

Drives Basics

Problems often occur because of the words we use to describe a project.

A Drive System is not a Motor Speed Control

Minding Your P's & Q's

With BEZ now offering drives, we must fully understand ASD's, which have also been called VSD's and VFD's. Some ASD's are VVI type and some are CSI type but many are being replaced with PWM. This is possible now with new devices replacing SCR's with GTO's or IGBT's.

We do this to control our RPM's and reduce KWH through higher EFF. Many ASD's must also connect to PLC's in a LAN which should also be backed up with a UPS.

Now, ASD's can readily be applied to TEFC or ODP motors with simple rules. However, using ASD's on XPF motors will require special approvals from UL or ETL in the USA, CSA in Canada or IEC in the EEC.

You must also be careful to watch your EMF with a true RMS meter as well as your FLA and I R. To get SPL down to lower dBA, we push to higher KHz. This can, however, cause problems with excessive dV/dT and PIV that MOV's can not fix and then your THD could exceed IEEE.

Obviously, in all ASD applications there are many things to consider, but the single most important item is your TLAs (Three Letter Acronyms).

A Drive System is not a Motor Speed Control

A drive system is defined by all of the components that are used to transmit power to the load.

- The power source
- The Control Circuit
- The Prime Mover
- The Drive Train
- The Coupling Devices
- The Feedback Devices



A Drive System is not a Motor Speed Control

The Power Source

- ...Incoming Power Stability
- ...Grounding
- ...Cable Distance
- ...Electrical Noise



The Power Source

Incoming Power Stability

460 VAC RMS



Peak Voltage = RMS x 1.414

120° degrees out of phase

High and Low Lines

The Power Source

Grounding



Good Grounding results in a successful installation

Avoid ground loops

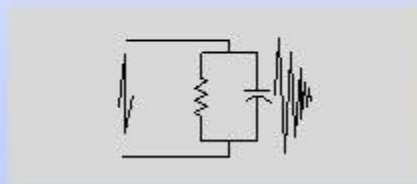
use adequate wire size

The Power Source

Cable Distance



Each wire has resistance
The cables have capacitance
the result is a bell circuit

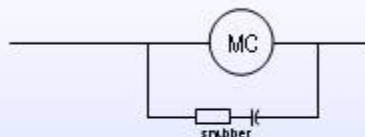


The Power Source

Electrical Noise

Contactors

Use snubber Circuit



Electronic Controls

Use Reactors and Filters



A Drive System is not a Motor Speed Control

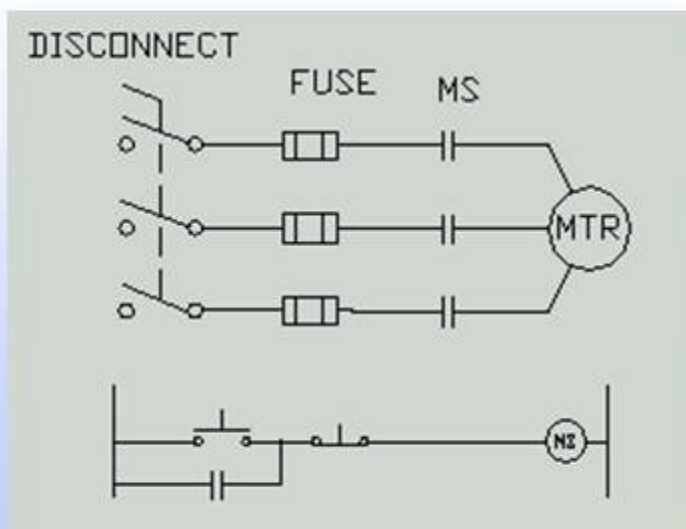
The Control Circuit

- ...The basic Control Scheme
- ...Load Control
- ...Speed Control
- ...Closed Loop Control
- ...Logic Control



