

“Application of VFD in Power Plants”

Made By:

Azeem Sajid

Electrical Engineer | HSE | Controls & Automation



[linkedin.com/in/azeemsajid53](https://www.linkedin.com/in/azeemsajid53)

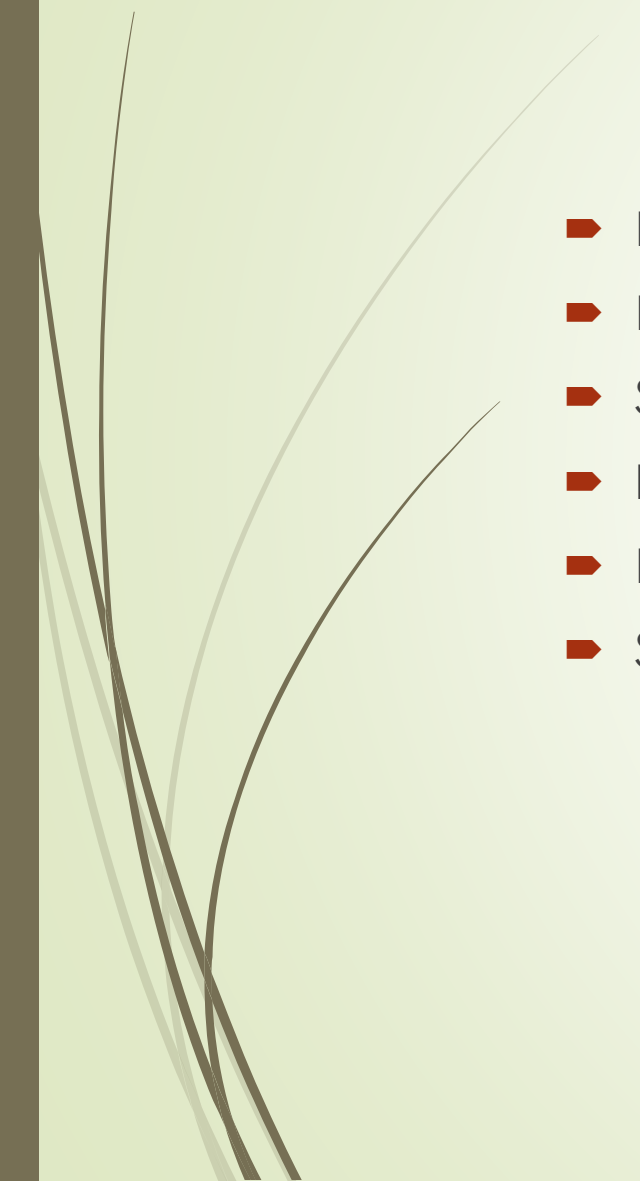


azeemsajid53@gmail.com





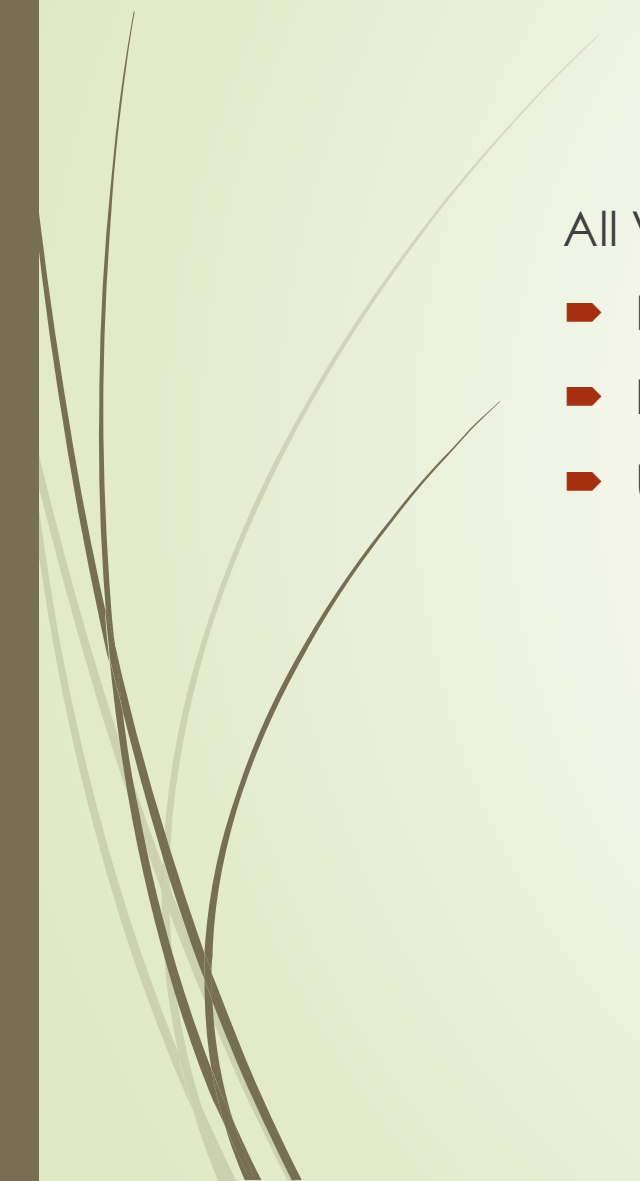
Why to Use VFD

- Energy savings on most pump and fan applications.
 - Better process control and regulation.
 - Speeding up or slowing down a machine or process.
