

Q&A

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Phase Switching Control for Unbalance Mitigation in Three-Phase Distribution Networks

Never Stand Still

Engineering

Electrical Engineering & Telecommunications

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Unbalance Issues in Low-Voltage Three-Phase Distribution Networks

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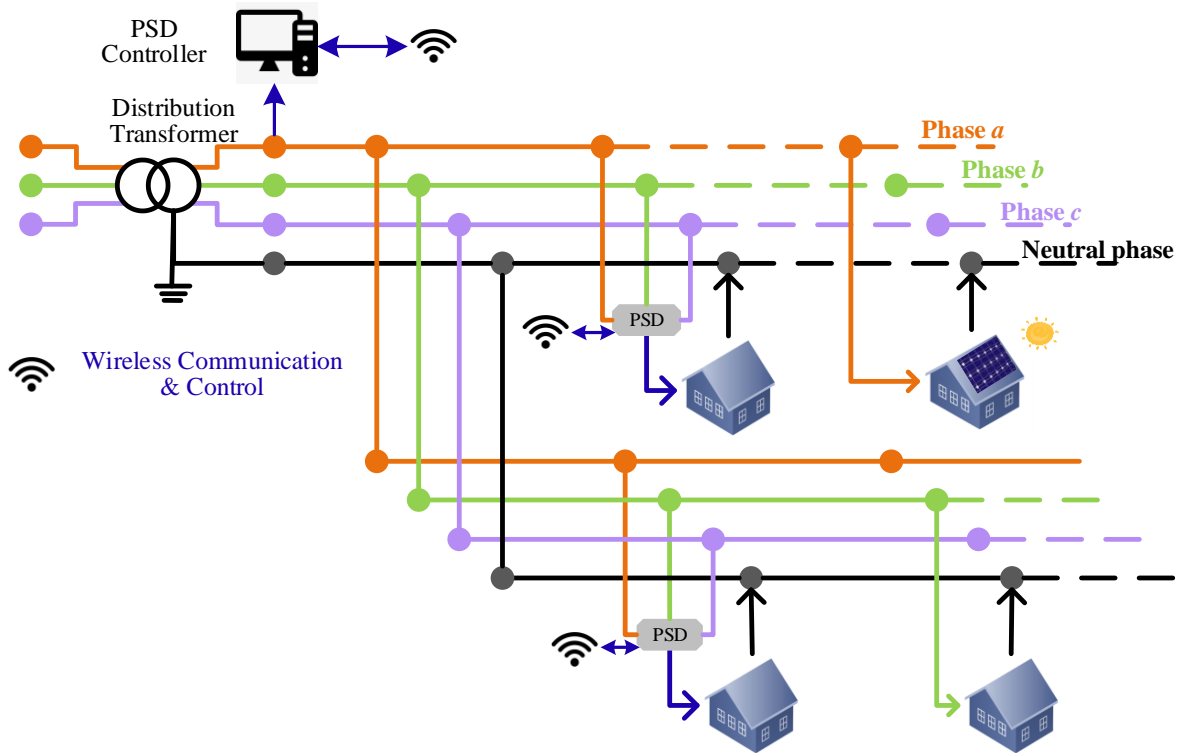
- Basic Information of Low-Voltage Three-Phase Distribution Networks
 - Providing electricity directly to residential customers, by single-phase (R, W or B) or three phases (RWB)
 - Voltage level: 230/400 V
 - Topology: Radial & asymmetric structure
 - Three-phase four wire from a distribution transformer (e.g. 22kV/230V)
- **Issues:**
 - **Strong load unbalance** compared to networks with higher voltage levels
 - **High neutral current**
 - **Unbalanced local voltages** inside the networks