The Control Circuit

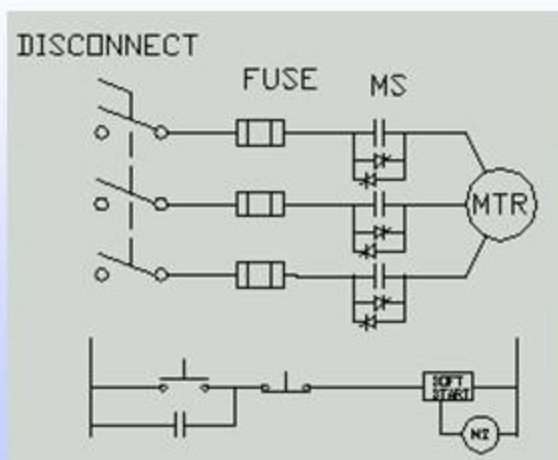
The basic Control Scheme



The Control Circuit

Load Control

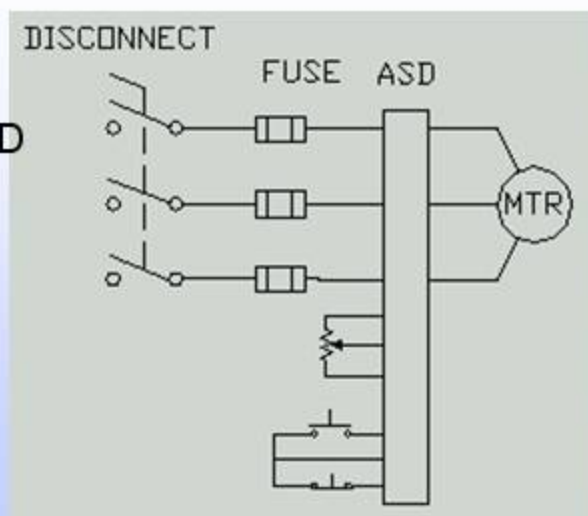
Soft start
wound rotor
eddy current



The Control Circuit

Speed Control

AC & DC ASD
MG SET



A Drive System is not a Motor Speed Control

The Prime Mover

The AC Induction Motor

...most common motor used in industry today.

...designed to convert electrical power into mechanical work.

...As designed it is a fixed speed device.



The Prime Mover

The AC Induction Motor most common motor used in industry today

Rugged

Low Cost

Requires Little or No Maintenance

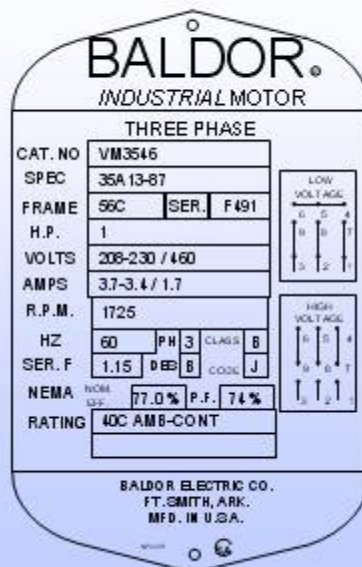
Easily Controlled

Good Efficiency

The Prime Mover

Name Plate Data

- NEMA (National Electrical Manufacturing Association) provides guide lines for the data that is used on a motor name plate. This insures that a motor can be built by many different manufactures. If the proper data is supplied to the motor manufacturer then a replacement can be supplied.



The Prime Mover

The AC Induction Motor is designed to convert electrical power into mechanical work.

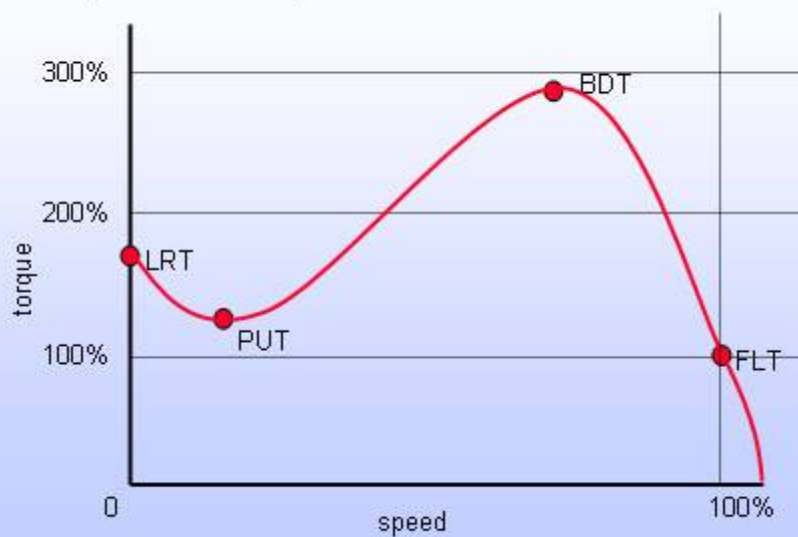
...The Speed/Torque curve

...Frequency is Speed

...Voltage is torque

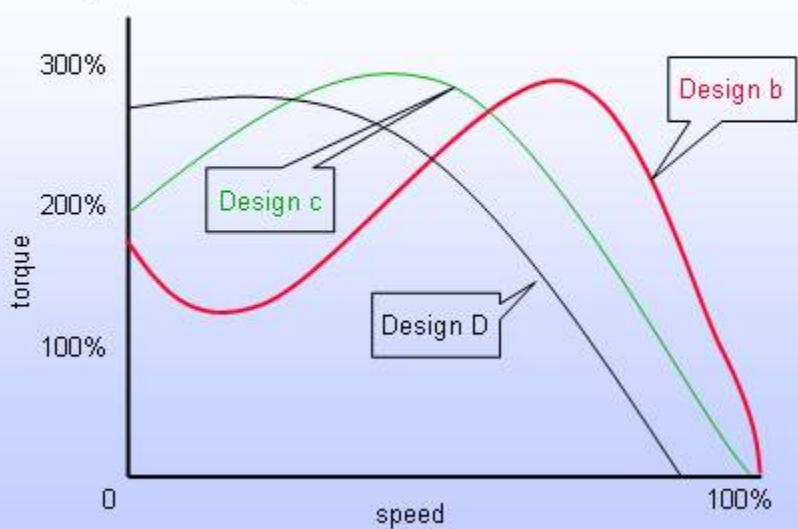
The AC Induction Motor

The Speed/Torque curve



The AC Induction Motor

The Speed/Torque curve



The AC Induction Motor

Frequency is Speed

$$N = \frac{Fq \times 120}{P}$$

Where:

