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Capacity and Rotational Speed Determination of Superconducting Flywheel Energy Storage System for Peak Reduction in an Urban Railway System

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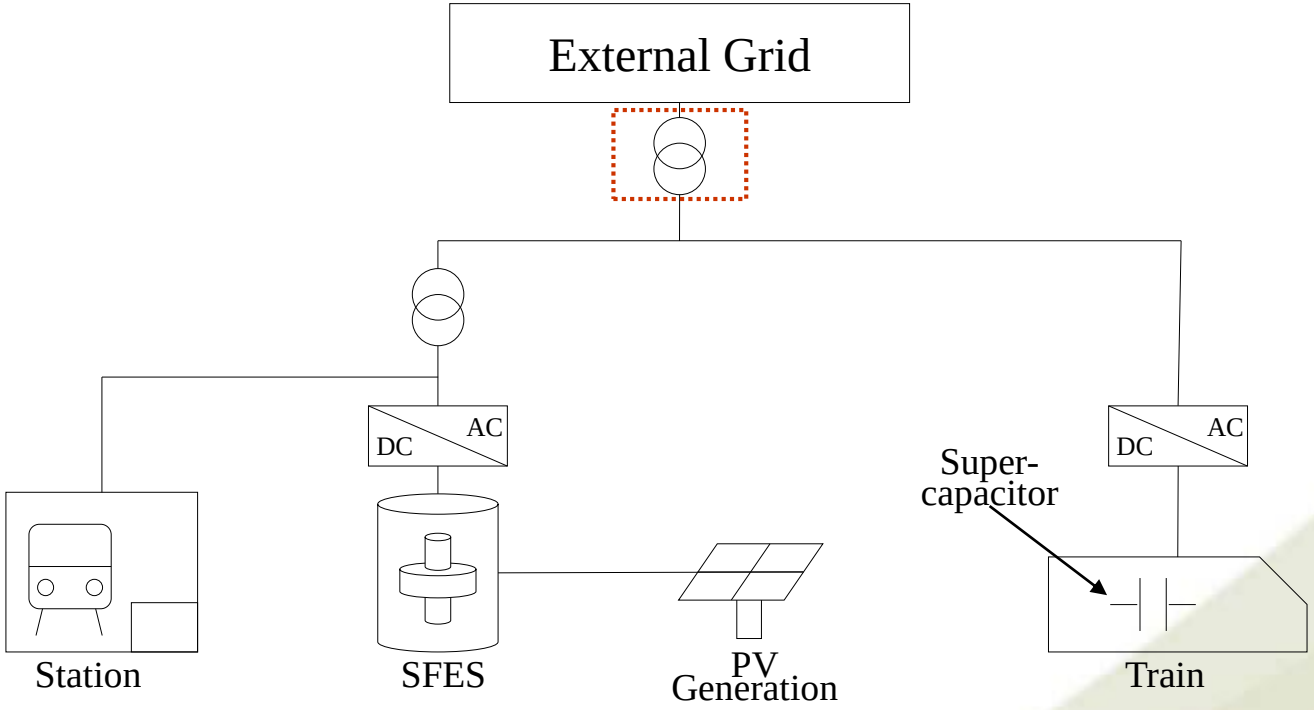
Introduction

