Cutting edge, energy efficient conveyor systems

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The article describes the selection of variable voltage, variable frequency (VVVF) drive systems for conveyor applications, highlights design considerations and shows the energy saving potential of modern drive systems. In cases studies, a few demanding conveyor applications are described to illustrate the drives system selection and system integration aspects. Finally, an innovative integrated control system solution for conveyors is shown that allows faster and easier design and installation of conveyor VVVF drive systems.

Introduction

Conveying is a critical part of mining and the selection of the drive solution directly impacts on the performance, flexibility of operation, total efficiency, reliability and the life of the conveyor system. These conveyors are the arterial veins that connect the heart of the mining operations. Conveyors are required to be the sort of equipment that is solid, dependable and have a process repeatable technology, to ensure the highest availability, under the most diverse conditions is achievable.

Based on our comprehensive applications portfolio for conveyors solutions with experience in supplying integrated conveyor systems for the mining industry for many decades various aspects of the drive system selection, design, installation and operation are analysed.

Conveyor applications

The belt is the most expensive and most exposed component of a conveyor. In addition to the selection of an adequate drive system, it is necessary to ensure that the stress on the belt is kept within the design limits. This basic requirement must be maintained for all possible operating conditions, including emergency situations.

The load sharing of the different drives has to be coordinated in such a way that all the associated drives develop a similar torque even under partial load conditions and during starting / stopping procedures, but especially under full load or in emergency situations. It has to be ensured that the torque peaks transmitted to the belt are never more than 20 to 30 % above the required torque, regardless of whether such peaks occur in the acceleration, operational or deceleration phases.

Torque peaks must be controlled and limited to a permitted magnitude for all the mechanical components such as gearboxes, couplings, shafts etc. Possible belt slipping has to be monitored.

The belt must be started and stopped very gently and in a controlled manner so that the belt is not overstressed. This can be achieved with an S-shaped acceleration and deceleration ramp. In cases where the belt conveyor is very long it may even be necessary to start the drives on the head end before the ones on the tail end in order to tighten the belt first.

The service speed is usually around 10 % of the nominal belt speed. The conveyor drive system needs either to be designed to operate at these conditions or an additional low-speed motor system is required.

Depending on the conveyor topology, no braking during operation is required for horizontal conveying systems. If the terrain is ascending and descending it may be necessary to use partial braking while the belt is being loaded and unloaded. Downhill conveyors require continuous braking during operation if the friction losses are smaller than the energy regenerated by the load.

Drive system selection

When a drive system is selected for conveyor applications, a large number of items need to be checked and many questions must be answered. The selection depends on the topographical conditions, the material to be transported, the environmental requirements and the operating methods. A key decision must be taken between fixed speed and variable speed drives.

This selection process is of course plant specific and may be biased by customer preferences or company guidelines. Several factors such as process, mechanical, electrical and cost considerations must be taken into account in the drive system evaluation. Choosing the correct factors is not easy. However, a proper evaluation and the right selection of the drive system are important for the plant design and have a high impact on future plant operation.

Conveyor applications require constant torque throughout their speed range, high breakaway torque, high inertias, high accelerating and decelerating torques and very commonly require load sharing between multiple drives, controlled stops and – depending on the topology – regeneration. Furthermore, the mechanics, especially for longer conveyors, can be rather complex with natural frequencies and possible critical speeds and belt tensions.

Variable speed drives are well suited for all types of conveyor applications, i.e. short and long distance, overland and downhill. They allow accurate load sharing between motors and a proper implementation of tripper / booster drives. Furthermore, the running speed can be accurately controlled and thus an optimisation of the belt load profile is possible. With an optimised belt load profile wear and maintenance of the conveyor can be reduced due to slower speed operation.

Variable speed drives give high flexibility in the design and the operation. There are no real design limits and starts and stops can be done with controlled acceleration / deceleration. This reduces the voltage drop and system disturbance during start by reducing the current draw. In addition, acceleration and deceleration times are not load dependant. Due to the smooth and controlled starting and stopping these drives reduce the mechanical stress on the equipment and thus improve the life expectancy. The mechanical equipment is not subject to the motor breakdown torque during starting and the torque is controlled and limited by the drive. Furthermore, acceleration and deceleration can be done with S-curves to reduce jerking.