N = Speed in RPM

Fq = Frequency in Hz

P = The number of motor poles

120 is a constant for time conversion

Note:

This formula is the synchronous speed of an induction motor

The AC Induction Motor

Frequency is Speed

Speed control has been achieved by the
changing the poles.

$$2 \text{ pole } 3600 = 60 \times 120 / 2$$

$$4 \text{ pole } 1800 = 60 \times 120 / 4$$

$$6 \text{ pole } 1200 = 60 \times 120 / 6$$

$$8 \text{ pole } 900 = 60 \times 120 / 8$$

The AC Induction Motor

Frequency is Speed

...The motor manufacturer controls the speed of the motor by controlling the number of poles.

...Multi speed motors can be built by designing multi pole motors.

2 speed single winding

3600/1800

1800/900

1200/600

2 speed two winding

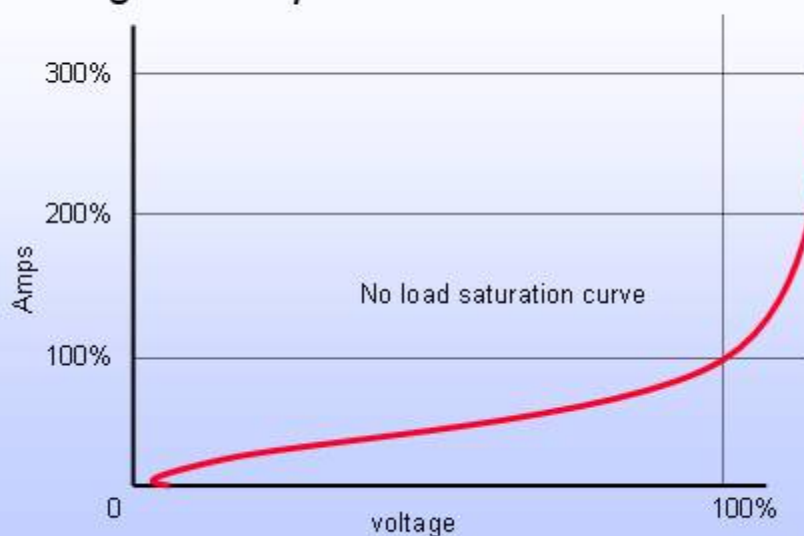
3600/600

1800/1200

1800/600

The AC Induction Motor

Voltage is torque



The AC Induction Motor

Voltage is torque

$$TQ = \frac{HP \times 5250}{N}$$

Where:

N = Speed in RPM

Fq = Frequency in Hz

P = The number of motor poles

120 is a constant for time conversion

Note:

For lb/in of TQ use 63025

A Drive System is not a Motor Speed Control

The Drive Train

...Torque transmission

...Speed Changer

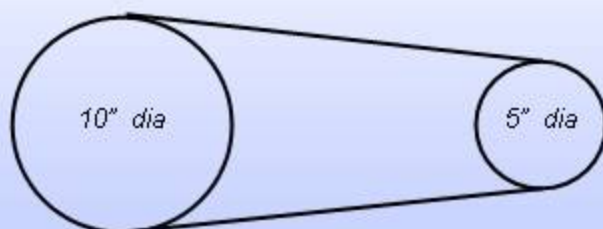
...enclosed Gearing



The Drive Train

Torque transmission

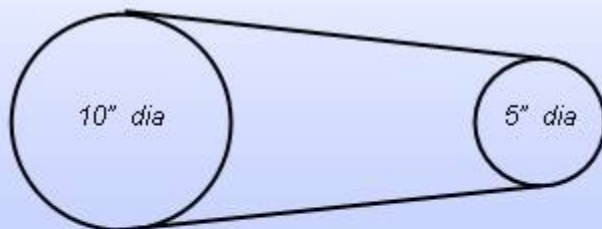
2:1 5 LB/FT INPUT RESULTS IN 10 LB/FT OUT



