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Economic Assessment of Mobilized Thermal Energy Storage for Distributed Users: A Case Study in China

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Abstract

Mobilized thermal energy storage (M-TES) system can be an alternative of the conventional heating system to meet the heat demand for distributed users. This paper conducted a case study of the M-TES system in China. The operating strategies (OS) of the M-TES with different transportation schemes were compared. Moreover, the economic assessment was performed based on the project's net present value (NPV) and payback period (PBP). The OS with 6 trips per day is the most profitable with pay-back time of about 2, 3 and 5 years if the waste heat costs at the level of 0 €/MWh, 3300 €/MWh, and 6600 €/MWh , respectively.

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"Keywords: Mobilized thermal energy storage (M-TES); Waste heat; Operating strategy; Economic assessment"

1. Introduction

As a promising alternative to supply heat for the distributed users, the mobilized thermal energy storage (M-TES) technology is taken into our consideration in recent years [1-4]. The thermal and flow behaviors in M-TES container were studied in reference [1]. The lab scale experiment and simulation on charging and discharging performances of M-TES system were carried out in references [1, 2]. The study about integration of combined heat and power plant with M-TES was conducted in reference [3]. From

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the available literatures, it reveals the research on characteristic and performance of M-TES in lab scale has been performed. However, more work concerning the economic feasibility of M-TES system shall be done further to promote its application. In our previous study, the work on the system economic assessment in Sweden has been conducted [4]. The purpose of this study was to evaluate the prospect of M-TES and provide the reference for harnessing the M-TES in China.

Nomenclature

Abbreviation

M-TES	Mobilized Thermal Energy Storage
NPV	Net Present Value
OS	Operating Strategies
PBP	Payback Period
PCM	Phase Change Materials

Symbols

C_i	Cost at Year i
C_0	Initial Cost
I_i	Income at Year i
n	Trip Number per Day
r	Discount Rate

Subscript

i	i-th Year
0	Beginning Year

2. Description

2.1. Studied case

A six-storey residential building with area of 6500 m^2 in the north of China is chosen as the heat user. The heating load per square area is given as 65 W/m^2 according to the reference [5]. The total heating load of the studied case is calculated as 422.5 kW during the 180 days of heating period. The exhaust steam generated from the local coking plant is utilized as the heat source. The parameters of the exhaust steam are presented as: pressure 0.361 MPa, temperature 140 °C and flow 10 t/h [6]. The distance between coking plant and user is about 13 km.

2.2. Operating strategy

Around 10.7 MWh of heat should be supplied everyday based on the load described above. The feasible operating strategy (OS) is to run two containers with numbers of trips per day. The two containers supply heat for users in turns and make the heating system run continuously in 24 hours. The OS comparison of M-TES system with 2, 3, 4, 6 and 8 trips per day are conducted, which is shown in Fig. 1.

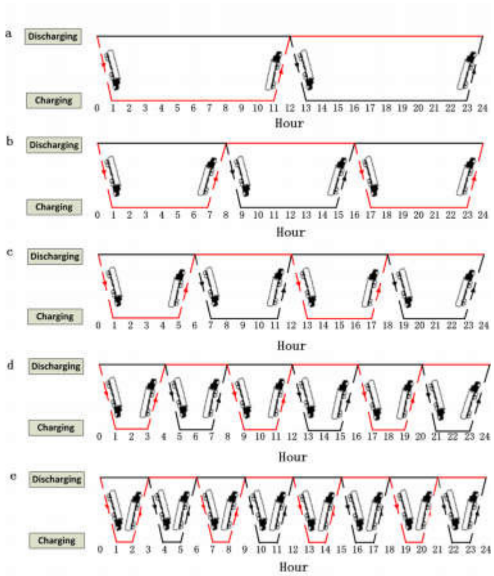


Figure 1 Five operating strategies of M-TES system with numbers of trips in 24 h: (a) n=2; (b) n=3; (c) n=4; (d) n=6; (e) n=8;

2.3. Container

As shown in Fig. 1a, each container is delivered only once a day. Hence, the capacity of each container is around 5.4 MWh. The cubic M-TES container is designed with 70% of PCM and 30% of thermal oil. If taking the M-TES efficiency (80%) [3] into consideration, the volume of container is about 42 m^3.

The container is designed based on the test rig in experiment [1]. As such, the container mass can be calculated as 64.32 t. The volume and mass details about containers in other OS are listed in Table 1.

Table 1 Volume and mass of M-TES container

Descriptions	Value				
OS	a	b	c	d	e
n	2	3	4	6	8
Capacity (MWh)	5.40	3.60	2.70	1.80	1.35
Container volume (m^3)	42	28	21	14	11
Container mass (t)	64.32	42.89	32.45	21.55	17.10
PCM (t)	43.5	29.0	22.0	14.5	11.4
Thermal oil (t)	9.8	6.5	4.9	3.3	2.6
Shell (t)	10.2	6.8	5.1	3.4	2.8
Pipes (t)	0.82	0.59	0.45	0.35	0.30

According to the regulation about load limits on road in China [7], the maximum load of vehicle is 49 t, which includes the load of goods, trailer and vehicle itself. Generally, the mass of trailer and vehicle adds up above 10 t. Thus, the transport loads in operating strategy a and operating strategy b are beyond the prescriptive limit, which will not be investigated further in this study.

