

PAPER • OPEN ACCESS

Application and Analysis of Air Source Heat Pumps in Countryside Home Heating with Substituting Electricity for Coal

To cite this article: Luming Zhou *et al* 2018 *IOP Conf. Ser.: Earth Environ. Sci.* **186** 012045

View the [article online](#) for updates and enhancements.

You may also like

- [Application and Analysis of Air-Source Heat Pump Heat Supply System in Cold Areas](#)
Shuo Ji, Yang Liu, Huixuan Xu et al.
- [A novel testing and theoretical approach for air-source heat-pump water heater with flash tank vapor-injection](#)
Liu Xianglong, Hu Guang, Zeng Zhi et al.
- [Research on the Frosting Rule and Frost Suppression Strategy of Air Source Heat Pump in Guiyang, China](#)
Ruiyong Mao, Yaxin Yang, Peng Pei et al.

ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

Application and Analysis of Air Source Heat Pumps in Countryside Home Heating with Substituting Electricity for Coal

Luming ZHOU^{1,2}, Hailong BAO², Kaiyuan JIN¹, Hongyu ZHANG², Zheng CHEN¹, Bin HOU¹ and Jianhua Yang^{1*}

¹College of Information and Electrical Engineering, China Agricultural University, Beijing, China

²Beijing Electric Power Economic Research Institute, Beijing, China

Email: yang.haag@163.com

Abstract. In the project of "Substituting Electricity for Coal" in northern rural areas, more and more air source heat pump units are being used for home heating. When the large-scale units are connected to rural distribution networks, the power quality problems should be considered because of the voltage sag and the current harmonics caused by these units. The characteristics of the air source heat pump units are compared with those of other domestic electric heating radiators. The efficiency indices, the operating circle and the types of air source heat pumps are introduced. The starting and operational characteristics of different air source heat pump units are given and compared. The power quality problems, the voltage sag and current harmonics are analyzed and discussed based on the parameters and the actual measurement data of the units in the rural distribution networks. Some solutions are presented for the problems caused by the units.

1. Introduction

One of the main sources of air pollution problem is burning bulk coal. Coal consumption severely affects air quality in the rural areas of northern China, and it is showed that the contribution of burning bulk coal to PM 2.5 is about 22.4% [1]. In recent years, a movement entitled "Reducing Coal Consumption and Replacing Coal to Clean the Air" has been carried out with the project of "Substituting Electricity for Coal" which directly consumes electricity instead of coal in the energy consumption to heat home in the winter [2]. The project aims at cleaning the air, reducing the pollution of smoke from coal burning, and partly solving the haze problem in northern China with the increase of electricity use in terminal energy consumption.

Heat pumps are designed to transfer heat energy from a source of heat, such as outside air and underground water, to a destination, i.e. a heat sink [3]. A heat pump unit uses a small amount of electric power to transfer energy from the source of low-grade thermal energy to the heat sink. The unit can be used for both heating and cooling at a high operating efficiency as an environmentally-friendly and reliable means of maintaining thermal comfort in buildings. After the first oil crisis in the 1970s, there was a real boom of heat pump technology. And the heat pump units were tested in cold weather in the 1980s. The market of heat pumps is currently experiencing high annual growth rates [4]. More and more heat pump units are used for indoor environmental control as a means of reducing net energy consumption and hence emissions of greenhouse gases [5].



The heat pumps include air source heat pump (ASHP) and ground source heat pump (GSHP). The ASHP unit absorbs heat from the outside air, which is different from the GSHP unit that absorbs heat from groundwater or ground with a ground heat exchanger or collector [4]. When properly installed, the ratio of the heat energy that is delivered to a home by ASHP unit to the consumed electric energy is 1.5 to 3 and even larger because the ASHP unit moves heat rather than converting it from a fuel, like in combustion heating units. In recent years, the performance improvement of the ASHP units has become one of the research foci, and some studies have been carried out on investigating the frosting, defrosting and low ambient heating performances of ASHP [6-9]. The impacts of frosting evenness of outdoor coil were experimentally investigated on the heating performances of an ASHP unit [6]. A review of the advances in ASHP units was presented on applying the units in cold weather [7]. Extensive experimental investigations were carried out on ASHP units to study their operating performance under frosting and defrosting conditions [8, 9]. Although the performance of the ASHP units was considered, the power quality influence of the units on rural distribution networks was not involved in the above literatures.