The Drive Train

Speed Changer

2:1 100 rpm INPUT RESULTS IN 50 rpm OUT

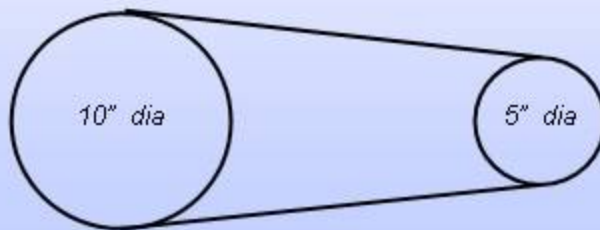


The Drive Train

Speed Changer

Torque transmission

1:2 50 rpm INPUT RESULTS IN 100 rpm OUT
10 LB/FT INPUT RESULTS IN 5 LB/FT OUT



The Drive Train

enclosed Gearing

Also known as speed reducers

Worm... Right angle... 60 to 80%
eff

Helical... in line... 90 to 98% eff

Planetary... in line... 95 to 98% eff

A Drive System is not a Motor Speed Control

The Coupling Devices

...Flex
...Mill Duty
...Universal



A Drive System is not a Motor Speed Control

The Feedback Devices

...Load
...Speed
...Temperature
...Vibration
...Process



How Does an Electronic Variable Frequency Control Work

An INVERTER is a motor control that adjusts the speed of an A.C. Induction motor.

The INVERTER adjusts the SPEED of a motor by varying the FREQUENCY of the A.C. Power to the motor.

$$\text{Synchronous Speed} = \frac{120 \times \text{Frequency}}{\text{Motor Poles}}$$

or

$$\text{Frequency} = \frac{\text{Synchronous Speed} \times \text{Motor Poles}}{120}$$

MOTOR POLES	RATED SPEED	SYNCHRONOUS SPEED
2	3450	3600
4	1750	1800
6	1150	1200
8	850	900

How Does an Electronic Variable Frequency Control Work

An INVERTER adjusts the VOLTAGE and the FREQUENCY.

There is a relationship between VOLTAGE and FREQUENCY Known as the VOLTS PER HERTZ RATIO (V/hz Ratio)

By Controlling the VOLTAGE to hertz ratio the motor will.

- Draw nearly full load current during operation (if full load is required).
- Eliminate high locked rotor currents at start-up.
- Maintain constant torque output up to base speed OR:
- Reduce output torque at low speeds on pumps and blowers.

How Does an Electronic Variable Frequency Control Work

Motor TORQUE control

Motor TORQUE is directly related to the amount of current flow into a motor, the INVERTER will limit the peak TORQUE output to the current capability of the INVERTER.

Typically, the motor will be capable of providing 150% RATED TORQUE at startup with a matched control.

Motor TORQUE Control

Typical constant torque speed ranges:

Motor Type	Service Factor	Inverter Type	CT Speed Range
Standard (pre-EEPact)	1.0	PWM	3:1
Standard (post-EEP act)	1.0	PWM	6:1
Super - E	1.0	PWM	20:1
Vector Duty	1.0	PWM	1000:1

Motor HORSE POWER Control

$$HP = \frac{T \times RPM}{5250}$$

If the motor's torque stays constant as the speed is changed, the motor's horsepower capacity will change directly with speed.

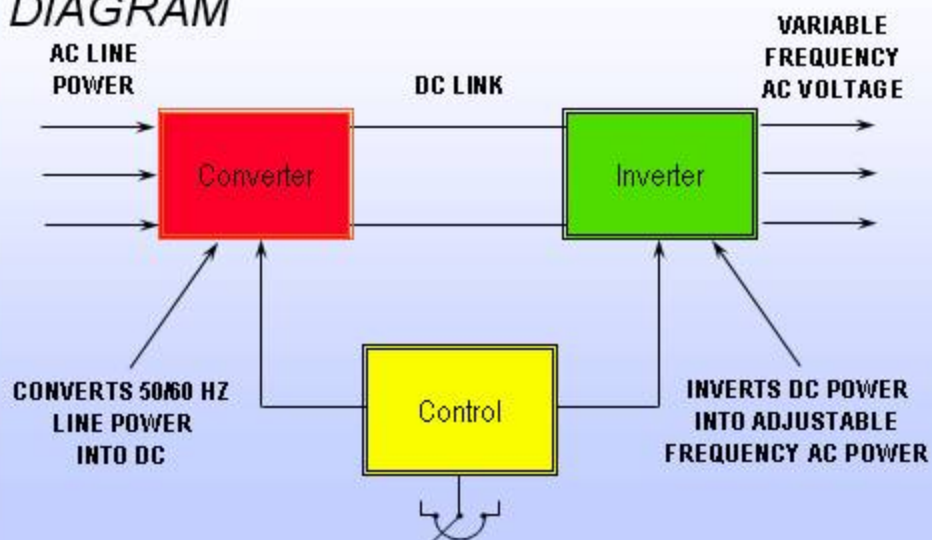
$$HP (60 \text{ Hz}) = \frac{3 \times 1750}{5250} = 1 \text{ HP}$$

