Revamp of an Electric Shovel with variable frequency drives in IGBT technology
iron-ore mine Peña Colorada, Mexico (1999)
Summary

ABB, Open-pit Mining Division, presents a modern solution for revamping electric drives and automation systems of shovel excavators. That solution is based on more than 10 years of experience in applying variable-speed drives, as well as many reference projects with AC drives in Germany and a number of other countries.

The project presented here concerns a Bucyrus-Erie 295BII shovel excavator and has been developed in cooperation with an iron-ore mine in Mexico (owned by the company Peña Colorada) and is one of the first applications of AC drives in IGBT technology on such a type of excavator. All main drives have been equipped with frequency converters of modular construction. The switchgear installed is specially tested to fit the very rough mining environment.

The revamp covers motors, converter system, drive controls and diagnostics tools. The motors have received completely overhauled windings of high electric strength. The converter system is of standard heavy-duty type and has been specially adapted for the project. A powerful AC 80 Advant Controller has been integrated into the existing plant, and a practical man-machine interface has been created for diagnostic purposes.

After two weeks of commissioning the equipment was in test run for another 10 days and has been in permanent operation since September 1999. The customer’s particular emphasis on high availability of the excavator requires an efficient service system. ABB has a local service organization and a manufacturer hotline available 24 hours on every day of the year.

Cost savings

The task was to install a state-of-the-art drive system of optimum efficiency. AC drives with IGBT frequency converters and squirrel-cage motors meet that requirement.

The total efficiency of the drive system can reach about 93.5 per cent as the sum of the individual efficiencies of motor (95%) and converter (98%). Compared with the old system, this represents considerable power savings.

System performance

ABB is the only supplier offering low-voltage frequency converters in as wide a range as 2.2 to 4300 kW for voltages of 380 – 830 V. The frequency converters are dimensioned to withstand very high overloads in the heavy-duty range which is a special asset for shovel excavators. The standard version is designed for the following overloads:

- 150% Load Duty Cycle (60 sec every 240 sec)
- 200% Load Duty Cycle (10 sec every 50 sec)

Another feature is the DTC (Direct Torque Control) of ABB which provides for very fast control cycles of 16 µs and also produces high acceleration also with fully-loaded shovels. Working cycles (acceleration speed) can even be optimized further, which depends on the condition and limits of the mechanical parts of the machine.
**Higher reliability and better service**
The fully digital frequency converter and its control system ensure highly reliable operation. The modular design of the hardware and the IGBT power semiconductors allow quick and easy replacement.

The project included four days of staff training, both in classroom and on the job.

**Benefits**

**Common DC busbar**
With ACS 600 MultiDrive there is a common DC busbar connecting all motor converters and load equalization for cyclical loads of individual drives. That carries the advantage that regenerative power can be used immediately for the whole drive system. Utilizing a braking chopper and resistor bank has eliminated excess power generated during braking. Regenerative braking is also possible with an IGBT supply unit. DC bus cable links permit a local separation of switchgear sections.

**Drive control by DTC (Direct Torque Control)**
The DTC technology has the following advantages:
- fast torque control for speed regulation; especially in case of load surges the speed closely follows setpoint values
- improved dampening of mechanical vibrations
- high accuracy at full torque and zero speed
- robust control with minimum risk of overcurrent tripping
- reduction of converter and motor noise

**Modular system**
IGBT powerplates are optimized modules in standardized types and optimized mechanical packaging. 6 conventional IGBTs are integrated in one powerplate module. The structure of the switchgear is such as to ensure good access to converter modules, fans and control boards. Modular units make it possible to replace defective components in minimum time and with limited engineering knowledge; thus, ensuring maximum uptime.

The shovel excavator drive is controlled by the ACS600 MultiDrive system of ABB. A rectifier unit (supply unit) feeds a DC busbar from which all inverters get their power.

**ACS 600 Multidrive**

**Supply unit structure**
Different ABB supply units can be used, depending on local grid conditions and power efficiency considerations.
Diode supply (DSU) and thyristor supply (TSU) offer, in combination with chopper braking, a reliable and cost-efficient solution (low investment costs) for weak and uneven networks. In this configuration, regenerative power cannot be fed back into the grid.
When highest reliability combined with power efficiency and network friendliness (“green network”) are issues it is advisable to use the IGBT supply unit (ISU). Power costs are reduced by regenerative braking and minimization of power transmission losses thanks to grid current with practically no harmonics and a power factor of \( \cos f = 1 \). This is especially beneficial when electric power prices are high. A braking chopper is not needed at all or can be used when the grid fails.
Motor inverters
Motor inverters get their power from a common DC busbar. All frequency converterees are installed in one cubicle together with the hardware components for basic inverter-related control and safety functions. This makes them work independently. The shovel excavator BE 295-BII is equipped with inverters in the range of 395 - 2156 kVA. The peripheral hardware is the same for all performance categories; thus, exchangeable.

Vibration and shock tolerance
The structure of the frequency converter system fits the rough mining environment. All component parts of the ACS600 MD come from ABB's specially developed ACS600 “MarineDrive” and have been adapted to the specific conditions of shovel excavators.

Strong and robust frame
The frame and the doors of the cubicles are made of strong metal sheets and have been strengthened with additional struts. The resulting stiffness prevents vibration; thus, ensuring a long life for the cubicles, and protecting the interior from vibration. A specially strengthened locking system keeps the doors safely closed while the excavator is in operation.

