Application of High-voltage Frequency Inverters in Arc Furnace Dust Fans in Steel Plants

Abstract: based on analysis of operation situations of equipment of arc furnaces and study of the characteristics of dust removal system of arc furnaces, this paper introduces realization of high-voltage frequency conversion technology in the arc furnace dust removal system in steel plants through the application example of INVT CHH100 series high-voltage frequency inverters in the arc furnace dust removal system of Hebei Yongyang Steel Plant. The example demonstrated that frequency conversion technology has very good application prospects in energy-saving and consumption reduction as well as enhancement of the automation control level.

Keywords: high-voltage frequency conversion technology, arc furnace dust removal system, energy-saving.

1. Preface

Hebei Yongyang Steel Plant is a Sino-foreign joint venture. It was founded in 1993 jointly by original Yongnian County Rolling Mill, Hunan Changde City Construction and Development Company of and Hongkong Yizhou Development Co., Ltd. It went into production officially in Oct 1994. Now it has more than 2000 employees, of which more than 150 are senior technicians and managers. The company has a floor area of 200,000 sqm and a total assets of 1.1 billion Yuan. There are 4 rolling lines (one # 800 rolling line, one 650# rolling line and two #500 rolling lines) and the annual production capacity is up to 0.7 million tons.

2. Alteration background

Steel plants have been considered for a long time as enterprises with a large amount of dust and smoke emissions, waste and pollution due to the features of dense resources, dense energy consumption, large production scale, and high goods throughput and so on. The arc furnaces for steelmaking are one of the main sources for dust and smoke pollution caused by some steel plants.

During smelting, arc furnaces can generate a large amount of hot fumes. If not collected and treated, it will cause very serious air pollution. In recent years, with the improvement of the smelting process, the smelting time has shortened greatly and the oxygen consumption of arc furnaces has increased abruptly. Along with these are multiplication of fume generation and constant increase of capacity of dust removal equipment. As auxiliary equipment in steelmaking enterprises, the fume and dust removal equipment has the features of high energy consumption and high operation cost. For a long period of time, no matter what operation stage the electric furnace is, the generated fumes and dust make the dust removal fan operate at full speed. It is adjusted with the opening of the inlet baffle. This has the disadvantages of low efficiency, high power and high electric energy waste. Moreover, according to the features of electric furnaces, the furnace bottoms shall be cleaned 2 to 4 times every month, the furnaces shall be overhauled once every month and it takes 24 hours generally. As the motor is a
2240kW high-voltage motor, it is very difficult to start if it operates in power frequency state. The high-voltage fan is not stopped generally except in special cases. That is to say the dust removal fan is not stopped generally while the electric furnace is overhauled. The motor is always operating at full load and electric energy waste is enormous. With increasingly intense market competition, reducing energy consumption and increasing production efficiency have become one of the effective means for enterprises to enhance competitive power. For the above reasons, we've made alterations on the dust removal equipment of the steel plant.

3. Technical solution study and selection of the system

During steelmaking of electric furnaces, harmful pollutants are mainly generated in 3 stages – furnace charging, smelting, and tapping. Smelting with electric furnace is generally divided into melting period, oxidation period and reduction period. Intensified de-carbon is conducted in the oxidation period and a large amount of auburn thick smoke is generated due to oxygen blow or addition of ore. In the above-mentioned three smelting periods, the fumes generated in the oxidation period is the highest amount, as well as dust concentration and temperature. Therefore, the dust removal system of an electric furnace is designed according to the max fume discharge in the oxidation period. The dust removal fan is selected and designed according to the max. air volume demand of the system with 1.1 to 1.3 times of safety margin. Oxygen blow accounts for 30 to 35% of the whole smelting process. The fan operates at high load during this period and at lower operating conditions in other time. It is obvious that the utilization rate of the dust removal system is low and the system efficiency is poor. For a long period of time, no matter what operation stage the arc furnace is, the generated dust make the dust removal fan operates at full speed. It is adjusted with the opening of the inlet baffle. This has the disadvantages of low efficiency, high power and high electric energy waste. With increasingly intense market competition, reducing energy consumption and increasing production efficiency have become one of the effective means for enterprises to enhance competitive power.

