Revamp of an Electric Shovel

A cost saving alternative between frequent repairs and the purchase of a new machine
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Many of the Shovels and Draglines in operation today were built in the 70ies and 80ies. Even though they are heavy-duty made and have been in regular maintenance, they reach a limit after 15 to 20 years were efficient operation gets more and more difficult. This is especially relevant for the electrical components. Decreasing availability, increasing difficulties in spare part-sourcing and immense conceptual disadvantages compared to modern systems make many miners seek for alternatives.

The electrical revamp is an alternative that becomes more and more popular. The investment that has to be taken is far lower than for new equipment, whereas a large number of problems with the running system can be erased.

ABB is an established supplier of electro technical equipment for huge open-pit mining machines. This document gives arguments for the three alternatives and describes an AC drive solution in IGBT-Technology (Insulated Gated Bipolar Transistor), which has been implemented. ABB installed such a system on a BE 295BII in 1999. Generally the solution is also applicable for bigger Shovels and also for Draglines.

1 Revamp, a new machine or Status Quo?

Many mining operations have gained an impressive expertise with their existing fleet over the years. Whether it is an in-house maintenance group or an external service group - most of the systems weak points are well known at least, even though a final relief can not be found in many cases. And some of these issues get more and more serious each year. Too much time is lost in unscheduled downtime, often taking hours to be repaired.

Many of the breakdowns result from failures that cannot be detected in advance. The maintenance system is rather reactive than preventive.

Three alternatives are up to choice.

Operating and further improving the old system
Purchase of a new machine
Electrical revamp

1.1 Operating and further improving the old system

Bearing the advantage of avoiding a large investment, there are also many disadvantages:

General:

- Availability that becomes more and more important cannot be guaranteed sufficiently. Typically machines of this age have annual unscheduled downtimes of about 400h. Production loss can likely be in an extent of 150,000 to 200,000 m³!

- MTBF (Mean Time Between Failure) and MTTR (Mean Time to Repair) are likely to worsen further.
- Spare parts, especially fuses and inverter components, increase in price and decrease in availability on the market.

- Preventive maintenance requires a high level of expertise and is often prevented by the technical concept of the system.

- The mechanical stress can have harmful peaks, especially when production is at a top limit. New control concepts with improved drive dynamics offer the same capacity with a protection of the parts involved.

**Analogue Control System**

- Susceptibility to errors: Vibrations can loosen electrical plug connections. In the worst case, these errors only occur temporarily and the machine continues operation with undefined values.

- Calibration set points require regular tune-ups due to drifting.

- Numerous features of modern control systems are not available, such as diagnostic tools, alarm- and event visualization, production protocols, etc.

**Drives:**

- It cannot be made sure that stress peaks will remain underneath the tolerated limit. On the other hand, if the machine is operated too far below the borderline of what it can bear, production is suboptimal.

- Loop Control dynamics and parameterizations are far beyond the level of what modern technology offers.

### 1.2 Purchase of a new machine

From the technical point of view, this alternative surely is the best. Unfortunately the investment is immense. Quite remarkable, the highest share of the cost is due for the mechanical parts of a new machine. However, these are often still in good shape on the old machine, in a way that a general overhaul would be sufficient. Instead of a huge investment that will not pay back in less than five years, a revamp seems more reasonable.
1.3 Electrical revamp

The electrical revamp (also called: reconstruction, modernization, rehabilitation) hovers around 0.5 to 2 Mio US$, depending on the scope and the size of the machine. A general overhaul of the larger mechanical components is usually well enough and saves the former investment. On the other hand, the replacement of basic electrical parts, the drive system and the control system will bear multiple advantages that the fast evolution of technology offers nowadays. They will be described below.

