Real Time Hardware Validation of Optimal Conservation Voltage Reduction Strategy with Measurement based Load Estimation

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Introduction

- **What is CVR?**
  - Reduce energy by lowering the voltage
  - Tap changer, Reactive power device

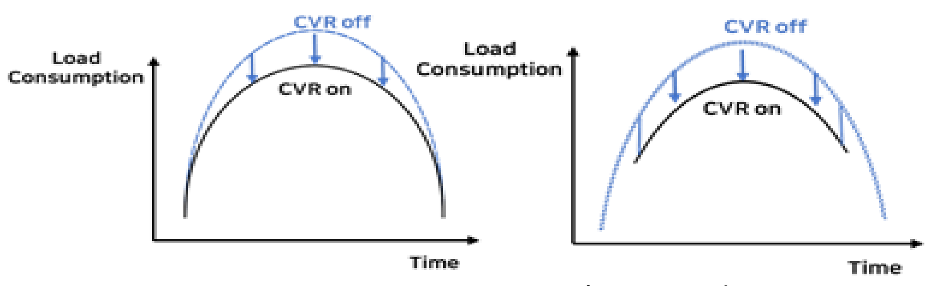
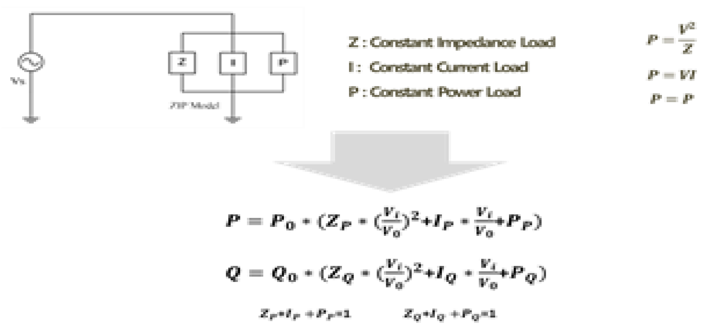


Fig. 1. Conservation voltage reduction

- **Voltage dependent load modeling**
  - Static Load Model



- **Load parameter estimation**
  - Voltage dependent load parameter
    - ZIP coefficient, CVR factor
  - Parameter classification
    - Residential, Commercial, Industrial
    - Time, Weather, Weekday-end, Season

Accurate estimation is essential

- To evaluate the performance
- System stability (Voltage violation)
- Optimal performance

Load parameter estimation

Approach

- Using the equation between power and voltage

$$P = P_0 * (Z_P * (\frac{V_i}{V_0})^2 + I_P * \frac{V_i}{V_0} + P_P)$$

$$\frac{P}{P_0} = (Z_P * (\frac{V_i}{V_0})^2 + I_P * \frac{V_i}{V_0} + P_P)$$

Using curve fitting method

Voltage($\frac{V_i}{V_0}$), power($\frac{P}{P_0}$) from AMI

- Need $P_{L,i,0}(t)$ which is the power when voltage is 1 p.u.

$$P_{L,i,0}(t) = P_{L,i,0}(t-1) + \Delta P_{L,i} - P_{L,i,0}(t-1) \times CVRf_i(t-1) \times \Delta V_i$$

Data Selection & Classification

- Use the AMI data(V, P, Q) right before/after Q compensation
  - Truth change due to voltage variation
- Similar to OLTC operation
- PV Q → System V → Load P, Q variation

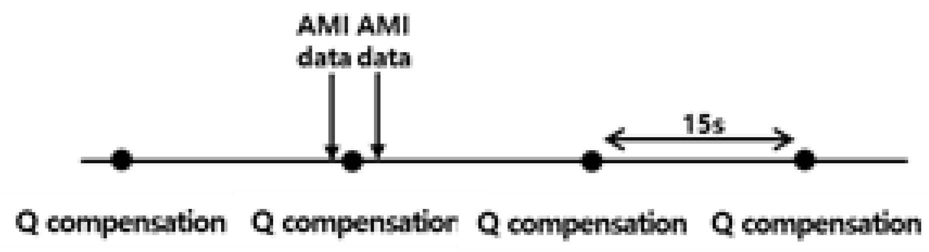


Fig. 2. Data acquition point

- Basic idea about data classification
  - Load characteristic of today is similar with yesterday
    - Use yesterday data to esimate today's parameter
  - If not, use standard data
    - Classified with weather/weekday-end/season/time.