 - Inherent power-factor correction
 - Protection from high in-rush currents
 - Safe Acceleration and braking
- 



Electric & Power Basics

All VFD's must:

- ▶ Run a machine or process at a desired speed.
 - ▶ Produce adequate torque to handle the load.
 - ▶ Use power efficiently to produce the necessary torque at a given speed.
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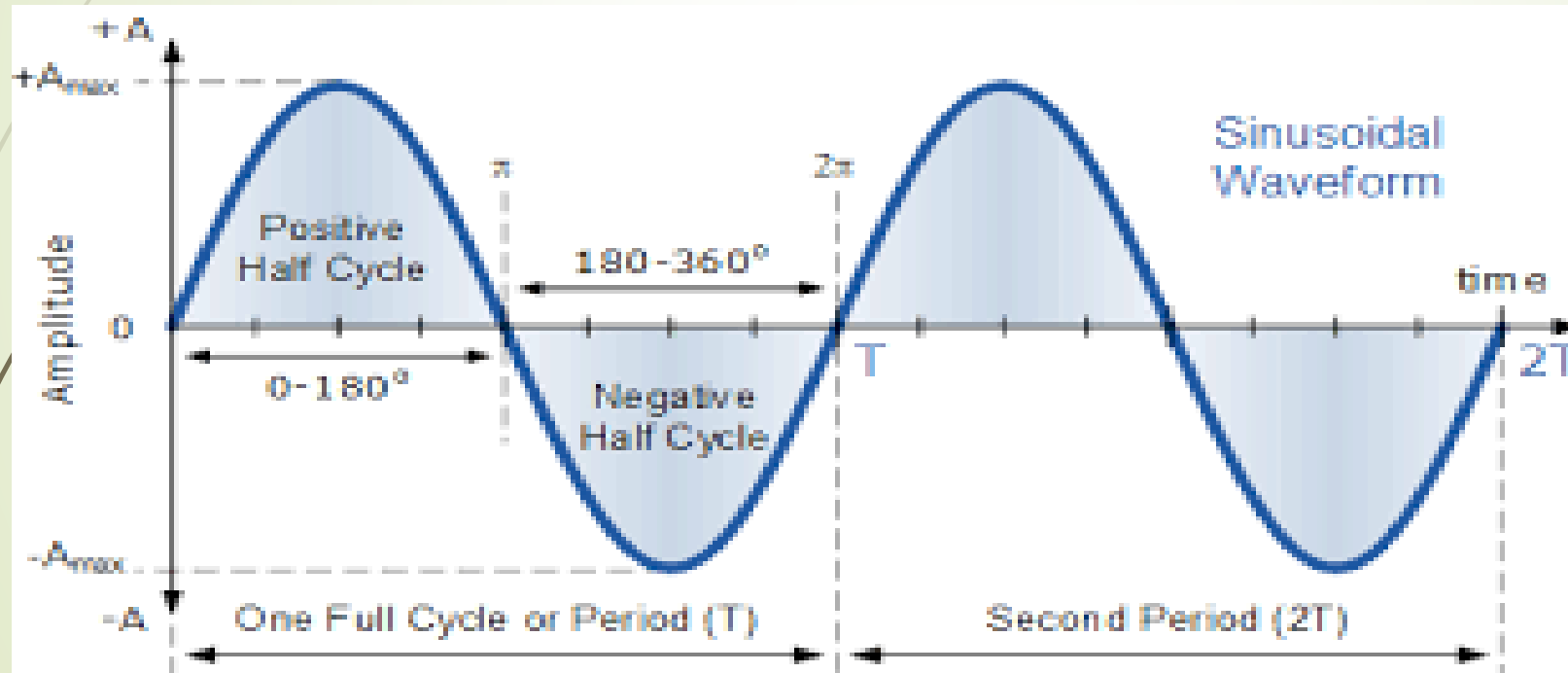


