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# Annex IX (Japan)

# Outline of Variable Speed Pumped Storage Hydropower System and Ancillary Service in Japan

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Variable-Speed Pumped-Storage Hydropower system (VS-PSH) has the ability to arbitrarily control rotational speed of rotor

➡ Wider frequency adjustment range than CS-PSH in ancillary service

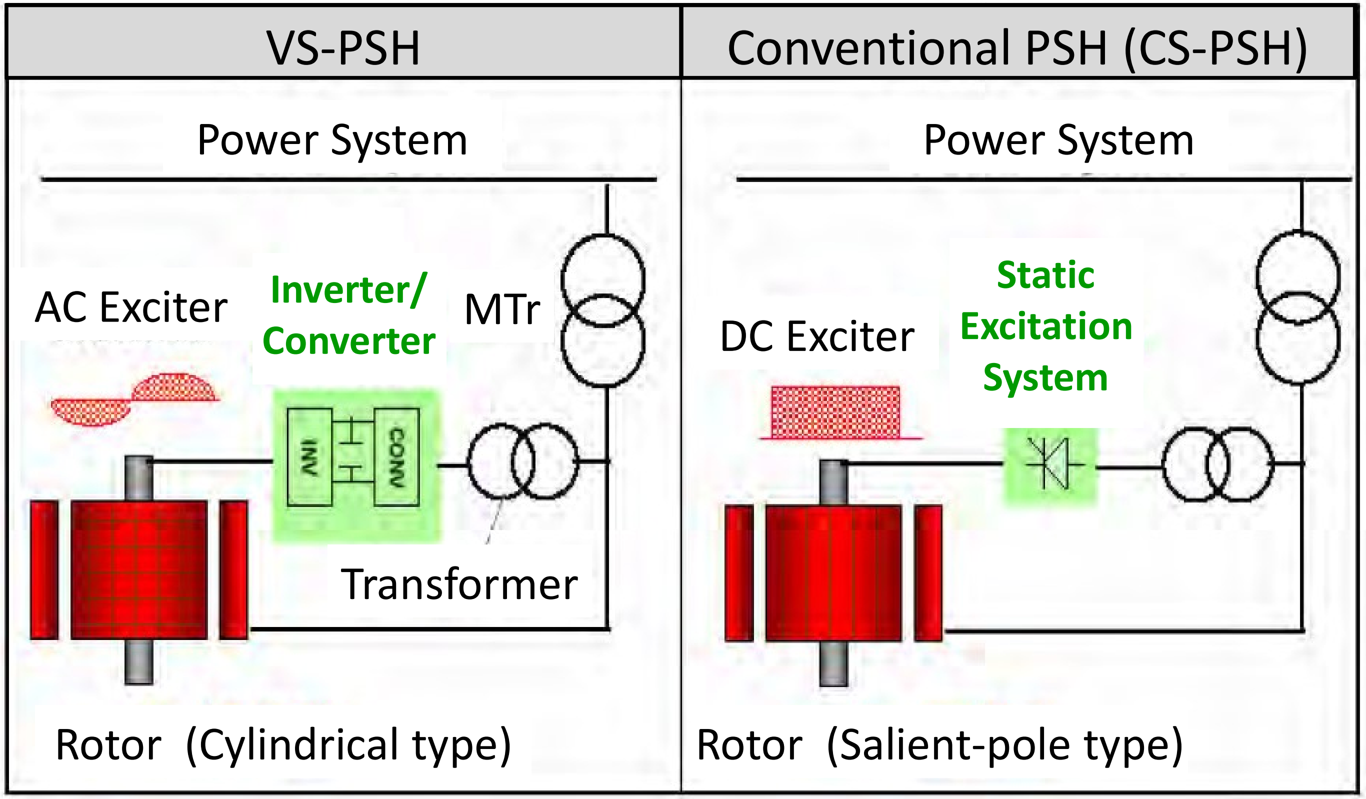


Fig .1 Comparison of constant-speed and variable-speed pumped-storage hydropower systems

※Reference for page 1-1 ,1-2,1-3,1-4,1-5 :
・JICA Report 2012.1 , Final report of investigation about VS-PSH technology , JICA, TEPCO, TEPSCO