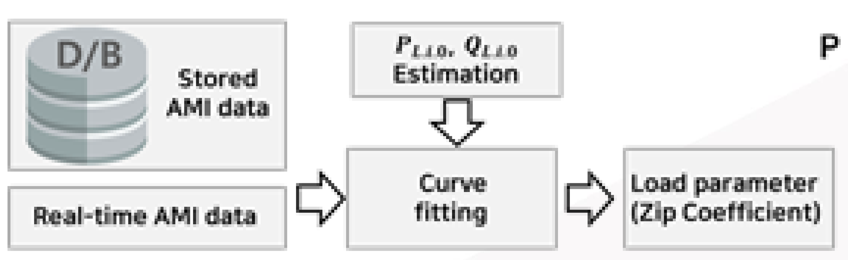


Fig. 3. Data selection/ Classification

- Basic idea about selection
  - Claculation the density of data
    - Using KDE fumction
    - Decide Yesterday data or Std. Data
- Case 1 : lower than denstity reference
  - Standard data + curren data from AMI
- Case 2 : Higher than density reference
  - Yesterday data + curren data from AMI

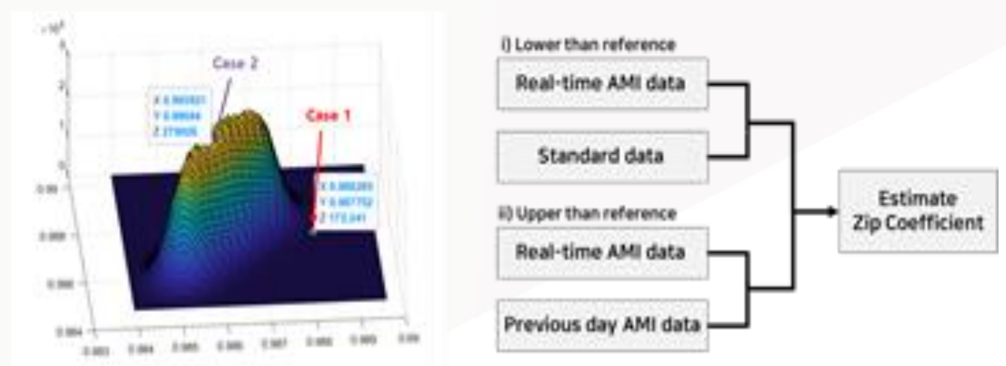
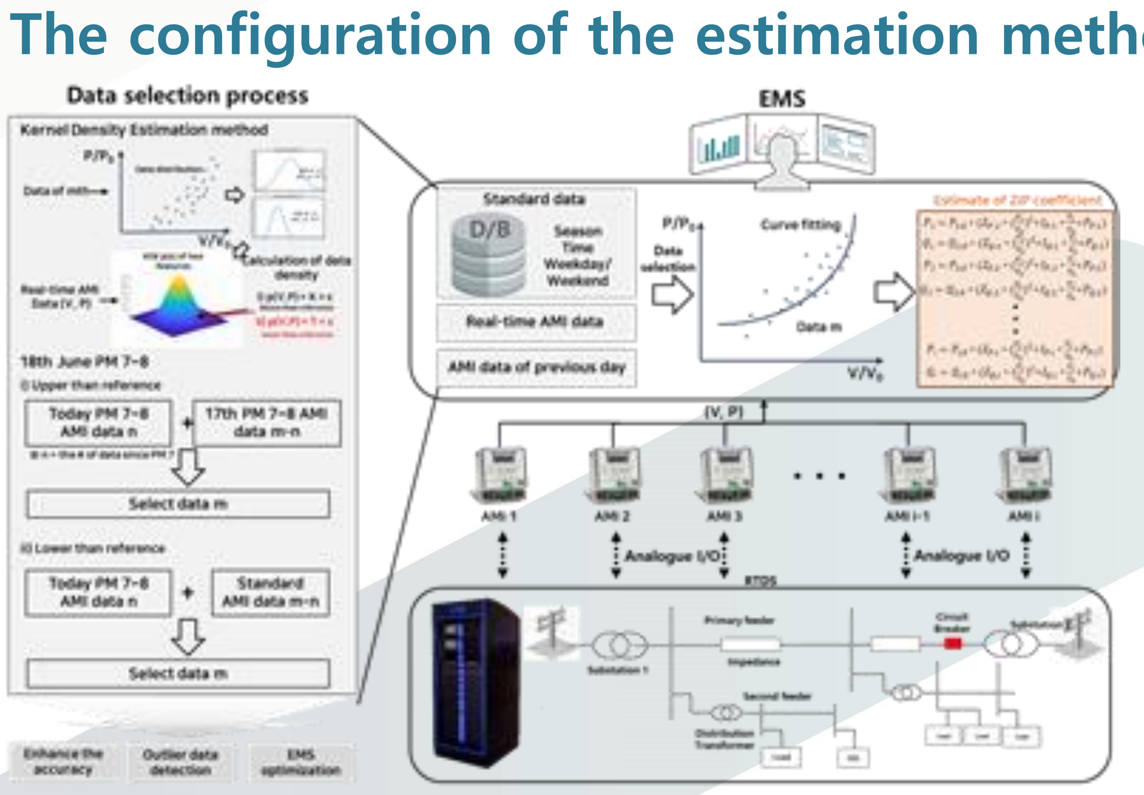


