Energy Saving and Effects by Introduction of Inverter to Large Capacity 2700 USRt Centrifugal Chiller

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This report presents an example of introducing inverters to a large-capacity centrifugal chiller and the resulting effects. A fixed-speed centrifugal chiller attains the highest COP at the rated capacity when the cooling water inlet temperature is at the rated value. However, the annual load variations show that operation under the rated conditions is rare and operation is mostly under partial load conditions or low cooling water temperature conditions. On the other hand, a variable-speed centrifugal chiller significantly improves the COP under partial load conditions or low cooling water temperature conditions. As a result of the improvement of system operation and the introduction of inverters to centrifugal chillers that were delivered as fixed-speed centrifugal chillers in the past, the cooling COP of the system in fiscal 2018 improved by 15% compared with that in fiscal 2012.

1. Introduction

In the present centrifugal chillers, a compressor which compresses a refrigerant which is driven by an electric motor is the mainstream. **Figure 1** illustrates the transition of the rated COPs (COP = Coefficient of Performance) and the highest partial load COPs, which indicate the efficiency, of the centrifugal chillers produced by Mitsubishi Heavy Industries Thermal Systems, Ltd. (MHI Thermal Systems). Centrifugal chillers produced in the 2000s or earlier are mainly fixed-speed machines with electric motors driven by a commercial power supply, and characteristically have the highest rated COP. However, the annual cooling load of typical factories, commercial facilities and office buildings shows that operation under the rated conditions is rare, and operation is usually conducted under partial load conditions below the rated capacity or under cooling water temperature conditions lower than 32°C, which is the cooling water inlet temperature condition specified by JIS.

We commercialized an inverter-driven centrifugal chiller around 2000, and have provided our customers with inverter centrifugal chillers that can achieve high COP under partial load conditions or low cooling water temperature conditions, in addition to a high-performance, fixed-speed centrifugal chiller that can handle the base load throughout the year. In 2002, we delivered the NART-270PLH fixed-speed centrifugal chiller with a cooling capacity of 2700 USRt and equipped with two compressors to Ikebukuro District Heating and Cooling Co., Ltd. (hereinafter referred to as "the customer"). To improve the annual efficiency of the centrifugal chiller, we upgraded one of its compressors in 2013 and the other in 2014 to be driven by an inverter. In addition, we upgraded the compressors further in 2018 to expand the operable range under low cooling water temperature conditions. This report presents the details of these upgrades and the resulting effects.

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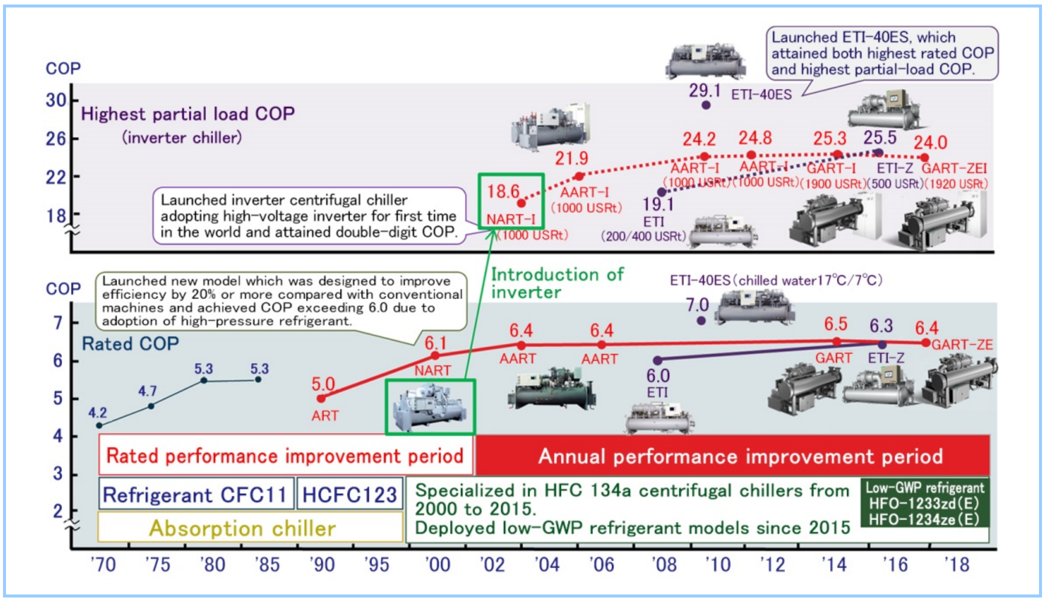