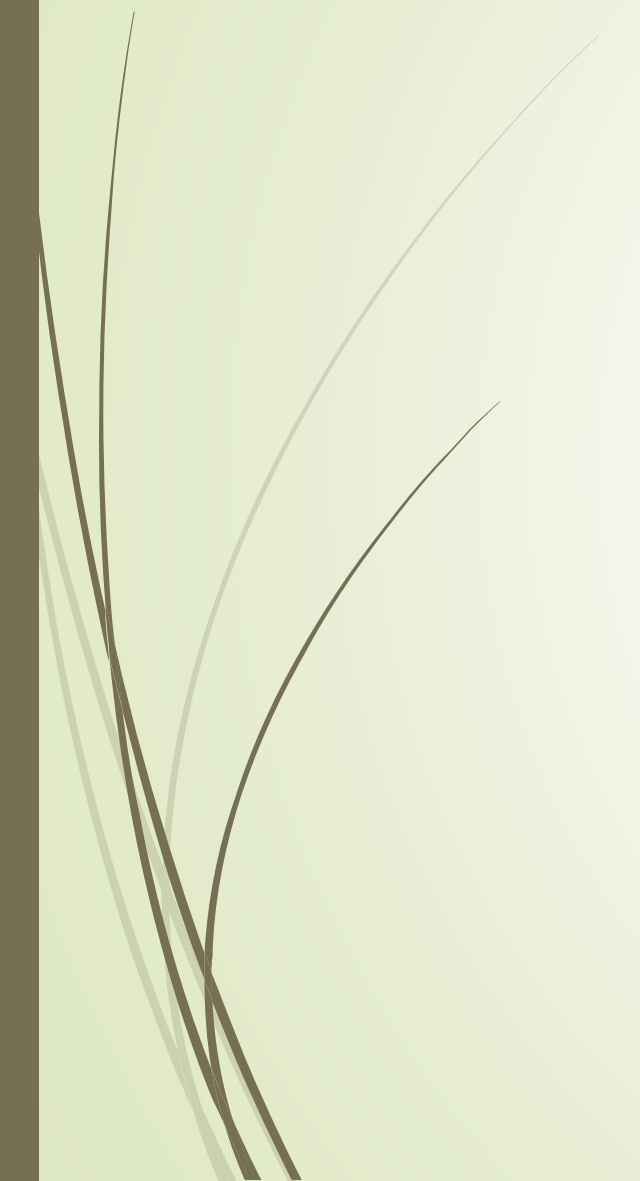
Electric & Power Basics

- The typical waveform consists of the frequency portion (time based) of the wave and the amplitude portion (the magnitude). This wave is actually in sine-wave form, commonly referred to as the fundamental.
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Electric & Power Basics