Vibration-damping system
The cubicles rest on a damping system specially designed to fit expected vibration. They are fastened to the structure of the excavator at a sufficient number of variable fixing points on bottom and top. The damping elements consist of durable and field-proven material compounds. All fixing and damping elements are pre-assembled and can be easily fastened on site with standardized fixtures. Because of their long life the damping elements need no periodic changing.

Special heavy-duty mounting
All interior power and control components have been carefully selected and mounted on profiles. Additional fasteners and bracing have been added to the larger components to ensure they will withstand the harsh operating conditions. The nut-and-bolt connections of the power assemblies and plates are tightened at a clearly defined torque and need no regular checking. The inverter modules are also securely mounted and fixed with additional fasteners.

The vibration and shock tolerance of the whole system has been tested according to IEC 68-2-6 up to +/- 1 mm (5 to 13.2 Hz) and 7 g (13.2 to 100 Hz).
Revamp of an electric shovel with variable frequency drive

Sectioning
The cubicles are divided into 4 sections and installed in different places in the electric house. Installation and marking correspond almost fully to the old system. This facilitates orientation.

Electrical installation
The drive units are easy to connect by cables or busbars via the common DC link. The cables for the DC link are put in coupling panels. Power is transmitted from there via busbars to the inverters which makes cable connections between inverters unnecessary. Cable entries can be made either through the bottom or the top, whichever the customer specifies. The cable glands are dust-proof and EMC-safe. All electrical and optical connections are vibration-proof.

Control concept
If only the frequency converter system is replaced there is no need to change the operational control of the old equipment. Identical signals enter the AC 80 (Advant Controller 80) drive control via digital I/Os or conventional bus systems.
It is also possible to rearrange the complete operational control of the excavator in the AC 80. In that case there is no need for costly interfaces, and standardized components make the control system more efficient.
The busable interface DriveBus connects the control system with the drives. The optical connection is reliable and reduces the necessary number of control cables to a minimum. Installation and faultfinding are made very easy.
An additional option is a supervision and diagnosis system via a remote radio link.

Air conditioning
A simple and robust system is used to get heat out of the cubicles. Every cubicle has its own fan which draws in cooling air through a filter and circulates it only through the power components to be cooled. There are no electronic components within the air stream. Varnished printed circuit boards are available as additional protection against conductive dust. Optimum cooling is guaranteed up to an ambient temperature of +40°C.

AC advantages
Principally, drive systems can be engineered in AC and DC, and both versions can be supplied by ABB.
For new equipment, but also for revamps of AC systems it is preferable to install modern AC systems which are cheaper in investment and operation and have a higher efficiency. The most important criterion for the decision about the drive concept is the type and the condition of the motors and the mechanical components.
Most shovel excavators in the world are equipped with DC drives. In such revamps DC motors should be kept in place as existing connections to the mechanical drive elements such as couplings and gears.

  High system efficiency
  Low expenses
  Control dynamics

  § frequency converter and motor up to 15% better
  § the purchase price of motor/inverter and the costs of operation and maintenance are lower (above 300 kW)
  § the traditionally high control accuracy of DC drives has been reached for AC as well due to developments in the 1990s
Estimation of Energy Consumption for Power Losses per Year in 3 Versions

- Ward-Leonard transformer
- DC motors with converters (thyristor bridge)
- Frequency converters with AC motors

The average mechanical performance ($P_{AVmech}$) has been estimated on the basis of information from Bucyrus-Erie for the excavator 295-BII (25 m³; inverter scheme).

- Average 15 min demand BE295-BII 567 up to 755 kW
- Calculation basis 700 kW mechanical power
- Operating time (90%/year) 7900 hours / year
- Price of energy (8 Can. cents/ kWh)

**DC drive with Ward-Leonard transformer**

$$\eta_{leo} = \eta_{SM} \times \eta_{G} \times \eta_{M}$$

$$\eta_{leo} = 0.965 \times 0.956 \times 0.925 = 0.853$$

$$P_V = P_{AVmech} \left( \frac{1}{\eta_{leo}} \right) = 700 \text{ kW} \times 0.172 = 120 \text{ kW}$$

W/ year = $P_V \times 7900h = 951.16 \text{ MWh}$  equivalent ~ 76 092,- Can$/year

**DC drive with Converter**

$$\eta_{DC} = \eta_{TR} \times \eta_{RE} \times \eta_{M}$$

$$\eta_{DC} = 0.988 \times 0.985 \times 0.925 = 0.90$$

$$P_V = P_{AVmech} \left( \frac{1}{\eta_{DC}} \right) = 700 \text{ kW} \times 0.099 = 77 \text{ kW}$$

W/ year = 77 kW * 7900h = 608.300 MWh  equivalent 48 664,- Can$/year

**DC drive with Frequency Converter**

$$\eta_{AC} = \eta_{TR} \times \eta_{FC} \times \eta_{M}$$

$$\eta_{AC} = 0.988 \times 0.98 \times 0.945 = 0.915$$

$$P_V = P_{AVmech} \left( \frac{1}{\eta_{AC}} \right) = 700 \text{ kW} \times 0.0928 = 64.96 \text{ kW}$$

W/ year = 64.96 kW * 7900h = 513.184 MWh  equivalent 41 054,- Can$/year