Figure 1 Transition of rated COP and highest partial load COP of our centrifugal chillers

2. District heating and cooling system(1)

Figure 2 depicts the customer's heat supply area. The heat-producing plant is located in the basement of Sunshine City, and the plant produces chilled water and steam to stably supply cooling/heating to users (total floor area of 600,000 m^2) in the Higashi-Ikebukuro area 24 hours a day, 365 days a year.

Figure 2 Supply area of Ikebukuro District Heating and Cooling Co., Ltd.

Figure 3 shows the configuration of the heat supply system. Four centrifugal chillers (TR) with a total capacity of 10800 USRt, six absorption chillers (AR) with a total capacity of 8100 USRt and an ice thermal storage system are used for chilled water supply. The chiller (customer's designation TR-4) surrounded by the square in this figure is the centrifugal chiller to which inverters were introduced as explained in this report. The three chillers (TR) beside the TR-4 chiller are fixed-speed centrifugal chillers that we also delivered.

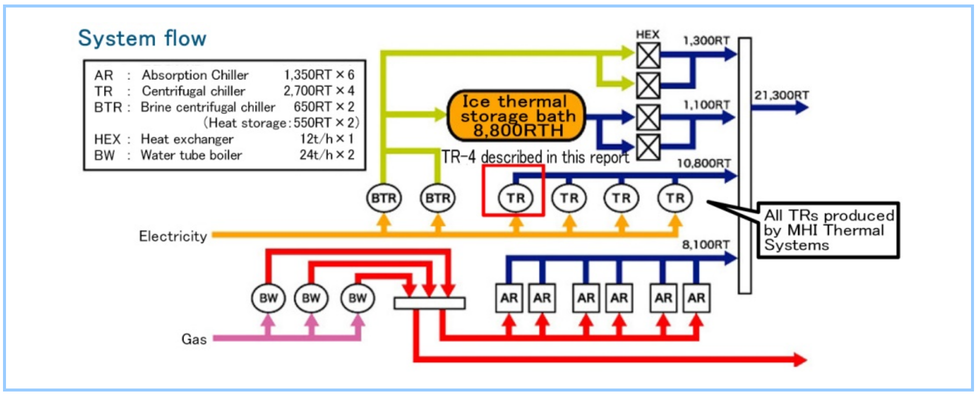

Figure 3 System configuration of Ikebukuro District Heating and Cooling Co., Ltd.

3. Introduction of inverters to TR-4

3.1 Chiller specifications and operational restrictions at the time of delivery in 2002

Table 1 lists the specifications of the centrifugal chiller (TR-4) to which inverters were introduced. This centrifugal chiller with a capacity of 2700 USRt has two compressors and can be switched between one-compressor operation and two-compressor operation according to the load. Initially, because of the restrictions of the compressors, we asked the customer to operate TR-4 in a way that the cooling water inlet temperature would always be 20°C or higher.

Table 1 Specifications of centrifugal chiller (TR-4) to which inverters were introduced

	Initial specifications at delivery in 2002	After introduction of inverters in 2013 and 2014	After improvement of internal parts of compressor in 2018
Chiller model	NART-270PLH		
Refrigerant	R134a		
Number of compressors	2		
Cooling capacity	2700 USRt (9494 kW)		
Chilled water temperature	14°C → 5°C		
Chilled water flow rate	907.2 m^3/h		
Cooling water temperature	32°C → 40°C		
Cooling water flow rate	1211.2 m^3/h		
Rated input*1	Electric motor 1770 kW	Inverter 1824 kW	
Rated COP	5.36	5.20	
Operational restrictions	Cooling water inlet temperature shall be 20°C or higher.	Refer to Figure 4.	Cooling water inlet temperature shall be 13°C or higher.