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# Fig .3 Comparison of VS-PSH and CS-PSH generation systems.

| | CS-PSH | VS-PSH | Remarks |
|---|---|---|---|
| Reservoir capacity | Almost equal | | VS-PSH can operate at lower water level than CS-PSH |
| Space for underground power station | 100% | 105% | Additional space is necessary for rotor and converter in VS-PSH |
| Cost of electrical equipment | 100% | 140% | Additional cost is necessary for rotor and excitation system in VS-PSH |
| Turbine efficiency | Standard | At maximum output: +0.5%; at intermediate load hours: +2.5% | Rotational speed control makes high efficiency operation possible in VS-PSH |
| Range of generating operation | 50-100% | 30-100% | Improved turbine efficiency in VS-PHS expands operation range |
| Range of pumping operation | Constant | 70-100% | Operation range can be controlled in VS-PHS (turbine input is proportional to the speed cubed) |
| Output response speed (at normal operation) | 0-100%/60sec | 0-100%/60sec | CS-PSH operation is dependent on turbine characteristics. VS-PSH can be electrically controlled making response to command quicker |
| Output response speed (at transient operation) | Unable to change | 20MW/0.1sec | High speed conversion from inertial energy to electrical energy is possible in VS-PHS |

Although it is more expensive to construct VS-PSH than CS-PSH, the advantages are improved frequency control by expanded operation range and high speed response.

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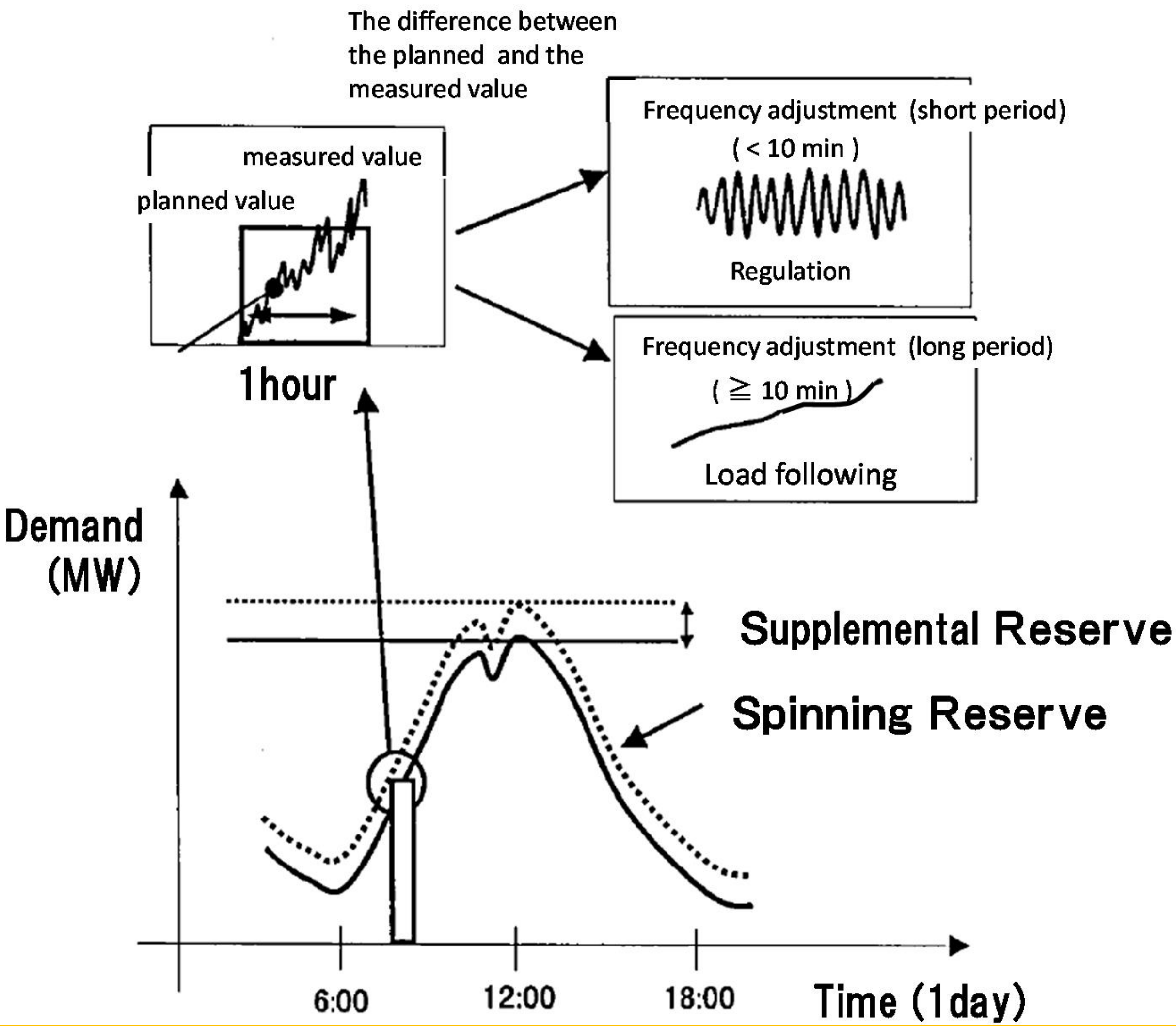
# Fig. 5 Ancillary service by supply and demand balancing