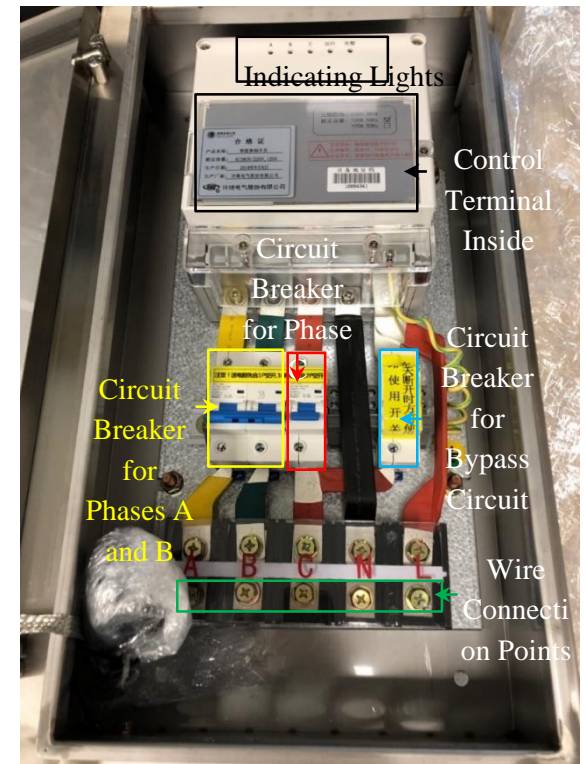
Phase Switching Device (PSD)

Manually or automatically shift customer loads from one phase to another

Control Framework of PSDs



Prototype Sample



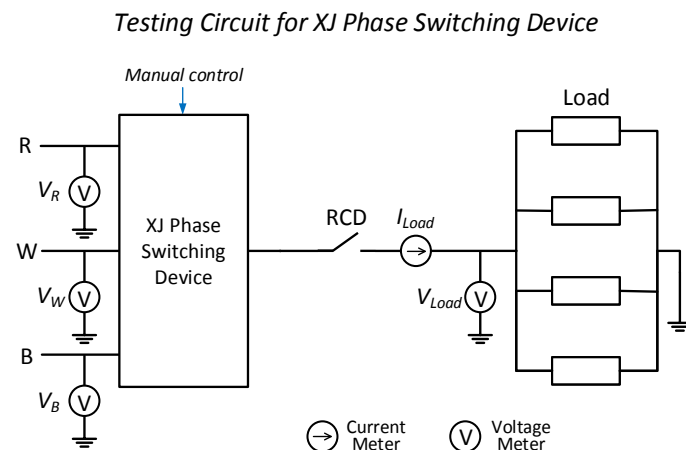
Bench Testing for Phase Switching Device (PSD)

Objectives:

1. **Test the performance** of the device, including: initialisation procedure, phase-switching and bypass power supply functions.
2. **Investigate the interaction** between the phase switching device and common customer appliances.

Testing Progress:

1. Investigation of Hardware and Control Logic
2. Design of Testing Circuit
3. Investigation of Device Initialisation Procedure
4. Testing Phase-Switching Function
5. Testing Bypass Power Supply Function



Bench Testing for Phase Switching Device (PSD)

Zero-crossing switching logic:

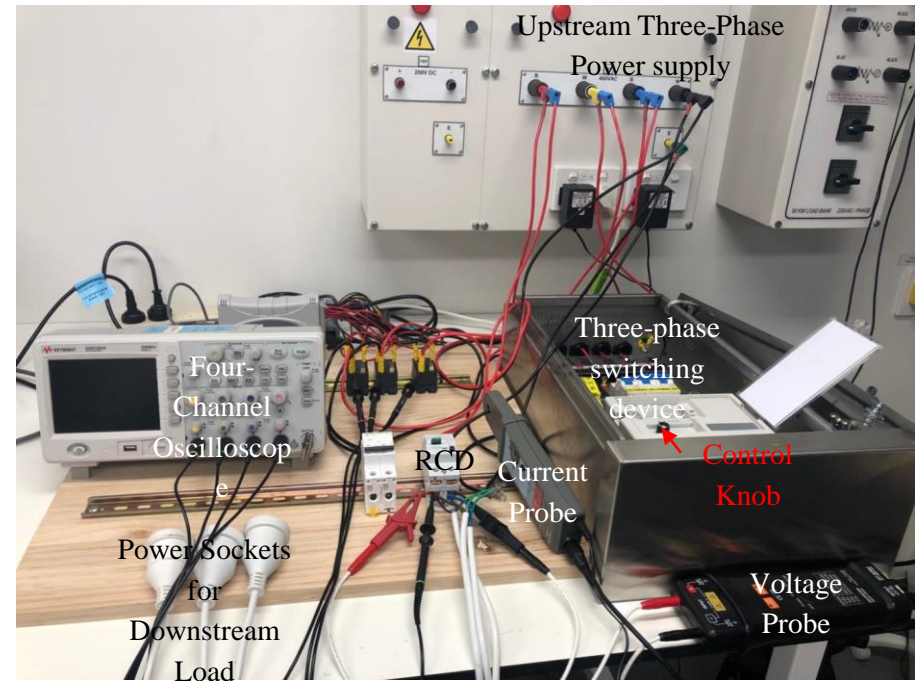
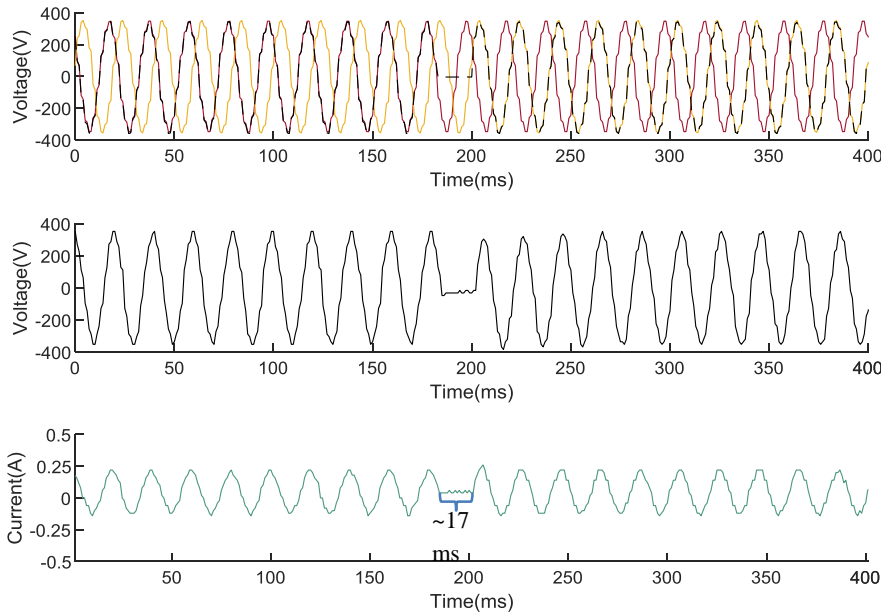
Zero current cut-off

Zero voltage reconnect

Testing Platform:

- Observe appliance operation during phase-switching action
- Measure transient voltage and current of appliance using high frequency oscilloscope

Halogen - Lighting - Switching Phase from Red to White



Bench Testing for PSD

Common Appliances for Testing:

30 appliances

42 individual common operation states

12 combined appliance operation states



More attention to

air-conditioner considering
Australian summer case

motor and compressor based
appliances due to high inductance

Bench Testing for Phase Switching Device (PSD)

Testing Results: Take the pool pump running state test as an example.

Phase-Switching Sequence	Positive (e.g. Red to White)	Negative (e.g. Red to Blue)
Operation Observation	Slight vibration	Heavy vibration
Waveforms	<p style="text-align: center;">Pool Pump - Running (No Load) - Switching Phase from Red to White</p>	<p style="text-align: center;">Pool Pump - Running (No Load) - Switching Phase from Red to Blue</p>
Reasons for Observation	<p>The load voltage changing tendency after connecting to the new phase (red arrow) was the same as before connecting (blue arrow)</p>	<p>The load voltage changing tendency after connecting to the new phase (red arrow) and that before connecting (blue arrow) were in the opposite directions</p>

Bench Testing for Phase Switching Device (PSD)

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Conclusions:

- Effectiveness of phase-switching was verified.
- The most common household appliances worked normally during the phase switching process.
- Some negative impacts of phase-switching process on appliance operation were found and reasons were explained with help of the waveforms. But no appliance damage was found.



