Variable Frequency Drives and Mining Applications
Drive Topologies
Topology Comparisons

Load Commutated Inverter (LCI)

Voltage Source Inverter (VSI)

Voltage Source Inverter (VSI) AFE

Multi-Cell Inverter (VSI)

SINAMICS GL150

SINAMICS GM150

SINAMICS SM150

PERFECT HARMONY
Assemble the Building Blocks

Typical Power Schematic - Standard Perfect Harmony Drive
Total Number of installed PH Drives: 385 PH drives
(approximately 10% of these are on conveyors or mills requiring some form of torque or load sharing)

- Applications:
  Conveyors, Slurry pumps, Tailing pumps, Rod mill, SAG mills, Ball mill, Mine ventilation fans, Conveyor, Rock crusher, SO₂ compressor, Grinding mills, Kiln drive, De-scale pumps, Roller Press

- North America: (NM, TX, MI, UT, NV, AZ, MN, MT, IL, PA, WY, CA)
- South America: (Peru, Chile, Brazil, Dominican Republic, Bolivia, Argentina, Costa Rica, Venezuela, Mexico)
- Other: (Australia, Canada, Indonesia, Korea, Czech Republic, Kazakhstan, United Kingdom, Russia, Turkey, Mongolia, South Africa, Philippines)
CAMECO Mine
Typical Drive Control Modes

**V/Hz (voltage/frequency) Control method**
- The most common inverter control method
- Requiring no feedback device
- Suitable for general purpose and multiple motor applications

**V/Hz Control with PG Feedback**
- Better speed regulation of a closed loop system

**Open Loop Vector Control Mode**
- Sometimes called *sensorless* vector control
- Utilizes a more complex control algorithm to give precision speed control
- Quick response and higher torque at low speed

**Flux Vector Control**
- Requires encoder feedback
- Gives precise speed and full rated torque control over a wide speed range
  sometimes even at zero RPM
Vector Control

All motors need a magnetizing current and a torque producing current

- DC motor: these two currents are fed to two different windings
  - The magnetizing current is fed to the stator or field winding
  - Torque producing current is fed to the rotor winding
  - This allows independent control of both the stator and the rotor fields

- In induction motors it is not possible to control the rotor field directly since there are no connections to it

- Parameters to be controlled can not be measured
  - their values are derived from parameters which can be measured and controlled
  - The only input over which control is possible is the input current supplied to the stator.
Vector Control

Vector Control or Field Oriented Control

- Independently varying the magnitude and phase of the stator current vectors

- Adapt to the instantaneous speed and torque demands on the motor

- Parameters over which no direct control is possible can be changed by changing parameters which can be measured and controlled.
Vector Control

The actual stator current is the vector sum of two current vectors

- The inductive (phase delayed) magnetizing current vector producing the flux in the air gap
- The in phase, torque producing, current

- To change the torque we need to change the in phase, torque producing, current

- The air gap flux must remain constant at its optimum level
  - the magnetizing current should also remain unchanged when the torque changes
Typical Control Block Diagram
Typical M-S Control Block Diagram

Master

Slave

$\omega_{cmd}$

Speed Regulator

$V_{FDBK}$

Torque Loop

$I_{FDBK}$

$M$

$\dot{\omega}$

$\dot{I}_q$

$V_{FDBK}$

$M$

$\dot{I}_q$

$\dot{\omega}$

Speed Regulator

Torque Loop

$I_{FDBK}$
Torque Sharing Plots

- Drive 1 - Phase U Current
- Drive 2 - Phase U Current
- Drive 3 - Phase U Current
- Drive 4 - Phase U Current

Graph displaying data from April 10, 2007 (Tuesday) from 2 PM to 5 PM.
Torque Sharing Plots
Customer / End User

- Companhia Vale do Rio Doce – CVRD
- Location: Mine N4E, Carajás - Brazil
- Iron Ore Mine Production – 50 Million Tons/year
- Application: Conveyor Belt
- Project Name: BSM II Primary Crusher

Objectives
- To provide smooth starting torque during acceleration (60 sec.) in order to extend belt's life and minimizing maintenance costs.
- Replace hydraulic coupling
**CVRD Location**