Structure of arc furnace dust removal system
Through analysis of the smelting process we know that the dust removal air volume in different stages of the steelmaking process of electric furnaces varies remarkably; it is highest in the oxygen blow smelting period and lowest in charging stage. According to the operation mode and equipment features of the dust fan in the electric furnace dust removal system and the fact that the dust fan is the power center of the dust removal and purification system, once the dust fan is unable to operate normally, it will not only affect production and cause enormous economic loss but also endanger personal safety of production persons on the field. In addition to this, the speed regulation system works in harsh environment and oxygen blow is conducted on the converter periodically and intermittently. So the high-voltage speed regulation system for the dust fan requires extremely high reliability. Based on the above operating features, the main requirements for the frequency conversion speed regulation system are as below:

1) The frequency inverter must have high reliability and is able to operate free of failure day after day.

2) The frequency inverter must have bypass function. Once it becomes faulty, the motor must be switched to power frequency operation.

3) Speed adjusting range must be large and the efficiency must be high.

4) Has resonance point skip setting, allowing the motor to keep away from the resonance point and eliminating fan surge.

Through large amount of investigation and comparison, the company finally decided to adopt a set of CHH100 series 10kV/2500kW multi-unit tandem high-voltage frequency inverter of high-voltage to high-voltage direct conversion independently developed, manufactured by Shenzhen INVT Electric Co., Ltd. Through cooperation of technicians of both parties, the following frequency conversion alteration solution for the dust fan of the arc furnace was set down:

**1) There are the following main features after the frequency conversion speed regulation technology is applied in the dust removal system of the electric furnace:**

a. the existing electric and valve control modes should still be reserved so that the fan system can operate in any cases.

b. according to previous engineering applications, in normal adjusting process of the fan equipment on the field, the CHH100 frequency inverter can meet the timing requirements for both accelerating and decelerating, there is no need to equip a braking unit separately.

c. the power consumption of the dust removal equipment varies with the smelting process of the electric furnace. This system efficiency is improved. The dust removal system operates in optimal operating conditions. Remarkable energy-saving effect is obtained.

d. the load rate of the dust removal system is effectively reduced and the service life of deduster, dust fan, dust motor, flue and other equipment.

e. it has certain function for reducing furnace heat loss, reasonably controlling process temperature, and ensuring final temperature.

f. performing frequency conversion alteration on the dust removal system is helpful for improving furnace blowing conditions, shortening steelmaking time, enhancing steel output and improving steel quality.

g. can reduce energy consumption during furnace patching as well as heat loss of the furnace liner.

**2) Configuration of the frequency inverter**

According to the rated parameters and actual operating conditions on the field combining application of CHH100 series frequency inverters in other projects, INVT configured the frequency inverter with the following parameters for this application:
1. Model of frequency inverter | CHH100-2500-10
2. Rated capacity | 3000kVA
3. Rated voltage | 10kV
4. Rated current | 175A
5. Control mode | “one-for-one”, manual bypass switching
6. Quantity of the frequency inverter | 1 set

(3) Bypass switching solution of the frequency conversion system

The bypass system of the CHH100 frequency inverter provided by INVT adopts “one-for-one” manual solution. The frequency inverter has the speed tracking function. The dust fan can be manually switched between variable frequency and power frequency. The primary system is as shown in the Figure below:

![Diagram of CHH100 series manual switching “one-for-one” high-voltage frequency conversion system](image)

The frequency conversion speed regulation system consists of the user’s switch, manual bypass cabinet, CHH100 series high-voltage frequency inverter, and high-voltage motor. The manual bypass cabinet consists of 3 high-voltage isolating switches QS1, QS2 and QS3. The manual bypass cabinet is designed strictly according to the “5-preventing” interlock requirements. The frequency inverter’s input and output high-voltage isolating switches QS1 and QS2 are mechanically interlocked with the bypass high-voltage isolating switch QS3. This can ensure safe operation of the frequency conversion speed regulation system.

1. When it is operating in variable frequency state, QS1 and QS2 are ON and QS3 is OFF. When it manually switched to power frequency (failure), the system first stops the frequency inverter output. Disconnect the user’s switch, and disconnect QS1 and QS2 in turn by mechanical operation, and then, close QS3 by mechanical operation to switch the motor to the power frequency side, and finally close the user’s switch to allow the motor to operate in power frequency mode (need soft start). This process is performed manually.

2. When it is operating in power frequency bypass state, QS3 is ON, and QS1 and QS2 are OFF. When it is manually switched to variable frequency, the system first disconnects the user’s switch. Disconnect QS3 by mechanical operation, and then, close QS1 and QS2 in turn by mechanical operation to switch the motor to the variable frequency side, and finally close the user’s switch to allow the motor to operate in variable frequency mode. This process is performed manually.