Fig. 4. Data selection Process

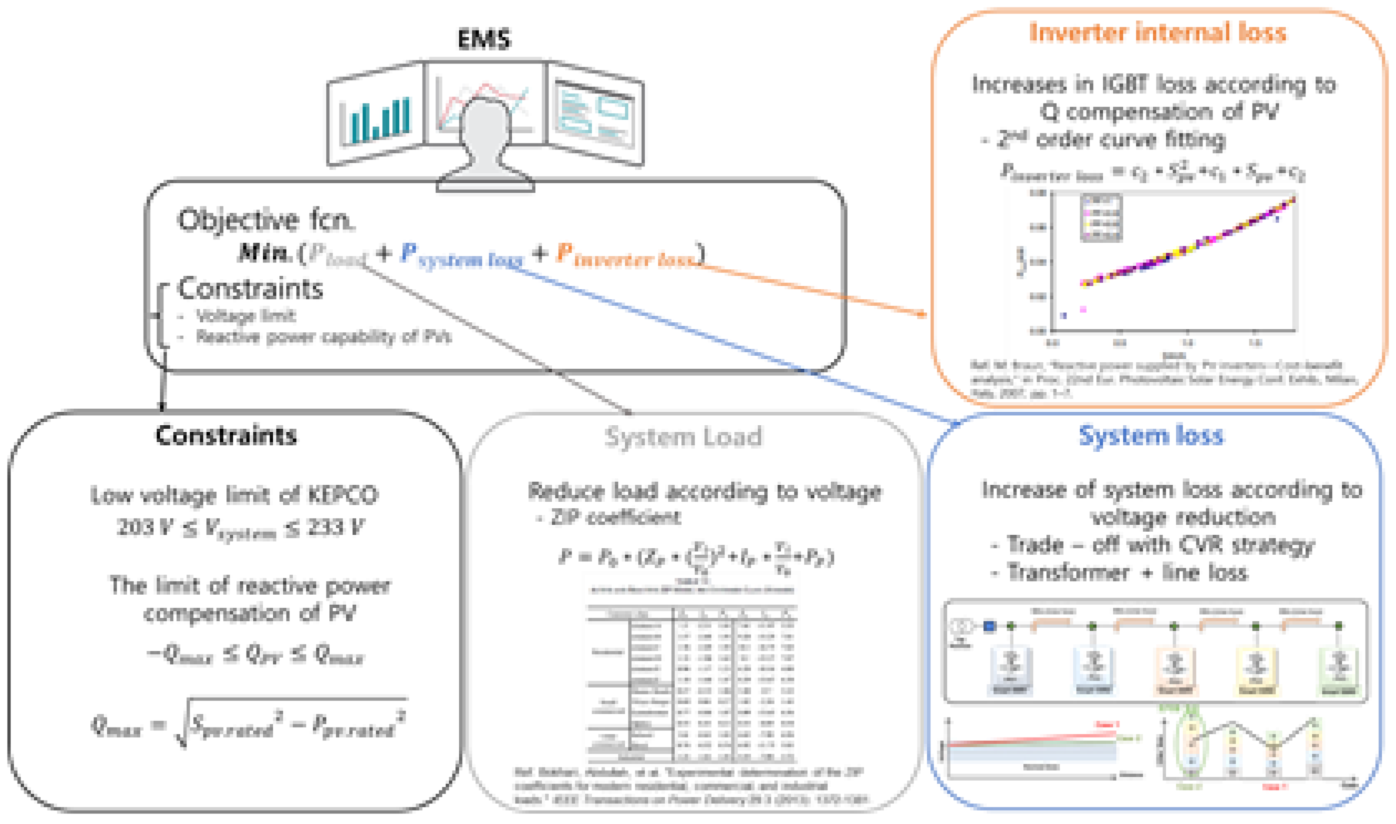
The configuration of the estimation method



