茨城大学
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Bendable Differential Power Processing Converter for Curved Photovoltaic Panels

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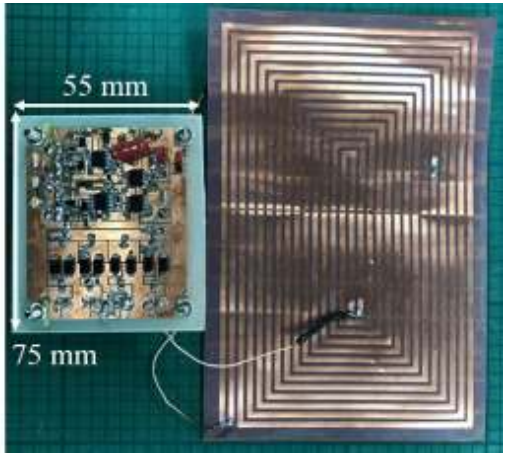
Highlights

- Propose novel differential power processing converter (DPP) using the flexible transformer
- Eliminated the mismatch issues due to curved photovoltaic panels
- Improved extractable power by 4.7% with proposed DPP converter

Outline

- Background
  - Characteristics and mismatch issues of curved photovoltaic panels
  - Conventional DPP converter
- Proposed DPP Converter
  - Features and operation
- Flexible Transformer
  - Design method and evaluation
- Experimental Results
- Conclusion



Prototype

Flexible panel

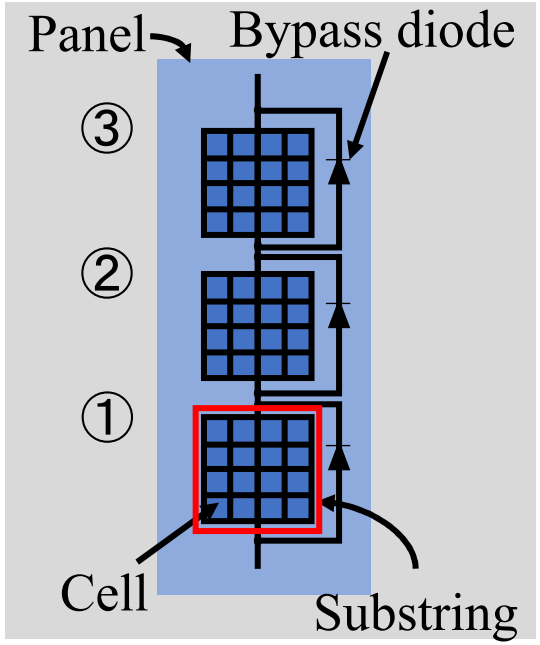
Background

Characteristics and Issues of Curved Photovltaic Panels

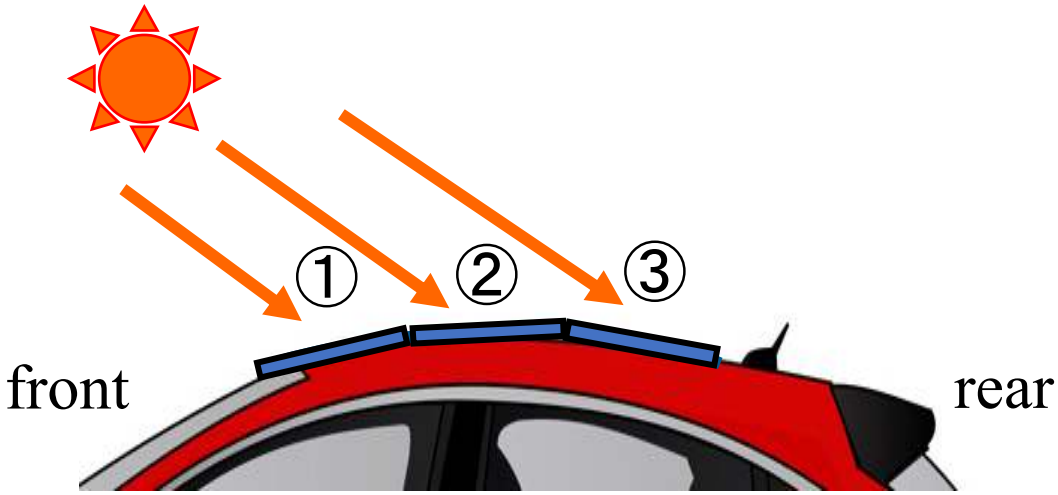
Curved solar roofs (PHEV)