*1 Total of 2 electric motors or 2 inverters

3.2 Introduction of inverters in 2013 and 2014 and operational restrictions

We introduced an inverter to one of TR-4's two compressors in 2013 and to the other in 2014. Since the outer diameter of the high-voltage inverter is as large as 5000 mm in width, 1500 mm in depth, and 3000 mm in height, we divided it into five boards for carrying-in, considering the dimensions of the entrance. For a board that needs to be laid down, heavy parts inside the board were removed in advance and reinstalled after placing the board in the machine room. In addition, for modifying the operation panel originally designed for a fixed-speed chiller to that for a variable-speed chiller, we examined the layout of the additional electronic components on the panel. Since a dedicated grounding for the inverter was required, a new grounding was made with the cooperation of the customer.

After the installation of the inverters, because of the restrictions of the compressors, we asked the customer to operate the chiller in a way that the conditions would be on the left side of the red line in **Figure 4**. Specifically, the restrictions were as follows:

- For 100% cooling load, the cooling water inlet temperature needed to be 20°C or higher.
- For 80% cooling load, the cooling water inlet temperature needed to be 18°C or higher.
- For 60% cooling load, the cooling water inlet temperature needed to be 15°C or higher.
- For 50% cooling load, the cooling water inlet temperature needed to be 13°C or higher.

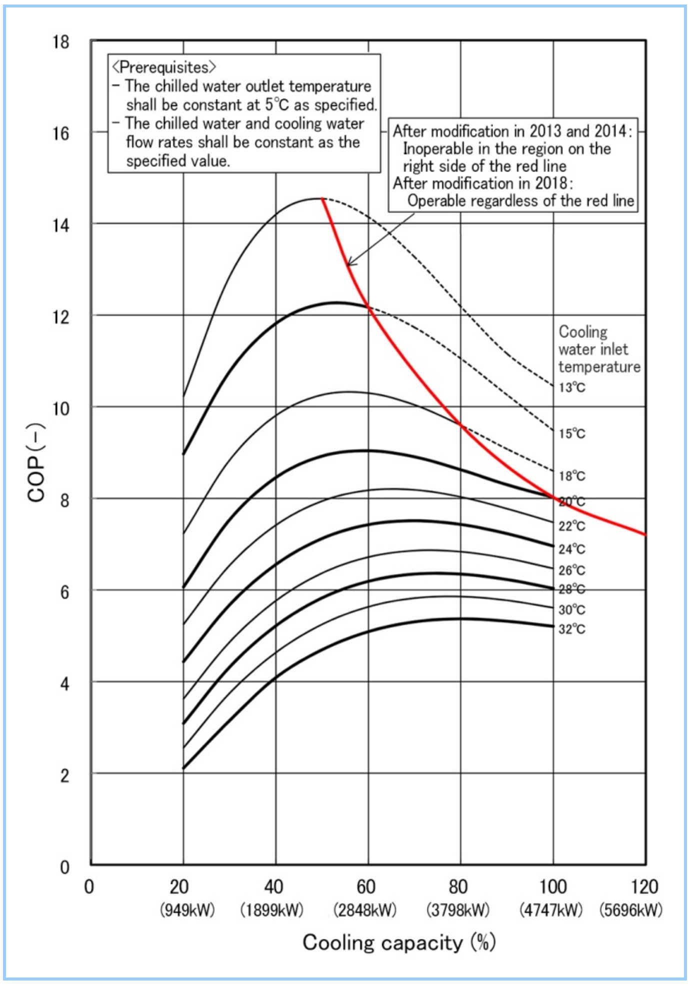

Figure 4 Expected partial load performance and operational restrictions after introduction of inverters to TR-4

3.3 Improvement of internal parts of compressor and lifting of operational restrictions in 2018

In 2018, the two compressors of TR-4 were overhauled, and the internal parts of the compressor were replaced. At this time, we improved the shape of the internal parts. Since the improvement of the internal parts, the operational restrictions delineated by the red line in Figure 4 have become unnecessary, and the chiller can be operated in the entire cooling capacity region as long as the cooling water inlet temperature is 13°C or higher. The cooling water inlet temperature of 13°C is the lowest cooling water temperature at which the chiller can be stably operated. In the case of our latest chillers, this temperature is 12°C (when the chilled water outlet temperature is 7°C).