The characteristics of the ASHP units are compared with those of other domestic electric heating radiators in this paper. The efficiency indices, the operating circle and the types of the units are introduced. The starting and operational characteristics of different ASHP units are given and compared for the actual project of "Substituting Electricity for Coal". The power quality problems such as the voltage sag and the harmonics caused by the units are discussed and analysed based on the parameters of the units and the actual measurement data in the rural distribution networks.

2. Comparison of ASHP and Other Electric Heating Radiators

In the project of "Substituting Electricity for Coal", different types of electric heating radiators are adopted according to the actual situation of different regions in northern rural areas. The main types of heating radiators include the direct-acting electric heating radiator, thermal storage electric heating radiator, the ASHP unit, the GSHP unit, and so on [10, 11]. Their characteristics are shown in Table 1.

Table 1. The characteristics of electric heating radiators.

Electric heating radiators	Characteristics
Direct-acting electric heating radiator	Radiant heating, the operating cost is high, the indoor temperature is uniform, and the thermal comfort is better
Thermal storage electric heating radiator	The operating cost is low, and the function of "clipping the peak and filling the valley" of the load to the rural distribution network can be realized
ASHP unit	The initial investment is high, the energy efficiency ratio is high, and the operation effect is good
GSHP unit	The initial investment is the highest, the energy efficiency ratio is the highest, the requirement for external conditions is strict, and the operation effect is the best

3. Typical Feature of ASHP

3.1. Efficiency Indices of ASHP

One of the efficiency indices for the ASHP units is the coefficient of performance (*COP*) used for heating, and the energy efficiency ratio (*EER*) used for refrigeration.

COP of a heat pump unit is defined as follows:

$$COP = q_{ASHP} / P_{ASHP} \quad (1)$$

where q_{ASHP} is the thermal power provided by the ASHP unit in kW, P_{ASHP} is the electric power input to the ASHP unit in kW. The power input P_{ASHP} and the heating capacity q_{Source} of the low-temperature heat source together produce the heat flow q_{ASHP} :

$$q_{\text{ASHP}} = q_{\text{Source}} + P_{\text{ASHP}} \quad (2)$$

If an ASHP unit with electric driven power $P_{\text{ASHP}} = 2$ kW produces heat flow of $q_{\text{ASHP}} = 5.6$ kW, then $COP = 2.8$. The difference of $q_{\text{Source}} = 3.6$ kW derives from the low-temperature heat source.

Normally COP only applies to transient values. Sometimes an annual coefficient of performance ($ACOP$) is applied, too. A high $ACOP$ is essential for the ecological and economical operation of an ASHP unit. The practical value of $ACOP$ of an ASHP unit is 3.0 with underfloor heating or 2.3 with radiators [4].

In cooling mode the definition remains the same and the calculation of EER is replacing the condenser heat flow rate with the evaporator cooling power.

To characterize the running status of the ASHP unit when the unit is under part load, the integrated part load value ($IPLV$) is applied [11]. $IPLV$ uses weight mean, calculated by the performance coefficient COP or EER when the load rate of the unit is respectively 100%, 75%, 50% and 25%, and the corresponding weight coefficient of each COP with the proportion of total heating or refrigerating quantity of the unit under any load rate, to show comprehensive performance during the whole operation period of the unit. The formula for $IPLV (H)$ for heating and $IPLV (C)$ for cooling are defined as follows, respectively, which are applicable to domestic climate and building characteristics within the standard [11]:

$$IPLV (H) = 8.3\% \times A_1 + 40.3\% \times B_1 + 38.6\% \times C_1 + 12.9\% \times D_1 \quad (3)$$

$$IPLV (C) = 2.3\% \times A_0 + 41.5\% \times B_0 + 46.1\% \times C_0 + 10.1\% \times D_0 \quad (4)$$

where A_1, B_1, C_1 and D_1 are COP when the heating load rate of the ASHP unit is 100%, 75%, 50% and 25%, respectively; A_0, B_0, C_0 and D_0 are EER when the refrigerating load rate of the ASHP unit is 100%, 75%, 50% and 25%, respectively.