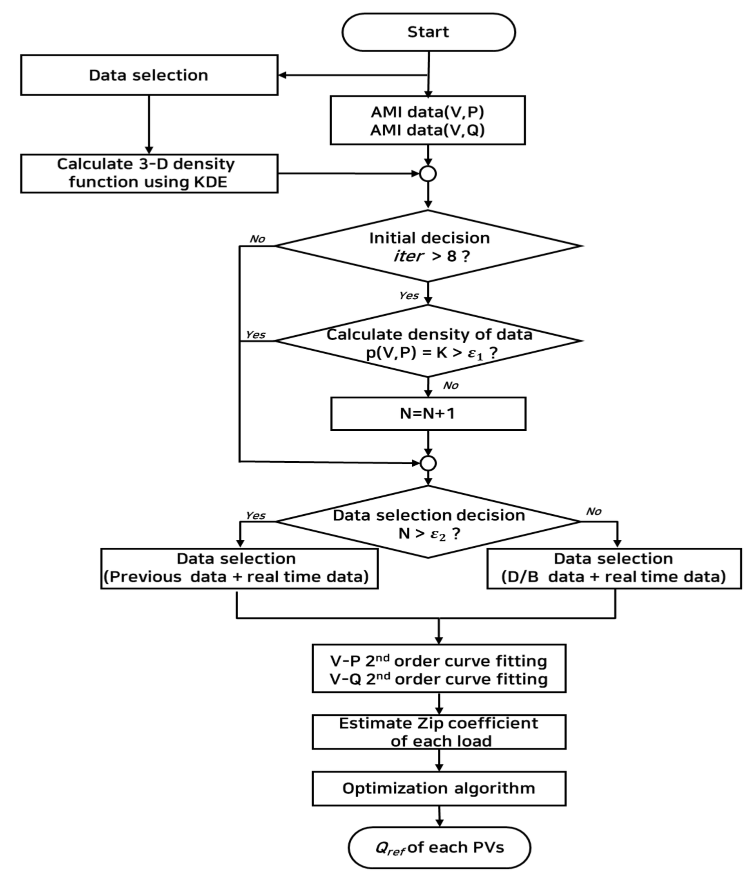
Proposed Control Strategy

Optimization method for energy saving

- Minimize the sum of Load, Line loss and Inverter loss



Flow chart of Strategy



Real time Validation Platform

HILs platform (C-HILs + P-HILs)