Flexible panel

- Bendable, lightweight
- Wide range of applications

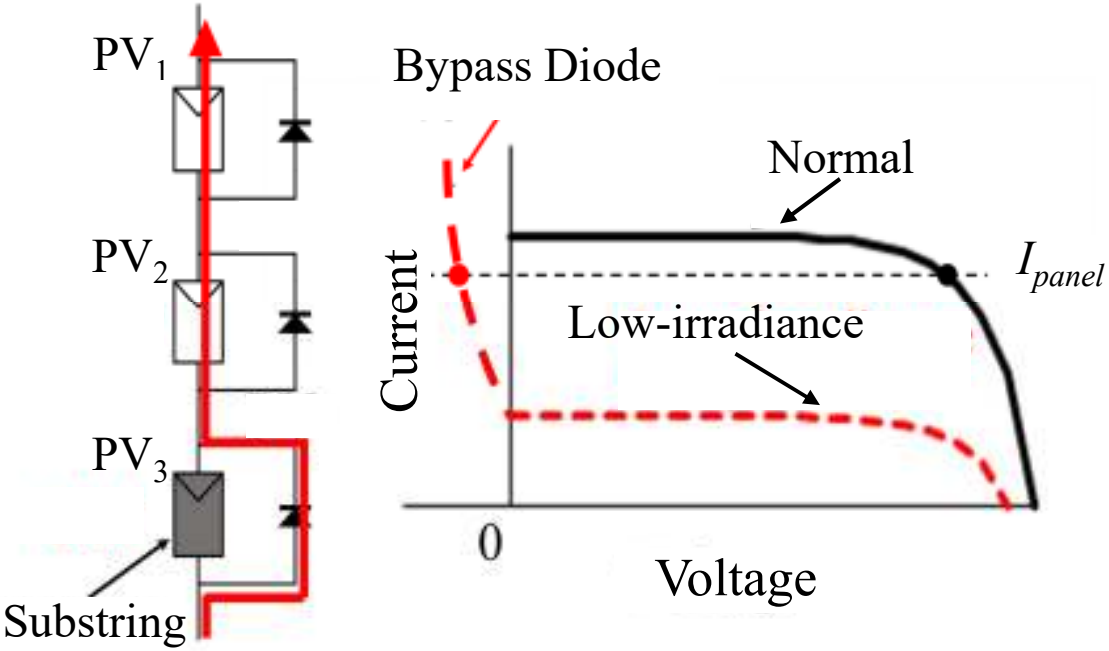


Configuration of PV panels

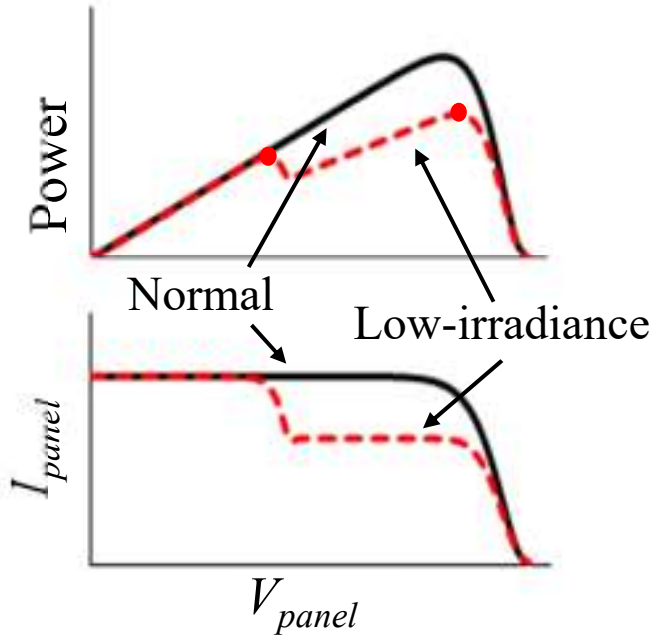


Mismatched substring characteristics due to uneven irradiance

Characteristics and Issues of Curved Photovltaic Panels



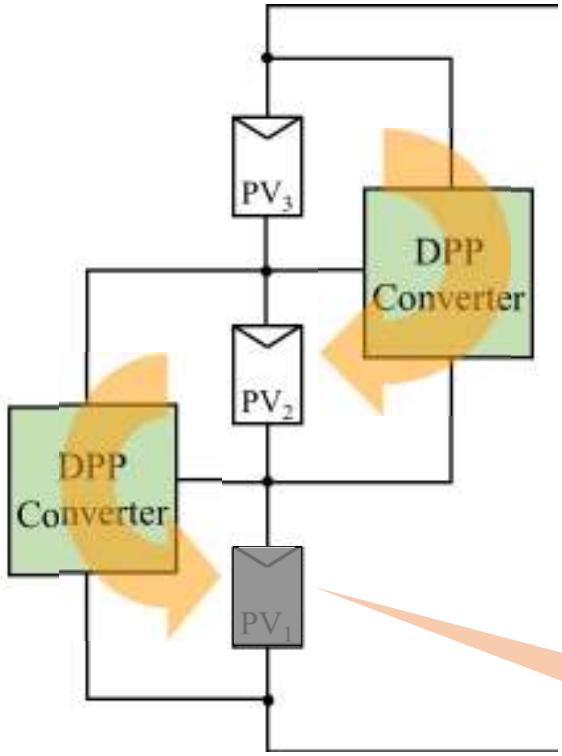
Substring characteristics



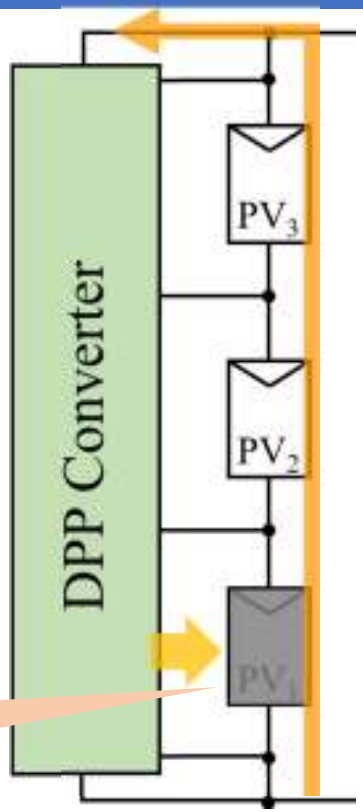
Panel characteristics

- Significant power reduction
- Occurrence of multiple maximum power points (MPPs)