3.2. Circulation System of ASHP

The ASHP units can get heat from the air even when the temperature is as low as -20°C . The ASHP unit exploits the physical property of a volatile evaporating and condensing fluid, i.e. refrigerant or working fluid. Heat from the outside air is absorbed at low temperature by the ASHP refrigerant and released when it is condensed. The compressor of the unit compresses the working fluid to make it hotter on the side to be heated. Electricity is required by the unit to drive the compressor. And the hot and highly pressurized vapor is cooled down in a heat exchanger, i.e. a condenser, until it condenses into a high pressure and moderate-temperature liquid. The condensed refrigerant then passes through a pressure-lowering device, i.e. an expansion valve or a metering device. The low-pressure liquid refrigerant then enters another heat exchanger, the evaporator, in which the fluid absorbs heat again. The circulation is repeated. A simple circulation diagram of the ASHP unit is shown in Figure 1.

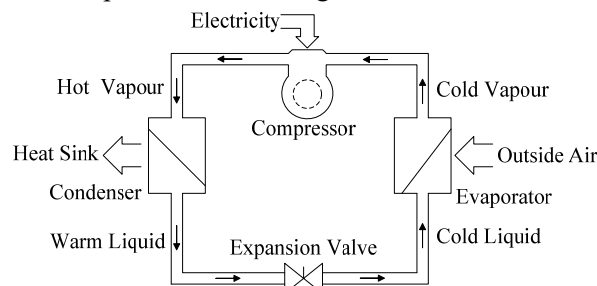


Figure 1. The circulation system of an ASHP unit.

3.3. Types of ASHP Units

There are two types of ASHP units according to different control forms of the compressor speed.

1) *Fixed-speed ASHP.*

2) *Variable -speed ASHP.*

The compressor speed of the fixed-speed ASHP unit is constant. Normally the ASHP unit operates intermittently in the on or off mode to adjust the heating power to the temperature required in the house with a fixed-speed. If the temperature reaches the set value, the compressor stops working. Otherwise, it starts working and adjusts the temperature by constantly starting and stopping the compressor. The technical specifications of a fixed-speed ASHP unit, Brand A, are shown in Table 2, which is used in the project of "Substituting Electricity for Coal". When a variable-speed compressor is used, the ASHP unit can advantage at partial loads from the oversized heat exchangers according to the load and thus increasing its efficiency. The technical specifications of a variable-speed ASHP unit, Brand B, are shown in Table 3.

Table 2. The specifications of a fixed-speed ASHP unit, Brand A.

Operation State	Refrigeration	Temperature at -7.6 °C	Temperature at -12.0 °C
Rated capacity /kW	10.0	10.2	8.9
Rated input power /kW	3.80	4.20	3.70
<i>EER</i> or <i>COP</i> /p.u.	2.63	2.43	2.40
Rated input current /A	19.2	21.2	18.7
Maximum input current /A		27.5	
Maximum input power /kW		5.46	
Rated voltage / V~		220	
Maximum discharge pressure /MPa		2.8	
Maximum inspiratory pressure /MPa		0.8	
Refrigerant gas		R22 / 4.4kg	
Ambient temperature /°C		-25~45	

Table 3. The specifications of a variable-speed ASHP unit, Brand B.