$$HP (120 \text{ Hz}) = \frac{3 \times 3550}{5250} = 2 \text{ HP}$$

$$HP (30 \text{ Hz}) = \frac{3 \times 850}{5250} = 0.5 \text{ HP}$$

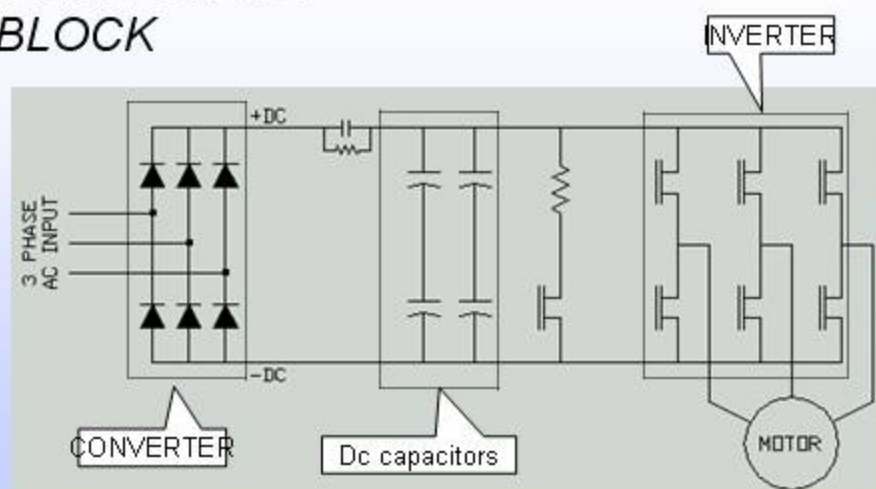
Variable Frequency CONTROL

BLOCK DIAGRAM



Variable Frequency CONTROL

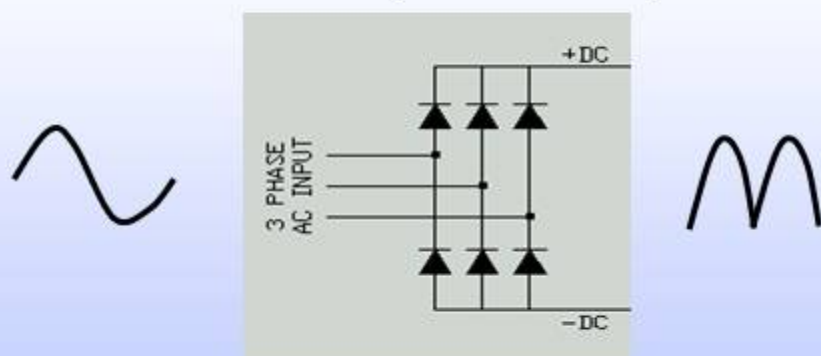
SOLID STATE BLOCK



Variable Frequency CONTROL

converter

Converts AC power to DC power

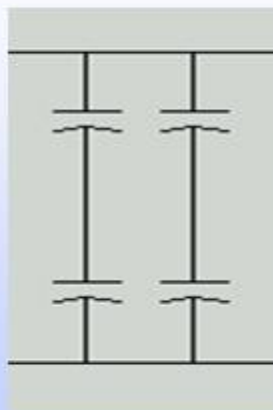


$$\text{DC Bus} = \text{RMS} \times 1.414$$

VFC Sections

DC Bus

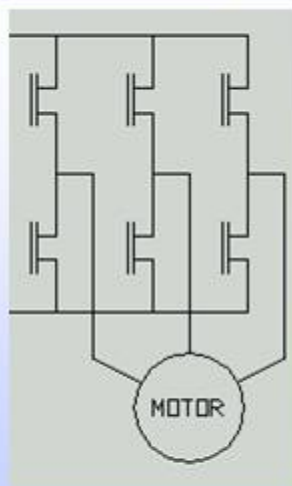
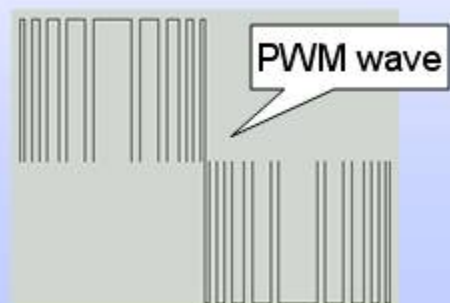
...FILTERS THE
VOLTAGE
...STORES POWER
FOR LOAD



VFC Sections

Inverter

- Inverts the DC Bus Voltage into a PWM AC sine wave
- Monitors the motor Back EMF to determine the load



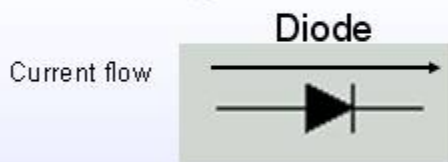
VFC Sections

Soft Charge Circuit

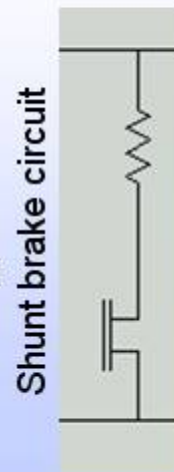
- ...At start up the the discharged caps look as a dead short to the AC line.
- ... The resistor allows the caps to charge softly and prevent fuse faults.