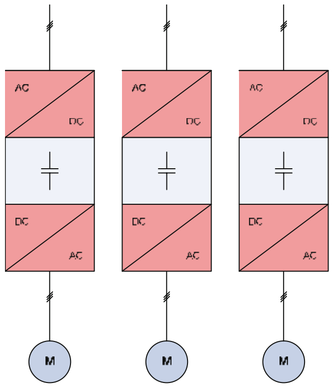


Figure 1: Basic configuration of single frequency converter drives.

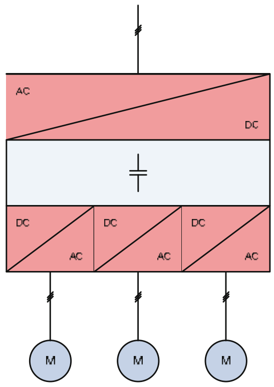


Figure 2: Basic configuration of multi-drive frequency converters.

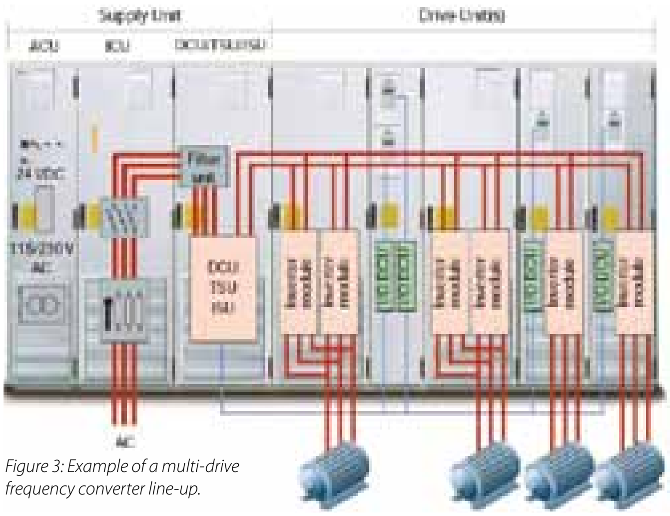


Figure 3: Example of a multi-drive frequency converter line-up.

The service speed is often in the range of 10 % of the nominal belt speed. With the variable-speed drive system all speeds can be achieved with the same equipment and thus no additional low-speed motor system is required.

The solution for a conveyor drive system with multiple drives can either use single drives or a multi-drive system. The single drive system consists of individual frequency converters, including rectifier and inverter, while the multi-drive has a common rectifier section and DC-bus, but individual inverters, which can be controlled independently of each other (see figure 1 and 2). The decision as to whether it should be single drive or multi-drive often depends on the drive arrangement of the conveyor.

The basic design feature of a multi-drive is a common rectifier with either a 6-pulse, 12-pulse or active front-end configuration for all individual inverters. The individual inverters may have different power ratings and even performance requirements because the drive control loop is independent for each of the individual inverters. Multi-drives allow motor-to-motor braking via the common DC-bus, independent of the type of rectifier used.

In cases where electrical braking is required, either a braking chopper and braking resistor in the DC link or a regenerative supply section can be used. The method with a braking chopper and braking resistor may be uneconomical, because the surplus energy is converted into heat. The second option, using the recovery unit, allows all of the energy – with the exception of mechanical losses of the conveyor system and internal losses of the drive – to be fed back into the network.

All variable speed drives generate harmonics. For drives with diode-bridge rectifiers the harmonic distortion can be reduced with higher pulse numbers whereas drives with active front-ends, by nature generate very low harmonic distortion.

Reducing harmonic distortion increases the cost of the equipment and the best overall solution for the installation needs be analysed considering all other related costs such as filters, de-rating of cables and transformers, etc. For multi-drives however the additional investment for an active front-end converter (i.e., also use IGBTs on the rectifier side) is in relative terms much lower than for single drives where all drives have their own rectifier.