3. Economic assessment

The capital cost mainly contains the cost of equipment components such as PCM (erythritol), thermal oil, steel plate and pipes, pumps, heat exchangers and so on. The installation cost is considered being included in the equipment cost. The prices of the above components are obtained from local dealers. The exchange rate from Euro to Chinese Yuan (CY) is regarded as 7.8135 in this study. The erythritol produced by Binzhou Sanyuan Bio-technology Company, China, costs 3200 €/t. The thermal oil YD-320 from Yantong Petrochemical Company, China, also costs 3200 €/t. The steel price is 589 €/t. The pumps and heat exchangers are chosen according to the flow rate of thermal oil, water and stream calculated based on the experiment. The initial costs of M-TES system with OS c, d and e are listed in Table 2:

Table 2 Cost of main equipment components

Description	Cost (10^4€)		
OS	c	d	e
PCM	7.0	4.6	3.7
Thermal oil	2.02	1.05	0.84
Steel plate and pipes	0.24	0.16	0.13
pumps	0.16	0.10	0.80
heat exchanger	0.30	0.20	0.18
Valve and pipe fittings	0.20	0.20	0.20
Total	9.92	6.31	5.85

The operating cost is composed of transport cost and steam cost. The transport cost includes the cost of hiring vehicles and trailers, labor, fuel, maintenance and so on. The transport cost in the daytime from 8 am to 5 pm is 0.3 €/h·t; while for night from 6 pm to the 7 am, it is 0.45 €/h·t. During the whole heating period, the transport costs of OS c, d and e are 1.93×10^4 €, 1.52×10^4 € and 1.94×10^4 €, respectively. The steam costs are assumed according to the affordable cost for the system, which can be known from the balance between income and transport cost. The different steam costs, i.e. 0, 3300, 6600 and 10000 €/MWh, are specified according to the affordable cost of system.

In China, fee is paid for space heating system by the owner of apartment, which is the main income in this study. It includes 7.68×10^{-4} €/m^2 for heating system construction and 3.46×10^{-4} €/m^2 monthly for the system operation. During 180 days of heating period, the total income of M-TES is calculated as 7.25×10^4 €.

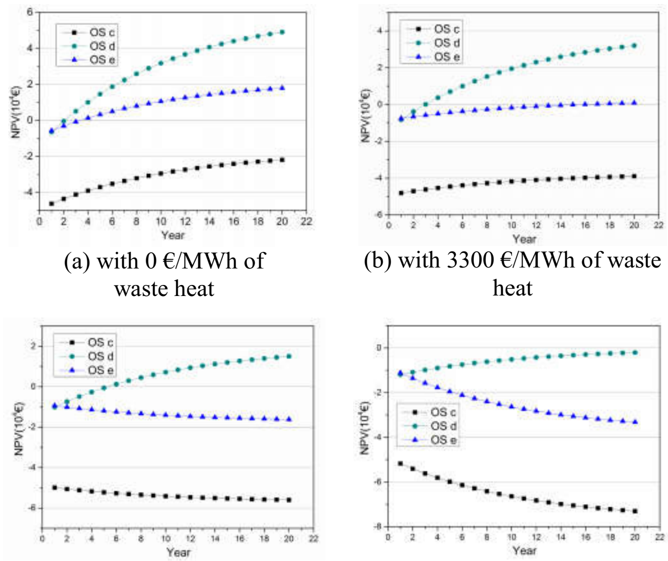
To further compare the economic performance of M-TES system with different operating strategies, net present value (NPV) and payback period (PBP) were analyzed with Eq. 1 and Eq. 2 [8, 9]:

$$NPV = -C_0 + \sum_{0}^{i} (I_i - C_i)/(1+r)^i \tag{1}$$

where C_0 is initial cost, I_i is income at year i, C_i is cost at year i, r is discount rate (10%).

$$C_0 = \sum_{0}^{PBP} (I_i - C_i)/(1+r)^t \tag{2}$$

The lifetime of M-TES project is assumed as 20 years. As demonstrated in Fig. 2, the NPV of OS c with different waste heat costs are all significantly lower than others during the whole lifetime of project. It is because the high cost of M-TES container in OS c makes the cost-recovering impossible in 20 years. Hence, OS c is rejected. By further comparing the OS d and OS e in Fig. 2, it is known that the OS d presents the better economic performance than that of OS e. The pay-back time of OS d is about 2, 3 and 5 years if the waste heat costs at the level of 0 €/MWh, 3300 €/MWh, and 6600 €/MWh, respectively. Hence, the OS d with 6 trips per day is the optimum option in this case study.



(a) with 0 €/MWh of waste heat

(b) with 3300 €/MWh of waste heat

(c) with 6600 €/MWh of waste heat

(d) with 10000 €/MWh of waste heat

Figure 2 NPV of M-TES system with different waste heat cost for OS c, OS d and OS e

4. Conclusion

This paper focuses on economic assessment of M-TES system for heating distributed users in China. A case study was presented to investigate the economic feasibility of M-TES system. The operating strategies with 2 M-TES containers and 2, 3, 4, 6 and 8 trips per day were proposed. By estimating the volume and mass of containers, it was found the OS with 2 and 3 trips per day were negative due to the excess of maximum load. The other three OS were compared further by economic assessment with calculating NPV and PBP. The results showed that the optimum OS is with 6 trips per day. Its economic profitability could be achieved respectively in around 2 years, 3 years and 5 years with 0 €/MWh, 3300 €/MWh and 6600 €/MWh of waste heat cost. The M-TES is applicable for the middle and small scale heat users in China.

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