(4) Control mode

As the fume temperature varies remarkably at different process stages, the temperature value directly reflects the operating conditions of the electric furnace. The system does not directly control dust removal air volume by detecting dust concentration during operation of the electric furnace. Instead of this, it collects flue temperature as the basic parameter for system regulation and reduces the dust removal air volume in different operating conditions with nonlinear function relation to participate in the system control. With regard to engineering, the temperature transducer can be used in harsh industrial situations. It has high anti-interference ability, operation stability, control accuracy, safety and reliability, and is maintenance-free and inexpensive. While the dust concentration detection device has the disadvantages of high cost, poor stability, high failure rate, high maintenance, and it is very difficult for the data of the detecting points acquired on the field to be broadly representative. For these reasons, the
temperature of fume in the dust removal flue is selected as the field process quantity. Additionally, the amount of blown oxygen and the opening of the cool air door are used as the correction parameters of the dust removal air volume to increase the system response speed, improve control quality, obtain good dust removal effect, realize automatic control of dust removal air volume, reduce the labor intensity of the attendant, enhance system efficiency, and reach optimal energy-saving effect. The specific control logic is as shown in the figure below.

To ensure system reliability, the manual control circuit of dust removal air amount is additionally provided. The band speed regulation method is used to control the dust removal volume. The operation frequency point is controlled by the furnace control board to realize the adjustment of air volume in different operation conditions. The control logic diagram is as shown in the figure below.

Practice proves that the two sets of control solutions have greatly improved the system’s practicality and maneuverability and can fully meet the production requirements on the field. Additionally, it plays an active role in improving working environment on the field, enhancing product quality, and reducing energy consumption per ton of steel.

4. Technical features of INVT CHH100 series high-voltage frequency inverters

Besides the functions of high-voltage frequency inverters of ordinary manufacturers, CHH100 series frequency inverters from Shenzhen INVT Electric Co., Ltd. have the following features:
1) Enhanced functions meet different operating conditions

CHH100 series high-voltage frequency inverters smartly combine the DSP system and programmable system. The control system is highly integrated. The components are mainly imported products. Their functions are more than the ordinary high-voltage frequency inverters. More than 300 functional codes can be used to make different settings for starting characteristic and operation mode and other functions according to the field conditions. CHH100 series high-voltage frequency inverters have standard RS485 port. They can connect with the DCS via either RS485 communication port (adopting standard communication protocol) or hard wiring. Several interface options enable the DCS system to conveniently monitor the frequency conversion speed regulation system. You can also make different parameter settings to meet various field operating conditions.

2) Comprehensive protection functions

The power unit of CHH100 series frequency inverters has protection to up to 11 kinds of failures. The main control system smartly combines DSP and FPGA. The electrical system has all-sided protection for output voltage, output current, input voltage and input current, and has more than 20 super-strong comprehensive protection functions for over-voltage, over-current, overload, under-voltage, temperature, etc. Moreover, important protection settings can be set according to the field operating conditions. The built-in lightning strike over-current protection device can effectively improve the equipment protection function and system protection function, and is absolutely able to ensure safe operation of the power supply and motors.

3) All-sided parameter record

CHH100 series high-voltage frequency inverters display many process variable operation parameters. The temperature of each module and bus voltage are detected and displayed. They have failure and event display and record function and self-diagnosis function. All information can be uploaded to the DCS system through communication. In the case of abnormality, the state of the frequency inverter is recorded completely for the field personnel to solve the problem accurately and quickly.

4) Maximal voltage and current margin design

Safe, reliable and long life are the first important design principle of CHH100 series high-voltage frequency inverters of Shenzhen INVT Electric Co., Ltd. They adopt 1700V high-voltage IGBT and 9- or 6-unit tandem. The voltage margin is about 2.0 times. The power component is designed with high voltage margin for safety.

5) Automatic motor speed tracking function

During switching of main power bus (within 10s), CHH100 series high-voltage frequency inverters can automatically track motor speed. After the main power recovers, the frequency inverter will operate automatically. This ensures safe, reliable operation of the generating set.

6) Automatic bypass technology of the power module

Automatic module bypass technology improves system stability. CHH100 series high-voltage frequency inverters adopt automatic bypass technology of the power module. It can bypass the faulty module in 1ms. The frequency inverter can operate derated for the long-term and wait for an appropriate time to be repaired after stopping.