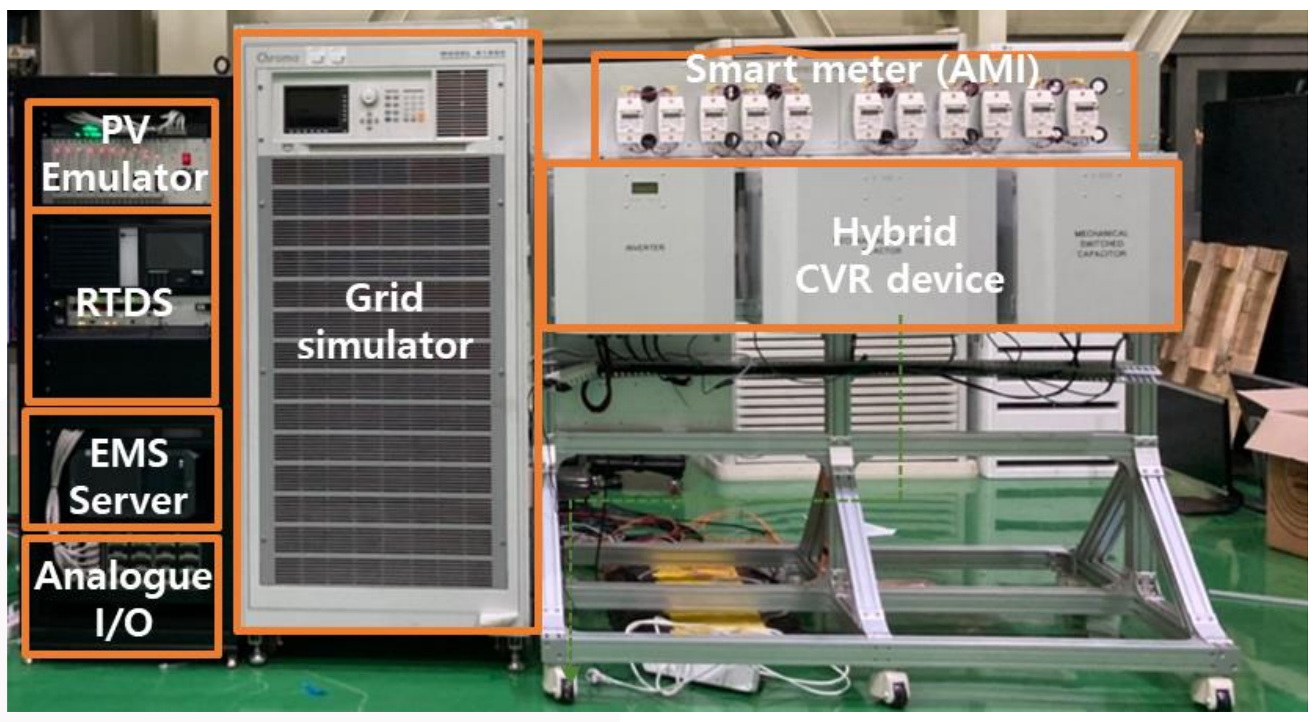


Fig. 5. The integrated HILs platform

Fig. 6. Monitoring systems of the platform

Component		Communication method
RTDS	EMS server	DNP 3.0
	PV emulator	Analogue I/O
	Grid simulator	Analogue I/O
	Hybrid CVR device	Analogue I/O
	Smart meter (AMI)	Analogue I/O
EMS server	PV emulator	IEC 61850 TCPIP
	Hybrid CVR device	Modbus TCPIP
	Smart meter (AMI)	Modbus RS485

