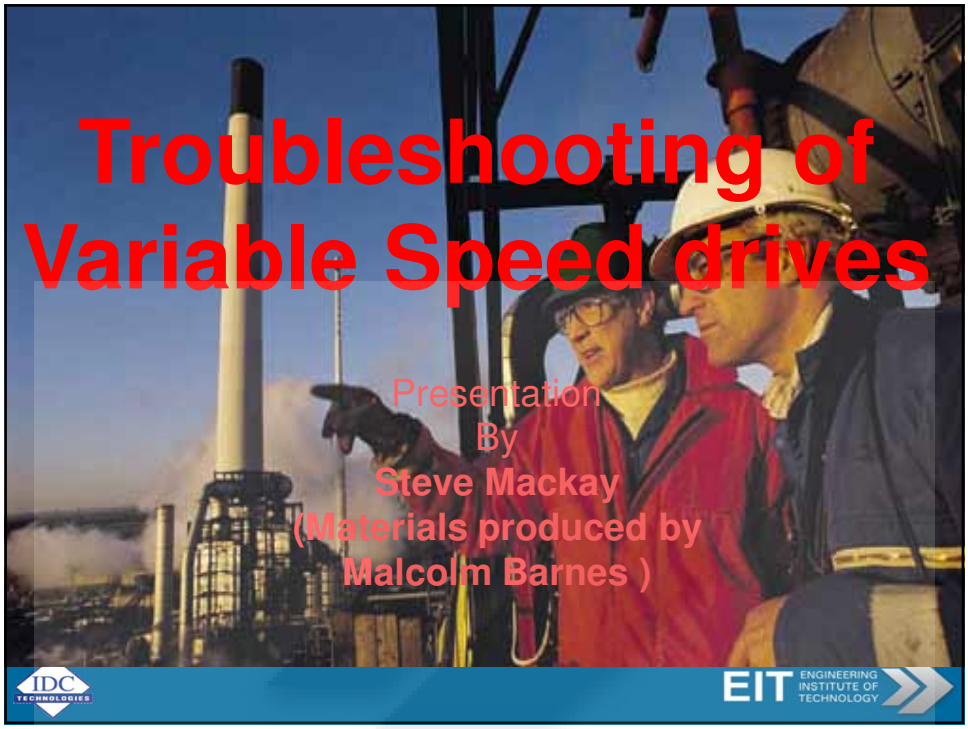

Presented by

Steve Mackay PhD

Dean of Engineering

of the

Engineering Institute of Technology

EIT Micro-Course Series

- Every two weeks we present a 35 to 45 minute interactive course
- Practical, useful with Q & A throughout
- PID loop Tuning / Arc Flash Protection, Functional Safety, Troubleshooting conveyors presented so far
- Upcoming:
  - Electrical Troubleshooting and much much more…..
- Go to http://www.eit.edu.au/free-courses
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ENVIRONMENTAL REQUIREMENTS

VVVF Converters usually supplied as *stand-alone* units …

- **IP00 Rating**
  - For Chassis Mounting into an Enclosure or MCC
- IP20/IP30 Rating
  - For mounting within a *Clean Environment* ….
  - such as a Weather-proof, air-conditioned room
  - Environment free of dust, moisture and contaminants
- **IP54/IP55 Rating**
  - For mounting outside in a partially sheltered environment
  - Environment may be dusty and/or wet

GENERAL SAFETY REQUIREMENTS

- Requirements for **Safety** .... should be carefully followed
  - Australian Standard *AS 3000 : SAA Wiring Rules* apply
  - Safety earths must be installed **before power connected**
- AC Converters have **Large Capacitors** on the DC link
  - After VSD switched off ..... wait several minutes
  - Allow internal capacitors to fully discharge
  - **Visual Indication** ... shows when capacitors are charged