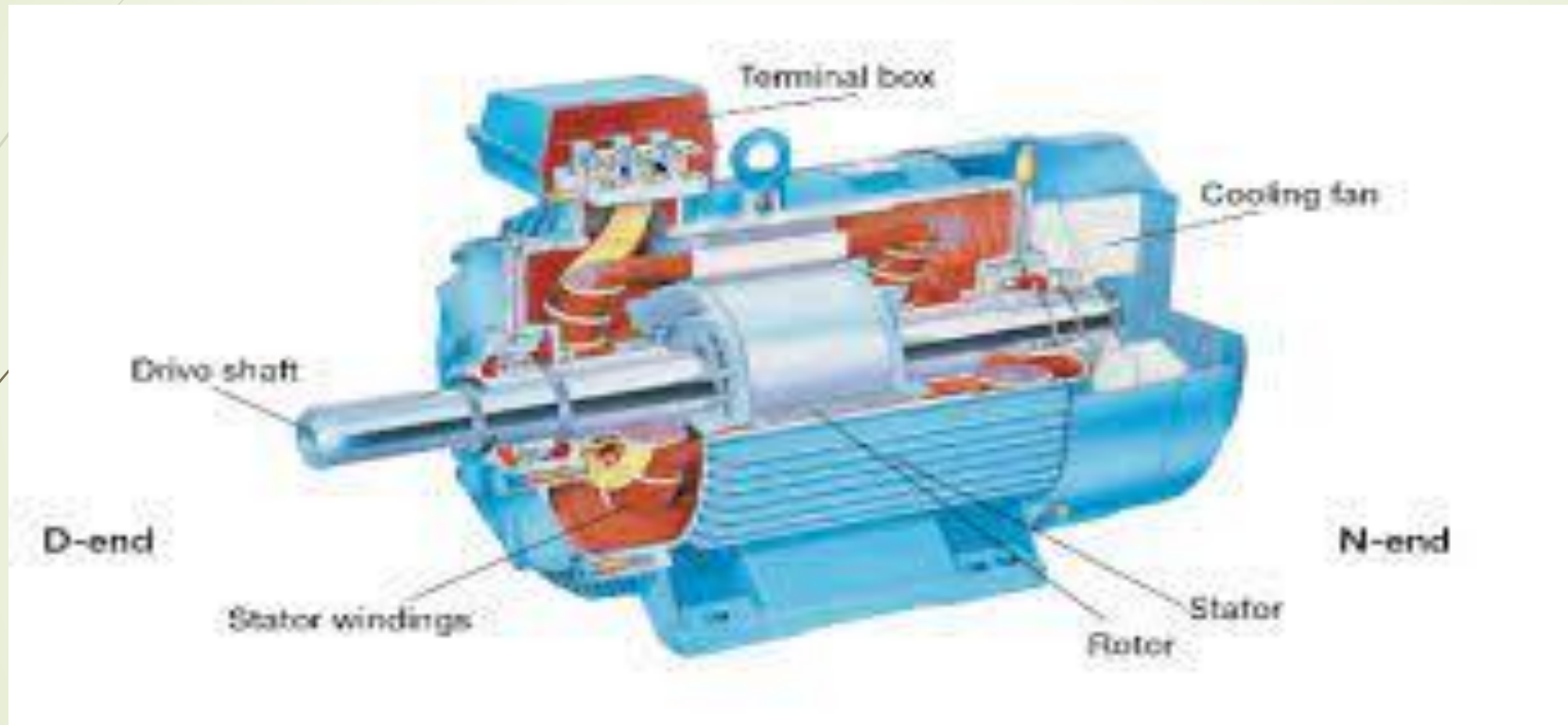
Sinusoidal Waveform With Frequency & Amplitude Components