An active front-end allows a 4-quadrant operation and therefore to feed energy back into the network. It can also compensate reactive power without the installation of additional capacitors or filters.

Energy efficiency

Beside the desired flexibility for the operation, today's drive systems provide as well high energy efficiency and system reliability. For conveyor applications, variable speed drives can significantly reduce energy consumption by optimising starting and stopping sequences, acceleration and deceleration ramps, belt loading and conveyor speed.

Studies for German lignite mines have shown that technological and operational optimisation of existing conveyor systems can result in 5 to 8 % energy savings. Kinematic modifications at belt conveyors and the modernisation of drives and control systems at belt conveyors can result in additional energy savings of about 10 % and 20 %, respectively. All conveyor lines in such a mine account for about 40 % of the total energy consumption and thus the potential for energy savings by optimising and modernising conveyor drive systems is huge.

Modern drive technologies, such as DTC (Direct Torque Control), give even better energy savings as well as more accurate speed and torque control across a wider speed range. Increased energy saving can be achieved with DTC-based drives compared to standard AC drives as the drive's flux optimization feature reduces the energy drawn by the motor.

Further energy savings can be achieved by using regenerative drives. These drives use the energy produced by a decelerating load. In this case, the spinning load is driving the motor, which acts like a generator, feeding current back to the drive through the supply cables. This means that large energy savings can be achieved in applications where energy from the braking of the motor can be fed back into the network and used by other applications. In addition, large braking resistors, which dump waste heat into the atmosphere, can be eliminated, freeing up floor space and reducing the need for ventilation.

Apart from energy savings, system availability effects productivity and therefore, profitability. In the case of today's drives, these offer not only very high availability of 99.9 % but efficiencies above 98 % too.

System integration

When selecting and sizing the drives for conveyors, system integration aspects and interface issues need to be addressed. For new installations the requirements of the drives for related equipment such as circuit breakers, transformers and cables need to be considered. Furthermore, mechanical interfacing, cooling requirements, harmonics and EMC aspects as well as control system interfaces need to be taken into account.

The motivation of most revamp or retrofit projects where drive systems are replaced in existing plants are either to modernize old, out-dated drive systems, to increase the efficiency or to increase the production capacity. These projects usually need a proper drive system selection as well as an evaluation of the specific boundary conditions such as existing mechanical and control interfaces, space constraints, and re-use of existing equipment. Following are some key points that need to be addressed properly, for the integration of drive systems.

Main circuit breaker

For medium voltage converters the main circuit breaker is one of the most important devices to protect the whole system in case of a failure. In spite of the high reliability of the drive, faults might happen because of certain unfortunate circumstances like human failure, material defects, etc. In such a situation the correct operation of the main circuit breaker will protect the drive for risks of damages. Therefore a correct operation of the main circuit breaker is very important.

The main circuit breaker must be able to connect and maintain nominal load currents and clear short-circuit currents, to tolerate the transformer inrush current without tripping, and to clear transformer primary side short-circuit instantaneously by breaking the fault current. The main circuit breaker is to be controlled entirely by the medium voltage converter and the closing command for the main circuit breaker must be given exclusively from the medium voltage converter. The closing command will be given upon a closing request to the medium voltage converter control. The closing request or command can be initiated from a local or a remote control location.

Manual closing of the main circuit breaker, e.g. directly from the switchgear panel, can cause major damage within the drive system or even risk for human life and is therefore strictly forbidden and has to be disabled. In order to ensure the correct operation of the medium voltage converter under fault condition a maximum total breaking time of the main circuit breaker has to be guaranteed. Breaking time is the defined time interval between the energizing of the opening coil and the extinguishing of the current flow in all poles.

Drives transformers

Drives transformers need to designed for converter operation and the harmonics generated by the variable speed drive as well as the voltage rise resulting from the switching of the semiconductors need to be thoroughly considered. The transformer losses and their internal distribution, the requirements for the insulation and the shielding between primary and secondary winding are different. The transformer design needs to consider the specifics of a certain frequency converter type as current and voltage waveforms differ significantly between different drives. Therefore, the necessary design modifications and their verification usually require close cooperation and good communication with the drives supplier.