Fig. 7. Communication methods

Case Study

System Configuration

- 48kW 12 Load (pf : 0.91~0.98)
- 8 PV(3kW - 6kW)

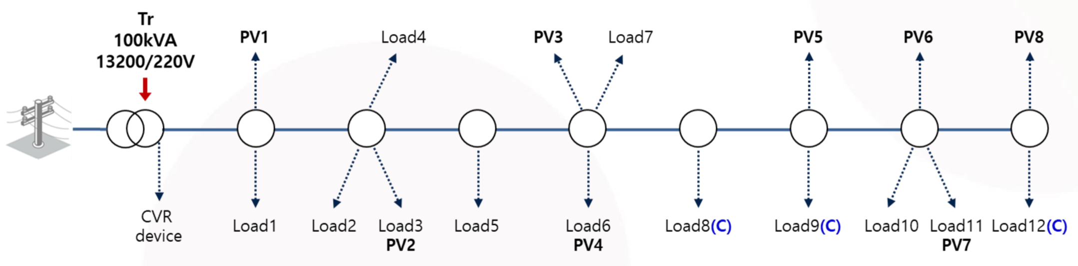


Fig. 8. System Configuration

Case result

- Winter – Weekday – Sunny
- 21.82 kWh(2.08%) saving

CVR On/Off	Type	Energy Saving
CVR Off	Total daily energy consumption	1,051 [kWh]
	Total daily energy consumption	51.26 [kWh]
CVR On	Daily energy reduction of load	29.44 [kWh]
	Daily energy increase of system loss	7.62 [kWh]
	Daily energy reduction	21.82 [kWh]
	Daily energy reduction rate (Daily energy reduction with CVR / Total daily energy consumption without CVR)	2.08 [%]