7) Good voltage fluctuation adaptability
For fluctuation within ±15% of the grid voltage, CHH100 series high-voltage frequency inverters can output at full load. When the grid voltage drops to 65% rated voltage for a short period (30s), they can continue to operate derated without protection.

8) Most effective electromagnetic interference solution

The design scheme of “wires incoming from back and outgoing from front” is adopted solely in module design of CHH100 series high-voltage frequency inverters of Shenzhen INVT Electric Co., Ltd. Countermeasures to electromagnetic interference is considered comprehensively in structural and electric aspects, especially core control boards, to most effectively ensure reliable operation of the frequency inverter.

9) Reasonable heat dissipation system

Good heat dissipation is obtained by independent heat transfer tunnel of the power module and centralized heat dissipation of the system. The temperature rise does not exceed 25℃ during full load long-period operation. Excellent heat dissipation system can ensure high reliability of the frequency inverter and prolong the service life of their internal components.

10) Modular design

CHH100 series frequency inverters follow modular design concept. The power units adopt modular structure. The structures and configurations of all identical power units are completely equal. They can interchange very conveniently. It is helpful to the standardization of production and repair.

11) Simplest operation and fastest maintenance

CHH100 series high-voltage frequency inverters of Shenzhen INVT Electric Co., Ltd. have personalized port design and simple, clear interface. They are easy to operate. Draw-out type module design is adopted. It takes only 5 minutes to replace a module. The replacing of the sieve is convenient and fast.
5. Analysis of energy-saving

In order to evaluate the alteration effect of the dust removal system, after one month since the system was put into normal operation, a measuring and data analysis were performed on the actual use and energy-saving of the equipment.

2 routine production days were sampled randomly when the system was switched to power frequency and the air volume was controlled with baffle. The electric energy consumption was measured with the grid side active electric meter. Then, we continuously collected the electric consumption for 2 routine production days of variable frequency operation and calculated the unit consumption in variable frequency operation so as to expect that the data of variable frequency operation are more near to true operating conditions. See the table below for the specific data sampling values.

<table>
<thead>
<tr>
<th>State</th>
<th>Operation duration (h)</th>
<th>Accumulated electric energy (KW/h)</th>
<th>Steel output (t)</th>
<th>Dust removal energy consumption per ton steel (KW/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power frequency operation</td>
<td>48</td>
<td>88668</td>
<td>2989.344</td>
<td>29.661</td>
</tr>
<tr>
<td>Variable frequency operation</td>
<td>48</td>
<td>50852.16</td>
<td>2989.343</td>
<td>17.011</td>
</tr>
</tbody>
</table>

From processing of the original data in the above table, we can deduce that, after the alteration, the electric energy consumption per ton steel of the dust removal system has reduced by 12.65kW•h compared with that before the alteration. The electric energy-saving rate of the equipment is up to 42.648% and the energy-saving effect is remarkable.
By comparing the current record curve of the dust fan for one heat in power frequency operation and the grid side current record curve for one heat in variable frequency operation, we can intuitively see that the fan current is obviously reduced and the operating conditions of the equipment can better meet the requirements of the actual production process.

6. Conclusion

We can see that after using one CHH100 high-voltage frequency inverter of Shenzhen INVT Electric Co., Ltd., the equipment can save up to about 3 million CNY electricity cost each year. Moreover, as the power factor of CHH100 series high-voltage frequency inverters of Shenzhen INVT Electric Co., Ltd. is up to 0.95 or more, higher than the power factor of motors, 0.89, it can reduce large amount of reactive power. Besides, soft starting of the motor is realized which can avoid effect on motor insulation caused by impact of high starting current, reduce motor maintenance, save repair and maintenance expenses, remarkably prolong motor life, and reduce the labor intensity of the attendants. The attendants and repairmen are very satisfied with it. After the alteration, the energy-saving effect of the dust fan is remarkable and meets the design requirements. The progress and reliability of these series frequency inverters have been proven in many industrial applications.

References:

[1] Energy-saving alteration guidance for fans and pumps (complied by the Resources Saving and Comprehensive Utilization Management Department of State Economic & Trade Commission)

[2] AC motor frequency conversion speed regulation energy-saving technology guidance (complied by the Energy-saving Information Transmission Center)