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Comparison on CHP Thermo-electric Decoupling Technologies with Heat Pump and Low Pressure Renovation

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Abstract. Thermo-electric decoupling is an effective way to improve the adoption capacity of renewable power of power grids. Therefore, theoretical analysis models are established in this study to evaluate the decoupling performance of CHP with absorption heat pump, compression heat pump and low-pressure turbine renovation. Results show that absorption heat pump, compression heat pump and low pressure cylinder can all expand the feasible operation area and reduce the minimum electricity load rate of the reference CHP plant. When the heat load is 250 MW, The minimal electricity load rate of unit decreases by 12.98%, 56.47% and 36.34% with absorption heat pump, compression heat pump and low-pressure turbine renovation, respectively. The maximal heat-to-electricity ratio of unit is also increased by integration with heat pump and low-pressure renovation. Besides, the compression heat pump has the best decoupling performance among these three decoupling technologies under the same max heating power.

1. Introduction

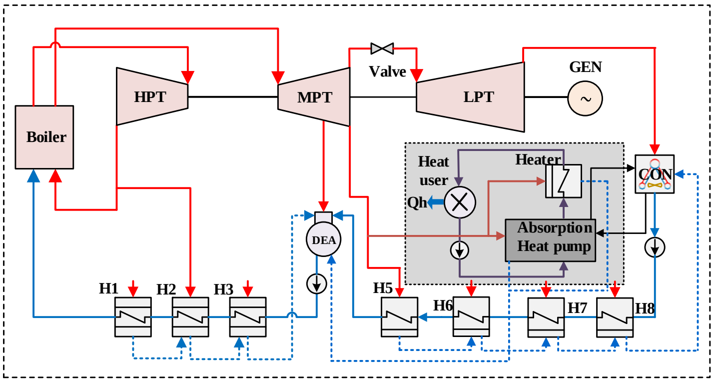
In recent years, the abandon of wind and solar power is a serious issue in some areas of China with the increase of renewable power. One of the main reasons is the operation mode of CHP plant that the power supply is determined by heating load. It causes an insufficient peak-shaving capacity of power grid. Therefore, many scholars have studied thermo-electric decoupling technologies. Liu et al. [1] compared the advantages and disadvantages of combined high and low pressure bypass to heat and the low-pressure cylinder cutoff operation. Li et al. [2] discussed the methods to realize large-scale thermo-electric decoupling for the steam turbines. Cheng et al. [3], Zhang et al. [4], Lin et al. [5] calculated the economics, energy saving and consumption reduction capacity of electric boilers for heating. It is better to use electric boilers to heat at the beginning and end of heating period.

As discussed above, most studies on thermo-electric decoupling technology only focuses on the calculation of energy consumption. However, comparison on the decoupling performance of different decoupling technologies is not quite a lot. Therefore, a 300MW unit is taken as the reference case in this study and the decoupling performances of unit with absorption heat pump, compression heat pump and low-pressure turbine renovation are quantitatively compared with the same conditions.

2. Thermo-electric decoupling technologies

2.1. Absorption heat pump

The absorption heat pump is an effective device to recover low-temperature energy, which is widely used to recover waste heat from power plants. The CHP unit integrated with absorption heat pump is shown in Figure 1. The backwater of the heat network is subsequently heated by an absorption heat pump and a heater, and then it is sent back to the heat user.The condenser circulating cooling water is heated by absorption heat pump and then returned to the condenser.



CON-condenser; DEA-deaerator; H1 to H8-regenerative heaters; HPT-High pressure turbine; GEN-generator; LPT-low pressure turbine; MPT-Medium pressure turbine.

Figure 1. CHP unit integrated with absorption heat pump

2.2. Compression heat pump

The compression heat pump needs to consume some power to realize heat transfer from low temperature heat reservoir to high temperature heat sink. The electricity consumed by the compression heat pump in this study is directly provided by the CHP unit, as shown in Figure 2. In this system, a part of the heat network backwater is heated by compression heat pump and directly mixed with remaining part hot water, and then the hot water is sent to the heat user. The condenser circulating cooling water releases heat in evaporator of heat pump and returns to the condenser.

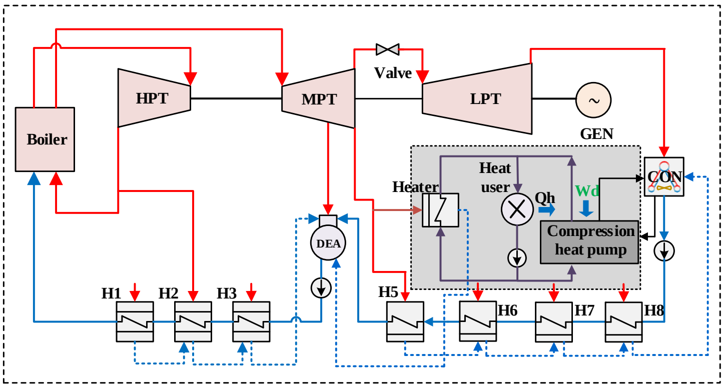


Figure 2. CHP unit integrated with compression heat pump

2.3. Low-pressure turbine renovation

Low-pressure turbine renovation is mainly classified into zero power output of low-pressure turbine and shaft bladeless of low-pressure turbine, as shown in Figure 3. The shaft of low-pressure turbine is replaced by a bladeless one. All the medium-pressure turbine exhausts are used for heating except for a small amount of steam used to cool the low temperature turbine. Zero power output of the low-pressure turbine is that the inlet of the low pressure cylinder is completely cut off and only a small part of the steam enters the low pressure cylinder by the newly added bypass to cool the blast heat generated by the rotation of the low pressure rotor. The other medium-pressure turbine exhausts are all used for heating.