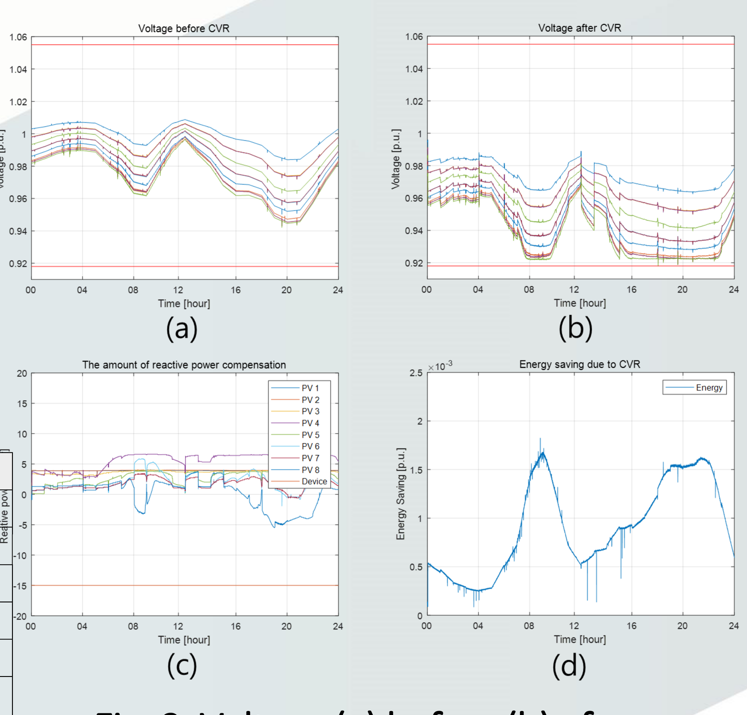


Fig. 9. Voltage (a) before (b) after CVR, (c) Q of PVs (d) energy saving

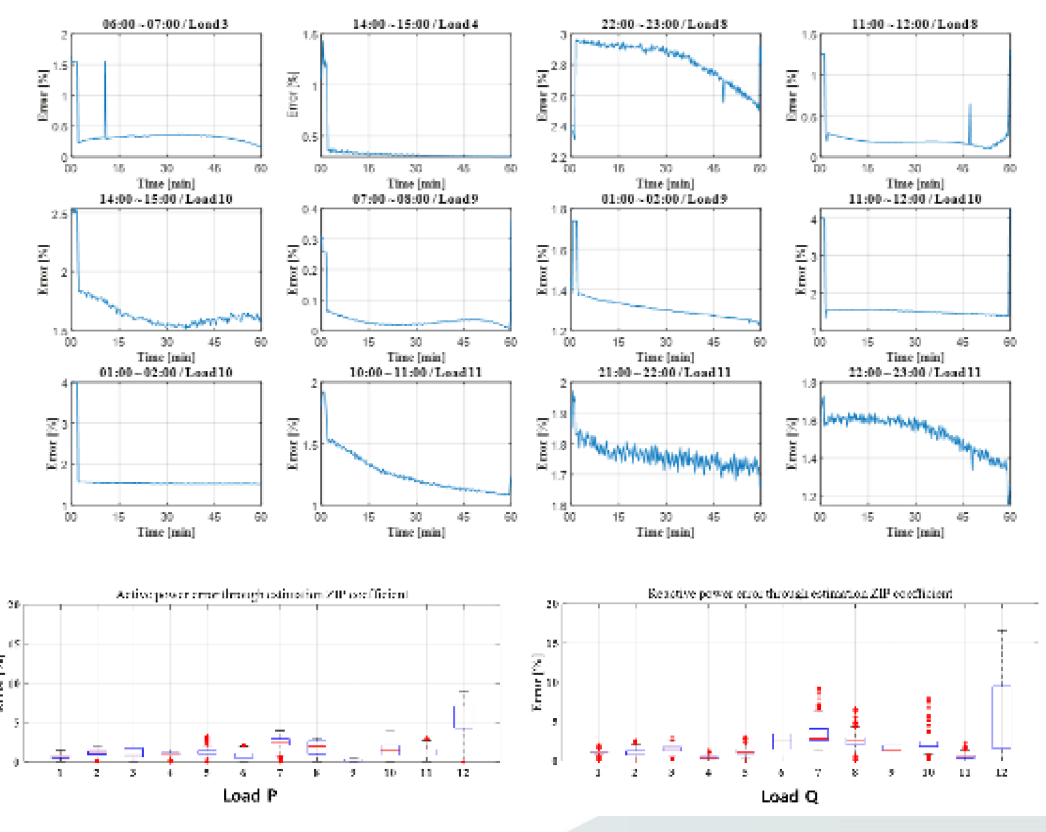
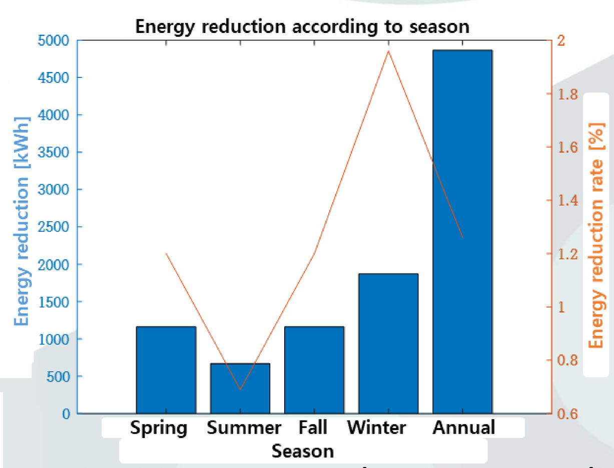


Fig. 10. Errors of ZIP parameter

Conclusion



- 4.9MWh(1.26%) of energy saving per year
- The performance is the highest in winter
  - Heating load

Fig. 11. Energy reduction according to season

	Spring	Summer	Fall	Winter	Annual
Energy reduction [kwh]	1160.9	668.1896	1160.9	1871.48	4864.47
Energy reduction rate [%]	1.20	0.69	1.20	1.96	1.26