Condo Power Interchange by Virtual Synchronous Generator

August, 2019

Yuko Hirase* (Toyo University)
Kenichi Sakimoto (Kawasaki Heavy Industries, Ltd.)
I. Backgrounds  what is “stable grid?”

Stable Grid

Unstable grid

Cause of Instability (Load, Renewables) without inertia/synchronization

Cause of stabilization (Sync. Gen.) with inertia/Synchronization
I. Backgrounds

VSG (Virtual Synchronous Generator)

Challenge: realize both the introduction of renewables and the grid stabilization

Increase INVs with virtual inertia ⇒ increase total inertia ⇒ stable grid
I. Backgrounds

APM (autonomous Power Management)

NG 1

VSG

BAT

Power ref

Hydrogen

conventional

APM

Power ref

NG 2

VSG

BAT

Power ref

Hydrogen

conventional

APM

Power ref

Without Hierarchical control and Mutual communication

NG 3

VSG

BAT

Power ref

Hydrogen

conventional

APM

Power ref

Power ref
I. Backgrounds  
APM (autonomous Power Management)
II. Control method  MG configuration
II. Control method  VSG control

1. P-F Control

Active Power Command
\[ P^* \rightarrow \frac{K_P}{1+sT_P} \Delta \omega_r \rightarrow f \]

Reactive Power Command
\[ Q^* \rightarrow \frac{K_Q}{1+sT_Q} \rightarrow H_{AVR}(s) \rightarrow \text{PI} \rightarrow \delta \]

Governor, Inertia
\[ \omega_N \]

Variation of Rotor Angular Velocity
\[ \Delta \omega_r \]

Reference of Rotor Angular Velocity
\[ \omega^*_r \]

Generator Phase Angle
\[ \delta \]

Impedance model

2. Q-V Control

Reactive Power Command
\[ Q \]

Active Power Command
\[ P \]

Power Calculation
\[ V_g = |V_g| = \sqrt{v_d^2 + v_q^2} \]

Inverter Voltage
\[ v_d, v_q \]

Inverter Current
\[ i_d, i_q \]

3. Impedance Model

 PLL, \( dq \) Transform

Current Feedback Control
\[ i_d^*, i_q^* \]

Current
\[ \theta \]

Voltage

PWM

Active Power Command
\[ P^* \rightarrow f \]

Reactive Power Command
\[ Q^* \rightarrow H_{AVR}(s) \rightarrow \text{PI} \rightarrow \delta \]

Governor, Inertia
\[ \omega_N \]

Variation of Rotor Angular Velocity
\[ \Delta \omega_r \]

Reference of Rotor Angular Velocity
\[ \omega^*_r \]

Generator Phase Angle
\[ \delta \]

Impedance model

1. P-F Control

\[ E_f = E_f \]

2. Q-V Control

\[ V_g^* = 1 \text{pu} \]

\[ V_g = |V_g| = \sqrt{v_d^2 + v_q^2} \]
II. Control method

Battery/FC outputs control in APM

**Cmd to Battery**

SoC<sub>ref</sub> + ΔSoC → SoC

\[ P_{BAT}^* \]

ΔSoC → SoC

\[ -G_{BAT}(s) \]

**Cmd to FC**

R<sub>p</sub> (Change rate from \( P_{MG}^* \))

\[ G_{FCp}(s) \]

R<sub>f</sub> (Change rate from \( F_{MG}^* \))

\[ G_{FCf}(s) \]

1

\[ Ts \]

Max.

Min.

ΔF

\[ F_{ref} \] (Reference of \( F_{MG}^* \))

\[ F_{MG} \]

\[ P_{MG} \]
II. Experimental condominiums

Osaka Gas conducts experiments on introducing SOFC in actual homes at the NEXT21, an experimental residential complex built by Osaka Gas.

II. Experimental condominiums

http://www.osakagas.co.jp/company/efforts/next21/system/system2.html (in Japanese)
II. Results  Equipment (FC and VSG INV)

ENE · FARM type S
- 200V 1p3w
- generate power 50～700W
- grid connected (conventional current control)
- stand-alone is OK (use designated outlet) ← unused

VSG INV + Battery
- 1p3w(100V/200V)
- rated output 4kW
- Built-in Li-ion battery (4.2kWh)
- VSG control by INV
- stand-alone and parallel run are OK
II. Results  results in 3 residences (50min)

FC at NG3 preferentially powers LD in NG3

※FC出力の増減レートはAPMの制御に依存
II. Results

results in 1 residence (5 days)

- Frequency (Hz)
  - Values range from 59 to 61 Hz

- Power (W)
  - Values range from 0 to 3 kW

- SoC (%)
  - Values range from 0 to 90%

- Time (HH:MM)
  - Days:
    - Mon.
    - Tue.
    - Wed.
    - Thu.
    - Fri.
    - Sat.
    - Sun.

- SoC (Theoretical value)

- Demand
- FC (Fuel Cell) generate power
- BAT (Battery) charge/discharge
II. Results

Simulation of 5 residences using actual remand data (5 days)

- Red: Actual demand of 1 residence with VSG battery (Partially load limited)
- Other than red: Actual demand of 4 residences connected to the commercial (without load limited)
- Orange: Parallel running with VSG of 5 residences using actual demand
- Other than orange: Each residence run in stand-alone with VSG using actual demand

Graphs showing LD Power (W), SoC (%), and Frequency (Hz) over time (HH:MM) from Thursday to Tuesday.
Demonstration tests

In order to **confirm the effectiveness of blockchain technology in inter-individual power transactions**, demonstration tests are planned using the resident's real-life environment.

Press release “Improvement of energy security and power transactions”

Surplus power generated by distributed energy systems will be able to **freely buy and sell without using power retailers**. Blockchain technology is expected to be effective in managing such trading.


http://www.osakagas.co.jp/en/whatsnew/1281331_11886.html (only title)
IV. Future outlook

http://www.osakagas.co.jp/en/whatsnew/1281331_11886.html (only title)
Thank you for your kind attention.

Inquiry

Yuko HIRASE
Toyo University

Kenichi SAKIMOTO
Kawasaki Heavy Industries Ltd.