C6 PS1

ACTIVE DISTRIBUTION SYSTEMS AND DISTRIBUTED ENEGY RESOURCES

10311_2022

Control Strategy of Conservation Voltage Reduction for Energy Saving in Low-Voltage Distributed Network

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Introduction

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

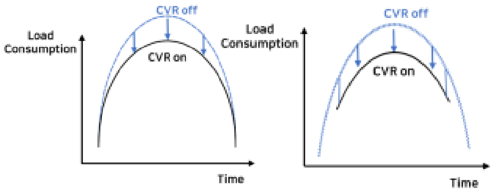

Fig. 1. Conservation voltage reduction

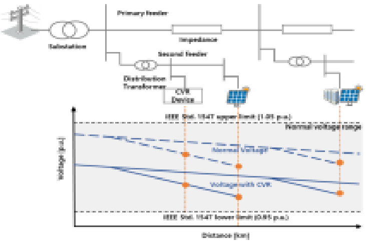

Fig. 2. Conservation voltage reduction in distributed network

Approach

- Voltage dependent load modeling
  - Static Load Model

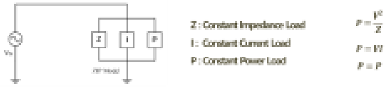

Fig. 3. ZIP model

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

$$Q = Q_0 * (Z_Q * (\frac{V_i}{V_0})^2 + I_Q * \frac{V_i}{V_0} + P_Q)$$

$$Z_P + I_P + P_P = 1 \quad Z_Q + I_Q + P_Q = 1$$

CVR Factor(load characteristic)

- Rate of change of active power according to voltage change

$$CVR_f = \frac{\%\Delta P}{\%\Delta V}$$

- Accurate CVR_f is required to evaluate the effectiveness of CVR
- Load classification
  - Residential, Commercial, Industrial
  - Time, Weather, Weekday-end, Season

Load parameter estimation

- Estimate the load parameter accurately
  - System instability (Voltage violation)
  - Increase system loss
  - To evaluate the performance of CVR
- The truth change of power by CVR
  - The change due to other factor
    - Light real on/off....

Load parameter estimation method

- Comparison-based method
- Synthesis-based method
- Regression-based method
- **Simulation-based method**

Simulation based method

- Compare the power flow(CVR-off) and measured data(CVR-on)
- The accurancy of system modeling is important
  - Load characteristic
  - Time
  - Weather and etc...

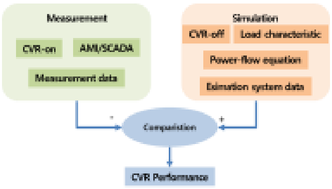

Fig. 5. Simulation based method

Estimation method for ZIP coefficient

- Using the equation between power and voltage

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

$$\downarrow$$

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

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Estimation method for ZIP coefficient

- Using curve fiting method with volatge($\frac{V_t}{V_0}$), power($\frac{P}{P_0}$) from AMI
- Need $P_{Li,0}$(t) which is the power when voltage is 1 p.u.

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

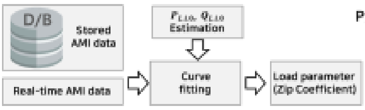

Fig. 6. Estimation selectiom Process

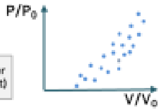

Fig. 7. Curve fitting method

Data selection process

- Case 1 : lower than denstity reference
  - Standard data + curren data from AMI
- Case 2 : Higher than denstity reference
  - Yesterday data + curren data from AMI

Fig. 10. Data selection process

Data acquition decision

- 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

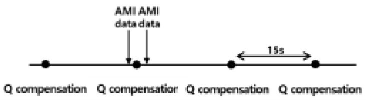

Fig. 8. Data acquition point

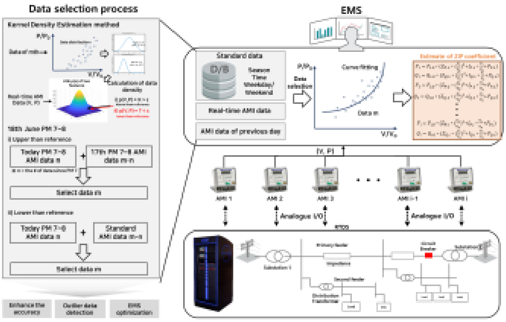

Fig. 11. The configuration of the estimation method for ZIP coefficient

- Assume that the load characteristic of today is similar with yesterday
- If not, use standard data which is classified with weather/weekday-end/season/time.
- The density of data is calculated with KDE function, and it is used to decide which data will be used. (yesterday or standard data)

