Belt Conveying Systems Development of driving system

Among the methods of material conveying employed, belt conveyors play a very important part in the reliable carrying of material over long distances at competitive cost. Conveyor systems have become larger and more complex and drive systems have also been going through a process of evolution and will continue to do so. Nowadays, bigger belts require more power and have brought the need for larger individual drives as well as multiple drives such as 3 drives of 750 kW for one belt(this is the case for the conveyor drives in Chengzhuang Mine). The ability to control drive acceleration torque is critical to belt conveyors' performance. An efficient drive system should be able to provide smooth, soft starts while maintaining belt tensions within the specified safe limits. For load sharing on multiple drives. torque and speed control are also important considerations in the drive system's design. Due to the advances in conveyor drive control technology, at present many more reliable. Cost-effective and performance-driven conveyor drive systems covering a wide range of power are available for customers' choices[1].

1 Analysis on conveyor drive technologies

1. 1 Direct drives

Full-voltage starters. With a full-voltage starter design, the conveyor head shaft is direct-coupled to the motor through the gear drive. Direct full-voltage starters are adequate for relatively low-power, simple-profile conveyors. With direct full-voltage starters. no control is provided for various conveyor loads and. depending on the ratio between full- and no-load power requirements, empty starting times can be three or four times faster than full load. The maintenance-free starting system is simple, low-cost and very reliable. However, they cannot control starting torque and maximum stall torque; therefore. they are limited to the low-power, simple-profile conveyor belt drives.

Reduced-voltage starters. As conveyor power requirements increase, controlling the applied motor torque during the acceleration period becomes increasingly important. Because motor torque 1s a function of voltage, motor voltage must be controlled. This can be achieved through reduced-voltage starters by employing a silicon controlled rectifier(SCR). A common starting method with SCR reduced-voltage starters is to apply low voltage initially to take up conveyor belt slack. and then to apply a timed linear ramp up to full voltage and belt speed. However, this starting method will not produce constant conveyor belt acceleration. When acceleration is complete. the SCRs, which control the applied voltage to the electric motor. are locked in full conduction, providing full-line voltage to the motor. Motors with higher torque and pull—up torque, can provide better starting torque when combined with the SCR starters, which are available in sizes up to 750 KW.

Wound rotor induction motors. Wound rotor induction motors are connected directly to the drive system reducer and are a modified configuration of a standard AC induction motor. By inserting resistance in series with the motor's rotor windings. the modified motor control system controls motor torque. For conveyor starting, resistance is placed in series with the rotor for low initial torque. As the conveyor accelerates, the resistance is reduced slowly to maintain a constant acceleration torque. On multiple-drive systems. an external slip resistor may be left in series with the rotor windings to aid in load sharing. The motor systems have a relatively simple design. However, the control systems for these can be highly complex, because they are based on computer control of the resistance switching. Today, the majority of control systems are custom designed to meet a conveyor system's particular specifications.

Wound rotor motors are appropriate for systems requiring more than 400 kW .

DC motor. DC motors. available from a fraction of thousands of kW , are designed to deliver constant torque below base speed and constant kW above base speed to the maximum allowable revolutions per minute(r/min). with the majority of conveyor drives, a DC shunt wound motor is used. Wherein the motor's rotating armature is connected externally. The most common technology for controlling DC drives is a SCR device. which allows for continual variable-speed operation. The DC drive system is mechanically simple, but can include complex custom-designed electronics to monitor and control the complete system. This system option is expensive in comparison to other soft-start systems. but it is a reliable, cost-effective drive in applications in which torque, load sharing and variable speed are primary considerations. DC motors generally are used with higher-power conveyors, including complex profile conveyors with multiple-drive systems, booster tripper systems needing belt tension control and conveyors requiring a wide variable-speed range.

1. 2 Hydrokinetic coupling

Hydrokinetic couplings, commonly referred to as fluid couplings. are composed of three basic elements; the driven impeller, which acts as a centrifugal pump; the driving hydraulic turbine known as the runner and a casing that encloses the two power components. Hydraulic fluid is pumped from the driven impeller to the driving runner, producing torque at the driven shaft. Because circulating hydraulic fluid produces the torque and speed, no mechanical connection is required between the driving and driven shafts. The power produced by this coupling is based on the circulated fluid's amount and density and the torque in proportion to input speed. Because the pumping action within the fluid coupling depends on centrifugal forces. the output speed is less than the input speed. Referred to as slip. this normally is between 1% and 3%. Basic hydrokinetic couplings are available in configurations from fractional to several thousand kW .

