Table 1. Fixed frequency performance test

Serial number	1	2	3	4	5	6	7	8
Environment temperature [°C]	24.3	24	23.45	24.5	25.8	24	26.3	26.2
Radiant lighting [Wm^{-2}]	502	386	284	658	756	363	728	757
Heating time [minute]	404	378	348	289	245	234	200	195
Initial temperature [°C]	15.15	13.6	15.1	14.6	15.3	15.4	15.45	14
Termination temperature [°C]	55.14	55.3	55.27	55.42	55.2	55.06	55.6	55.45
Heating capacity [W]	1372	1501	1587	1920	2216	2303	2732	2892
Average power consumption [kw]	0.243	0.27	0.312	0.357	0.476	0.59	0.671	0.759
COP	5.54	5.56	5.03	5.38	4.66	3.91	4.07	3.81
Frequency [Hz]	38	42	46	50	60	75	80	86

It can be seen from tab. 1 that the direct expansion solar heat pump water heater has a relatively high heating performance in June, with a COP basically above 4.0 and a maximum of 5.56. In tab. 1, when the compressor runs at 42 Hz and 75 Hz, under the same ambient temperature and slight difference in radiation intensity, the system's performance when running at 42 Hz is significantly higher than when running 75 Hz. Therefore, when the external environment is the same, passing the compressor frequency and extending the heating time will help improve the COP of the system. When running at 38Hz or lower, the heating time of the system is close to 7 hours. The heating time is longer, but the system efficiency is not significantly improved. Therefore, the compressor operating frequency cannot be reduced indefinitely [8]. It is necessary to select the appropriate operating frequency. The control system to complete the heating in a proper time can meet the user's demand for hot water time, and it is also beneficial to improve the system performance.

Table 2 shows the performance data of the variable frequency system under different frequency and water temperature conditions. When the compressor's operating frequency remains unchanged, and the water temperature rises, the heating capacity does not change much, but the system COP gradually decreases. When the compressor's operating frequency increas-

Table 2. Performance data of variable frequency system under different frequency and water temperature conditions

Environment temperature [°C]	Radiant lighting [Wm^{-2}]	Initial temperature [°C]	Termination temperature [°C]	Heating capacity [W]	Average power consumption [kW]	COP
24.1	257	14.6	22	1624	0.181	8.97
23.4	212	22	30	1728	0.211	8.19
23.5	310	30	36	1540	0.242	6.37
23.7	331	36	42	1944	0.278	6.99
24.4	381	42	48	1201	0.275	4.37
24.2	384	48	55	1465	0.371	3.95
23.3	424	14.6	22	2189	0.232	9.44
22.8	707	22	30	2093	0.272	7.7
23	744	30	36	1944	0.327	5.94
23.3	744	36	42	2093	0.368	5.69
24.2	736	42	48	2268	0.413	5.49
24.3	670	48	55	1868	0.466	4.01

es, the water temperature does not change. In the variable interval, the heating capacity gradually increases, and the compressor operating frequency gradually decreases. It can be seen that the system heating capacity and system COP are closely related to the compressor frequency and water tank water temperature and have a significant impact on the performance of the whole machine. Therefore, the compressor operating frequency adjustment is the key to the natural expansion variable frequency solar heat pump hot water system [9].

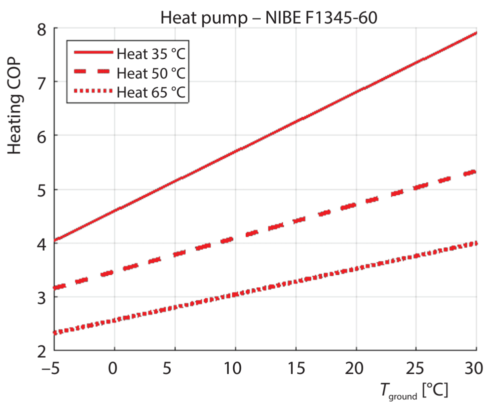

Figure 3. The COP value under three heating methods

Under the same environmental conditions, heating time, and heating water volume, the analysis of the influence of frequency changes on the system can be divided into three modes: constant speed heating, rising speed heating, and falling speed heating, as shown in fig. 3. Based on the experimental data, the three methods are theoretically calculated through mathematical techniques, and the differences in COP of the three heating methods are compared:

– when the ambient temperature is 24±2°C, the radiation intensity is 750 W/m^2. The water temperature is 45 °C, the system heating capacity and COP are shown in fig. 4 at different press operating frequencies.