Operation State	Refrigeration	Temperature at -12.0 °C
Rated capacity /kW	11.00	8.75
Rated input power /kW	4.78	4.15
<i>EER</i> or <i>COP</i> /p.u.	2.30	2.10
Maximum input current /A		35.5
Rated voltage / V~		220
<i>IPLV</i> (C) /p.u.		2.45
<i>IPLV</i> (H) /p.u.		2.69
Refrigerant gas		R410A / 3.5kg

There are three basic types of ASHP units according to different installation position of ASHP components.

1) *Split Systems.*

2) *Packaged Systems.*

3) *Ductless Room Heat Pumps.*

The split ASHP units are the most common ASHP type in the project of "Substituting Electricity for Coal". There are one heat exchanger coil indoors and one heat exchanger coil outdoors for the split

unit. For packaged system ASHP units, both the coils and the fan are installed outdoors. Ductless room heat pumps are actually another form of the packaged system that does not use ductwork. These pumps can efficiently heat a room or small house with an open floor plan. They can normally be installed through a window.

4. Power Quality Analysis of ASHP

4.1. Voltage Sags

According to the actual measurement data of different types of ASHP units in several villages which have completed the project of "Substituting Electricity for Coal", the main indexes to evaluate the power quality in the rural distribution networks are voltage sags and current harmonics. The fixed-speed ASHP unit requires large current during the startup process, which is usually 4~7 times of the maximum operational current. The startup current of the unit can easily cause severe voltage sag in the rural distribution networks.

The variables of the ASHP units, such as starting current, residual voltage, the duration of transient process of voltage sags, and harmonic currents, are measured respectively. Ambient temperature is about $-1 \sim -8^{\circ}\text{C}$. The voltages of the measurement nodes are near 220V when the ASHP units are not in operation. The ASHP unit, Brand A, uses the technology of entropy increase and jet for the compressor, which does not change the run speed of the compressor, i.e. fixed-speed. Its basic specifications are shown in Table 2. The voltage change curve of the normal starting process for this unit is shown in Figure 2. The other measurement data are shown in Table 4 showing the total harmonic distortion (THD) generated by the unit although it is small. Its minimum startup voltage is 193.65 V, which is lower than the threshold of the voltage sags of the rural distribution network, i.e. $220 \times (1 - 10\%) = 198 \text{ V}$. Therefore, after the fixed-speed ASHP units are connected to the rural distribution network, a large voltage drop will be generated in the distribution network during their start-up process, which may affect the normal operation of the distribution network.

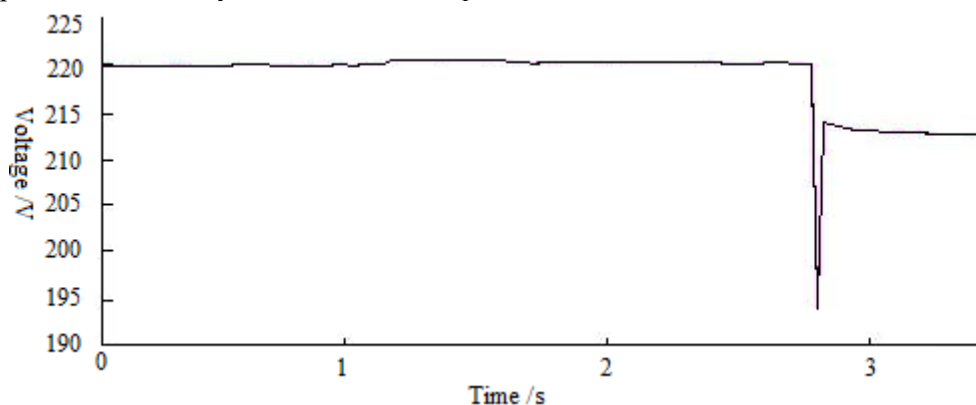


Figure 2. The voltage change curve of normal starting process for the ASHP unit, Brand A.

Table 4. The starting characteristic data of the ASHP unit, Brand A.