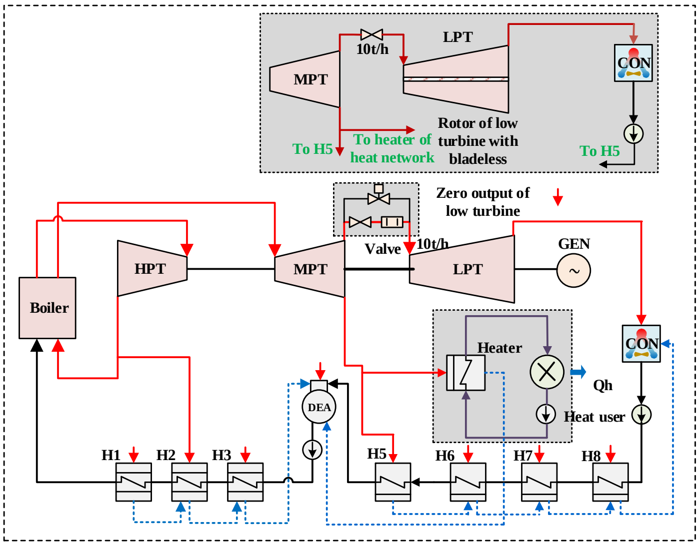


Figure 3. CHP unit with low turbine renovation

3. Theoretical models

The operation domain of CHP unit is restricted by the following constraints:

a) The steam flow rate of turbine cannot exceed the maximum steam flow rate of the steam turbine and should not lower than boiler minimum evaporation rate.

b) The steam flow rate of the low-pressure turbine must not be less than the minimum condensate steam flow rate and heating extraction parameters must meet the needs of heat users.

The off-design calculation models are used to obtain the operation domain of CHP plant. The off-design calculation of heating unit is based on Friuli Siegel formula and it can be expressed with the following formula:

$$\frac{D_1}{D_{10}} = \sqrt{\frac{P_1{}^2 - P_2{}^2}{P_{10}{}^2 - P_{20}{}^2}} \cdot \sqrt{\frac{T_{10}}{T_1}} \tag{1}$$

In the formula, D represents the steam flow rate of the stage-group, kg/s; P indicates the steam pressure at inlet and outlet of stage-group, MPa; Subscripts with 0 and without 0 denote the design and off-design conditions, respectively; Subscripts 1 and 2 represent the inlet and the outlet of the stage-group, respectively.

The steam extracted from steam turbines is taken as the driving heat souse of absorption heat pump and the steam flow rate consumed by absorption heat pump can be obtained by the following formula:

$$D_{xb} = \frac{Q_{xb} \times 3600 \times 1000}{COP_x \times (H_g - H_n)} \tag{2}$$

Where Q_{xb} represents the heat load of absorption heat pump, MW; COP_x is the performance coefficient of the absorption heat pump; H_g and H_n are enthalpies of driving steam feeding into and leaving the absorption heat pump , respectively, kJ/kg;

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When the compression heat pump is integrated, it will consume some electricity to drive the compressor. The power consumption rate can be obtained by

$$W_{yb} = \frac{Q_{yb} \times 3600 \times 1000}{COP_y} \tag{3}$$

Where Q_{yb} indicates the heat load of compression heat pump, MW; COP_y is the performance coefficient of the compression heat pump.

4. Reference case

A 300MW cogeneration unit is selected as the reference unit in this study. The boiler efficiency the pipe and generator efficiencies are 93.8%, 99% and 99%, respectively. Turbine key parameters are listed in the Table 1. The design heat load of the absorption heat pump is 40MW, and the COP of absorption heat pump under the design working condition is 1.656. A total of five absorption heat pumps are selected. The maximum heating power of the compression heat pump is 200MW and the COP is 2.8.

Table 1. Parameters of steam turbines

Parameters	Basic data
The live steam flow rate/t h^{-1}	915.092
Design power load/MW	300
Live steam pressure/MPa	16.70
Live steam temperature/ºC	538
Reheat steam pressure/MPa	3.18
Reheat steam temperature/ºC	538
Pressure of low pressure turbine exhaust /kPa	5.20
Temperature of feed water/ºC	274.6
Heating steam pressure/MPa	0.38

5. Analysis on thermo-electric decoupling performance

In this study, the thermo-electric decoupling performance will be evaluated from the three aspects of thermo-electric characteristics, maximum heat-to-electricity ratio and minimum electricity load rate.