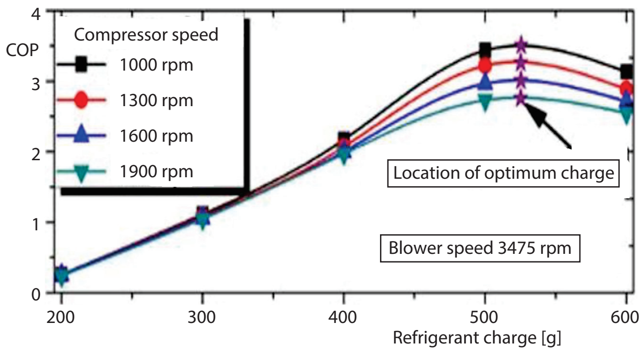

Figure 4. Variation curve of heating capacity and COP with frequency

– when the ambient temperature is 24±2 °C, the radiation intensity is 750 W/m^2, and the compressor operating frequency is 60 Hz, the system heating capacity and COP are shown in fig. 5.

The heating power and COP curves with frequency and water temperature in figs. 4 and 5 show that the healing power and COP have a linear relationship with the operating frequency after fitting.

When the temperature irradiation is high, reduce the operating power to achieve the most energy-saving effect. When the temperature irradiation is low, increase the active management to ensure that the unit is in the most effective heat-absorbing state. The system water temperature heating range is set to 15-55 °C. The heating limit time needs to be determined based on experimental tests of parameters such as ambient temperature and solar irradiation conditions. The empirical test data is summer operating condition data, so the heating time is set

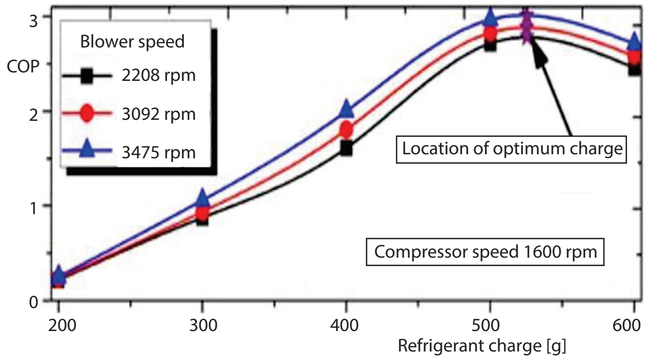

Figure 5. Heating power and COP change curve with water temperature

to 270 minutes, and the experimental test data can be imported to obtain the system parameters. When the heating time is different, the system COP changes significantly. The longer the heating time, the higher the COP. Therefore, operating at a lower speed and extending the heating time within the allowable range of the specified time is the key to obtaining a higher COP. Adjust the compressor's operating frequency by controlling the heating time of the system. Adjust the compressor's operating frequency according to the temperature rise rate of different water temperature sections [10]:

– Determine the required heating time according to heating requirements and real-time environmental parameters, and calculate the average heating power required to complete the heating of the solar water heater [11].
– Determine the initial frequency of the compressor according to the formula between the heating capacity and the initial frequency f.
– Calculate the actual heating capacity of different water temperature sections in the heating process of the compression mechanism, and compare the actual heating capacity with the expected heating capacity. When the actual heating capacity is more significant than expected, it can be judged that the external environment or the irradiation conditions are better than when heating is started. Therefore, it is beneficial to heat pump heating, reducing the operating frequency of the compressor and extending the healing time. On the other hand, when the actual conditions are less than expected, it can be judged that the external environment or the irradiance is worse than when the heating is started. According to the comparison result, the most effective heating state.
– Adjust the compressor frequency in real-time.

Conclusion

Many factors are influencing the performance of direct expansion variable frequency solar heat pump hot water system. This article only analyzes system operation and heating time and uses a fixed frequency method to obtain the change law of system operating parameters under different compressor operating frequencies. To better adapt to changes in the external environment and meet users' needs for hot water time, controlling the heating time according to the operating frequency of the compressor is proposed. After data simulation and experimental analysis and verification, a method to control the press's operating frequency is obtained. The control system's heating time is maintained through data analysis and experimental validation and the feasibility of adjusting the operating frequency of the press according to the comparison between the expected temperature rise and the actual temperature rise. This method can accurately control the heating time while ensuring the variable frequency heat pump system's efficient operation, and the system has apparent energy-saving effects. Therefore, it has a particular guiding significance for promoting the direct expansion variable frequency heat pump hot water system.

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