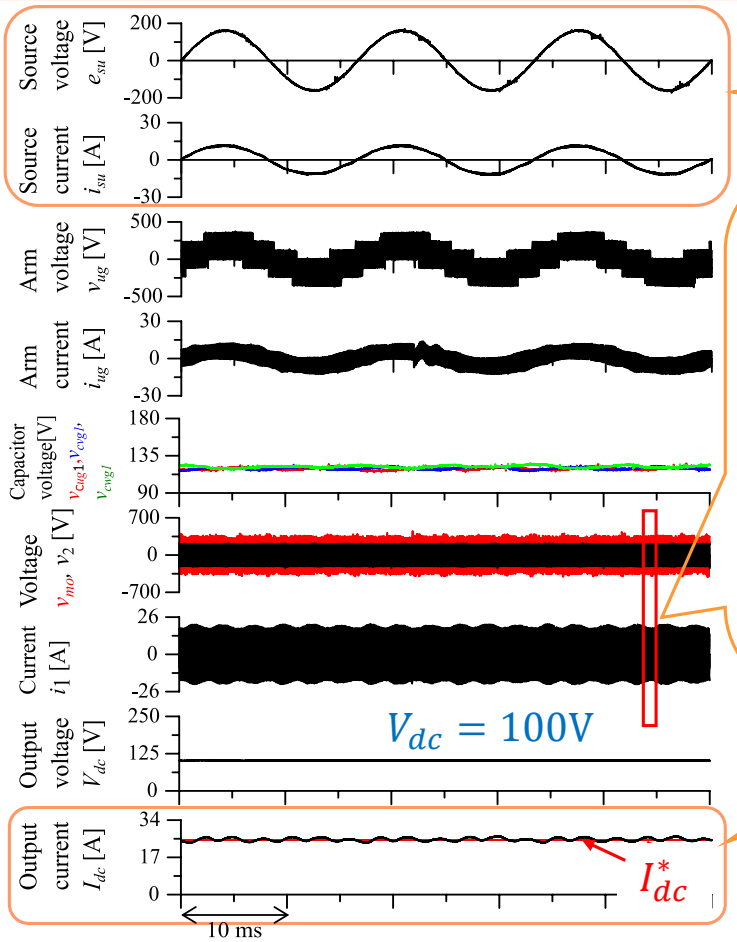
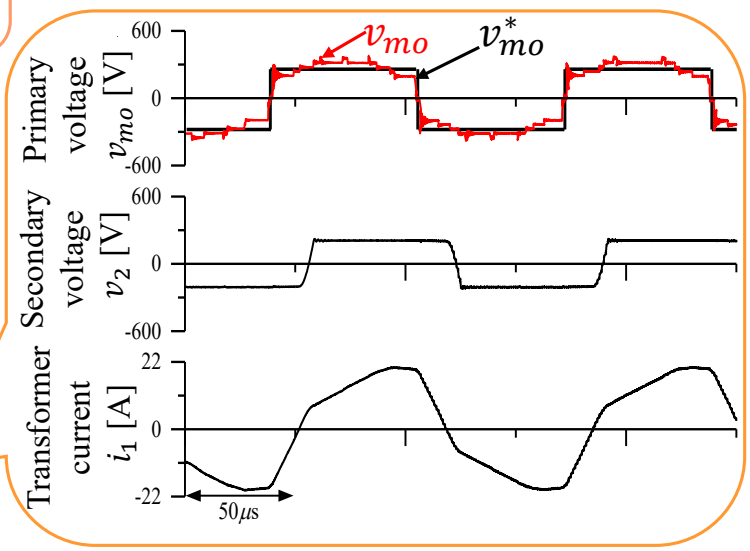