4. Effects from introduction of inverter to TR-4

4.1 COP of TR-4 alone

Figure 5, **6**, and **7** give the COP of TR-4 for various cooling water inlet temperatures before the introduction of the inverters, after the introduction of the inverters, and after the improvement of the compressors, respectively. These figures show the COP in one-compressor operation. Another compressor being in operation will indicate a similar COP. The COP in the case of the fixed-speed operation in fiscal 2012 (shown in Figure 5) became highest when the load factor was around 100% of the rated capacity, and became higher when the cooling water inlet temperature was lower. TR-4 without the inverters attained a COP that was similar to or higher than the expected performance curve. The COP in the case of variable-speed operation in fiscal 2017 (shown in Figure 6) increased higher when the cooling water temperature was lower, and the highest value was larger than 14. TR-4 with the inverters attained a COP that was similar to or higher than the expected performance curve of the variable-speed chiller shown in Figure 4. This resulted from the fact that the customer, using the red line as a guide, controlled the operation almost within the range of performance we planned, although some data stepped over the line. Figure 7, which indicates the COP after improvement of the compressor in fiscal 2019, indicates that the chiller could be operated in the low-cooling water temperature and high-load factor region surrounded with the black frame compared with Figure 6.

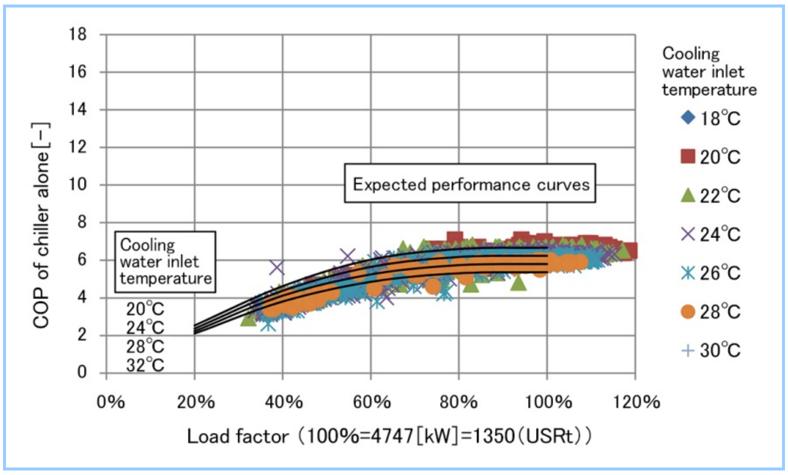

Figure 5 COP of TR-4 alone (in FY2012 before introduction of inverters)

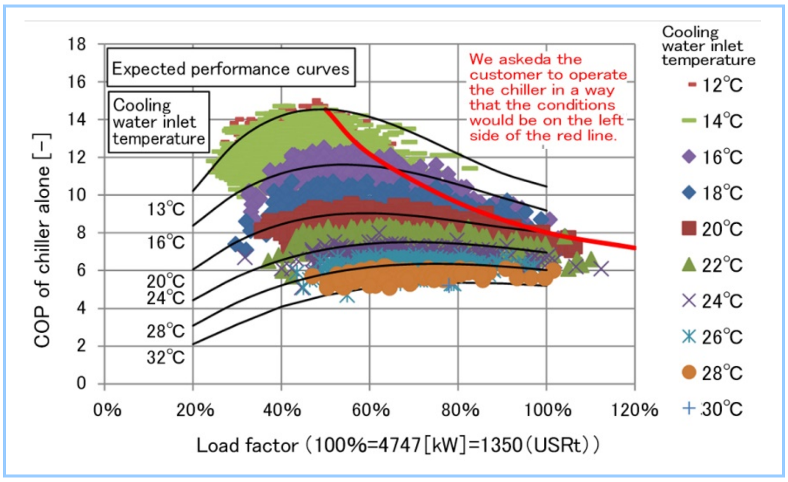

Figure 6 COP of TR-4 alone (in FY2017 after introduction of inverters)