Fixed-fill fluid couplings. Fixed-fill fluid couplings are the most commonly used soft-start devices for conveyors with simpler belt profiles and limited convex/concave sections. They are relatively simple, low-cost, reliable, maintenance free devices that provide excellent soft starting results to the majority of belt conveyors in use today.

Variable-fill drain couplings. Drainable-fluid couplings work on the same principle as fixed-fill couplings. The coupling's impellers are mounted on the AC motor and the runners on the driven reducer high-speed shaft. Housing mounted to the drive base encloses the working circuit. The coupling's rotating casing contains bleed-off orifices that continually allow fluid to exit the working circuit into a separate hydraulic reservoir. Oil from the reservoir is pumped through a heat exchanger to a solenoid-operated hydraulic valve that controls the filling of the fluid coupling. To control the starting torque of a single-drive conveyor system, the AC motor current must be monitored to provide feedback to the solenoid control valve. Variable fill drain couplings are used in medium to high-kW conveyor systems and are available in sizes up to thousands of kW . The drives can be mechanically complex and depending on the control parameters. the system can be electronically intricate. The drive system cost is medium to high, depending upon size specified.

Hydrokinetic scoop control drive. The scoop control fluid coupling consists of the three standard fluid coupling components: a driven impeller, a driving runner and a casing that encloses the working circuit. The casing is fitted with fixed orifices that bleed a predetermined amount of fluid into a reservoir. When the scoop tube is fully extended into the reservoir, the coupling is 100 percent filled. The scoop tube, extending outside the fluid coupling, is positioned using an electric actuator to engage the tube from the fully retracted to the fully engaged position. This control provides reasonably smooth acceleration rates. to but the computer-based control system is very complex. Scoop control couplings are applied on conveyors requiring single or multiple drives from 150 kW to 750 kW.

1. 3 Variable-frequency control(VFC)

Variable frequency control is also one of the direct drive methods. The emphasizing discussion about it here is because that it has so unique characteristic and so good performance compared with other driving methods for belt conveyor. VFC devices Provide variable frequency and voltage to the induction motor, resulting in an excellent starting torque and acceleration rate for belt conveyor drives. VFC drives. available from fractional to several thousand(kW), are electronic controllers that rectify AC line power to DC and, through an inverter, convert DC back to AC with frequency and voltage control. VFC drives adopt vector control or direct torque control(DTC)technology, and can adopt different operating speeds according to different loads. VFC drives can make starting or stalling according to any given S-curves. realizing the automatic track for starting or stalling curves. VFC drives provide excellent speed and torque control for starting conveyor belts. and can also be designed to provide load sharing for multiple drives. easily VFC controllers are frequently installed on lower-powered conveyor drives, but when used at the range of medium-high voltage in the past. the structure of VFC controllers becomes very complicated due to the limitation of voltage rating of power semiconductor devices, the combination of medium-high voltage drives and variable speed is often solved with low-voltage inverters using step-up transformer at the output, or with multiple low-voltage inverters connected in series. Three-level voltage-fed PWM converter systems are recently showing increasing popularity for multi-megawatt industrial drive applications because of easy voltage sharing between the series devices and improved harmonic quality at the output compared to two-level converter systems With simple series connection of devices. This kind of VFC system with three 750 kW /2. 3kV inverters has been successfully installed in ChengZhuang Mine for one 2. 7-km long belt conveyor driving system in following the principle of three-level inverter will be discussed in detail.

2 Neutral point clamped(NPC)three-level inverter using IGBTs

Three-level voltage-fed inverters have recently become more and more popular for higher power drive applications because of their easy voltage sharing features. lower dv/dt per switching for each of the devices, and superior harmonic quality at the output. The availability of HV-IGBTs has led to the design of a new range of medium-high voltage inverter using three-level NPC topology. This kind of inverter can realize a whole range with a voltage rating from 2. 3 kV to 4. 1 6 kV Series connection of HV-IGBT modules is used in the 3. 3 kV and 4. 1 6 kV devices. The 2. 3 kV inverters need only one HV-IGBT per switch[2,3].