Differential Power Processing (DPP) Converter



Low-irradiance



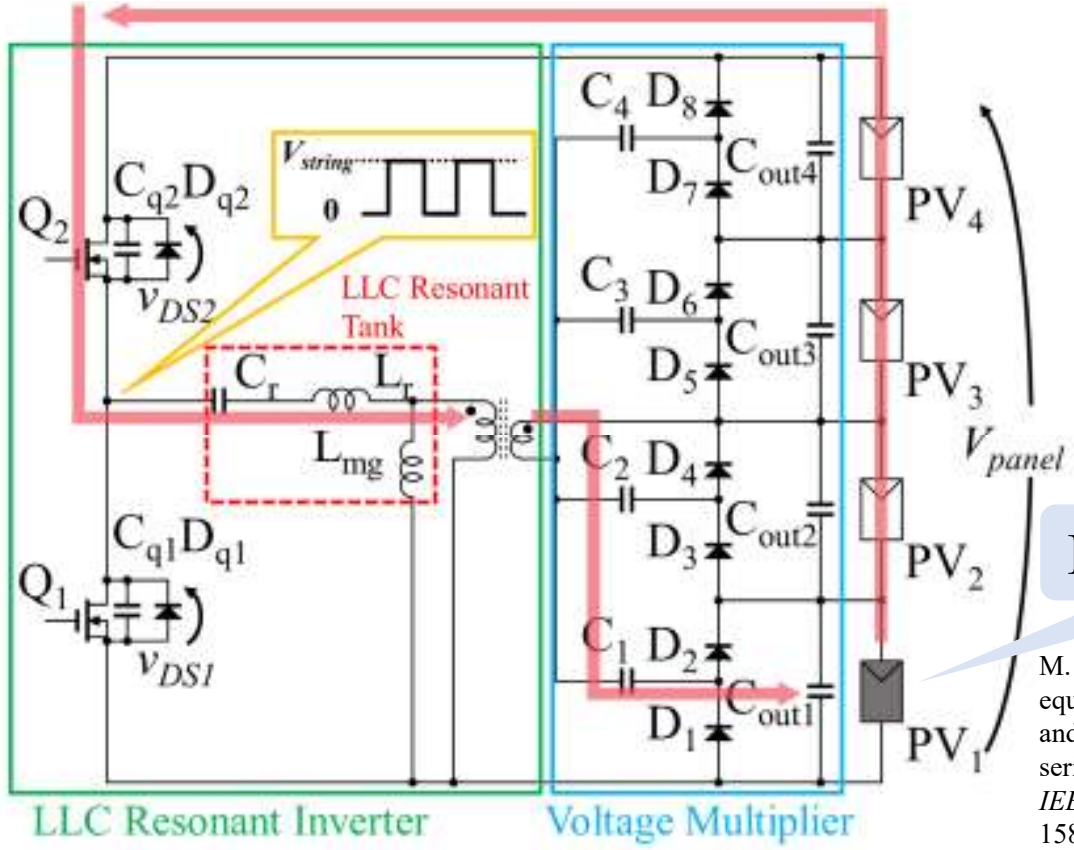
Adjacent substring-to-substring

- Complex system
- Collective power conversion loss

Panel-to-substring

- Simply system
- High power conversion efficiency

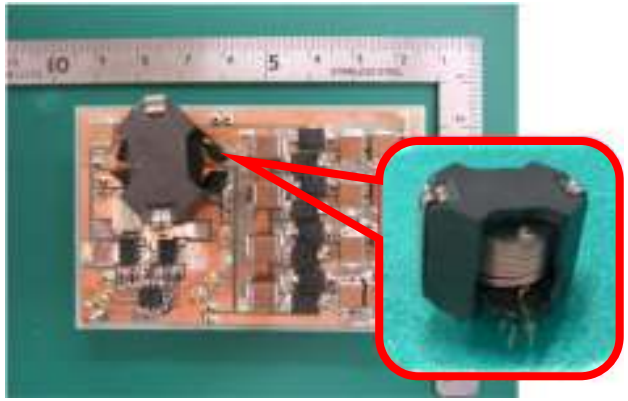
Conventional DPP Converter



M. Uno and A. Kukita: "Two-switch voltage equalizer using an LLC resonant inverter and voltage multiplier for partially-shaded series-connected photovoltaic modules," *IEEE Trans. Ind. Appl.*, vol. 51, no. 2, pp. 1587–1601, Mar/Apr. 2015.

- Combination of LLC resonant inverter and voltage multiplier (VM)
- Automatic current supply to low-irradiance substrings

Issues and Solutions of Conventional DPP Converter



Transformer

Impaired PV panel's shape

Flexible transformer

G.K.Y. Ho, C. Zhang, B.M.H. Pong, and S.Y.R. Hui, "Modeling and analysis of the bendable transformer," *IEEE Trans. Power Electron.*, vol. 31, no. 9, pp. 6450–6460, Sep. 2016.

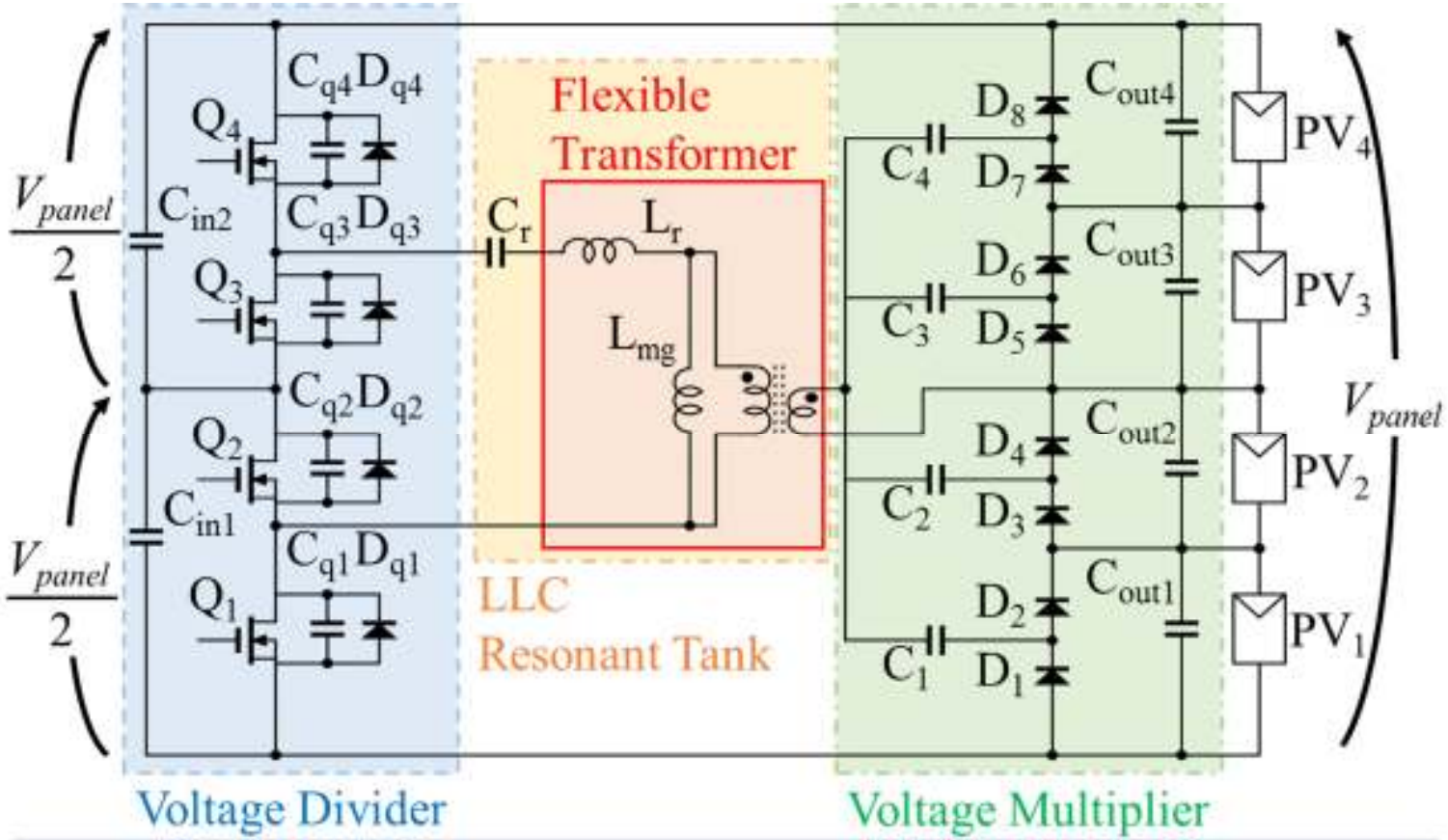
Larger copper losses due to increased i_{Lmg}