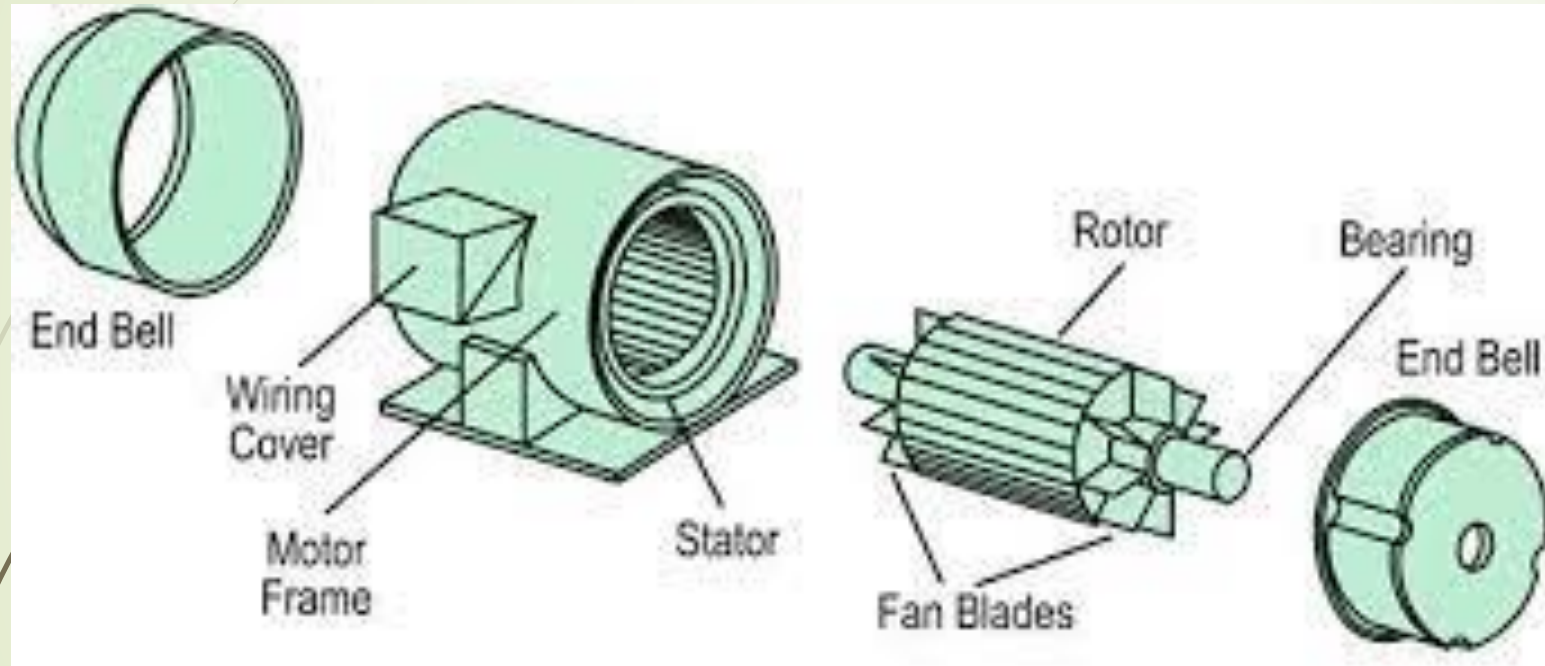


AC-Induction-Motor Theory

AC Induction Motor Theory



AC Induction Motor Theory



Three-phase induction motor



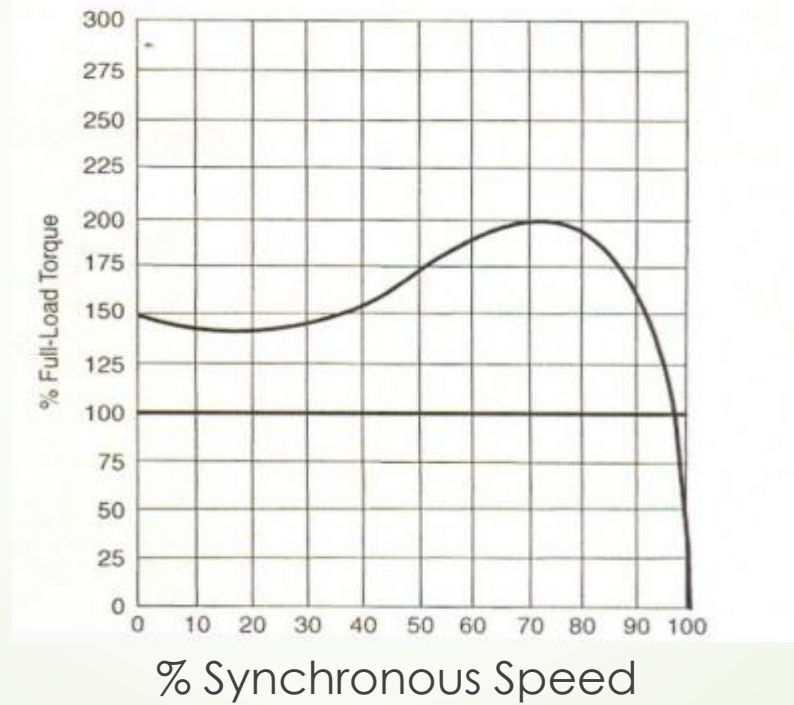
AC Induction Motor Theory

How a motor shaft rotates?

- ❖ Torque is produced as the induction motor generates flux in its rotating field.
- ❖ As shaft torque load increases, the slip increases and more flux lines cut the rotor windings, which in turn increases rotor current, which increases the rotor magnetic field and consequently the rotor torque.

AC Induction Motor Theory

Typical speed versus torque curve for a NEMA design B motor.





AC Induction Motor Issues

Starting Induction Motors

- ❖ The starting current is very high, between 3 to 8 times the full load current. Depending on the size of the motor, this can result in voltage sags in the power system.
- ❖ The full torque is applied instantly at starting and the mechanical shock can eventually damage the drive system, particularly with materials handling equipment, such as conveyors.
- ❖ In spite of the high starting current, for some applications the starting torque may be relatively low, only 1.0 to 2.5 times full load torque.