2. 1 Power section

To meet the demands for medium voltage applications. a three-level neutral point clamped inverter realizes the power section. In comparison to a two-level inverter. the NPC inverter offers the benefit that three voltage levels can be supplied to the output terminals, so for the same output current quality, only 1/4 of the switching frequency is necessary. Moreover the voltage ratings of the switches in NPC inverter topology will be reduced to 1/2. and the additional transient voltage stress on the motor can also be reduced to 1/2 compared to that of a two-level inverter.

The switching states of a three-level inverter are summarized in Table

1. U. V and W denote each of the three phases respectively; P N and O are the dc bus points. The phase U, for example, is in state P(positive bus voltage)when the switches S_{1u} and S_{2u} are closed, whereas it is in state N (negative bus voltage) when the switches S_{3u} and S_{4u} are closed. At neutral point clamping, the phase is in O state when either S_{2u} or S_{3u} conducts depending on positive or negative phase current polarity, respectively. For neutral point voltage balancing, the average current injected at O should be zero.

2. 2 Line side converter

For standard applications. a 12-pulse diode rectifier feeds the divided DC-link capacitor. This topology introduces low harmonics on the line side. For even higher requirements a 24-pulse diode rectifier can be used as an input converter. For more advanced applications where regeneration capability is necessary, an active front. end converter can replace the diode rectifier, using the same structure as the inverter.

2. 3 Inverter control

Motor Control. Motor control of induction machines is realized by using a rotor flux. oriented vector controller.

Fig. 2 shows the block diagram of indirect vector controlled drive that incorporates both constant torque and high speed field-weakening regions where the PW M modulator was used. In this figure, the command flux ψ_r^* is generated as function of speed. The feedback speed is added with the feed forward slip command signal ψ_r^* . the resulting frequency signal is integrated and then the unit vector signals(cosθ_e and sinθ_e)are generated. The vector rotator generates the voltage $V*$ and angle θ_e^* commands for the PW M as shown.

PWM Modulator. The demanded voltage vector is generated using an elaborate PWM modulator. The modulator extends the concepts of space-vector modulation to the three-level inverter. The operation can be explained by starting from a regularly sampled sine-triangle comparison from two-level inverter. Instead of using one set of reference waveforms and one triangle defining the switching frequency, the three-level modulator uses two sets of reference waveforms U_{r1} and U_{r2} and just one triangle. Thus, each switching transition is used in an optimal way so that several objectives are reached at the same time.

Very low harmonics are generated. The switching frequency is low and thus switching losses are minimized. As in a two-level inverter, a zero-sequence component can be added to each set of reference waveform s in order to maximize the fundamental voltage component. As an additional degree of freedom, the position of the reference waveform s within the triangle can be changed. This can be used for current balance in the two halves of the DC-link.

3 Testing results

After Successful installation of three 750 kW /2. 3 kV three-level inverters for one 2. 7 km long belt conveyor driving system in Chengzhuang Mine. The performance of the whole VFC system was tested. Fig. 3 is taken from the test, which shows the excellent characteristic of the belt conveyor driving system with VFC controller.

Fig. 3 includes four curves. The curve 1 shows the belt tension. From the curve it can be find that the fluctuation range of the belt tension is very small. Curve 2 and curve 3 indicate current and torque separately. Curve 4 shows the velocity of the controlled belt. The belt velocity have the "s" shape characteristic. All the results of the test show a very satisfied characteristic for belt driving system.

4 Conclusions

Advances in conveyor drive control technology in recent years have resulted in many more reliable. Cost-effective and performance-driven conveyor drive system choices for users. Among these choices, the Variable frequency control (VFC) method shows promising use in the future for long distance belt conveyor drives due to its excellent performances. The NPC three-level inverter using high voltage IGBTs make the Variable frequency control in medium voltage applications become much more simple because the inverter itself can provide the medium voltage needed at the motor terminals，thus eliminating the step-up transformer in most applications in the past.

The testing results taken from the VFC control system with NPC three. level inverters used in a 2. 7 km long belt conveyor drives in Chengzhuang Mine indicates that the performance of NPC three-level inverter using HV-IGBTs together with the control strategy of rotor field-oriented vector control for induction motor drive is excellent for belt conveyor driving system.