Novel DPP converter using a flexible transformer

- Operation at high frequency
- Low voltage stress of transformer

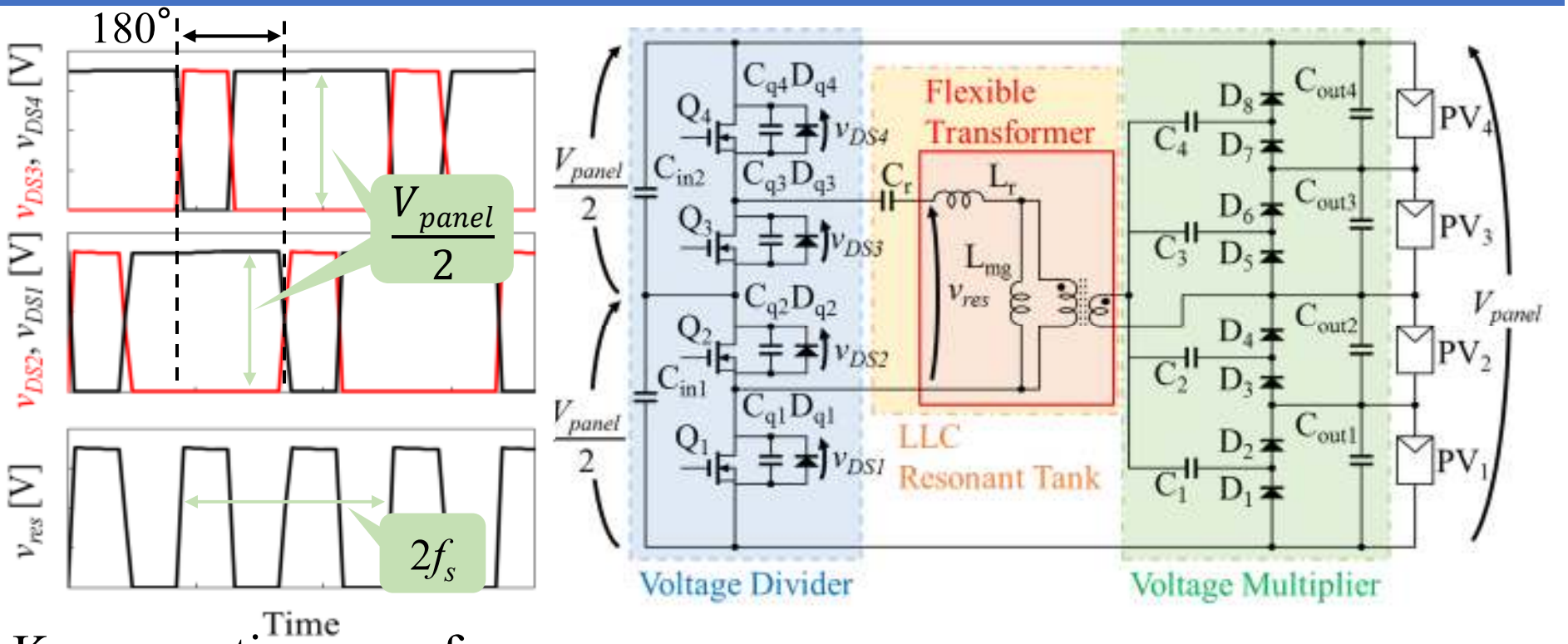
Proposed DPP Converter

Proposed DPP Converter



- LLC resonant VM with a voltage divider (VD)
- Similar the basic operation principle to that of conventional DPP converter

Features

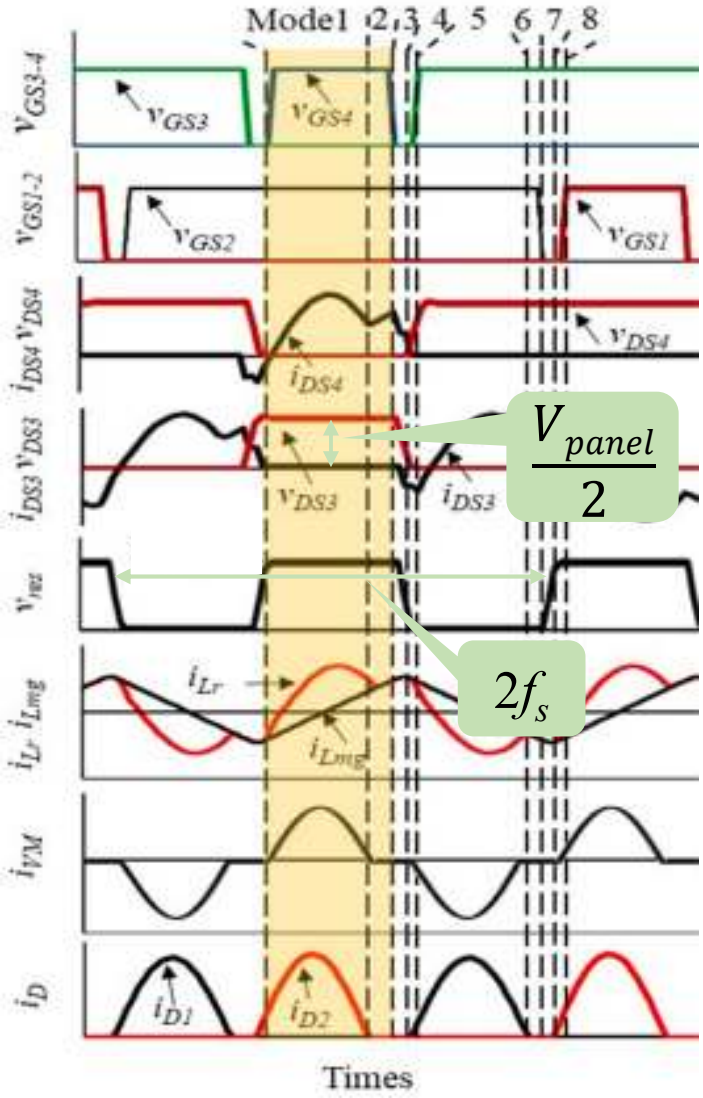


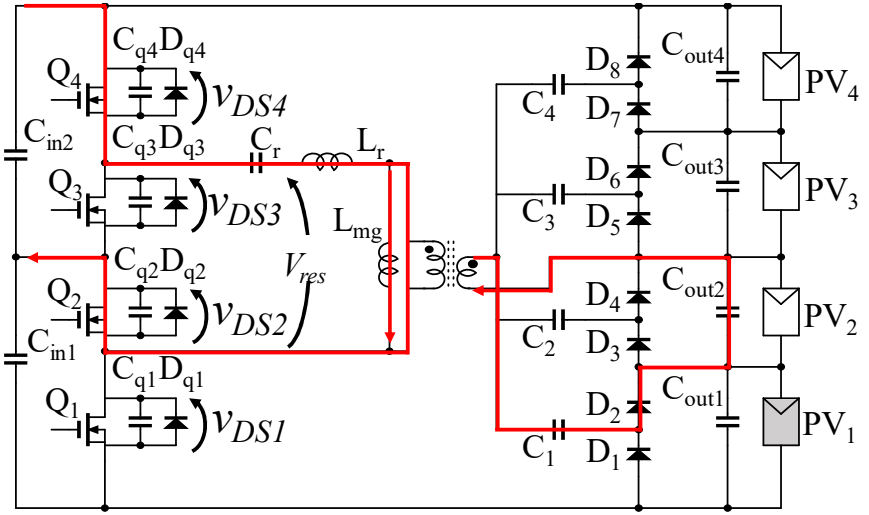
Key operation waveforms

- Transformer operates at doubled switching frequency f_s
- Halved voltage stresses of switches and transformer
- ZVS operation