- **Customer:** CVRD
- **Project:** N4W/N4E Mine
- **Industry:** Mining
- **Location:** Carajás – PA Brazil
- **System Voltage / Frequency:** 4160V / 60 Hz
- **Qty / Size / Application(s):** (2) Conveyors belt 4 - 600 HP, 4 – 900 HP
- **Motors:** New WEG motors purchased by CVRD and Existing ABB motors.
Loading Sharing Strategy
Conveyor Belt
Conveyor System
Automation Control System
Conveyor TR 14

Tool Suite
Monitoring/Diagnostic
Settings

DeviceNet network

Ethnet TCP-IP (optical link – future)

Existing PLC
Load Sharing sw

I/O

M1
600 HP
4160V
1200 RPM

M2
600 HP
4160V
1200 RPM

M3
600 HP
4160V
1200 RPM

M4
600 HP
4160V
1200 RPM
Conveyor TR 14
Automation Control System
Conveyor TR 15

Ethernet TCP-IP (optical link – future)

DeviceNet network

M1
900 HP
4160V
1200 RPM

M2
900 HP
4160V
1200 RPM

M3
900 HP
4160V
1200 RPM

M4
900 HP
4160V
1200 RPM

Existing PLC
Load Sharing sw

I/O
Master-Slave Load Sharing

* Control Interlocks
  Two outputs and two inputs required for control.
  Master is selected and faulted.
  Master is selected and on.
Case Study (Conveyor)

The conveyor:

- 13 km (about 8 miles) long with an almost 90 degree corner just before the head end
- 3 x 930 kW motors at the head end in droop control.
- One tail drive 13km away operating independently
  - It has an over speed reference and is actually speed limited by a belt tension signal which is used to control the torque limit on the tail drive.

- The Tail End motor (VS401) has been set to Speed control (With a fix speed SP=110%), but it actually works on Torque Control through the Torque Limit reference from PLC (via Profibus).

- Also, all motors have interlocks with the minimum belt tension for safety.

- Droop in M3 has been set to take slightly more torque than M1-M1, the reason is to keep some belt tension between both rolls.
Case Study (Conveyor)

Sharp angle near Head of the conveyor

Tail 13 km away
Conveyor

DRIVE CONTROL STRATEGY – OLC RIO TINTO CLERMONT MINE

Ethernet (via 13Km of FO)

Conveyor Speed SP  PLC Head End

PLC Tail End

Run/Stop

Tension SP=70kN
Tension Feedback

SP PI

0-100%

PLC PROFIBUS

VSD NETI PROFIBUS

VSD

Coast Stop

Run/Stop Command

Speed SP1 = 110%

SPEED REGULATOR

Torque Limit = 0-100%

TORQUE REGULATOR

VSD401 Torque SP 0-100%

Load Cell

T1

T2

SECONDARY DRIVE

HEAD DRIVES

VSD1

VSD2

VSD3

T3

Droop

Droop

PRIMARY DRIVE (2 Motors)

TERTIARY DRIVE

Notes:
- The Droop Control is done by the VSDs.

Ruben Diaz 27-04-2010
Siemens Australia
Speed Droop Control
Load Sharing Strategy

Harmony Torque Follower Control

- Control Interlocks
  Two outputs and two inputs required for control.
  Master is selected and faulted.
  Master is selected and on.
Iron Ore Process

Roller Press
- More efficient process compared to Ball Mill crushers. Energy savings of 10 to 30% compared to ball mills

Reasons to use VFD with Roller Press
- Using variable speed motors it is possible to adjust system demand for upstream and downstream process.
- VFD allows higher efficiency and power factor as seen by the power system regardless of motor characteristics
- VFD minimizes heating of motor while providing sufficient starting torque and overload requirements
Customer: MBR/CVRD Group  
Project: Pelletizing Plant #1  
Location: Belo Horizonte – MG Brazil  
System Voltage: 13800V / 60 Hz  
(1) Roller Press by Polysius  
VSD: (2) – Gen3e 1650 kW/4160V/500A  
Motor: (2) – SIEMENS 1RN4 456-6FW90-Z

Customer: CVRD  
Project: NIBRASCO Pelletizing Plant  
Location: Vitória – ES Brazil  
System Voltage: 4160V / 60 Hz  
(2) Roller Press by Polysius  
VSD: (4) – Gen3e 1350 kW/4160V/500A  
Motor: (4) – SIEMENS 1PQ4 504-6CW90-Z