Table 1: Revamp – possible scope

<table>
<thead>
<tr>
<th>Issue</th>
<th>Condition after 15 years</th>
<th>Alternatives</th>
<th>Costs</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical parts</td>
<td>Need overhaul/ replacement</td>
<td>New machine</td>
<td>Very expensive</td>
<td>Not necessary</td>
</tr>
<tr>
<td></td>
<td></td>
<td>General overhaul</td>
<td>Low priced compared to new machine</td>
<td>Recommended</td>
</tr>
<tr>
<td>Power supply/ auxiliaries</td>
<td>Normally in sufficient condition</td>
<td>New components</td>
<td>Expensive</td>
<td>Specific parts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>General overhaul</td>
<td>Low priced</td>
<td>Recommended</td>
</tr>
<tr>
<td>Motors</td>
<td>Electrical and mechanical wear</td>
<td>New motors DC/AC</td>
<td>Very expensive for DC, mechanical adaptation necessary</td>
<td>New-AC preferred Revamp of DC – change to AC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overhaul existing motors</td>
<td>Low-priced</td>
<td>Recommended with old DC system</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Specific overhaul for IGBT Frequency converter</td>
<td>Low-priced</td>
<td>Recommended with old AC System</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No overhaul</td>
<td>No costs but frequent repair</td>
<td>Not recommended DC/AC AC - Possible with dU/dt filters and limited performance.</td>
</tr>
<tr>
<td>Drives</td>
<td>Wear/ spare part problems/ ‘old fashion’</td>
<td>System upgrade</td>
<td>Low priced</td>
<td>Not recommended/ limited improvability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>New converter system</td>
<td>Expensive but profitable</td>
<td>Recommended</td>
</tr>
<tr>
<td>Auxiliary control</td>
<td>Digital control normally in sufficient condition</td>
<td>Keep system</td>
<td>Low-priced</td>
<td>Recommended/ standardized interface to drives control</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Replacement by up-to-date digital control with standardized interface</td>
<td>Low-priced</td>
<td>Not necessary but possible and advanced</td>
</tr>
<tr>
<td></td>
<td>Relay control, disadvantages comparing to digital controller</td>
<td>Replacement by up-to-date digital PLC with standardized interface</td>
<td>Low-priced</td>
<td>Recommended/ lower downtime</td>
</tr>
</tbody>
</table>

Generally, 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. They 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 usually be kept in place as existing connections to the mechanical drive elements such as...
couplings and gears can be reused. If the old DC motors are not worth overhauling, converting to an AC system would be the best choice.

### 1.4 Commercial resumes

The decision between the three alternatives depends on three incompatible targets:

- Save on liquidity in short-term
- Fast amortization
- Continuously low production cost

Fig.1: Comparison of three alternatives

![Machine-related cumulated cash-flow](image)

The graph shows the machine-related cumulated cash-flow. The figure is calculated from the income from the production with this machine on the one hand. On the other hand all machine-related expenditures are subtracted. Machine-related expenditures can be spare parts (parts but also stock keeping), personnel costs, energy costs, maintenance and service costs. The figure is cumulated over the periods to show how the initial investment pays back.

As the machine is always involved in a complex production process, the Machine-related cumulated cash-flow is always a theoretical construction. For example, problems with the Truck fleet or the blasting process will also have a negative influence.

In any case and independent from the accounting methodology of the mine, conclusions about the quality of the results of these three alternatives may be drawn though. A revamp and a new machine will cause a negative cash-flow in the first year. What is remarkable, the investment for a revamp is typically only 15 to 20% compared to the investment for a new machine.
With the investment a rationalization will come into effect for the following periods. Higher production output and less cost of operation will increase the periodical cash-flow. Of course, the degree of rationalization is highest in the case of the new machine.

We estimate that a revamp has amortized after about two years (i.e. cumulated cash flow = 0). After less than a year later, the break even to the alternative „old machine“ is reached. As can be seen in the graph, the alternative “new equipment” needs much longer to reach these targets.

In conclusion, the revamp is a combination of several incompatible targets. Production costs can be lowered, but payback time is still quite short so that the risk of falling commodity prices in the future is taken into account.

2  A report of a successful revamp

In 1999 ABB conducted an electro-technical revamp of a BE 295 BII Shovel. The machine was one of the first of this type to have all main drives equipped with frequency converters in IGBT technology. This reference object can still be seen as a modern example for a revamp solution.

The mining company Peña Colorada conducted the project in cooperation with ABB. The machine had been in operation for about 13 years with a PWM-System in Thyristor technology. Beside other, especially commutation problems and thus overcurrent caused frequent loss of fuses and capacitors at the main drives. The objective was to raise availability and performance of the machine.

2.1 Technical Summary

The revamp included motors (rewinding), converter system, drive controls and diagnostic tools. All main drives have been equipped with frequency converters of modular construction in IGBT technology. Some modifications had to be carried out to make the components proof for the rough mining environment. Thus, the switchgear installed was specially tested against shocks and vibrations. The converter system needed little modification, as the standard ABB marine-type is already a heavy-duty design.

Another remarkable highlight is that the project was completed in an extremely short time-span. After two weeks of commissioning the equipment was in test run for another 10 days. Since then, it has been in permanent operation.
2.2 Drives

Voltage level 380 V - main drives

<table>
<thead>
<tr>
<th>Drive</th>
<th>Inverter</th>
<th>Motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoist</td>
<td>1x1760kVA</td>
<td>1x1000kW</td>
</tr>
<tr>
<td>Crowd</td>
<td>1x495kVA</td>
<td>1x165kW</td>
</tr>
<tr>
<td>Propel</td>
<td>1x935kVA</td>
<td>1x500kW</td>
</tr>
<tr>
<td>Swing</td>
<td>2x325kVA</td>
<td>2x165kW</td>
</tr>
</tbody>
</table>

In Mexico the motors were kept in place. Having a compact size, which is not available for new standard AC motors at a reasonable price, the choice was to reuse the old motors. All of them have been rewound.