HAZARDOUS AREAS

- AC Converters should NOT be mounted in *Hazardous Areas* ..... even when connected to an Ex rated motor
- When necessary .....
  - AC converters may be mounted in Approved Enclosure
  - Certification should be obtained for entire **VSD System** .... including both Converter and Motor

ENVIRONMENTAL REQUIREMENTS

- Main advantages of AC Variable Speed Drive System .....
  - TEFC squirrel cage motor is extremely reliable
  - Motor **well protected** from poor environmental conditions
  - Motor usually rated at IP54 or better
  - Motor can be used in **Dusty and Wet environments**

- AC converter is far more Sensitive to its Environment and must be located in a protected environment that is free from ...
  - Dust and other abrasive materials
  - Corrosive gases and liquids
  - Flammable gases and liquids
  - High levels of atmospheric moisture

ENVIRONMENTAL REQUIREMENTS

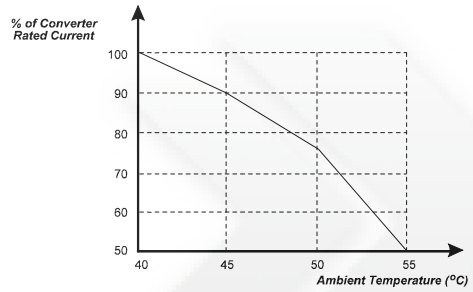
- Following environmental limits should not be exceeded ...
  - Ambient Temperature : ≤ 40°C
  - Altitude : ≤ 1000m above sea level
  - Relative Humidity : ≤ 95%

- When environmental conditions exceed these .....
  - Provide additional cooling
  - Provide other environmental protection
  - Alternatively .... Apply de-rating factors

- Temperature de-rating needs to be strictly applied
  - PWM converter will NOT be destroyed if limits exceeded
  - Main problem is associated with ***Nuisance Tripping***

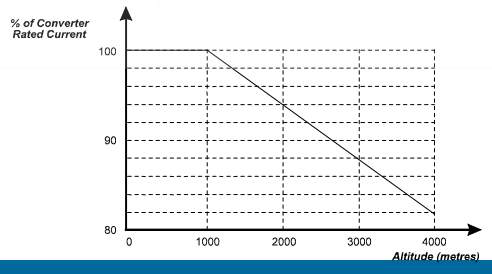
DE-RATING FOR TEMPERATURE

- De-rating Converters for High Temperature
  - Environment temperature should not exceed 40°C
  - Air-conditioning should be used where necessary
  - Temp inside enclosures should be within limits
  - If not .... de-rating tables should be used



DE-RATING FOR ALTITUDE

- At ***high altitudes*** .... cooling is less effective
  - Air Pressure and Density **fall with increased altitude**
  - Reduced ability of air to carry heat from the heatsink
  - Higher de-rating for BJTs than IGBTs (lower losses)
  - **Typical table** is given below for IGBT-type AC converter

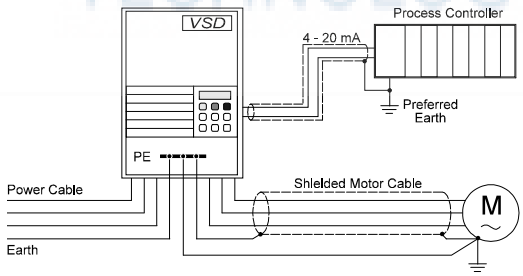


POWER SUPPLY CABLES

- Accepted practice and Australian Standards ....
  - Power to a VSD provided from a DB or MCC
  - Safety Isolation Switch is essential
  - Short-circuit protection required ... Fuses or CB to protect Power Cable and Input rectifier bridge
  - Thermal Over-load Protection is NOT normally required (Provided as part of VS Drive protection system)
- **Safety earthing** essential ... *AS 3000 : SAA Wiring Rules*
  - Manufacturer also requires metal frames to be earthed
  - Keep touch potentials within safe limits
  - Path to earth for the generated EMI ...