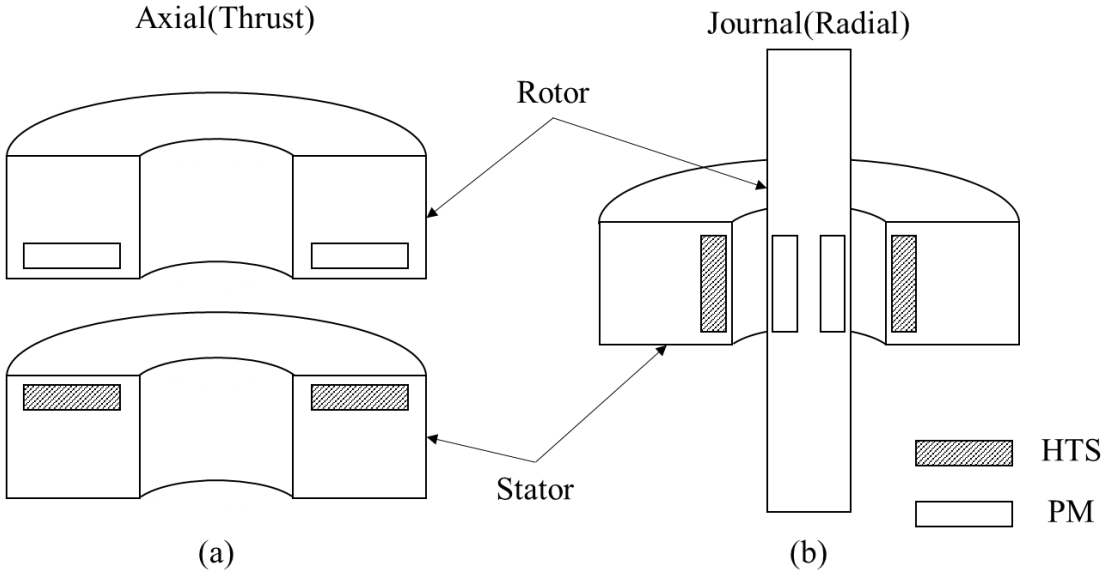
- Since peak load of an urban-railway-system steeply increase, peak reduction is essential to operation
- A methodology is required for efficiently utilizing the generated electricity from the PV generation due to a characteristic of the urban railway, wherein the peak power generation time does not coincide with peak of the railway system power generation time
- Since SFES has low losses, high energy density and long life time, peak-load reduction in urban railway systems and the efficient use of electricity from the PV panel through SFESs are both achievable
- However, SFES since the high installation cost, capacity determination is crucial. Additionally, it is important to calculate the SFES rotational speed because it has significant impact on the operational stability

Urban Railway Electric System Configuration



- SFES is installed in station to charge from both of the external grid and the PV generator
- Electricity charge is calculated on transformer with external grid

Superconducting Flywheel Energy Storage System



- SFES is FES that utilize superconductor magnetic bearing (SMB)
- Compared to other energy storage system, the SFES takes advantage such as the high output, energy density, and long lifetime
- Consequently, the SFES is expected to have potential application in the peak reduction which needs frequent discharging with deep DoD

SFES Intraday Scheduling

- For SFES capacity determination, an intraday SFES scheduling method is required

$$Minimize \quad \sum_{t=0}^{T} c_t P_t^{buy}$$

Balancing conditon	$P_t^{load} + P_t^{SFES} = P_t^{buy}$
SFES output limit	$P_t^{SEFS} \le P_{\max}$
Peak reduction	$P_t^{buy} \le P^{Peak}$
SoC calculation	$SoC_t = SoC_{t-1} + (P_t^{SFES} + P_t^{PV}) / Cap_{SFES}$
SoC limit	$SoC_{\min} \le SoC_t \le SoC_{\max}$