Daytime: both thermal and hydro generators are used to absorb fluctuation over long and short periods.
Nighttime: both thermal and hydro generators are used to absorb fluctuation over long periods.
Short period fluctuations during nighttime have been absorbed by thermal generators.
VS-PSH can replace thermal to reduce thermal reserves.

# Cost recovery of pumped storage hydropower generation (Japan)

At present, pumped storage hydropower generation cost is recovered in wheeling charge.

Points:

①Cost-based expenditure is calculated.

②Expenditure is classified as “power system adjustment fee” (ancillary service fee) with hydropower generation.

③In addition, the ancillary service fee is charged to the customer to recover the cost, corresponding to the voltage level of each contract.
The government approves the wheeling charge (including the ancillary service charge) in each contract.

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# Evaluation of Japanese Hydro PS ' Ancillary Service (5)

– Step3: Calculate the unit ancillary cost for each type of hydro PS in the order of Group A, B and C

(Assumption formula) $C_T = A_X \cdot W_X + A_Y \cdot W_Y + A_Z \cdot W_Z$ ･･･①

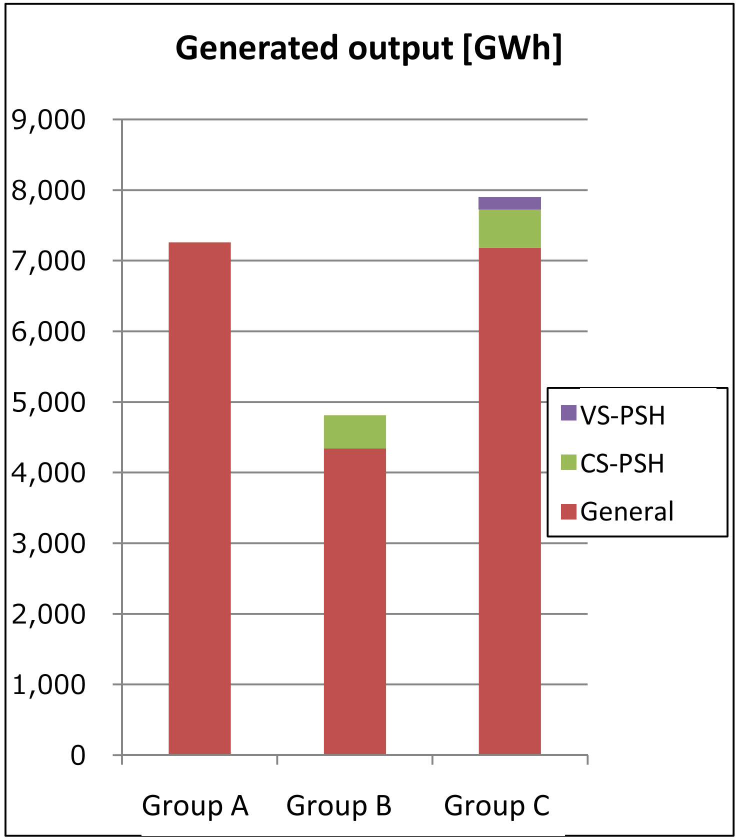
- Group A: To calculate unit ancillary cost provided by general hydro PS, $C_T, W_X$ of Group A and $W_Y = 0, W_Z = 0$ are substituted into the assumption formula which yields
  $\underline{A_X = 0.15[\text{yen/kWh}]}$ ･･･(1)