MAIN CABLE CONNECTIONS

- Major Groups of Cable Connections are ...
  - **Power Supply** : 3-Core plus Earth ... Neutral not required
  - **Motor Cables** : 3-Core plus Earth ... Neutral not required
  - **Control Cables** : Must be Shielded



POWER SUPPLY CABLES

- Power cable mm^2 ... adequate for current rating of the VSD
  - Selected to normal economic cable selection criteria
  - Consider length, S/C current, continuous rating
  - **AS 3008 : Cable Tables** is a good reference
  - 10% de-rating for harmonic heating in upstream components
- **EMI can be radiated** from Power Cable ...
  - Power cable ideally in metal duct or cable ladder
  - Cable preferably Trefoil with Concentric Shield ... SWA **earthed at Both Ends**
  - Control Cables at least 300mm away from power cable

MOTOR CABLE

- Motor cable has **non-sinusoidal PWM voltage** .... high EMI
  - Harmonic frequencies in spectrum 100kHz to 1MHz
  - Motor cable should be shielded or located in metal duct
  - Avoid 3 separate cores laid horizontally on cable ladder
  - Prefer Trefoil Cable with concentric Shield
  - Control and Comms ..... NOT located close to this cable
- Motor Cable Size preferably same as Power Supply Cable
  - Similar current rating apply .... also with harmonics
  - Easier to add bypass device later
  - Cable protected by the Converter S/C Protection
- Separate earth conductor recommended for Safety & Noise

CONTROL CABLES

- Control cables should be according to normal local practice
  - Cross section at least 0.5 mm^2 for volt drop performance
  - Capacitive Shield to provide protection from EMI
  - Shields **earthed at one end** ... prefer to PLC earth
  - Individual screen for every pair ... best protection
- Control Cables preferably with Magnetic Shield as well ...
  - On separate cable ladders or ducts
  - Inside steel conduit
  - As far away from the power cables as possible
  - If on same cable ladder ... minimum separation 300mm
  - **Avoid Long parallel runs on same cable ladder**

COMMON CABLING ERRORS

- Earth conductor to AC converter in same duct as other cables .... Control Cables and other Power Cables
  - Run instrument cables in separate metal ducts or conduit
- Unshielded motor cable running next to other Cables
  - Coupled HF harmonic voltages and currents
  - Separation should be a minimum of 300mm
- Excessively long cables from AC converter to the Motor ... these should be no longer than 100m
  - Longer cables require filters to reduce leakage current
  - Reduced Switching frequency will help

STOP/START CONTROL OF AC DRIVES

- Stop/Start control of the AC Drive can be achieved by ...
  - Wire to Start/Stop input of the **Converter Control Circuit**
  - Breaking the power circuit by means of a supply side **Contactor** .... sometimes called the ***Start on Power-up Option***
- **The First Method is the recommended method**
- The Second method is derived from DOL Starting
  - Quite commonly used ... but there can be some problems
  - Most commonly used for Conveyors or **Emergency Stop**
  - Problems can occur ..... !!!

CONTACTOR - MAINS SUPPLY SIDE

- Contactor on the **Mains Supply** side often used for ....
  - Starting and Stopping
  - Emergency Stop or Conveyor Pullwire Stop
- **Advantages** ...
  - Follows traditional Motor Control strategy
  - Gives Physical break in the power circuit ... extra Safety
  - Physical Break a requirement for Conveyor Safety Circuits
- **Disadvantages** ...
  - Power to the control circuits is lost when OFF
  - Control & Diagnostics info lost when VSD is Stopped
  - Delay at every start for DC Charging Sequence (±2sec)
  - Repeated Starts stress the DC bus Charging circuit
  - Charging Resistors Overheat or Bypass Relay may fail

CONTACTOR - MAINS SUPPLY SIDE

- Extract from Manual of one of the leading manufacturers ...