AC Induction Motor Theory

The speed of the rotating electric field within the induction motor.

$$\text{Synchronous Speed} = 120 \times \text{frequency} / \text{No. of motor poles}$$



AC Induction Motor Theory

AC motor speed change can be accomplished in three ways:

- Change the number of poles in the motor; this means separate windings.
- Change the slip characteristics of the motor; this is done with varying resistors, such as is done with a wound-rotor motor or by varying the stator voltage; or
- Change the frequency of the power supplied to the motor. This can be achieved by VFD .



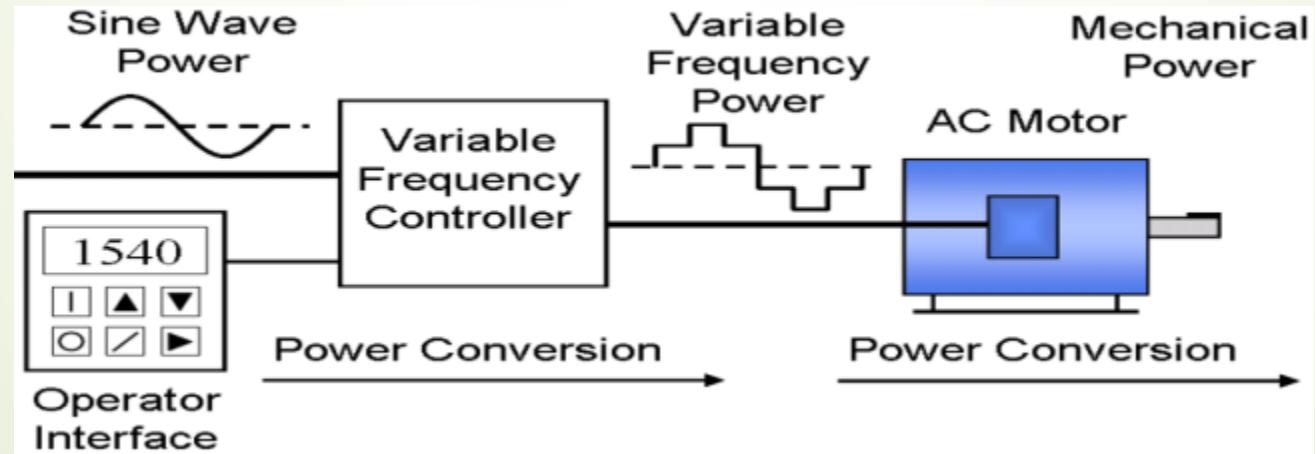
VFD Basics



The main objective of the VFD is to vary the speed of the motor while providing the closest approximation to a sine wave for current (while pulsing DC voltage to the motor).

Components of VFD System

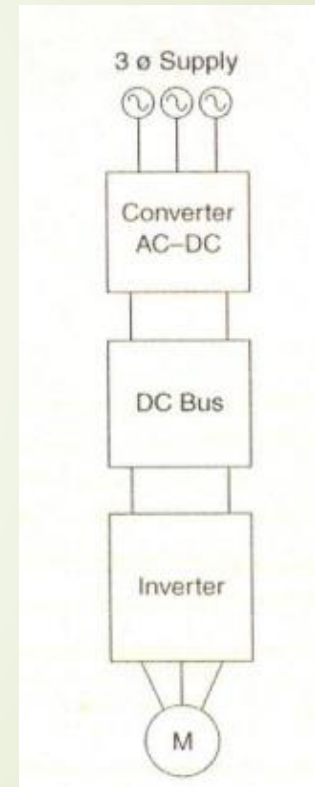
1. Operator Interface
2. Variable Frequency Controller
3. AC Motor



VFD Controller

The variable frequency drive controller is a solid-state power electronics conversion system consisting of three distinct sub-systems