5.1. Feasible operation domain of CHP plant

Thermo-electric characteristics is used to describe the coupling relationship between heat and power of cogeneration unit. In this study, the thermo-electric characteristics of the reference CHP plant is calculated, as shown in Figure 4.

In Figure 4, the live steam flow rate of turbine is the maximum live steam flow rate of unit in line AB, and the steam flow rate of low-pressure turbine maintains minmium condensate flow rate in line BC, and it is the minimum boiler evaporation rate in CD. It can be known from Figure 4 that there is a limitation domain of heat and electricity adjustment of CHP plant. When the heat load is 250MW, the electricity adjustment range of CHP plant is from 195.55MW to 274.64MW.

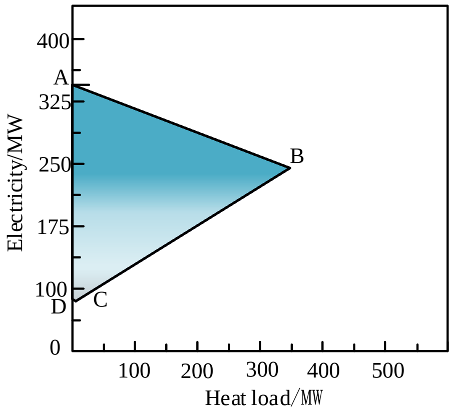

Figure 4. Thermo-electric characteristics of CHP plant

5.2. Comparison of the minimum electricity load and maximal heat-to-electricity ratio

The minimal electricity load rate reflects the operation flexibility of CHP unit, which is defined as the ratio of the electricity on off-design condition to benchmark condition. The heat-to-electricity ratio is defined as the ratio of the heat load to the electricity of the CHP unit. The calculation results are shown figure 5. It can be seen from Figure 5 that minimal electricity load rate and maximum heat-to-electricity ratio of the unit with different decoupling ways vary greatly. However, the minimal electricity load rate of the unit (heat load is 250MW) can all be decreased and the maximum heat-to-electricity ratio of the unit (electricity is 150MW) can all be increased with decoupling. The minimal electricity load rate of unit with compression heat pump is lowest and decreased from 65.18% to 8.71%, which is decreased by 56.47%. The following is low-pressure turbine renovation, which is reduced by 36.34% compared with the original unit. The largest is the absorption heat pump, which is only 12.98% lower than the original unit. The maximum heat-to-electric ratio of unit with compression heat pump is biggest and its value is 3.4, which is increased by 2.36 compared with original unit. The following is low-pressure turbine renovation, which is increased by 1.49. The smallest is the absorption heat pump, which is only improved by 0.49.

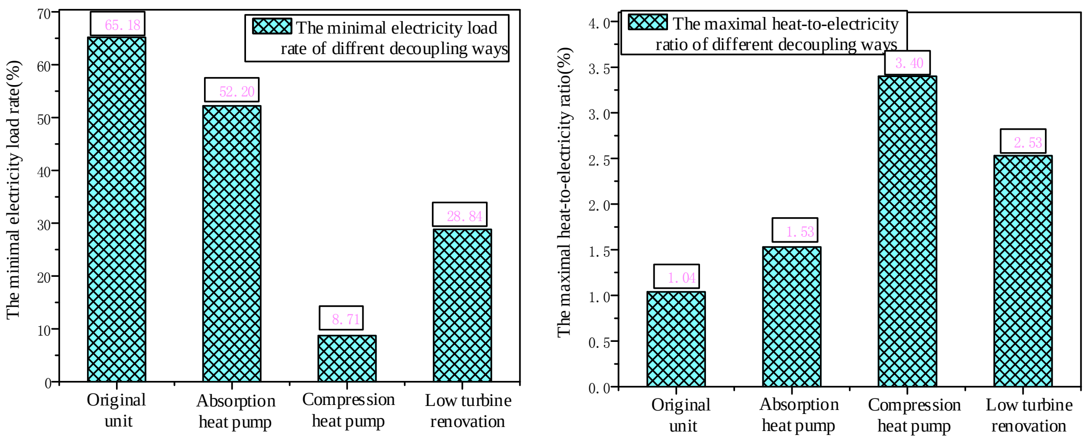

Figure 5. Comparison of the minimal electricity load rate and maximal heat-to-electricity rate

6. Conclusion

Thermo-electric decoupling technology is one of the most effective ways to improve the operation flexibility of CHP units. Therefore, theoretical analysis models are established to compare the decoupling performance of different thermo-electric decoupling methods based on a reference case. It can be obtained that:

1) Decoupling technologies as discussed above can all expand the feasible operation domain of the CHP unit, increase the maximum heat-to-electricity ratio of the unit, and reduce the minimum electric load rate of the unit. The relatively reduction of minimal electricity load rate of unit are 12.98%, 56.47%, and 36.34% with absorption heat pump, compression heat pump and low turbine renovation, respectively. The maximal heat-to-electricity ratio of unit increases 0.49, 2.36, and 1.49 with absorption heat pump, compression heat pump and with low turbine renovation, respectively.

2) Regardless of energy consumption, the decoupling performance of the compression heat pump is the best among the thermo-electric decoupling technologies discussed in this paper.

Acknowledgments
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