The task was to install a state-of-the-art drive system of optimum efficiency. ABB ACS600 Multidrive with IGBT frequency converters and squirrel-cage motors meet that requirement. The total efficiency of the drive system can reach about 93.5% being the sum of the individual efficiencies of motor (95%) and converter (98%). Compared with the old system, this represents considerable power savings, at least 5%.

2.2.1 Key Drive-System features

Working with very inhomogeneous sized material, the Shovel drive system needs to withstand very high overloads sometimes. ABB frequency converters fulfill that requirement. They are dimensioned to withstand in the heavy-duty range and are able to cope with load peaks over short periods without any electrical or mechanical damage. Also, they have some other outstanding features. ABB is the only supplier offering low-voltage frequency converters in a range as wide as 2.2 to 4300kW for voltages of 380 to 830V.

The converter version implemented is designed to withstand certain overloads, measured by load duty and time, as for example:

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

Inverter over load is prevented. An internal control algorithm cuts down the current within the IGBT modules before they reach a critical value. Also, the temperature of the power-plates is taken continually.

The most advanced feature of ABB ACS Multidrive is the DTC (Direct Torque Control) that provides for very fast control cycles of 16 µs and also produces high acceleration even with fully loaded
shovels. The working cycles could even be shortened further, but are limited by the conditions and restrictions of the mechanical parts. ABB DTC technology has the following advantages:

- Fast torque control for speed regulation; especially in case of load surges the speed closely follows set point values
- Improved dampening of mechanical resonance
- High accuracy at full torque, even at zero speed (e.g. holding the hoist in position for truck loading)
- Robust control with minimum risk of over current tripping
- Reduction of converter and motor noise
- Reduction of motor temperature

Fig.2: Single line diagram, Shovel
2.2.2 Common DC busbar and electrical braking

A rectifier unit (supply unit) feeds a DC busbar from which all inverters get their power. 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.

All frequency converters are installed in one cubicle together with the hardware components for basic inverter-related control and safety functions. This makes them work independently. The DC busbar connection enables electrical load equalization for the individual drives. Regenerative power can be used immediately for the whole drive system.

2.2.3 Supply unit structure

Multiple ABB supply units are available to choose, depending on local grid conditions and power efficiency considerations. In Mexico, a thyristor supply unit was implemented. Diode supply (DSU) and thyristor supply (TSU) offer, in combination with chopper braking, a reliable and cost-efficient solution (low investment) for weak and uneven networks.

If highest reliability is available in a robust network it is advisable to use an IGBT supply unit (ISU). Regenerative braking reduces this way power consumption and network friendliness minimizes power transmission losses and voltage distortions. With a grid current having practically no harmonics a power factor of \( \cos \phi \rightarrow 1 \) can be achieved. The estimated power savings can be up to 25%.

2.2.4 Hardware Design

Converter Cubicle Sectioning and Air Conditioning

The cubicles are divided into four sections and installed in different places in the electric house. Installation and marking correspond almost fully to the old system. The new installation is completed in protection class IP42.

A simple system is used to get heat out of the cubicles. Each cubicle has its own fan. It draws in cooling air through a filter and circulates it through the power components. There are no electronic components within the air stream. Varnished printed circuit boards are standard as additional protection against conductive dust. Optimum cooling is guaranteed up to an ambient temperature of +40°C. Higher temperatures can also be mastered with different measures.

As an option, ABB offers the water-cooled ACS600 W Multidrive, which is designed more compact and has an improved cooling mechanism.
2.2.5 Modular Structure – optimized for quick Service

The IGBT power-plates are optimized for handling and exchange. Six conventional IGBTs are integrated in one power-plate 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.

2.2.6 Heavy-duty modifications and mounting structure

The structure of the frequency converter system conforms to the rough mining environment. All component parts of the ACS600 Multidrive come from ABB’s heavy-duty proof ACS600 “MarineDrive” with a minimum of modifications for the specific conditions of shovel excavators.

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.

Cubicles rest on a damping system specially designed to fit the expected vibration. 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.

All interior power and control components have been carefully selected and mounted on profiles. Additional fasteners and bracings have been added to larger components.

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 +/- 1mm (5 to 13.2Hz) and 7g (13.2 to 100Hz).

The drive units are easy to connect by cables or busbars via a common DC link. Cables for the DC link are put in coupling panels. Power is transmitted from there via busbars to the inverters that make 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.
2.3 Software and Control System

In the case of the BE 295BII Shovel, the overall relay-based machine control system, has been kept in place. Generally the control infrastructure of the old equipment can remain the same. The main advantage of this decision is the low price and the few changes the operator has to get accustomed to afterwards. Here the AC80 (ABB Advant Controller 80) is the interface between the old system and the new drive control.