Motors

The design and sizing of motors need to consider the requirements from the conveyor system as well as the specific issues with frequency converter operation. Voltage drop from the drive to the motor, voltage rise due to the switching of the semiconductors, harmonics and the related losses, increased insulation requirements, bearing currents and common mode voltages are issues that need to be addressed in the system design.

Cables

Cables are dimensioned on a case-by-case basis in accordance with the local regulations concerning short-circuit protection, operating voltage, permissible touch voltage appearing under fault conditions and current-carrying capacity of the cable. In addition, the cable type must support the EMC protection and availability of installed equipment.

The cables from the main circuit breaker to the transformer primary side generally have no special requirements with respect to frequency converter operation.

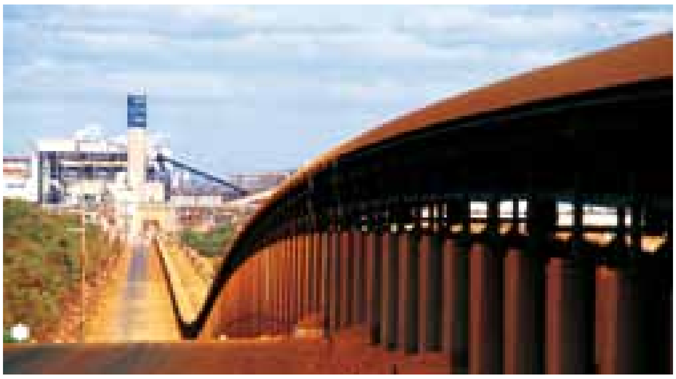
The transformer secondary cables (the cables from the transformer secondary windings to the frequency converter) as well as the motor cables (the cables from the frequency converter to the motor) need special attention. Whether there are special requirements to be considered with respect to frequency converter operation depends on the type of frequency converter and the use of output sine filters. If the cable type is not selected correctly and complying with the frequency converter requirements then problems with common mode voltages resulting from normal inverter operation, with bearing currents or with EMC may occur. It is therefore necessary to check the cable specifications of the supplier of a frequency converter and follow the given recommendations and guidelines. These documents describe the correct cable type, its shielding, screening, termination, grounding, protection, insulation rating and the maximum cable length.

Case studies

In the following a few case studies are described that show the demanding conveyor applications and the drive system solution that has been applied.

Long-distance belt conveyor Worsley Alumina (Western Australia)

Bauxite from Worsley Alumina's mine in Western Australia is transported to a refinery 51 km away by a conveyor. This conveyor was originally driven by DC drives, which did not deliver the required levels of reliability, thus leading to high maintenance.


Worsley conveyor.

Downtime was occurring with one motor having to be inspected every six weeks and, on average, brushes on one section being replaced each weekend.

The fundamental problem was that DC technology was underpowered for the requirements of the expansion. As a result of the Worsley expansion project (designed to increase the refinery's capacity to 3.1 million tons of alumina per annum) the ACS 1000 Medium Voltage Drives was a requirement for increased conveying capacity through increased conveyor speed, increased drive capacity, the integration of new conveyor controls, and reduced downtime.

ABB took the lead role and overall project responsibility in implementing a complete engineered solution incorporating both hardware and custom developed software. This necessitated the coordination and management of a multinational project task force involving more than 100 personnel, from seven companies, in three countries.

The conveyor upgrade required the replacement of high-maintenance DC drives with low-maintenance AC drives. In addition to equipment procurement and commissioning, ABB was responsible for engineering, project management, complete systems responsibility, creation of the monitoring and control software, start-up and handover procedures with guaranteed and proven capacity. The length of the conveyor imposed special challenges, requiring the coordination of all drives along the two transportation units, over a distance of 51 km. Load sharing was to be realized not only between the double drive units coupled on one shaft, but also superimposed with the regulation algorithms of the belt mechanical characteristics between the double drive sets in the three electrical rooms. Finally, an extremely short start-up time was requested: just fourteen days.