Customer: SAMARCO/CVRD Group  
Project: Pelletizing Plant #3  
Location: UBU – ES Brazil  
System Voltage: 13800V / 60 Hz  
(1) Roller Press by Polysius  
VSD: (2) – Gen3e 1650 kW/4160V/500A  
Motor: (2) – SIEMENS 1RN4 456-6FW90-Z
Customer: Anglo Ferrous Brazil  
Project: Sistema Minas-Rio  
Location: Conceição – MG Brazil  
System Voltage: 13800V / 60 Hz  
(3) Roller Press by Polysius  
VSD: (6) – Gen3e 2400 kW/4160V/660A  
Motor: (6) – SIEMENS 1RQ4 560-6FW90-Z

Customer: VALE  
Project: 1 & 2 Pelletizing Plant  
Location: Vitória – ES Brazil  
System Voltage: 13800V / 60 Hz  
(1) Roller Press by KHD  
VSD: (2) – Gen3e 1750 kW/3300V/500A  
Motor: (2) – Existing

Customer: CMP  
Project: Huasco  
Location: Vallenar - Atacama Chile  
System Voltage: 13800V / 50 Hz  
(1) Roller Press by KHD  
VSD: (2) – Gen3e 1850 kW/4160V/500A  
Motor: (2) – Existing
Perfect Harmony
Single Quadrant Operation
1650KW

Circuit Breaker

# 1A
13,8KV

PLC

Siemens
Scope of Supply

Torque reference

AO

AI

Fixed Roll
Direction of Rotation
CCW

M

MASTER
1RN4 456-6FW90-Z
1650KW
4160V
320-1320 RPM

Fixed Roll
Direction of Rotation
CW

M

SLAVE
1RN4 456-6FW90-Z
1650KW
4160V
320-1320 RPM

Profibus DP
Load Sharing Strategy

- **Master/Slave Torque Control Mode** is used if Slave drive speed remains in the +/- Δ% bandwidth interval compared with Master drive speed.

- If Slave speed exceeds the Speed/Torque bandwidth the Slave drive control will assume the Speed Control Mode until came back to the bandwidth interval returning to the Torque Control Mode.
Roller Press Requirements

High Torque Fluctuations

For most applications, roller press is started unloaded (Rollers UP) starting torque approximately 30% of full load.

But when the rollers are down, torque can fluctuate between 120% and 150% of FLT.
“Inching” of Rollers

For maintenance:

• Rollers are run at a slow speed to inspect for damage.

• Requirement is highly dependant on gear box and motor.

• If precise speed control and quick start and stop is needed, VFD can handle a limited inching capability when precise speed control is not required and the roll does not need to be stopped quickly.

• Verify the motor can handle the required speed range for the inching.
Other VFD Issues

- Availability and Reliability
- Input Power Quality
  - Harmonics
  - Power Factor
- Environment
  - Altitude
  - Explosive Environments
  - Dust and debris
- Energy Savings
- Process Improvement
- Equipment Improvement
  - Lifetime
  - Torque
Availability and Reliability

Uninterrupted operation:

- Required for safety (e.g., Vent Fans)

- MTBF and MTTR Numbers
  - 3 to 5 years typical
  - Component Redundancy

- Process Tolerant Control
  - Allows the User to decide how to respond to an alarm
  - Provides time for a smooth process transition
  - Communicates through a hierarchical service messages

- Alarms (Something is wrong but no process impact)
- Process Alarms (Advisory not to increase process)
- Trip Alarms (Initiate a trip if process action is not taken)
Input Power Quality

Remote Locations and Long feeders: low short-circuit ratings and Voltage disruptions

Continuous Operation is desired

- Sustained operation with voltage sags of 35%
- Continued operation at reduced torque
- Below 35%, motor remains synchronized (motor voltage is present)
- Power Ride through (typically 5 cycles) Can be as high as 0.5 seconds
Input Power Quality

Input VFD Voltage Within +/- 10% of Rated Value:

- 100% VFD continuous output power available.

Input VFD Voltage Falls Within 90% to 65% of Rated Value:

- VFD output power is rolled-back linearly from 100% power @ 90% input voltage down to 50% power @ 65% input voltage.
- During roll-back, the highest available voltage will be sourced to the motor.
- The output power is reduced by limiting the available motor torque.
- The VFD can operate continuously in this mode.