In the Drive Control the usable interface DriveBusTM connects the control system with the drives by an optical connection. It is reliable, can carry many signals and thus reduces the necessary number of control cables to a minimum. The signals interface to the machine control system can be digital I/Os or conventional bus systems, depending on the kind of overriding control.

Of course ABB also offers to change the whole control system, up to a full integration of data exchange to a central control station for the whole mine. Our recommendation is to have the machine control system and the drive system changed at least. A modern digitally based control system bears multiple advantages compared to a relay-based system.

- Faster switching
- Less risk of failure
- Fewer parts
- Easier location of failures
- Data transmission via bus-system (one cable – many signals)
- No regular check of calibration points
- Fail-safe in a high range of temperature, vibration and electromagnetic influence
• Multiple possibilities for the visualization of data for maintenance staff and the operator – alarms, events, protocols, etc.

Thanks to the digital interface of ABB ACS 600 Multidrive, a radio link was implemented to make the data available outside the machine. By this way, many of the diagnostic and commissioning work could be done from outside while the machine was already starting its trial run.

With a digital interface to the machine, multiple benefits are made possible:

1. Remote Service - Service staff can conduct diagnosis from a laptop just beside the machine, in the office near the pit or even over the globe via Internet. The question of access rights and security needs to be carefully discussed with the customer in advance – technology to solve these critical points exists after all.

2. Automated communication - Communication is important to manage the whole process of the mine. Some common tasks are: Distribution of ore and waste, management of intermittent breakdowns or simply answering the question: How much is the machine producing at the moment?

3. Information Management Systems - Digital Protocols of production, power consumption, downtime, etc.

ABB has a lot of powerful products under the IndustrialIT umbrella and a lot of experience how to make the best possible use out of data in a mine. From field devices up to control software, data integration can make information available over the whole plant instantly.

2.4 Time Schedule and project organization

The time schedule for the electrical Revamp of the BE295II was agreed upon like this:

• 30 days of maximum total downtime
• 2 weeks installation
• 2 weeks commissioning
• 1 week trial run with limited production

As Peña Colorada has their own maintenance personnel, many things could be quickly coordinated during the project. Pena Colorada organized the installation of the drive system with one experienced supervisor from ABB being responsible. Auxiliary systems such as power supply, lighting, lubrication and the relay-control system were at the full responsibility of the customer.

From our experience and also that of Peña Colorada it is most advisable for both sides to have an experienced engineer of the customer involved in the process.

• The customer can be trained during the commissioning period to use ABB diagnostic software to troubleshoot smaller breakdowns by himself or give useful advice for ABB Service staff on the phone.
• Arising issues during the project about the interfaces of the drive system, control system and power supply and auxiliary system can be clarified quickly.

• Critical parameters like starting and braking ramps, maximum torque etc. will get their final tune when the machine starts to run.

Also, theoretical trainings should take place for the operating and maintenance staff. This can take place at the customer’s site or at a local ABB training center. The project included four days of staff training, both in classroom and on the job.

2.5 Service

The type and level of service depend on the customer’s objectives and on the offerings ABB can make in this particular location of the world. ABB has experienced engineers in almost every country of the world. However, the central expertise for the open-pit mining business is located in Cottbus, Germany.

Usually, the customer gets a training to troubleshoot and maintain the machine for the most common tasks. For further help, ABB organizes a 24-hour / 365 day-hotline. Depending on the level of digitalization of the system, a powerful and informative remote service can be implemented. This enables ABB experts in Germany to give helpful advice in many cases.

2.6 Project Summary

The 13-year-old Shovel was equipped with a modern ACS 600 Multidrive System. Productivity was raised dramatically. The availability of the drive system is about 98%. The availability of the whole machine has raised to 76%. The way of cooperation and the result were to the full satisfaction of the customer. Generally the main benefits of such a revamp are

• Increased MTBF and reduced MTTR
• Up to 80% less unscheduled downtime
• Excellent drive dynamics with DTC
• Constant operation at a pre-defined mechanical limit; thus higher productivity and less wear
• Reduction of time and costs of maintenance
  - less critical wear parts
  - reduced spare parts stock (about 80%)
  - multiple diagnostic features
  - easy-to-change wear parts
• None-drifting calibration settings
• Shock proof cabinets and components
• Adjustable drive dynamics, depending on the demand of the mine
• Up to 25% less power consumption
• Many service activities can be trained
• 24hrs –365 day ABB hotline
3 More information about ABB

For ABB, the revamp of this shovel was the first with a machine of this kind. Due to the success of the new system, ABB received further orders for the revamp of shovels of this size. We are also optimistic to implement such an electrical revamp on draglines in the near future. For further information, please contact us.

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