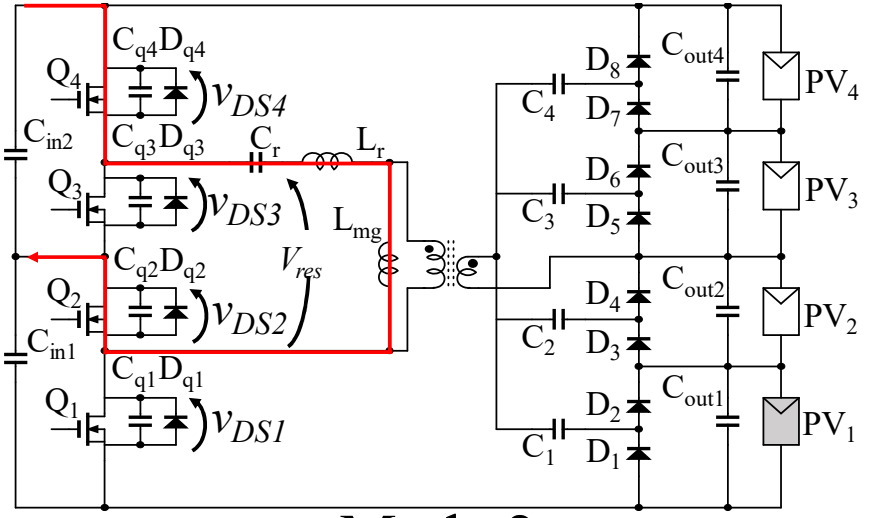
Allowing of using flexible transformer

Operation under Mismatched Conditions



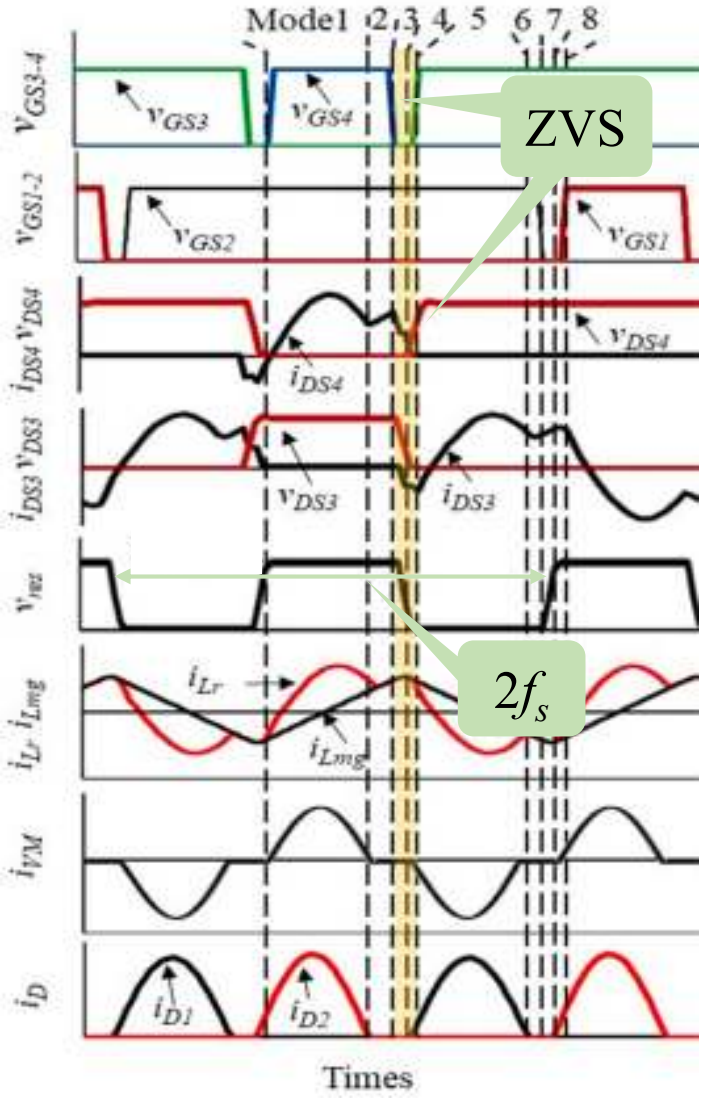


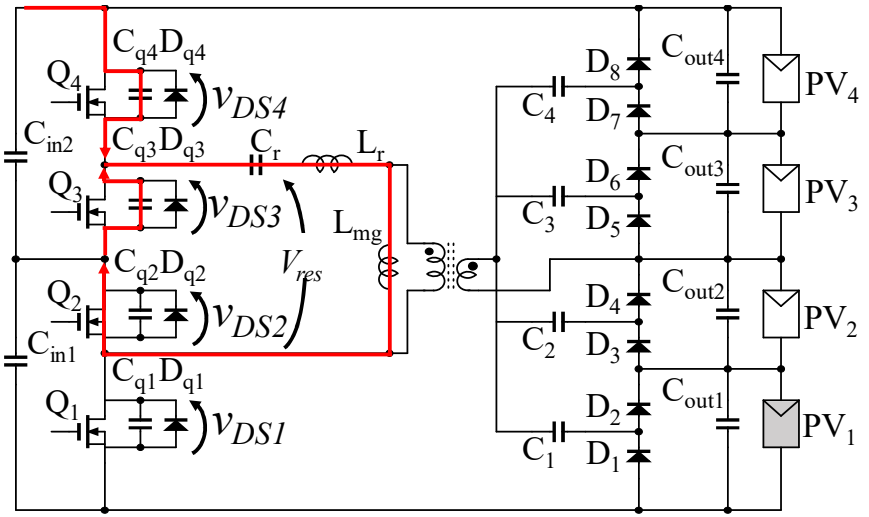
Mode 1

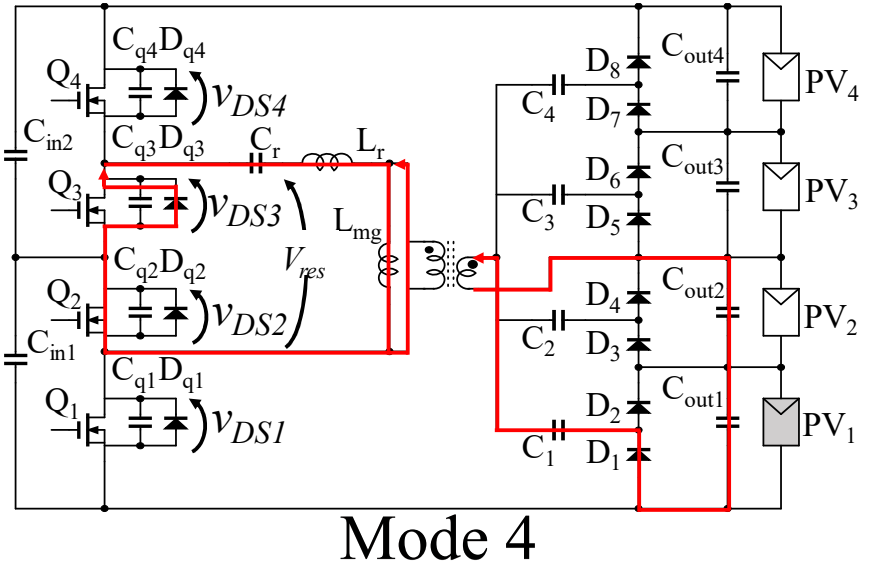


Mode 2

Operation under Mismatched Conditions

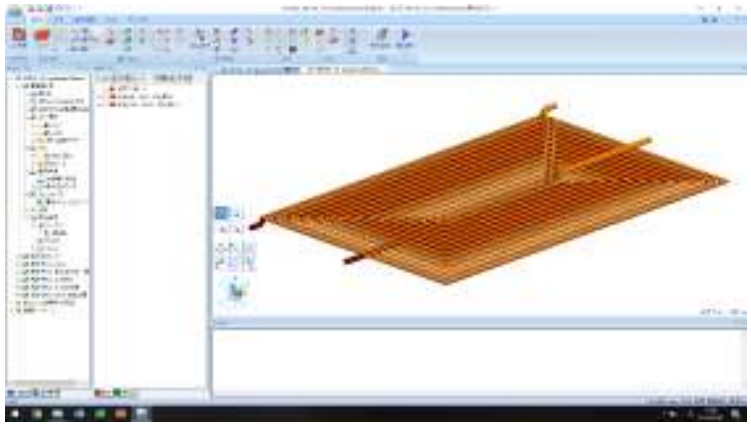






Flexible Transformer

Design Method



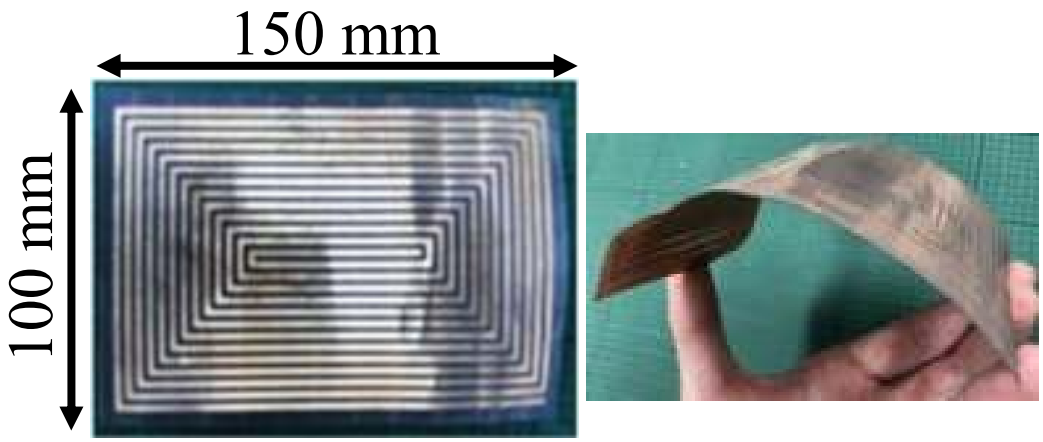
P : Pattern width
S : Interval between patterns
T : copper foil thickness

Numerical analysis using FEMTET®

Design Constraint

- Size limitation : 150 mm × 100 mm
- Upper frequency limitation due to using silicon MOSFETs
- Influence of skin effect and proximity effect

Prototype Evaluation



Prototype of flexible transformer