Input VFD Voltage Falls Below 65% or Disappears All Together:

- The VFD will “ride-through” without tripping for at least five cycles.
- During “ride-through” the motor voltage is maintained but no torque is produced until input VFD voltage is re-established.
- If input voltage is not re-established before the energy stored in the power cells is depleted, the VFD will trip.
Power electronics introduce harmonics into the supply network

<table>
<thead>
<tr>
<th>Features</th>
<th>Customer benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harmonic filter inherent:</td>
<td></td>
</tr>
<tr>
<td>▪ “Clean power” sinusoidal converter</td>
<td>▪ Meets all new requirements of IEEE 519 1992 for both current and voltage distortion</td>
</tr>
<tr>
<td>▪ Near zero harmonics</td>
<td>▪ Eliminates needs to do harmonic analysis</td>
</tr>
<tr>
<td></td>
<td>▪ Eliminates costly harmonic filters required for distortion control</td>
</tr>
</tbody>
</table>

Robicon "Perfect Harmony" Drive

Total Harmonic Distortion Current = 0.8%
Total Harmonic Distortion Voltage = 1.2%
Pulse Count Comparison

- Current THD = 31.4%
  6-Pulse Front-end

- Current THD = 24.2%
  6-Pulse Front-end plus 3% Line Reactor

- Current THD = 9.1%
  12-Pulse Front-end

- Current THD = 4.8%
  18-Pulse Front-end
Lower speed operation results in energy cost savings (I^2R losses).

<table>
<thead>
<tr>
<th>Load</th>
<th>VFD Eff. w/o XFMR</th>
<th>VFD Eff. With XFMR</th>
<th>Power Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>105 %</td>
<td>99.04 %</td>
<td>97.0 %</td>
<td>0.95</td>
</tr>
<tr>
<td>100 %</td>
<td>99.05 %</td>
<td>97.2 %</td>
<td>0.95</td>
</tr>
<tr>
<td>75 %</td>
<td>99.05 %</td>
<td>97.4 %</td>
<td>0.959</td>
</tr>
<tr>
<td>50 %</td>
<td>99.01 %</td>
<td>97.6 %</td>
<td>0.966</td>
</tr>
<tr>
<td>25 %</td>
<td>98.65 %</td>
<td>97.2 %</td>
<td>0.96</td>
</tr>
</tbody>
</table>
Output Quality (Motor Friendly)

- No common mode motor insulation stress
  - Drive is compatible with both new and existing motors
  - Isolation transformer integral in common mode elimination

- Less than 1% VFD induced torque ripple for any given frequency

- No additional VFD induced motor heating
  - Harmonic Voltage Factor < 0.020, well below MG1 limit = 0.03

- No dV/dt problems
  - Drive creates no motor voltage insulation stress
PWM Output Levels

- PWM Output Levels indicate the purity of the output waveforms (THD) The more levels, the more sinusoidal the output waveform can be.

- Lower DV/DT levels that stress the motor insulation.

- Lower voltage switching levels appear (Voltage transients) on the motor insulation.
PWM Output Levels

Output Waveforms @ 60 Hz and 30 Hz

Waveforms Remain High Quality at Lower Speeds Due to Multi-Level PWM Output
PWM Output Levels

Multi-Level, Pulse-Width Modulated, Output-Voltage Waveform

ROBICON Perfect Harmony Output Waveforms at 100% Speed

Motor Voltage

Motor Current
Motor Thermal Performance

Recirc Pump Motor 2B Temperature Rise
(Based on 3 hour Averages)
Environmental Considerations

- **Altitude**
  - Most drives rated up to 3300ft (1000m)
  - Derating for thermal performance 3301 to 13,200ft (1000m to 4000m)
  - Above 4000m, the voltage may become an issue (Partial Discharge)
  - 750VAC de-rated to 630 or 535VAC operation
  - BIL ratings increased (65kV to 95kV BIL)

- **Dust and Harsh Environments**
  - Aluminum parts coated or anodized
  - Galvanized parts removed or replaced with Stainless Steel
  - Double vacuum impregnation (VPI) of magnetic components
  - Paint Finish and primer for caustic environments
  - Conformal coated printed circuit boards

- **Explosive Environments**
  - Investigate remote location of drive