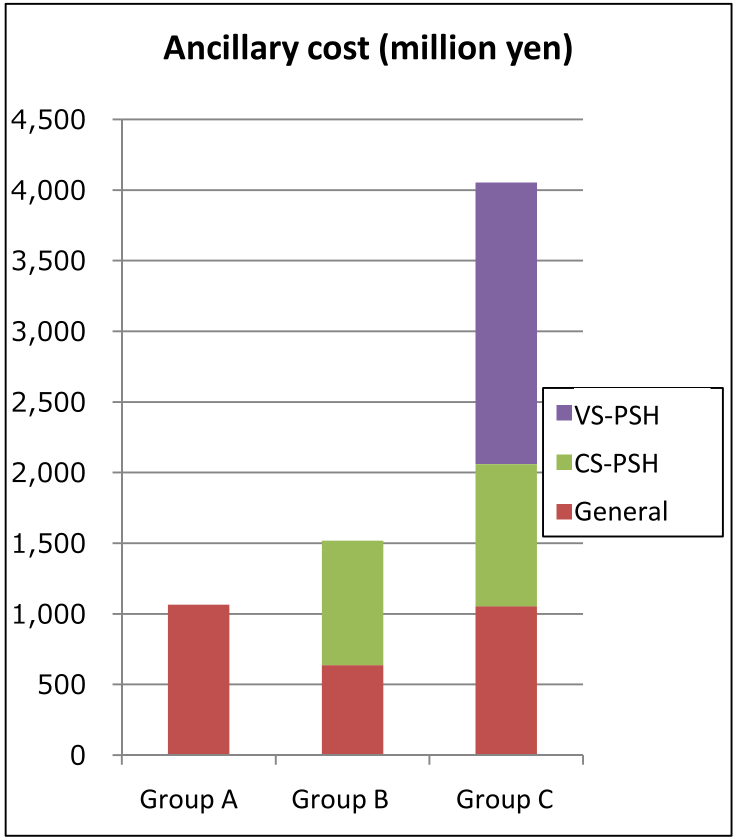
- Group B: To calculate unit ancillary cost provided by CS-PSH based on (1), $C_T, W_X, W_Y$ of Group B and $A_X = 0.15, W_Z = 0$ are substituted into the assumption formula which yields
  $\underline{A_Y = 1.86[\text{円/kWh}]}$ ･･･(2)

- Group C: To calculate unit ancillary cost provided by VS-PSH based on (1) and (2) $C_T, W_X, W_Y, W_Z$ of Group C and $A_X = 0.15, A_Y = 1.86$ are substituted into the assumption formula which yields
  $\underline{A_Z = 11.18[\text{円/kWh}]}$

# Evaluation of Japanese Hydro PS ' Ancillary Service (7)

- Calculation results
  - Comparison of average generated output and average ancillary cost among different hydro PS types in each group of utilities