Outline of prototype

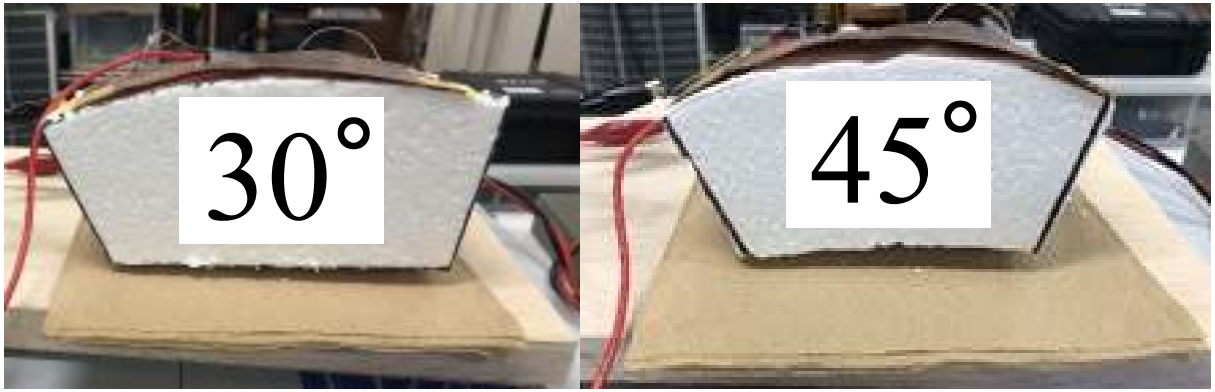
	Primary	Secondary
P [mm]	2.0	2.0
S [mm]	1.5	1.3
T [μm]	35	35
Number of turns	13	7 (2 parallel)
Total thickness [μm]		300

Key parameters

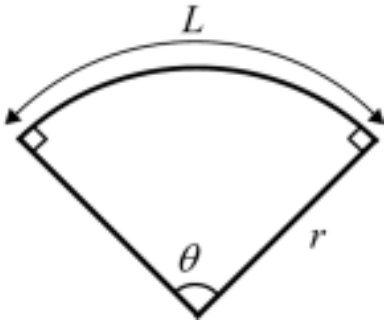
	Theoretical	Measured
L_{mg} [μH]	10.6	11.5
L_r [μH]	0.83	1.48
R_{Tp} [Ω]	2.83	2.68
R_{Ts} [Ω]	0.77	0.67

- Made of copper foil and insulted plastic
- Operating frequency of transformer : 600 kHz

Bending of the Flexible Transformer



Styrene foam supporters



L : Arc length
r : Radius
θ : Bending angle

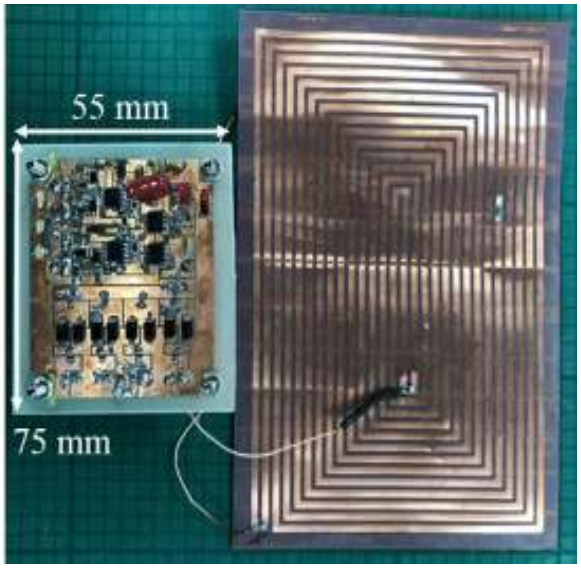
Measured key parameters

	0° (Flat)	30°	45°
L_{mg} [μH]	11.5	11.4	11.3
L_r [μH]	1.48	1.46	1.45
R_{Tp} [Ω]	2.68	2.70	2.73
R_{Ts} [Ω]	0.67	0.68	0.70