ATTENTION : *The drive is intended to be controlled by control input signals that will start and stop the motor. A device that routinely disconnects and then reapplies line power to the drive for the purpose of starting and stopping the motor is not recommended. If this type of circuit is used, a maximum of 3 stop/start cycles in any 5 minute period (with a minimum period of 1 minute rest between each cycle) is required. These 5 minute periods must be separated by 10 minute rest cycles to allow the drive pre-charge resistors to cool. Refer to codes and standards applicable to your particular system for specific requirements and additional information.*

CONTACTOR - MOTOR SIDE

- Contactor on Motor Side often used for ...
  - Starting and Stopping
  - Emergency Stop or Conveyor Pullwire Stop
- Advantages ...
  - Gives Physical break in the power circuit ... extra Safety
  - Power not removed from Control circuit when VSD is OFF
- Disadvantages ...
  - If Opened on load ... transient over-voltages at IGBTs
  - If Closed on load ... large inrush currents through IGBTs
  - Repeated operation stresses the Inverter Components

CONTACTOR - MOTOR SIDE

- Extract from Manual of one of the leading manufacturers ...

ATTENTION : *Any disconnecting means wired to the drive output terminals U, V and W must be capable of disabling the drive if operated during drive operation. If opened during drive operation, the drive will continue to produce output voltage between U, V and W. An auxiliary contact must be used to simultaneously disable the drive or output component damage may occur.*

- Ensure that **AC Converter is OFF** before contacts between the converter and the motor are **Opened or Closed**.
- This will avoid IGBT damage due to transient over-voltages and large inrush currents.

CONTACTOR - SOLUTION

- Try to avoid use of a Contactor in the Power Circuit !!!!!
- Introduce control circuit interlocks to avoid problems ...
- Contactor in the Supply Side
  - Use contactor for the "*Emergency Stop*" ONLY
  - Use separate "*Process Stop*" for normal Start/Stop
  - If using a PLC ... build in an **Operator Override**
- Contactor in the Motor Side
  - Use contactor for the "*Emergency Stop*" ONLY
  - Use separate "*Process Stop*" for normal Start/Stop
  - If using a PLC ... build in an **Operator Override**
  - Use "*early break*" auxiliary contact to stop the drive before opening
  - Use "*late make*" auxiliary contact to enable drive after closing

MOUNTING IN METAL ENCLOSURES

- Efficiency of modern AC converters is high ... ≥ 97%
  - Generate heat .... mainly due to the commutation losses
  - Manufacturers provide figures for full load losses (Watts)
  - Converters usually air-cooled ... Convection or Fan
  - Provision made to transfer heat to external environment
- Obstruction to air flow volume .... reduce cooling efficiency
- For effective Cooling ... there must be a **Temperature differential** between the heatsink and the cooling air
  - AC converters rated for operation in temperature ≤40°C

MOUNTING IN METAL ENCLOSURES

- AC Converters allow two alternative mounting arrangements :
- Surface mounting
  - Back plane of converter mounted onto vertical surface
- Recessed mounting
  - Heatsinks project through back of enclosure
  - Heat more effectively dissipated to environment
- **Separation** from other equipment is necessary ....
  - Permit unrestricted flow of cooling
  - **Free space of 100mm** around all sides recommended
  - For more than one VSD in the same enclosure
  - Prefer side by side rather than one above the other
  - Avoid locating temperature sensitive equipment above VSDs

MOUNTING IN METAL ENCLOSURES

- Dimensions large enough to dissipate the heat
  - Generated by Converter & other Electrical Equipment
  - Internal heat .... transferred to External Environment
  - Mainly Radiated from Surface of Enclosure
- Surface Area of Suitable Enclosure calculated ....

$$A = \frac{P}{k(T_{Max} - T_{Amb})} \quad m^2$$

A	Effective heat conducting area in m^2
P	Power Loss of heat producing equipment in Watts
T_{Max}	Max operating temperature of Converter in ^oC
T_{Amb}	Max temperature of the external ambient air in ^oC
k	Heat transmission coefficient of enclosure material

MOUNTING IN METAL ENCLOSURES

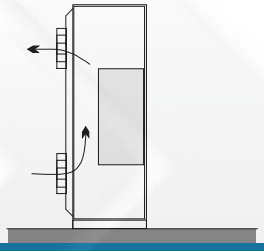
Example (Page 222) :

Calculate the minimum size of an IP54 Cubicle for a typical PWM type AC Frequency Converter rated at 22kW.