Suggestions:

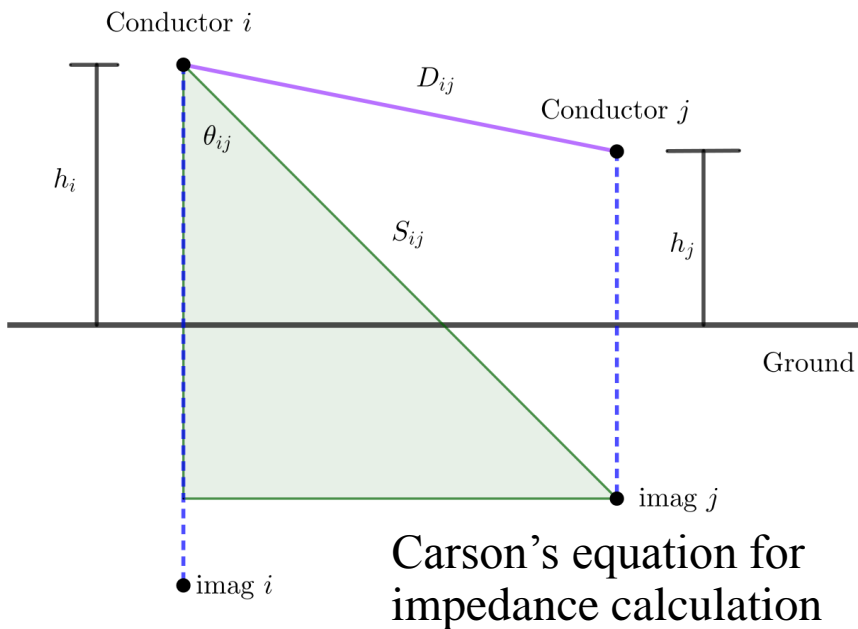
- Apply **consecutive positive sequence** switching to replace direct negative sequence switching.
- Select **periods when less appliances** are used, such as night time, to perform phase switching.
- **Reduce phase switching actions** during a day to minimise disturbance to customers.

Placement and Control Scheme of PSDs

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Design Progress:

1. Network data preparation
2. Network modelling and power flow algorithm design
3. PSD placement optimisation
4. PSD daily control scheme design



Algorithm 1: Iteration-based algorithm to solve power flow in LVDN

Input: $S_i = P_i + jQ_i (\forall i), Z_{ij} (\forall ij), V_1, V^0 = [V_1, \dots, V_1]^T$

Result: V

- 1 Initialization: $k = 0, V_i^0 = 1 + j0 (\forall i \neq 1), \epsilon = 10^{-6}$.
- 2 **while** $|V^{k+1} - V^k| > \epsilon$ **do**
- 3