Independent on bending angles

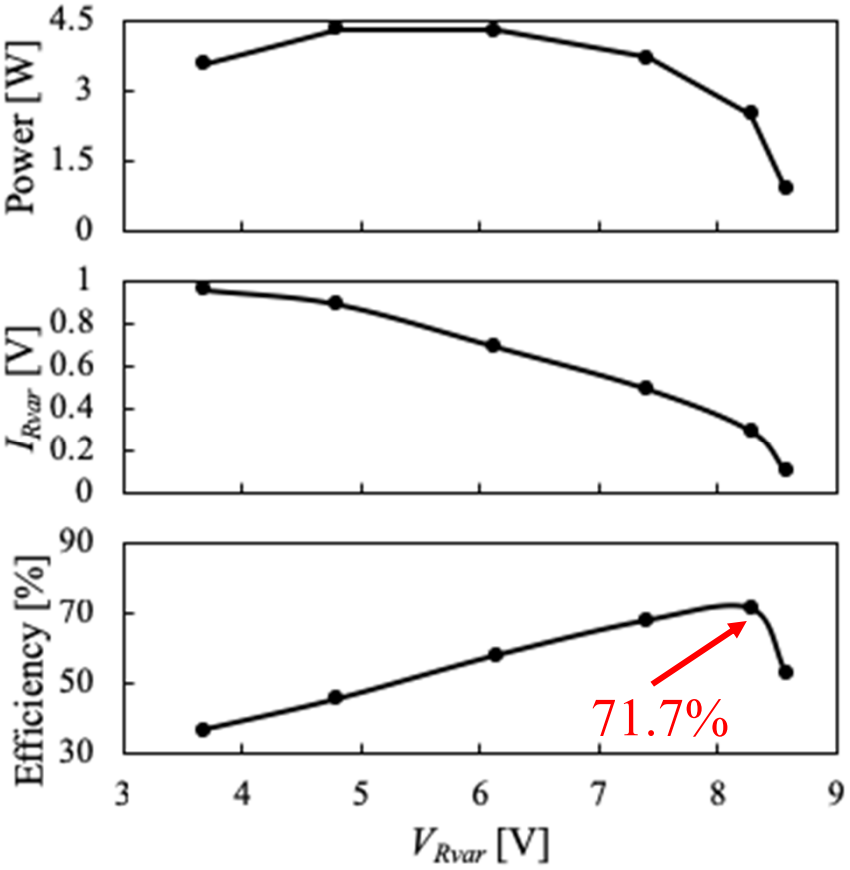
Experimental Results

Output Characteristics

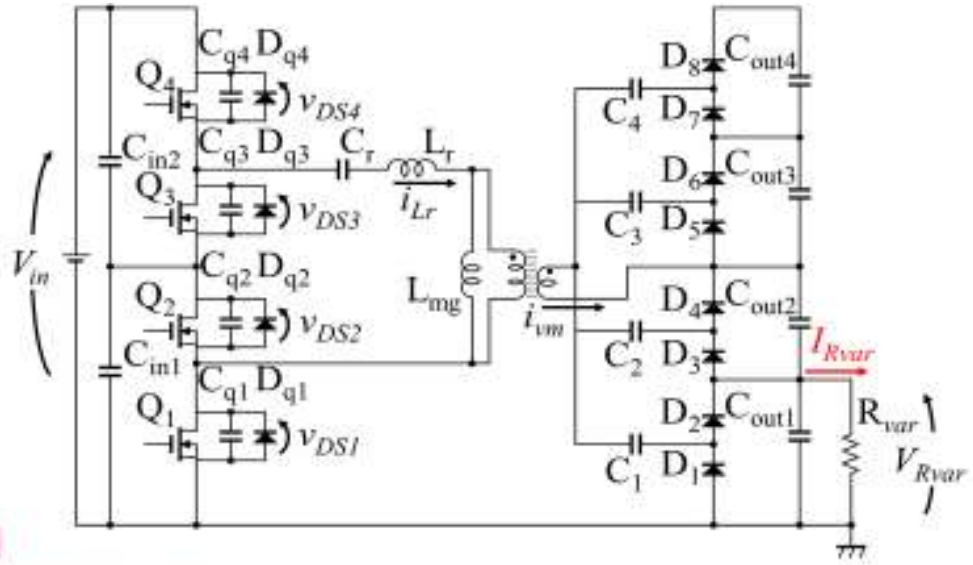


Prototype

Experimental setup
V_{in} = 36 V
(MPP voltage)
f_s = 300 kHz

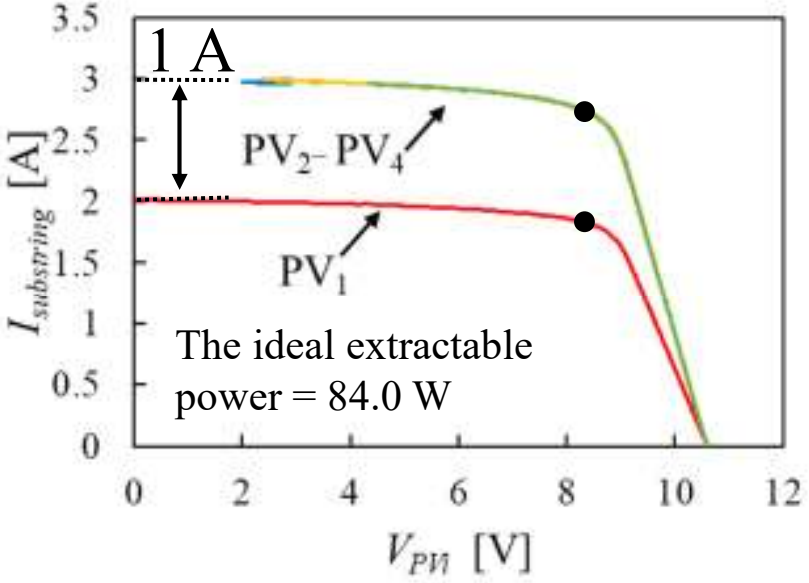


Power conversion efficiency

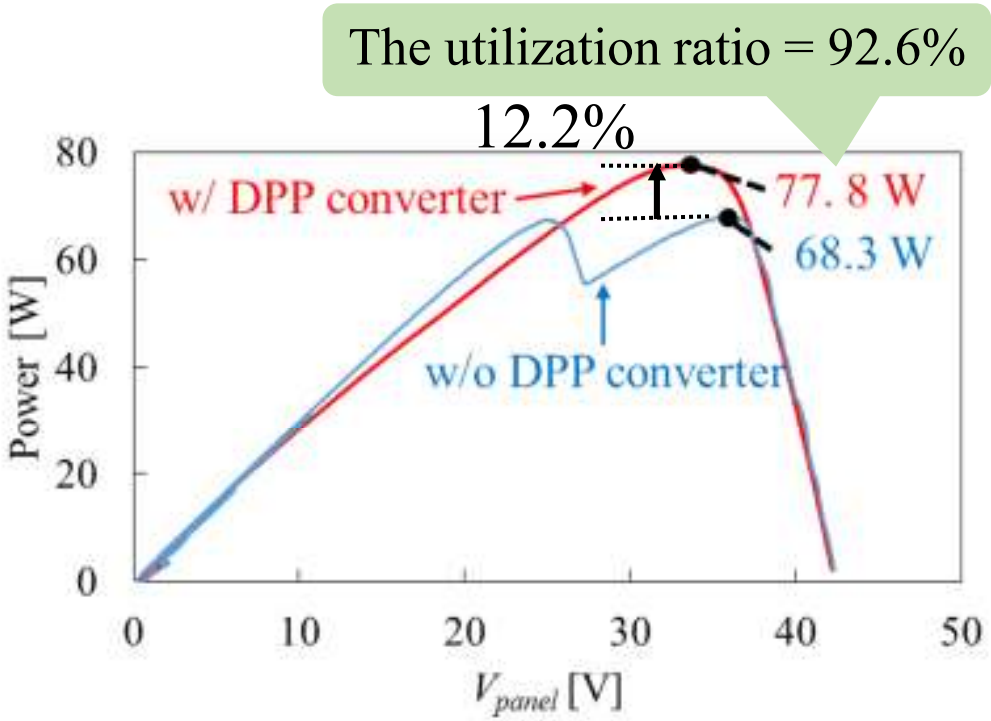


Adverse effects due to Joule loss of winding resistance

Laboratory Experiment



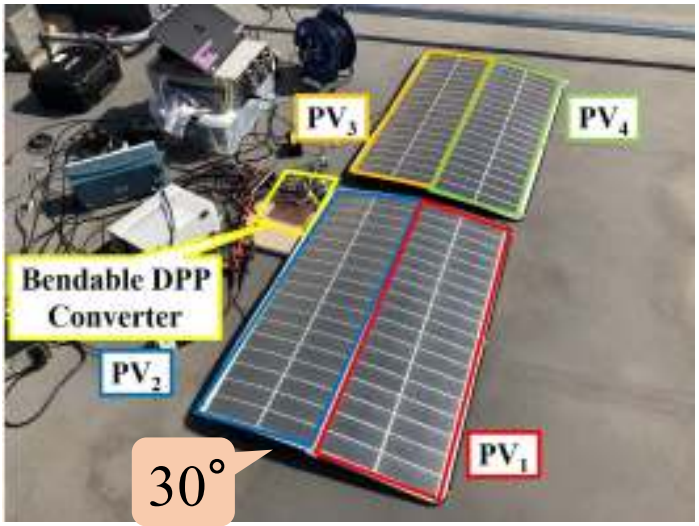
I-V characteristics of substrings
under mismatched condition



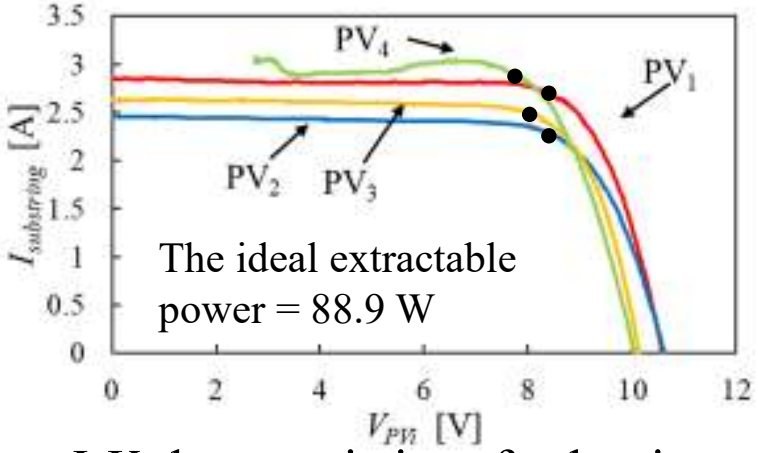
P-V characteristics
with/without DPP converter

Eliminated the mismatch issues
with the proposed DPP converter