- *The following assumptions are made :*
  - *Converter losses are 600 Watts at full rated load*
  - *Converter mounted in IP54 cubicle made of 2mm steel*
  - *Enclosure effectively sealed from the outside. Heat can only be dissipated by radiation from external surface*
  - *Enclosure stands on floor with its back against the wall in an air-conditioned room. Max ambient temp 25^oC.*
  - *Converter can operate in a max temp of 50^oC.*
  - *Heat transmission coefficient is 5.5 (typical for painted 2mm steel).*

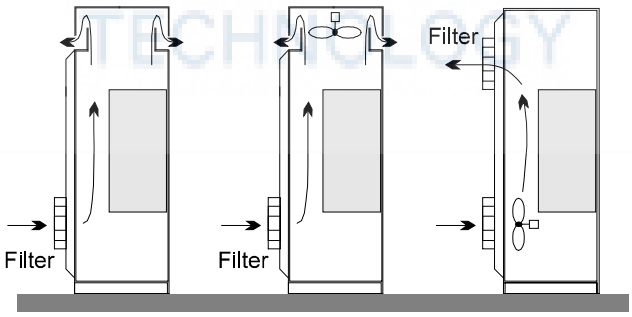
NATURAL VENTILATION

- Enclosure can be **Smaller** ... additional Ventilation required
  - Exchange air between Inside and Outside of enclosure
- Natural Ventilation
  - Convectional cooling airflow through air vents
  - Vents at **Bottom and Top** ..... the "chimney" effect



FORCED VENTILATION

- Cooling airflow assisted by fan at Top or Bottom of cubicle



FORCED VENTILATION

- Difficult to maintain a high IP rating with Ventilated Cubicles
  - Need to be in *Clean Environment* .... **dust-free room**
- For Cooling .... certain **Volume of Airflow** is required
  - Transfer heat Inside to the External Environment
- Required airflow Calculated from the formula :

$$V = \frac{3.1\,P}{(T_{Max} - T_{Amb})} \quad m^3/hr$$

V	Required airflow in m^3/hour
P	Power Loss of heat producing equipment in Watts
T_{Max}	Max permissible operating temp of Converter in ^oC
T_{Amb}	Maximum external ambient temperature in ^oC

FORCED VENTILATION

Example (Page 225) :

Calculate the airflow ventilation requirements of the 22kW Drive in the previous example, using same assumptions.

ALTERNATIVE MOUNTING

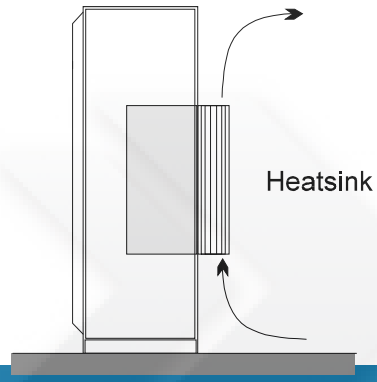
- Major problem with Ventilation of Converter Cubicles ...
  - Difficult to achieve a high IP rating with ventilated cubicle
  - If filters are used ... additional problem are introduced
    - Filters restrict the volume of airflow
    - When they get dirty ... cooling efficiency is reduced
    - Maintenance Problem to check and replace filters
- **Recessed Mounting** ... Solution rapidly gaining popularity
  - Adopted by many of the AC Converter Manufacturers
- Heat mainly generated by power electronic components
  - Rectifier, Inverter, Capacitors, Choke and Power Supplies
  - These items usually mounted directly on the heatsink
  - Most heat dissipated from Surfaces of the Heatsink
  - Electronic Control Cards ... losses are small