$$I_i^k = \left(\frac{P_i + jQ_i}{V_i^k} \right)^*$$

$$\Delta V^{k+1} = \text{DLF} I^k$$

$$V^{k+1} = V^0 - \Delta V^{k+1}$$
- 4 **end**

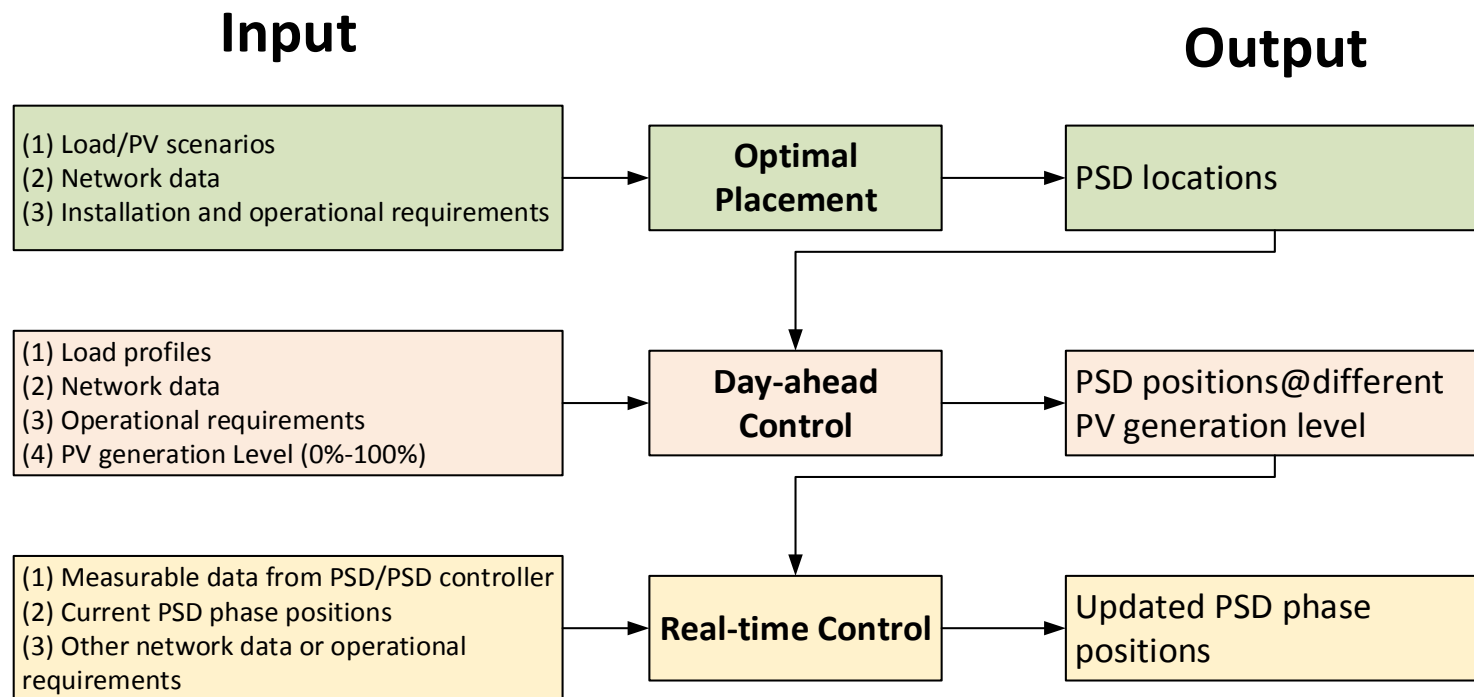
power flow algorithm

Placement and Control Scheme of PSDs

Optimal Placement: seeking optimal locations to install PSDs for unbalance reduction.

Day-Ahead Control: optimal static strategies (switched @ 2:00 AM) considering various PV generation levels.

Real-Time Control: Update phase switching actions when operating constraint violations occur.



Placement and Control Scheme of PSDs

Mathematical formulation:

Objective: To minimise **power unbalance** among three phases in each circuit.

Installation constraints:

Maximum 2 PSDs at each pole (space limitation).

Maximum 14 PSDs for all customers (71 and 106 in two networks).

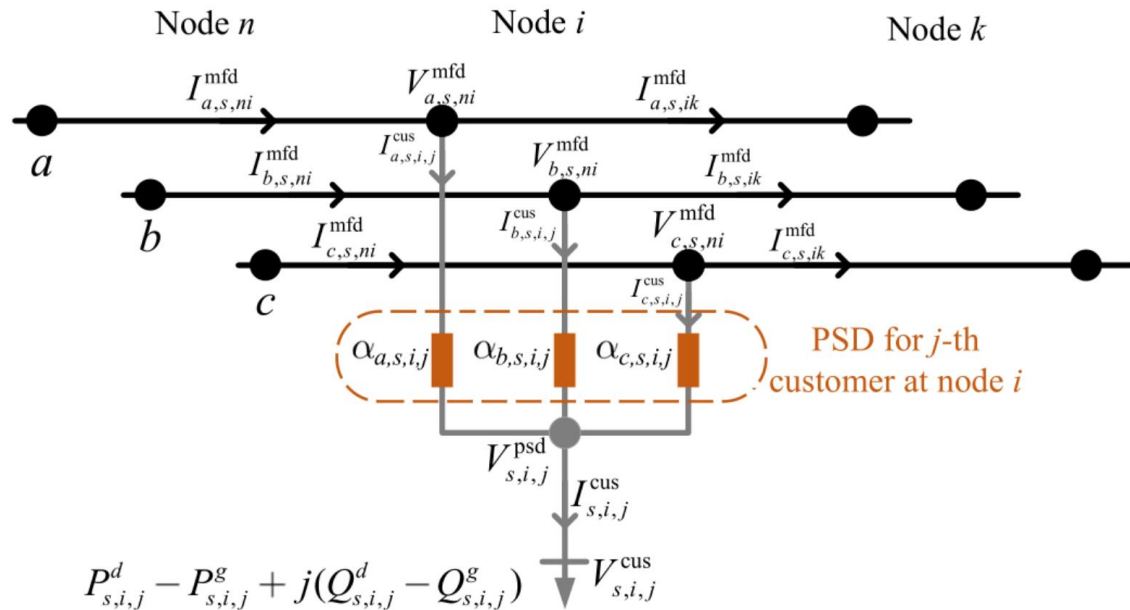
Operating constraints:

Current balance at each pole

Voltage magnitude/unbalance

Capacity of transformer

Phase connection

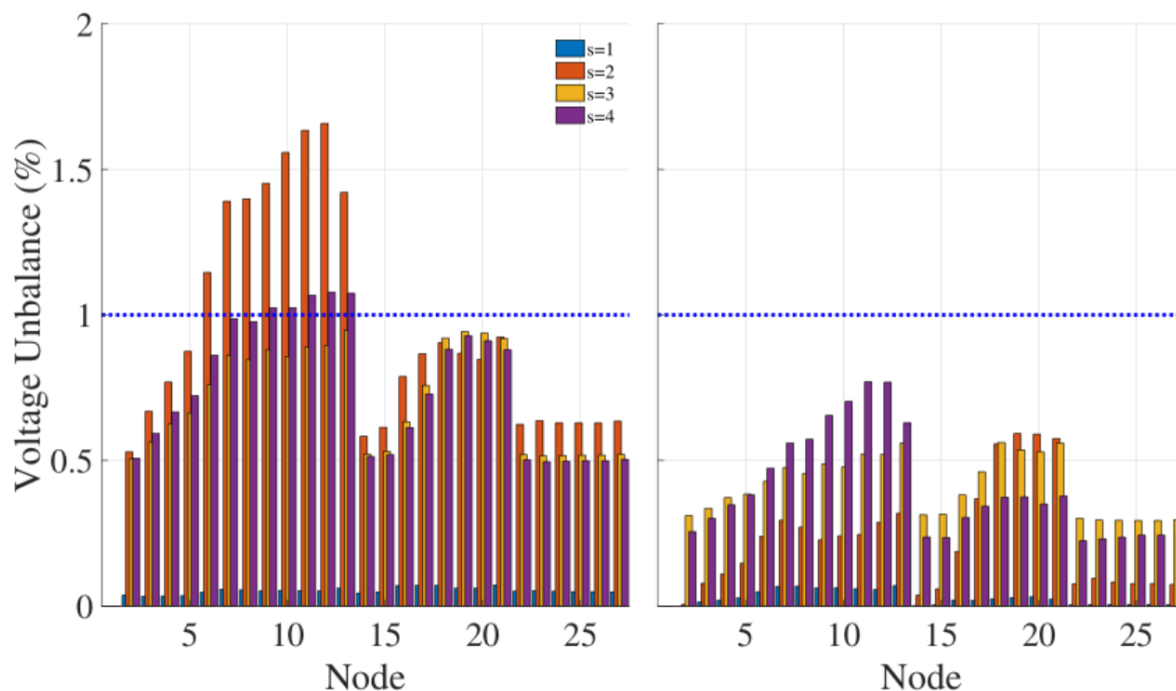


Placement and Control Scheme of PSDs

Simulation Results:

Power unbalance reduced by **67.94%**

Voltage unbalances (percentages of negative sequence voltage component over nominal voltage) - all below **1%**