The system was delivered, passing all capacity and performance testing, exactly on schedule. Compared with the DC system it replaced, the new ACS 1000 powered Worsley conveyor system provides a higher conveying capacity with less maintenance and less down-time. New controls, integrated at the drive and group level, enable coordinated control of the complete start and stop sequences and provide an interface with the plant control system.

The increased conveyor speed has resulted in significantly increased conveying capacity, raised to an average of 2700 tons/hour. Two particular benefits derive from the use of ABB ACS 1000 drives. Network harmonics had previously been a problem with the DC drives but this was eliminated by the use of 12-pulse drives, with the input transformers connected to give an effective 24-pulse effect to the network. In addition the high and smooth starting torque delivered by the ACS 1000 DTC motor control has proved important during the winter months, when the conveyor must be started from cold on a daily basis (resulting in a starting torque requirement of 120 %).

Collahuasi conveyor.

Downhill conveyor Collahuasi (Chile)

Collahuasi is one of the world's highest, harshest job sites. The landscape is so desolate it is sometimes described as "moon like". Extreme climatic conditions and a low oxygen environment put thoroughgoing challenges to men and equipment. Since 1995, ABB delivered and installed the automation system for the open-pit copper mine located in the middle of the Andes, in a historical mining area. The latest project, the automation system based on the Industrial IT System 800xA for a crusher including the delivery conveyor, intermediate bunker and a feeding conveyor to the Collahuasi copper proceeding facility seamlessly integrates with the already installed systems. The project demonstrated the system reliability.

Stranded 4,200 to 4,700 meters above sea level in the Andes and surrounded by northern Chile's brutally barren Tarapacá Desert, the Collahuasi copper mine is subject to conditions that are unprecedented, and unrelenting. Breathing is a struggle in the thin air with barometric pressure of about 0.5 to 0.7 bar. Temperatures rarely top 11 degrees Celsius during the day and normally plunge below freezing at night. Ferocious blizzards, lightning storms, and active volcanoes batter the region. There are no trees, signs of animal life are rare, and humans are almost unheard of with the nearest settlement is nearly 100 kilometres away.

The extreme temperatures and the low in oxygen air put the electrical equipment of the mining machinery to the test every day:

- Extreme high dust formation,
- Vibration, earth quake,
- Electric storms and extreme thunder storms
- Reduced cooling power
- High range of temperature oscillation between day and night from – 20 to + 25 °C

The operating company of the mine, the Compañia Minera Doña Ines de Collahuasi SCM (CMDIC) bore those conditions in mind when placing the latest extension order for the electrical equipment of a crusher and a belt conveyor system: the company decided on an extremely rugged solution with the reliable Industrial IT Extended Automation System 800xA and ACS 6000 water-cooled medium-voltage frequency converters from ABB.

A belt conveyor system to transport the mined material consisting of two rising and one downhill belt, an intermediate bunker and three feeder belts completes this order, which is now successfully commissioned and in operation. The automation system controls and supervises the transport copper ore from a new mine to the existing processing plant.

Redundant controllers of type AC 800M execute the application programs to control the application for the crusher and the conveyor belts. Because of the high power requirement and the altitude of the mine, medium voltage frequency converters of the type ACS 6000 with low-power modules are first choice. They are interfaced and controlled by controllers of type AC 80. This controller manages access to drive information using fast built-in communication possibilities and eases their integration into the overall control system.

ACS 6000 is designed for use under extreme environmental conditions. A total of five 2 MW motors with ACS 6000 medium voltage frequency converters are used in the two rising belts with a length of 234m and 2800m surmounting an altitude difference of 52 and 223 meters, respectively.

Three ACS 6000 drives power another belt conveying the material down an altitude difference of app. 340 meters. The regenerative drives of this belt, which spans a distance of about 5400 m, returns braking energy back to the power network resulting in substantial energy saving because it does not waste the energy as heat.