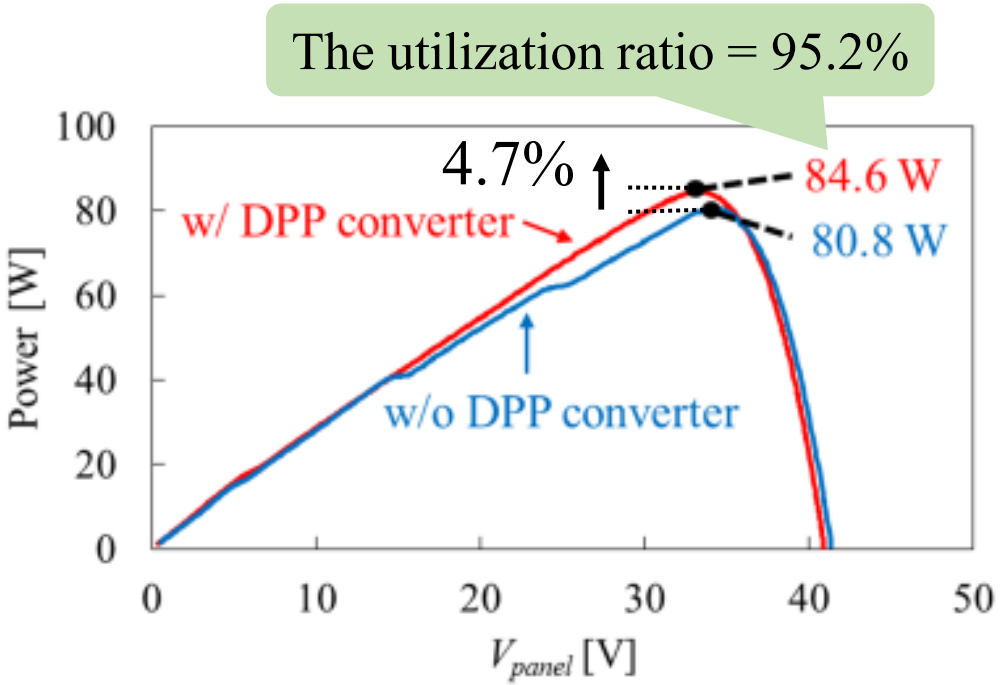
Field Test



Field test setup
(Ibaraki, Japan, at 11:50 on February 24th)



I-V characteristics of substrings under mismatched condition



P-V characteristics of panel

Confirmed the effectiveness of proposed DPP converter

Conclusion

- The bendable DPP converter using flexible transformer has been proposed to eliminate mismatch issues in curved PV panels
- The proposed DPP converter can flexibly be applied to curved PV panels
- Experimental results demonstrated increased energy yield, and local MPPs disappered

<u>Future works</u>

Employing GaN devices to increase the switching frequency and miniaturize the prototype