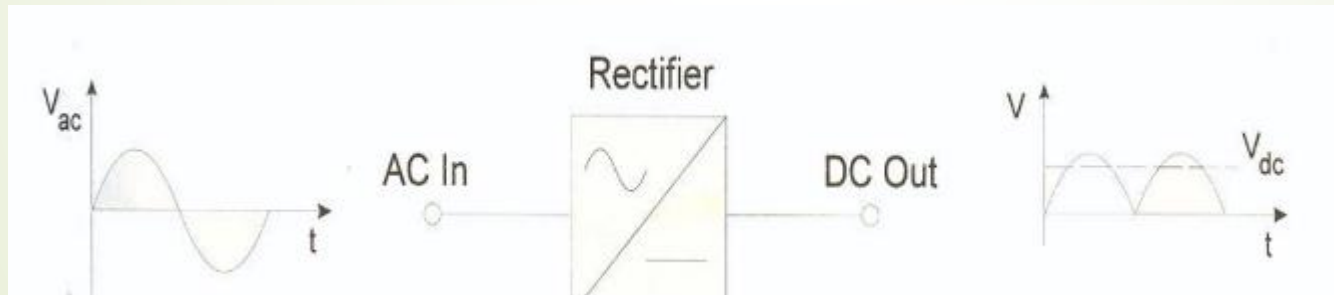
1. A rectifier bridge converter
2. A direct current (DC) link
3. An inverter



Rectifier bridge converter

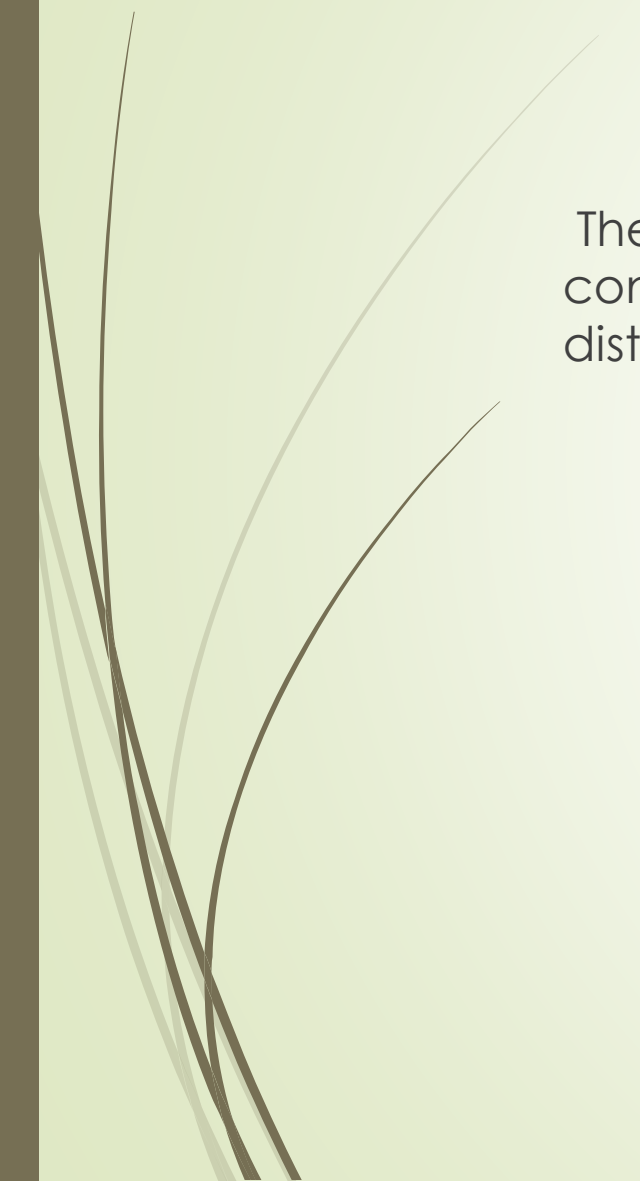
All VFD's need a power section that converts AC power into DC power. ❖ This is called the Rectifier bridge.

❖ The Rectifier is commonly a three-phase, full wave-diode bridge.