Minimum start-up voltage / V	Maximum start-up current / A	Maximum active power / kW	Duration of transient process / s	Ratio of maximum start-up current to rated heat current / per unit	THD / %
193.65	98.53	10.87	0.22	4.65	10.31~10.89

Therefore, it is necessary to guide the users to start the fixed-speed ASHP units as orderly as possible to avoid multiple starting processes at the same time. Some attention should be paid to the design and plan. For example, the section area of the power line should be large enough with large-

scale ASHP units, and the protection curve of the circuit breaker must be reasonably selected to avoid the startup current of these units over the tripping current of the circuit breaker.

4.2. Harmonics

Although the starting current of the variable-speed ASHP unit can be profoundly reduced, the harmonic content caused by the unit cannot be neglected. This unit may inject harmonic current, and its current THD is possibly larger than the permissible value set in the corresponding national standard [12].

The ASHP unit, Brand B, uses the frequency conversion technology. Its technical specifications are shown in Table 3. Its starting voltage is basically stable at about 220V. Table 5 shows the results of harmonic measurements during the operation of this unit.

Table 5. The current harmonics caused by the ASHP unit, Brand B.

1 / %	3 / %	5 / %	7 / %	9 / %	11 / %	13 / %	15 / %	17 / %	THD / %
100	39.5	30.7	16.6	21.0	18.5	8.9	9.6	13.6	11.2~23.6

Therefore, when large-scale variable-speed ASHP units are connected to the rural distribution network, the influence of the current harmonics should be considered. The current harmonics should be limited to meet the requirements of the corresponding standard [13].

5. Conclusion

In recent years, more and more ASHP units are applied in the countryside of northern China with the project of "Substituting Electricity for Coal". It is necessary to consider the power quality problems, such as the voltage sag caused by the fixed-speed ASHP units and the current harmonics caused by the variable-speed ASHP units. The length and the section area of the power line affect the allowable starting number of the fixed-speed ASHP units at the same time. With the increase of the number of the variable-speed ASHP units, the current harmonics content may increase and some measures should be taken to suppress the harmonic content in the rural distribution network. The distribution transformer capacity and power line parameters should be tested and analyzed according to the new load demand of the ASHP units.

Acknowledgments

This work is financially supported by Science and Technology Projects of SGCC and State Grid Corporation Beijing Electric Company (520234160007).

References

- [1] ZHANG J P, NING Y C and LIU C X 2017 *Journal of Ecology and Rural Environment* **33** 10 pp 898-906
- [2] Gao Z, Chen D M, Yang J H and Ji B 2015 *Electrotechnics Electric* **209** 5 pp 1-5
- [3] Byrne P, Miriel J and Lenat Y 2011 *Applied Energy* **88** pp 1841-47
- [4] Quaschnig V 2010 *Renewable Energy and Climate Change* (New York: Wiley-IEEE Press)
- [5] Mattinen M K, Nissinen A, Hyysalo S and Juntunen Jouni K 2015 *Industrial Ecology* **19** 1 pp 61-70
- [6] Song M J, Xia L, Mao N and Deng S M 2016 *Applied Energy* **164** pp 36-44
- [7] Col D D, Azzolin M, Benassi G and Mantovan M 2015 *Energy and Buildings* **91** pp 105-14
- [8] Zhu X, Nie X, Wang C and Su Y 2012 *Res Jour of Applied Sciences, Eng and Tech* **16** 4 pp 2740-43
- [9] Song M, Dong J, Wu C and Jiang Y 2017 *Trans. HK Inst. of Engineers* **24** 2 pp 88-98
- [10] JG/T 236-2008 *Electric heating radiator* (Beijing: Stand. Press of China)

- [11] *GB/T 25127.2-2010 Low ambient temperature air source heat pump (water chilling) packages-Part 2: Heat pump (water chilling) packages for household and similar application* (Beijing: Stand. Press of China)
- [12] *GB 17625.1-2012 Electromagnetic compatibility-Limits-Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)* (Beijing: Stand. Press of China)
- [13] *GB/T 14549-1993 Quality of electric energy supply-Harmonics in public supply network* (Beijing: Stand. Press of China)