VFC Sections

Dynamic braking

- ... Diodes are one way valves.
- ... Motors regenerate during stopping and deceleration.
- ... Brake Circuits re-channel the regenerative energy



Tools & Safety Issues

Test Equipment

- **Electronic Multi-meters**
 - Used to Measure Voltage, Current & Resistance
- **“Clamp” Current Meter**
 - Used to Measure Large AC & DC Currents
- **Digital Oscilloscope**
 - Required for “real time” voltage & Current Measurements



Tools & Safety Issues

Electronic Multi-meters

- **Minimum Required Features**
 - Category III 1000v
 - AC to 750v
 - True RMS w/Cres I Factor = 3
 - DC to 1000v
 - Resistance
 - Diode Check
 - Min/Max/Avg. Record
 - Optional
 - Frequency
 - Temperature



Tektronix TX1
~\$325.00



Fluke 87-III
~\$350.00

Tools & Safety Issues

"Clamp" Current Meter

- **Minimum Required Features**

- Category III 600v
- AC current - 45 to 400hz
- True RMS w/Cresl Factor = 3
- Optional
 - Connect to DMM/Oscilloscope
 - Min/Max/Avg. Record
 - Frequency
 - DC Current



Fluke 36
~\$225.00



Tektronix A621
\$400.00

Tools & Safety Issues

Portable Oscilloscopes

- **Minimum Required Features**

- UL Listed Device
- Electrically Isolated Input Channels!
- 50Mhz Bandwidth or Greater
- Digital Storage Capability
- AC to 600v
- DC to 1000v



Tektronix THS-730A ~\$2,200.00



Tektronix THS-720P ~\$3,000.00

- Optional

- Built-in Multi-meter
- Complex Power & Math

Tools & Safety Issues

Don't do it!

...Don't take short cuts

- Always measure
- use good test leads and other tools
- know the power rating of the equipment
- be sure you use the right tool
- lock-out Tag-out
- know who's around the equipment
- inspect for broken parts before starting
- walk the equipment to insure your safety, the safety of others and the equipment.

What Makes a Drive Application Successful?

The Load

• There are four load types

– Constant Torque

- LOAD IS NOT A FUNCTION OF SPEED. (CONVEYORS, POSITIVE DISPLACEMENT PUMPS.)

– Constant Horse power

- MOTOR TORQUE ABOVE BASE SPEED WILL DECREASE. (GRINDERS, WINDERS)

– Variable Torque

- TORQUE INCREASES WITH THE SQUARE OF SPEED. (CENTRIFUGAL PUMPS & FANS)

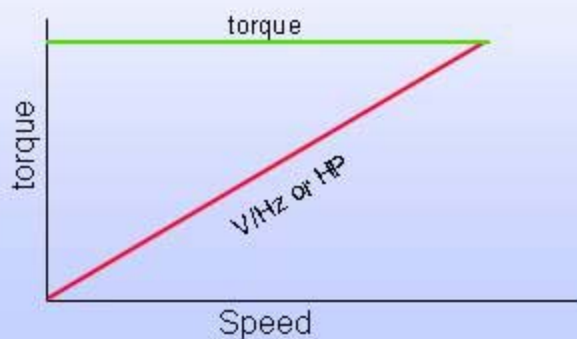
– Impact Load

- TORQUE LOADING IS INTERMITTENT. PEAK TORQUE REQUIREMENTS MUST BE CONSIDERED. (PUNCH PRESS)

The Load

Constant torque

The Torque remains constant from a low speed to base speed



The Load

Constant Horse power

The Horse power remains constant from base speed to max speed

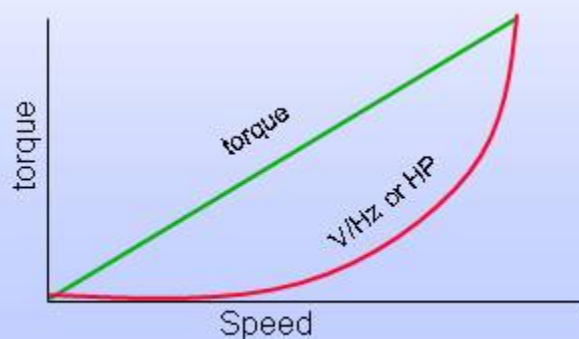


The Load

Variable torque

The Torque Varies by the Square of the speed

The HP Varies by the Cube of the speed



The Load

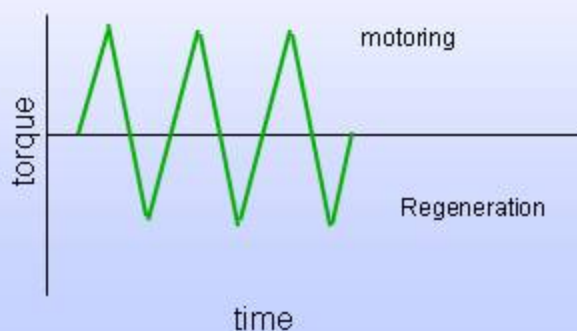
Inverters for Variable Torque

- Adjustable speed drives are the state of the art for flow control
 - Variable Speed Fan
 - No air restrictions
 - Volume varies directly with the speed
 - Pressure varies with the square of the speed
 - Power varies with the cube of the speed