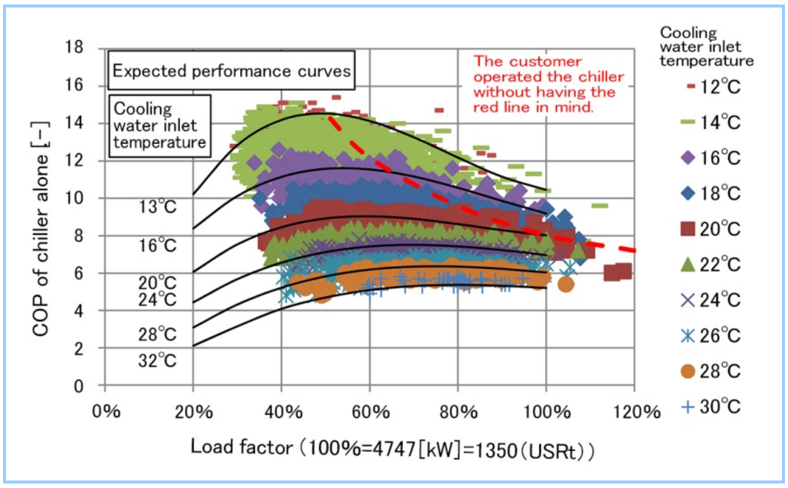

Figure 7 COP of TR-4 alone (in FY2019 after improvement of compressor)

4.2 COP of cold heat production with centrifugal chillers

Figure 8 gives the COP of all four centrifugal chillers including TR-4. In fiscal 2012 before the introduction of the inverters to TR-4, the COP was around 4 throughout the year. However, in fiscal 2017 after the introduction of the inverters, the COP in the summer when the cooling water temperature is high was the same as in fiscal 2012, but the COP in other seasons increased to around 6. This is considered to be a result of operating the fixed-speed centrifugal chillers only near the rated capacity in seasons other than winter and operating TR-4 with inverters under partial load conditions, in which the efficiency is high, throughout the year. In addition, the COPs in fiscal 2017 and fiscal 2019 are almost the same, which indicates that the high COP after the introduction of the inverters has been maintained.