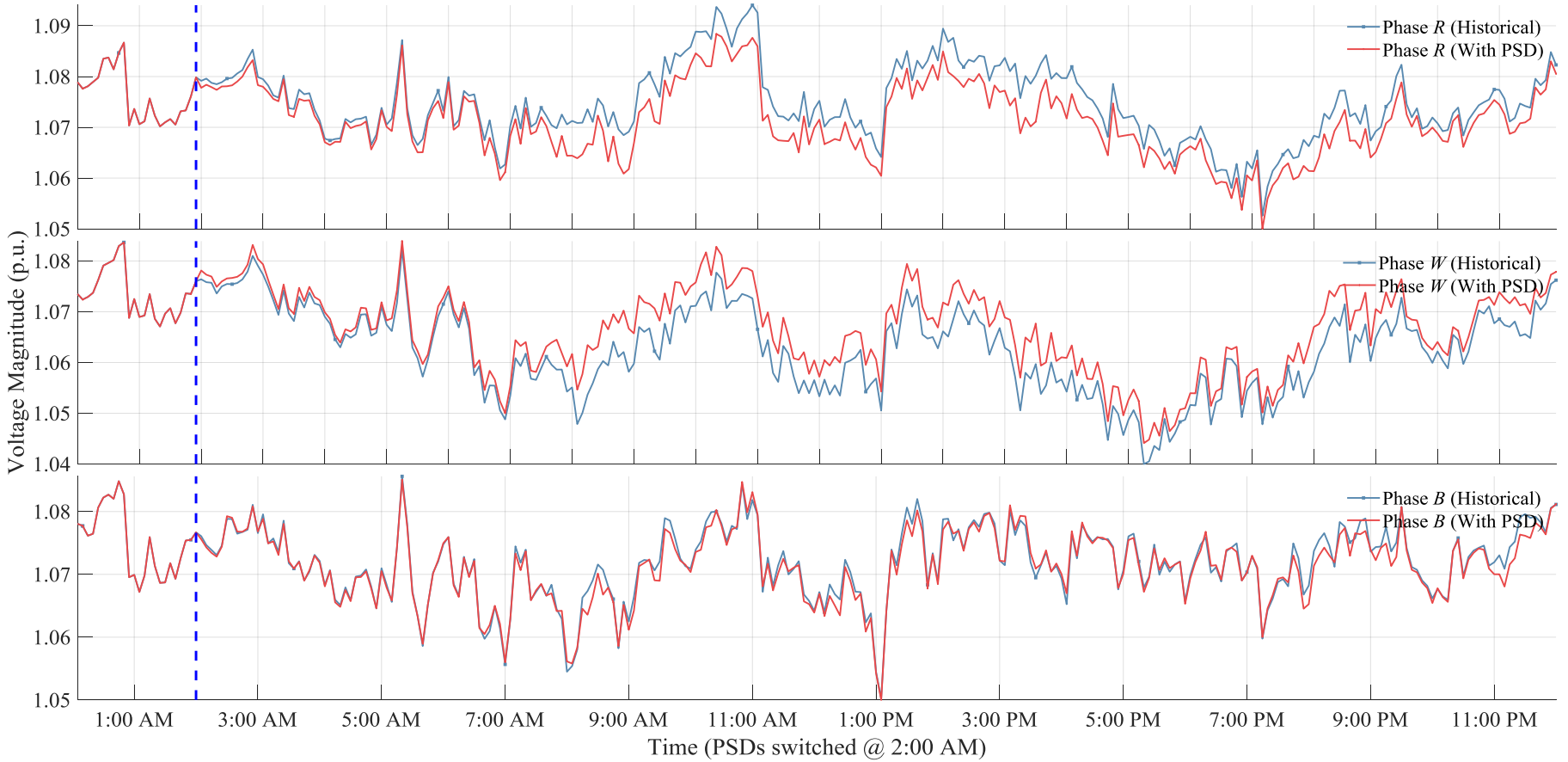


Left: without PSDs; **Right:** with PSDs

Placement and Control Scheme of PSDs

Simulation Results:

Voltage magnitudes before/after switching PSDs



Placement and Control Scheme of PSDs

Conclusions:

1. Data preparation: Generating necessary data for network analysis.
2. Network modelling: Developing **an efficient power flow algorithm** for unbalanced three-phase distribution networks.
3. Placement of PSDs: Providing **optimal locations** to install PSDs.
4. Control Scheme of PSDs: **Efficiently reducing power and voltage unbalances** in networks under various PV generation levels.

Trials are ongoing...

PSDs have been installed in two distribution networks, data is being collected for further control result analysis.



References

Project Website:

<https://arena.gov.au/projects/demonstration-of-three-dynamic-grid-side-technologies/>

Project Report:

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<https://arena.gov.au/assets/2020/08/jemena-der-hosting-capacity-interim-knowledge-sharing-report.pdf>

Research Publications:

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Bo Wang, Cuo Zhang, Ke Meng, et. al., "Improving hosting capacity of unbalanced distribution networks via battery energy storage systems," *11th IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC 2019)*, Macao, Dec. 2019, pp. 1-5. (**Student paper award**)

Bin Liu, Ke Meng, Peter K. C. Wong, et. al., "Improving operation feasibility of low-voltage distribution network by phase-switching devices," *8th Renewable Power Generation Conference (RPG 2019)*, Shanghai, China, Oct. 2019, pp. 1-6. (**Best conference paper award**)

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