RECESSED MOUNTING

- Heatsink recessed through back of enclosure
  - Most heat dissipated to environment external to cubicle
  - Control Portion of converter remains within the enclosure
- High IP Ratings possible without Cubicle Ventilation
  - Suitable seal around the Heatsink base
  - Enclosure can be relatively small
  - Enclosure can be rated at >IP54
  - Heatsink is outside with a lower IP rating (eg IP20)
  - Heatsink can also project into a cooling airduct system

RECESSED MOUNTING

- Small Cubicle with high IP rating ... no Ventilation Slots



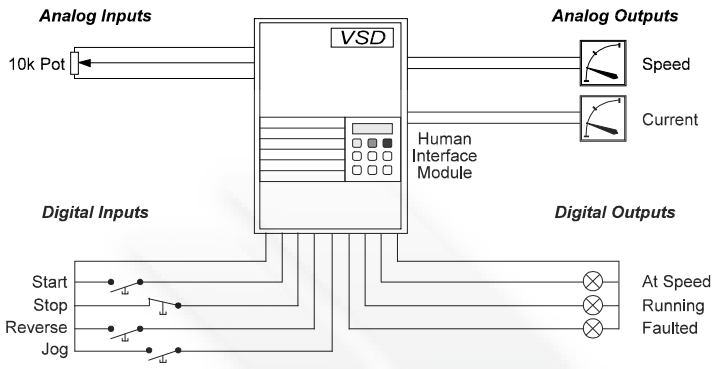
MANUAL CONTROL WIRING

- ***Local*** *Manual Control* for VSDs by means of
  - Push-buttons
  - Switches
  - Lamps
  - Potentiometers

Sometimes also need ...

- ***Remote*** *Manual Control* close to the Process ...
  - Push-buttons
  - Switches
  - Lamps
  - Potentiometers

MANUAL CONTROL

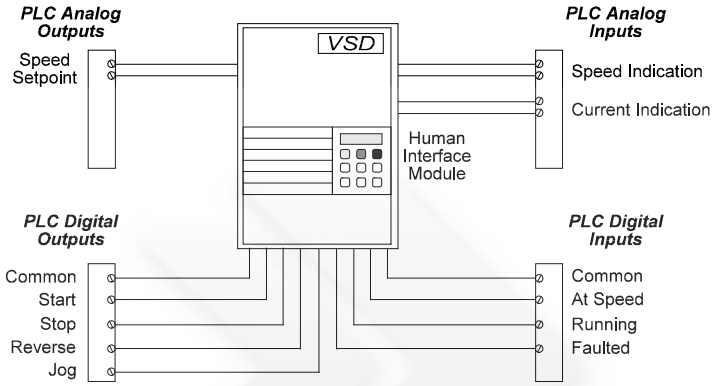


PLC CONTROL WIRING

- **PLC Digital Outputs** for controls such as :
  - Start, Stop, Reverse, Jog, etc
- **PLC Digital Status Inputs** for Status Indications such as :
  - Running, Stopped, At Speed, Faulted, etc
- **PLC Analog Outputs** for remote setpoint values such as :
  - Speed Reference, Torque Reference, etc
- **PLC Analog Inputs** such as remote Indications such as :
  - Current, Speed, Temperature, etc

- All DOs & DIs require one wire per function ... plus common
- All AOs & AIs require two wires per function ... plus a shield