The Load

Impact Load

The Torque is a function of the RMS value



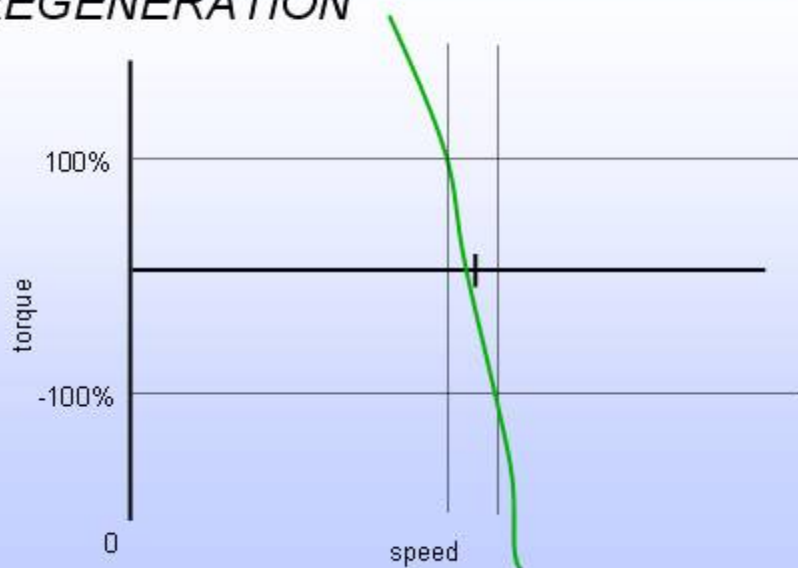
The Load

REGENERATION

When the rotor frequency is greater than the stator frequency the motor will begin to act like a GENERATOR. This will occur during deceleration and when the load drives the motor shaft. This GENERATED power is called REGENERATIVE ENERGY.

The Load

REGENERATION



The Load

Stopping the load

- ...Dynamic Braking
 - Shunt Brake
- ...Line Regenerative Braking
- ...DC Injection braking

Stopping The Load

LINE REGENERATIVE

A LINE REGENERATIVE motor control will route the REGENERATIVE energy from the motor back onto the input power line. Yes, this is desirable in applications where a significant amount of REGENERATIVE energy will be present such as engine dynamometers.

Stopping The Load

DC INJECTION BRAKING

DC INJECTION BRAKING of an AC Induction Motor is accomplished by sending the motor DC power rather than AC power. An Induction motor rotates because of the Alternating Current (AC) power supplied to the motor leads. When the Direct Current (DC) power is supplied to the motor leads, the motor's magnetic poles will try to align themselves in a stationary position, causing the motor to stop.

David Ruehle:

Total cost 10084.00
 Labor 16 hours @ 200/hr
 VFC about twice motor

3600 RPM centrifugal pump. The pump requires a 20 horse power motor with a C-face and feet. The application will have a speed pot to set the operating point.

2 HP 2 Pole motor	\$ 1814.00
pressure transducer	\$ 200.00
speed pot	\$ 56.00
Variable Frequency Control	\$ 3536.00
Input & output Reactors	\$ 988.00
Start/Stop Station	\$ 290.00
Installation & Start-Up	\$ 3200.00

Applications

Vector Control

DC - Like Performance with an Induction Motor

Field Weakening Above Base Speed for Higher Speeds with Constant HP

Microprocessor Controls All Simultaneously

Applications

Vector Control

Performance

Speed Regulation = 0.1% (Analog Signal)
 = Exact (Digital Mode)

(Closed Velocity Loop with Encoder)

Full Rated Torque: Zero to Base Speed

Limitations

System Cost Higher than Inverter

Motor Heating (greater than across the line, much less than an inverter with similar cooling)

Applications

Vector Control

1. Variable Speed AC Drive Package that Includes:
 - A. Control (Vector Type)
 - B. Motor (AC Induction)
 - C. Feedback Device (encoder or resolver)
2. Control is Microprocessor based.
3. Closed loop communications vs. open loop communications.

What a Vector control does

1. Converts AC fixed line frequency and voltage into variable frequency and voltage to control speed and torque of an AC Induction motor.
2. The encoder senses direction and speed of the shaft. The encoder signal is fed back to the control.
3. The control compares what the motor is doing vs. what the motor should be doing and changes the output frequency, current and voltage to correct for changes such as load, temperature, friction, etc.