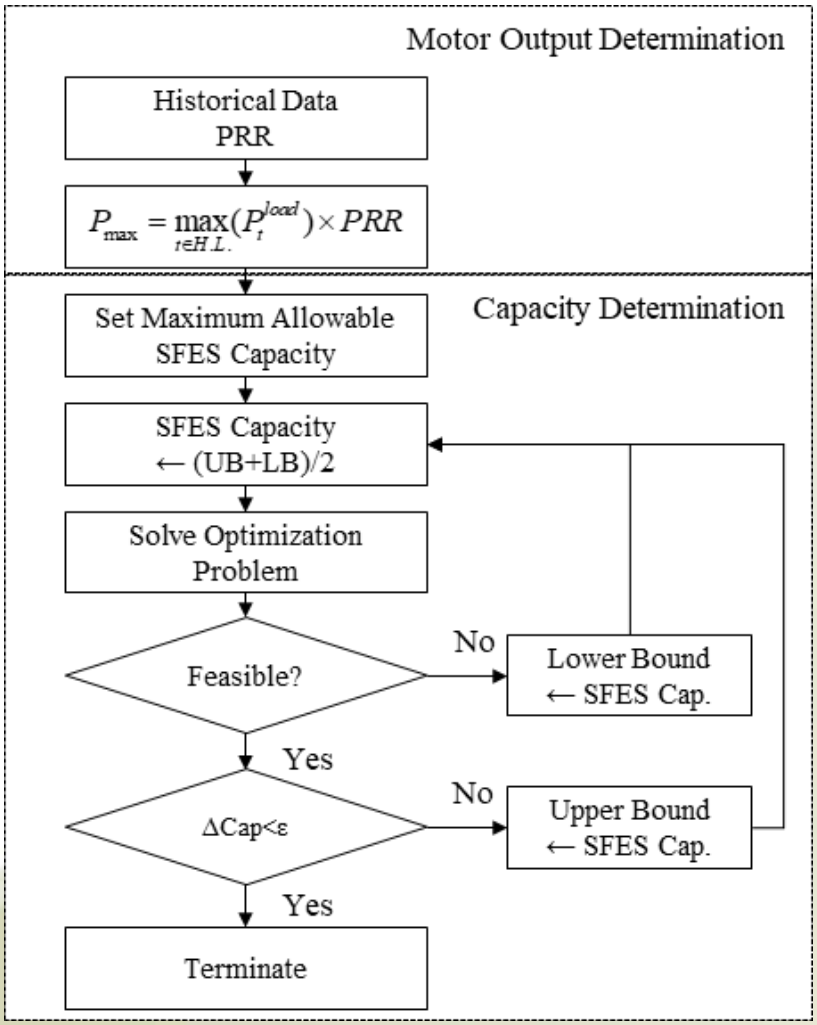
SFES Capacity Determination

- The capacity of SFES can be calculated using the historical load data of the urban railway system and the target peak-reduction
- When the desired peak-reduction is determined for the past data of a certain period, the capacity necessary for the target performance should be determined accordingly.
- There are two major decision variables involved in determination of capacities of the SFES
  1. SFES output which is related with the amount of peak reduction
  2. SFES capacity which is related with the period of peak reduction
- The output of the SFES is calculated as follows

$$P_{\max} = \max_{t \in H.L.}(P_t^{load}) \times PRR$$

SFES Capacity Determination

- Capacity of SFES is determined through the binary search method
- If the problem is infeasible
  - The SFES capacity becomes increased, since this infeasibility is due to the insufficient capacity
- If the problem is feasible
  - the capacity becomes reduced to prevent calculation of the excessive capacity
  - If ($\Delta cap < \varepsilon$), terminate;



Rotation Speed Determination

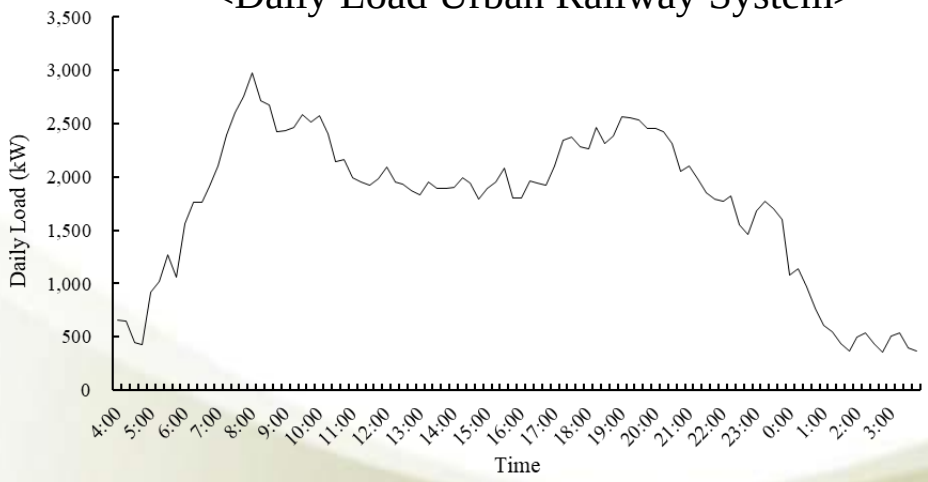
- Due to the SFES characteristic, which rotates heavy rotors rapidly, the prediction of the maximum rotational speed is critical
- After the SFES capacity is determined, the rotational speed of the rotor can be calculated according to the moment of inertia of the rotor as follows:

$$Cap_{SFES} = \frac{1}{2} I \omega^2$$

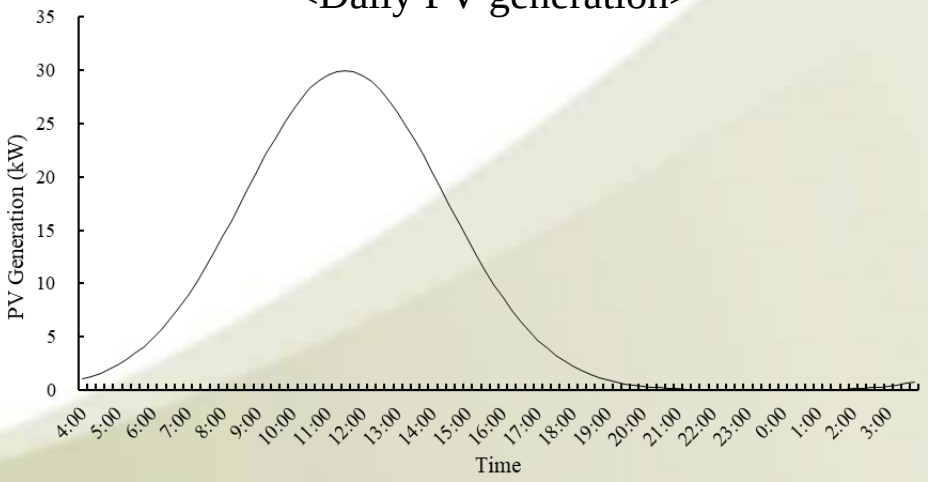
Numerical Results

- Numerical result demonstrated using the modified historical load data of the urban railway system in Korea
- Since the peak charge is calculated with 15-minute granularity of energy consumption in the Korean electricity billing system, the 15-minute interval data was used

<Daily Load Urban Railway System>

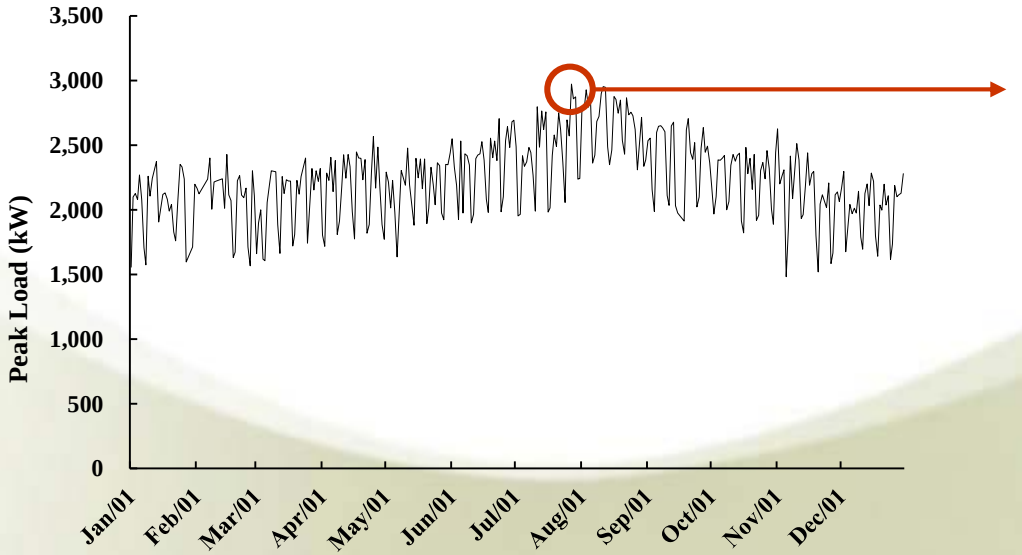


<Daily PV generation>



Numerical Results

- Figure demonstrates intraday peak load of the urban railway system. The highest peak load during the period occurred on July 27th
- with a value of 2972.4 kW. Assuming a peak reduction ratio (*PRR*) of 10%, the output of SFES was calculated to be 297.24 kW