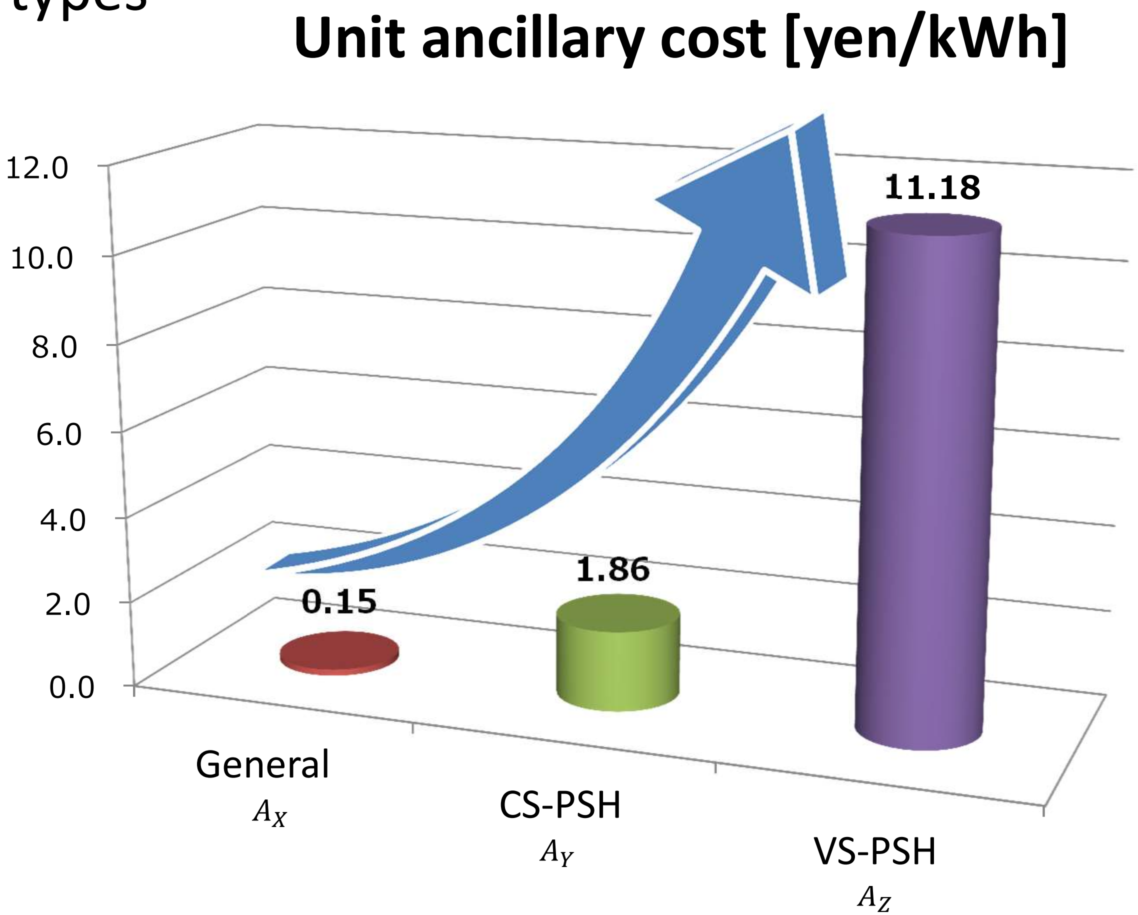



- Ancillary cost of different hydro PS types are compared against respective generated output
- Compared with general hydro PS, pumped storage PS are more valuable because ancillary cost per unit generated output is higher
- Especially VS-PSH stations are valuable among pumped storage hydro PS

# Evaluation of Japanese Hydro PS' Ancillary Service (8)

- Discussion of calculation results
  - Comparison of unit ancillary cost among different hydro PS types




- Unit ancillary cost is calculated for each type of hydropower stations as the cost per unit generated output [yen/kWh]
- Unit ancillary cost is by far the highest in VS-PSH, followed by CS-PSH and general hydro PS
- Unit ancillary cost is related to the value of hydro PS of the particular generation type. Therefore VS-PSH is the most valuable type of hydro PS

# Contribution of Hydro PS to Thermal PS Ancillary Service Costs Reduction ④

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- Reduction rates of thermal PS ancillary service cost per 1kWh generated output of CS-PSH and VS-PSH are calculated as follows

(Assumption formula) $C_{TT} = \alpha_t \cdot C_{TH} - D_Y \cdot W_Y - D_Z \cdot W_Z$ ･･･②