Applications

Vector Control

Comparison with an Inverter

1. The Vector Drive is essentially an enhanced Inverter Drive and can therefore do anything an Inverter can do.
2. Additionally, a Vector Drive can have the ability to:
 - A. Speed regulate (0.1% regulation)
 - B. Torque follow
 - C. Provide full torque down to and including 0 speed
 - D. Wide speed range (6000:1)
 - E. No cogging at low speeds
 - F. Homing or Orienting
 - G. Positioning with Motion Control Card

Applications for Vector Drives

- Cranes
- Extruders
- Conveyors
- Winders
- Glass Production Lines
- Printers
- Conveyor Cars
- Stirrers/Mixers
- Precision Pump
- Dynamometers
- Spindles
- Hobbing Equipment
- Winches
- Electric Vehicles
- Elevators
- Variable Pitch Pulley Replacements

Vector Drives vs. Inverters

Application	Inverter	Vector
Conveyor	Min. Speed > 3Hz (90 RPM w/4 pole)	Any Speed
Fans & Blowers	Any Speed	Overkill
Pumps, Centrifugal	Any Speed	Overkill
Cranes, Hoists	Possible, Size for Starting Torque & Regen Slip Comp Preferred	Superior to Inverter. Full torque at Zero Speed Less Jerk with S-Curve
Spindle Drives	Yes, No orientation	Yes, Orientation included
Feed to Length	No	Yes with External Motion Controller
Indexer	No	Yes, with External Motion Controller
Presses - Cyclic Load	Yes, Size for Torque Requirement	Yes
Extruder	Possible, Size for Starting Torque	Yes, Cost Premium

Caution!

Important Information on VFD Selection and Operation

The Motor/Inverter Package must be carefully selected to assure system component compatibility. Operation of rotating machinery with non-sinusoidal waveforms may contribute to the following altered motor operating characteristics:

- Increased Motor Full Load Amps
- Increased Mechanical Stresses
- Increased Motor Temperatures
- Increased Motor Vibration
- Increased Motor Noise
- Reduced Motor Efficiency
- These altered characteristics should be understood and anticipated in the design of the system.

Some Application Considerations

- Line Impedance
 - If the impedance is less than 3 % then consider
 - Line Reactors
 - Isolation Transformers
 - If the impedance is greater than 10 % then consider changing transformers
- Long Cable Runs
 - If you have long cable runs – consider some type of filtering

Other Application Considerations

- Does the Drive need to run on a Generator?
- If the drive goes down, would running off the line be acceptable and beneficial?
- Is there a factory network that the drive needs to communicate with?
 - Device Net
 - Profibus
 - Modbus Plus
 - Can Open

Other Application Considerations

- What environment is the motor and drive in?
 - Moisture
 - Heat
 - Dust and Dirt
 - Vibration
 - Shock
 - Altitude
- Are any agency approvals required
 - CSA
 - UL
 - CE
 - Explosion Proof

Trouble Shooting

10 Most Common Problems

1: Lack of Knowledge

- Read and Know the Manual!
- Attend Manufacturer/Supplier Training Courses
- Contact OEM for System Operation Issues

2: Under/Over Voltage

- Check the Incoming Power Line

3: Intermittent Operation

- Check for Loose Wires

Trouble Shooting

10 Most Common Problems

4: Overheating

- Check for Proper Airflow - fans, blowers, etc...
- Check for Contamination

5: Ground Fault

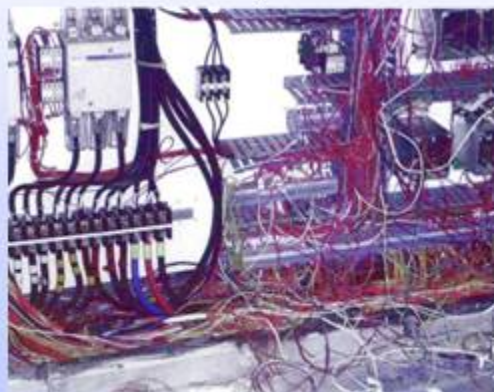
- Check for Failed Motor Conductor Insulation
- Check for Failed Winding Conductor Insulation

Trouble Shooting

10 Most Common Problems

6: Unexplained Nuisance Faults

- Separate Low & High Voltage Wires
- Use Shielded Cable for Signal Wires



Trouble Shooting

10 Most Common Problems

7: Overload

- Check for Mechanical Jams

8: Blown Fuses

- Do Not Just Replace - Determine Cause!
- Check Basic Components

9: Motor Damaged

- Check for Free Rotation of Shaft
- Check for Open Circuit in Windings

Trouble Shooting

10 Most Common Problems

10: Application Considerations

- Environment
 - Contamination
 - Temperature / Altitude
 - Vibration
- Sufficient Motor Torque & HP for the Load
- Match Motor Control Type to Application
 - Speed Control
 - Torque Control
 - etc...