The four-quadrant drive, the ACS 6000 MultiDrive is provided with direct water cooling, which makes the converter extremely compact and silent. The enclosing cabinets meet up to protection class IP 54, thus providing the robust design needed for those harsh environmental conditions. Direct water cooling provides for a much smaller design, saving up to 50% of space. It delivers an extremely low audible noise level and avoids excessive ambient temperature variations. Additionally it reduces the need for high-power filtered air-cooling in the installation rooms. Along with the high efficiency, direct water-cooling offers effective and easy heat transfer without air filtering problems.

Integrated conveyor control

ABB has developed the Mining Conveyor Control Program (MCCP) which is a software package loaded on to the drives control board of ABB's ACS 800 variable speed drives. The software package is configured specifically for conveyor applications, allowing the setting (by parameter) of the essential conveyor functions. The MCCP was developed to manage the critical and high speed conveyor communication requirements on multi-motor conveyors, and has been successfully applied in several projects.

The conveyor start / stop control, acceleration & deceleration profiles, mechanical brake control, alarm processing, over & under speed limits and torque limits are all set by parameters in the MCCP. Figure 6 demonstrates how the MCCP becomes the speed regulator, or Master for the entire conveyor. It sends the torque reference signals to each of the individual drives, which then act as Followers. Each of the Followers transmits information back to the Master, which is then used as inputs to the speed regulator. The communication cycle time is less than 5ms.

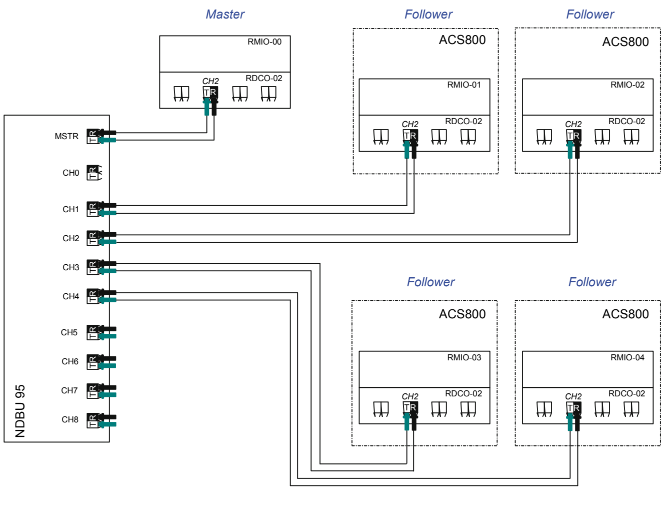


Figure 6: Communication topology of integrated conveyor control.

Traditionally, every conveyor required these functions to be custom developed for each application in the over-riding PLC program. With the use of the MCCP, these functions are no longer required in the PLC, which provides savings in time and overall cost.

As a result, the engineering effort for the drives related conveyor control functions is reduced. This pre-engineered solution significantly reduces the engineering effort required for PLC programming, results in less interface issues between the conveyor control and the drives control, and allows that every conveyor in the operation has the same control configuration and will operate in exactly in the same manner. Commissioning time is reduced as well because the sometimes complex communication between multiple drives is easily and simply taken care of, “out of the box”. In addition, the interconnecting cabling is reduced to a single fibre optic connection between each ACS 800 variable speed drive.

When the system is in operation, maintenance or optimisation of the installation is easier because conveyor parameters (i.e. start & stop times) can be altered without the need for specialized staff.

Summary and conclusions

It has been shown how variable speed drives can be applied for conveyor applications and what issues need to be considered in the design of the drive system. Variable speed drives offer significant advantages for conveyor operation and optimisation, and can significantly reduce maintenance and energy costs.

References

1. Standing the environment, atp International, p.11-13, 3 (2005) No. 2
2. Variable Speed Control of Conveyor in the Mining Industry, ABB Fact File, 3B HT 490 369 R0001 Rev. A
3. Gerard, B.: Optimisation of overland conveyor performance, Australian Bulk Handling Review, p. 26-36, January/February 2009

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