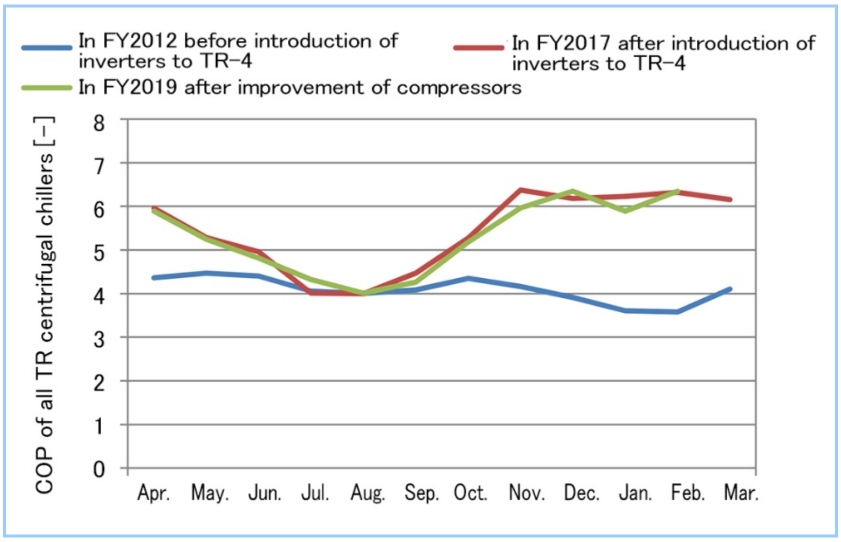

Figure 8 COP of all TR centrifugal chillers

4.3 Overall COP by cold heat production

Figure 9 is the system data of the cold heat production from fiscal 2008 to fiscal 2019. The data for fiscal 2019 are those up to the end of February 2020. The COP of cold heat production was obtained by the cold heat production amount of all cold heat source machines, the power consumption, and the heat amount of steam usage of the absorption chillers. The cold heat production amount ratio of TR-4 indicates the ratio of the cold heat production amount of TR-4 to the total cold heat production amount of the ice thermal storage system, the absorption chillers and centrifugal chillers. As a result of introducing inverters to TR-4 in fiscal 2013 and fiscal 2014, the COP of cold heat production in fiscal 2015 was improved by approximately 12% compared with that in fiscal 2012. The ratio of the amount of heat by cold heat production of TR-4 was 27% in fiscal 2012, but exceeded 40% in fiscal 2015. It is considered that the introduction of inverters to TR-4 improved the partial load COP of TR-4, the operation time of TR-4 outside the rated capacity increased, the operation time of the ice thermal storage system and the fixed-speed centrifugal chillers decreased and then the COP of cold heat production increased. Furthermore, since fiscal 2017, the COP of cold heat production has increased significantly. This is probably because the operation time of the absorption chillers and the ice thermal storage system was reduced by changing the system operation. The improvement in system operation and the introduction of inverters to TR-4 brought about a 15% increase in the COP of cold heat production in fiscal 2018 compared with fiscal 2012.

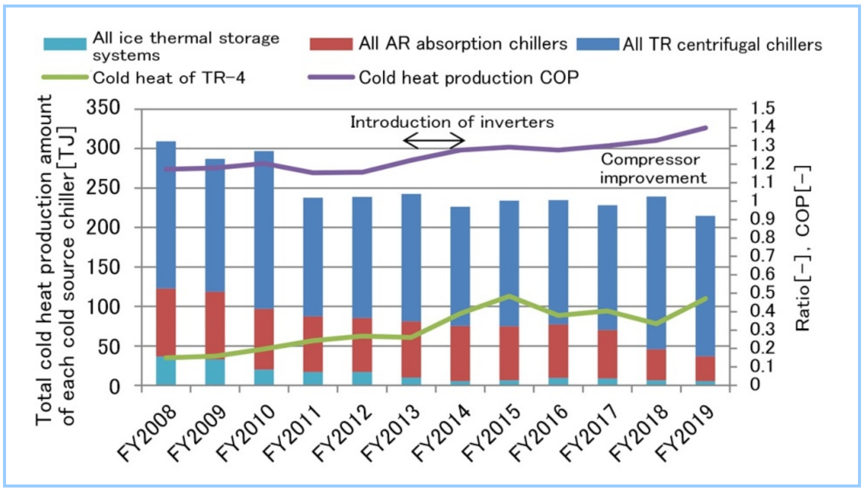

Figure 9 Cold heat production amount of each cold source chiller and cold production amount ratio of TR4

5. Conclusion

For cold heat production equipment with a total cooling capacity of 18900 USRt (66.5 MW) excluding the ice thermal storage capacity, the operational improvement of equipment such as the reduction of operating time of the absorption chillers and ice thermal storage system and the introduction of inverters to the TR-4 fixed-speed centrifugal chiller (2700 USRt (9494 kW)) resulted in a 15% increase in the COP of cold heat production in fiscal 2018 compared with fiscal 2012. In addition, the improvement of the internal parts of the compressor implemented in fiscal 2018 enabled operation at the lowest operable cooling water inlet temperature of 13°C, which is equivalent to that of the latest centrifugal chiller. Because the efficient partial-load operation time of TR-4 can be increased, the improvement of equipment operation, such as high-efficiency rated operation of other fixed-speed chillers, was realized, resulting in the increase of the COP of cold heat production. From now on, we will continue to examine the possibility of operating the equipment in such a way that the performance of TR-4 can be fully utilized, and propose maintenance measures to maintain the high efficiency of chillers over the long term. Lastly, we would like to express our gratitude to Mr. Hirai, Mr. Yamaguchi, and Mr. Kikuchi of Ikebukuro District Heating and Cooling Co., Ltd., who made efforts to plan the operational improvement of the system, agreed to and supported the performance improvement of TR-4 and provided us with valuable equipment data.

References

(1) Hirai, Yamaguchi, Goto, Introducing Inverter to Existing Fixed Speed Compressor of Centrifugal Chiller and the effect, Japan Heat Supply Business Association 23rd Technology Symposium, 2016.11, p.45 to 54