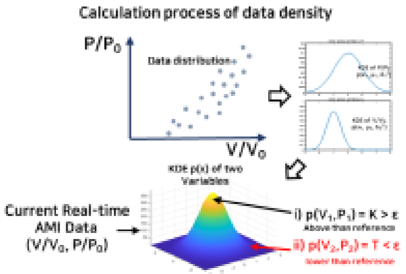

Fig. 9. Calculation process of data density

Optimization method for energy saving

- Voltagw dependent load + system loss + PV inverter loss

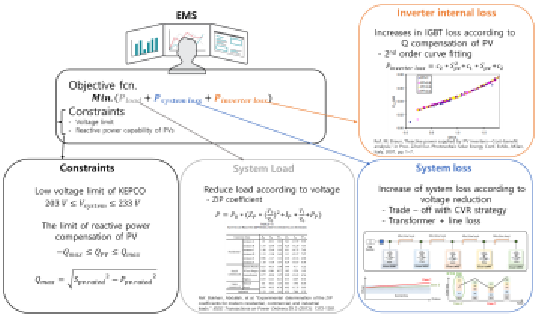

Fig. 12. The optimization method for enegy saving

Control Strategy of Conservation Voltage Reduction for Energy Saving in Low-Voltage Distributed Network continued

Control strategy

- Flow chart of the strategy (15s period)

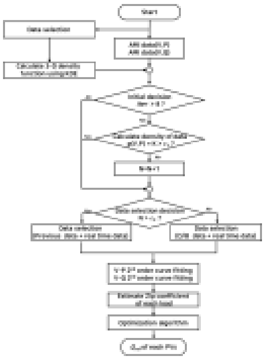

Fig. 13. Flow chart of the strategy

Verfication platform

- HILs platform(C-HIL + P-HIL)

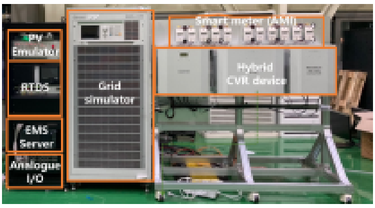

Fig. 14. The HIL platform for verification

Table 1. Communication methods between the components

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

Monitoring system

- (a) overall system and essential information for system operator
  (b) shows the AMI and PV active/ reactive power data
  (c) status of the additional reactive power compensation device
  (d) the operation result of the proposed CVR strategy

Fig. 15. Monitoring system of the platform

System configuration

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

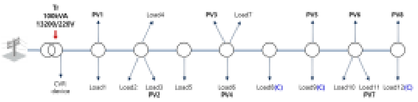

Fig. 16. System configuration

Simulation result

- Winter – Weekday – Sunny
  - 21.82 kWh(2.08%) energy reduction

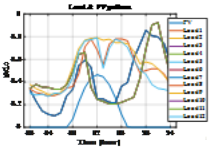

Fig. 17. PV & load ratio

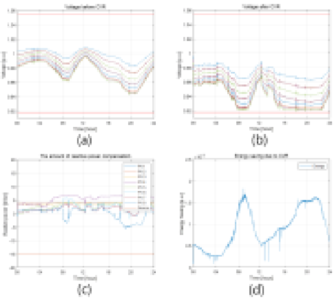

Fig. 18. Voltage (a) before (b) after CVR, (c) Q of PVs (d) energy saving

Table 2. CVR result

CVR On/Off	Type	Energy Saving
CVR Off	Total daily energy consumption	1,051 [kWh]
CVR On	Total daily energy consumption	51.26 [kWh]
	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 [%]

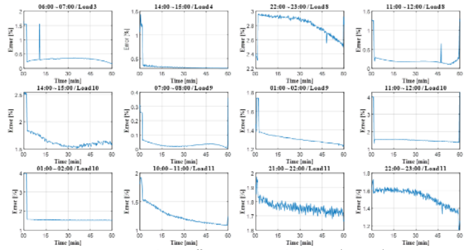

Fig. 19. Estimated ZIP coefficient error according to time(iteration)

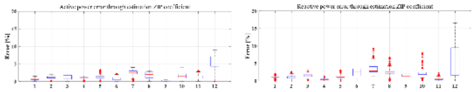

Fig. 20. The estimated ZIP coefficient error of P and Q

Conclusion

Table 3. CVR performance 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

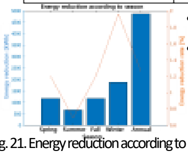

Fig. 21. Energy reduction according to season

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