2972.4 kW × 10 %
= 297.2 kW

Numerical Results

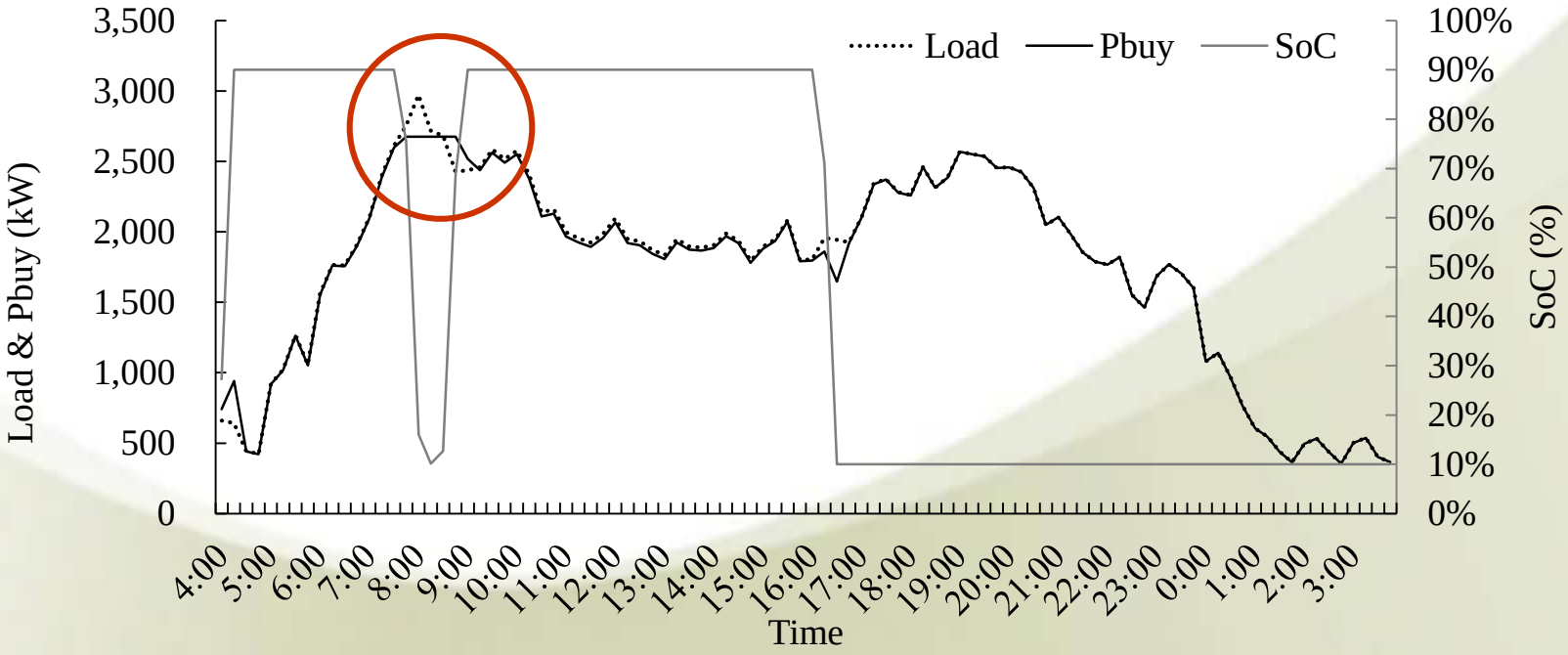
- The maximum tolerable value of the capacity of SFES was assumed to be 600 kWh which is over twice the output
- Lower bound, upper bound and SFES Capacity of each iteration are represented

Lower Bound	SFES Capacity	Upper Bound
0	300	600
0	150	300
0	75	150
75	112.5	150
112.5	131.25	150
112.5	121.875	131.25
112.5	117.1875	121.875
117.1875	119.53125	121.875
117.1875	118.359375	119.53125
118.359375	118.9453125	119.53125

Determined Capacity

Numerical Results

- Demonstrates the result of peak reduction through SFES with a capacity of 297.24 kW / 118.95 kWh
- The rotational speed when generating 118.95 kWh was measured to be approximately 6544 rpm



Conclusion

- In this paper, the output and the capacity of SFES for peak-load reduction of urban-railway-system were determined and its rotational speed was calculated
- Through the numerical result demonstrated by applying the data of the Korea urban railway system, the actually required capacity was calculated
- Thus, further researches on determination of the optimal SFES capacity in consideration of economic aspect need to be conducted