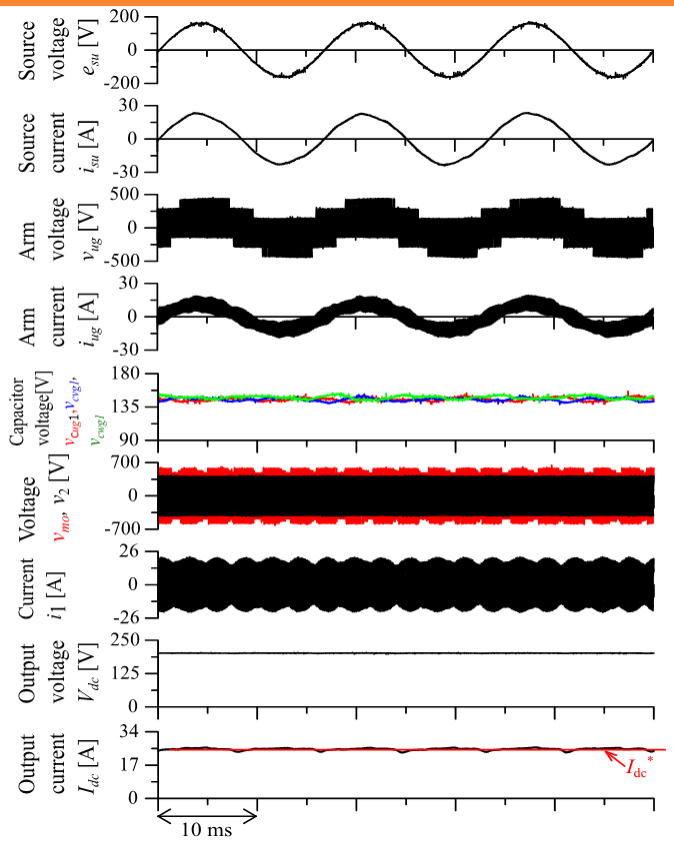
Sinusoidal source current with unity power factor



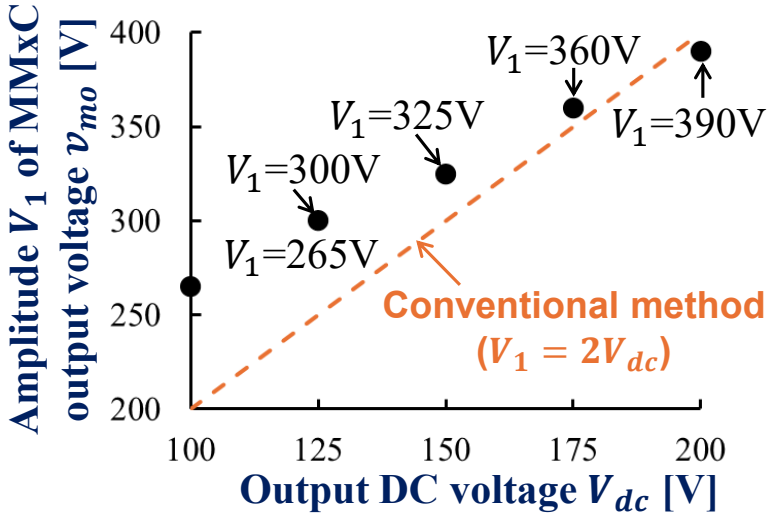
Output current reference $I_{dc}^* = 25\text{A}$ is achieved

Verify to achieve stable operation and output current reference by experiment

Experimental Results



Experimental waveform at $V_{dc} = 200\text{V}$



Experimental result

I calculated the appropriate amplitude V_1 of achieving output current reference $I_{dc}^* = 25\text{A}$ at five output DC voltage points ($V_{dc} = 100,125,150,175,200\text{V}$) by proposed control method

→Effectiveness of proposed method is verified

Conclusion

Research Purpose

This paper presents **constant output DC current control** for proposed isolated medium-voltage AC-DC modular matrix converter

Feature of Proposed Control Method

- Realize **output DC current reference at any output DC voltage**
- MMxC generates **source current with unity power factor** and **high-frequency voltage** at the same time

Achieve constant DC current control and stable and high-efficient operation of AC to DC conversion

Result

Verify the effectiveness of proposed control method by experiments using laboratory prototypes