- Group A:To calculate $\alpha_t$,

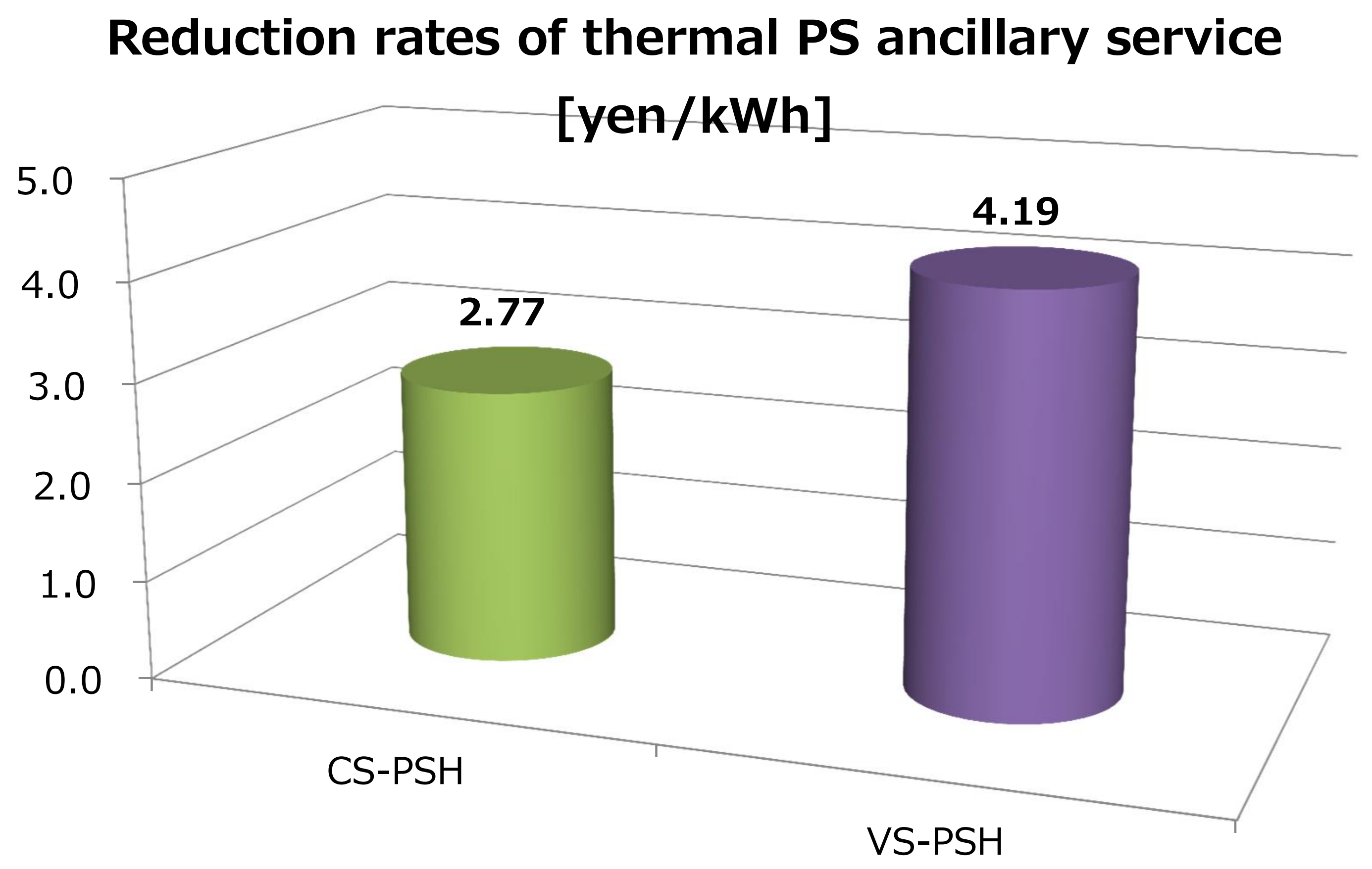
  $C_{TT}, C_{TH}$ of Group A and $W_Y = 0, W_Z = 0$ are substituted into the assumption formula which yields
  $\alpha_t = 3.67$･･･(1)
- Group B:To calculate $D_Y$ based on (1),

  $C_{TT}, C_{TH}, W_Y$ of Group B and $\alpha_t = 3.67, W_Z = 0$ are substituted into the assumption formula which yields
  $D_Y = 2.77$[yen/kWh]･･･(2)
- Group C:To calculate $D_Z$ based on (1) and (2),

  $C_{TT}, C_{TH}, W_Y, W_Z$ of Group C and $\alpha_t = 3.67, D_Y = 2.77$ are substituted into the assumption formula which yields
  $D_Z = 4.19$[yen/kWh]

# Contribution of Hydro PS to Thermal PS Ancillary Service Costs Reduction ⑤

- Reduction rates of thermal PS ancillary service cost per 1kWh generated output of CS-PSH and VS-PSH



# Thank you