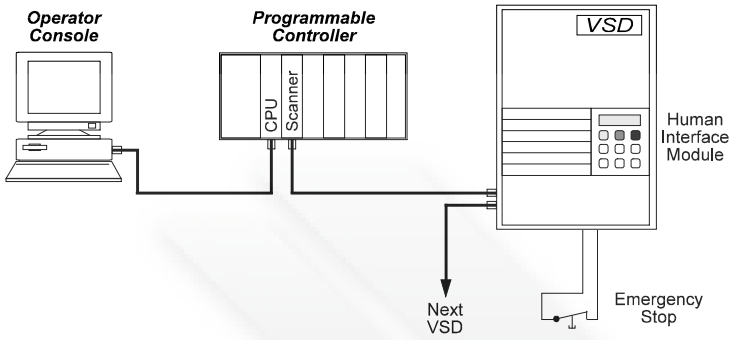
PLC CONTROL WIRING



PLC CONTROL WIRING

- Control systems have grown in complexity
  - amount of information from field sensors has expanded
  - number of control wires has become a major problem
- Typical hard-wired interface between VSD (PLC) would **typically require about 15 conductors** as follows :
  - 5 for controls ... Start, Stop, Enable, Reverse, etc
  - 4 for status/alarms ....Running, Faulted, at Speed, etc
  - 2 or 3 for analog control ... Speed setpoint
  - 4 for analog status ... Speed indication, Current indication
- For several VSDs in the overall system, the number of wires is multiplied by the number of VSDs in the system.

SERIAL COMMUNICATIONS WIRING



PRE-COMMISSIONING

- Main Purpose of commissioning VSDs is to ensure that :
  - AC Converter & Motor are correctly installed
  - Install the **correct Settings for the Application**
  - Functional tests ... make sure that it works
- Pre-commissioning Checks ...
  - Power and Motor Cables are correct ... size & termination
  - Power Cable shields correctly earthed to PE terminal
  - No faults on the cables prior to energisation ... **Megger**
  - Control Cables correctly installed and terminated
  - Control Cable shields correctly earthed at **one end only**
  - Check Cooling Fan Connections ... and confirm that the correct Voltage Tap is selected on the auxiliary transformer

Note : Do NOT Megger the Converter

COMMISSIONING

- When Pre-commissioning Complete ... ready for Energisation
  - First ... Disconnect the Motor Cable
  - This will avoid unexpected motor starts ... wiring errors
  - Turn on the Power ...
- Check all basic electrical parameters ...
  - Measure the Power Supply Voltages
  - Measure the DC Bus Voltage ... Why?
  - Confirm that Microprocessor has completed test sequence
  - Confirm that Control System is "*READY*"
  - Confirm Cooling Fan is running ... Correct Direction??
- Record tests and Settings in "*Commissioning Test Report*"

BASIC SETTING PARAMETERS

- Before VSD connected to Mechanical Load .....
  - Basic Parameters must be correctly set
- **Base Voltage** ... selected for Motor Rated Voltage
  - Ensures correct output Volts/Hz ratio to Motor
  - In Australia 415V, 3-phase
- **Base Frequency** ... selected for Motor Rated Frequency
  - Ensures correct output Volts/Hz ratio to Motor
  - In Australia .... use 50Hz
- **Motor Details** ... required on some AC Converters
  - Required for Motor Model and Protection

BASIC SETTING PARAMETERS

- Remaining Parameters settings can be selected as follows :
  - **Maximum speed** ... usually set to 50Hz or higher
  - **Minimum speed** ... usually 0Hz for a pump or fan drive and higher for constant torque applications
  - **Rated Motor Current** ... size of motor may be small
  - **Current Limit** ... determines Starting Torque
  - **Acceleration Time** ... determines the Ramp-up Time
  - **Deceleration Time** ... determines the Ramp-down Time
  - **Braking Method** ... 3 Options usually available
  - **Starting Torque Boost** ... cover *Breakaway Torque*

Note : Avoid over-fluxing the motor !!!

- Other Settings ... possibly adjust "default" settings

Thank You For Your Interest

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