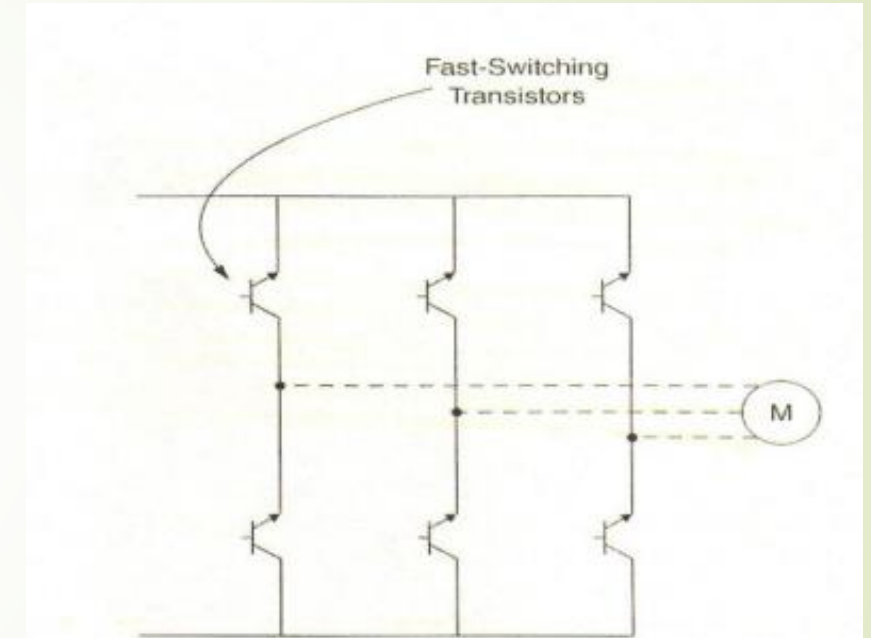
Direct current (DC) link



The DC link may consist of a capacitor/inductor which smoothens out the converter's DC output ripple and provides a stiff input to the inverter. If not, this distortion will show up in the output to the motor.

Inverter

- ❖ The inverter section is made up of modules that consist of a transistor and diode in combination with each other which inverts the DC energy back to AC.
- ❖ The power semi-conductors in the inverter section act as switches, switches of the DC bus, and therefore, are pulsing the motor with some voltage.
- ❖ By switching the inverter transistor devices on and off many times per half cycle, a pseudo - sinusoidal current waveform is approximated.



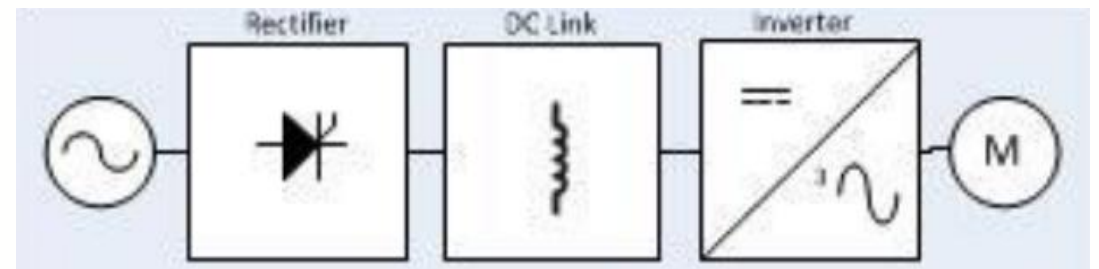
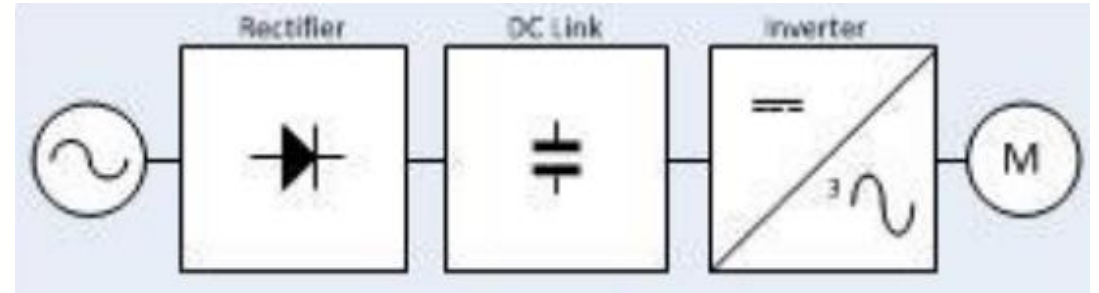
VFD Types

1. Voltage-source inverter (VSI) drive

The DC output of the diode-bridge converter stores energy in the capacitor bus to supply stiff voltage input to the inverter. The vast majority of drives are VSI type with PWM voltage output.

2. Current-source inverter (CSI) drive

The DC output of the SCR-bridge converter stores energy in series-reactor connection to supply stiff current input to the inverter. CSI drives can be operated with either PWM or six step waveform output.





VFD Types Cont..

3. **Six-step inverter drive**

The DC output of the SCR-bridge converter is smoothed via capacitor bus and series-reactor connection to supply via Darlington Pair or IGBT inverter quasi-sinusoidal, six-step voltage or current input to an induction motor.

4. **Load commutated inverter (LCI) drive**

The DC output of the SCR-bridge converter stores energy via DC link inductor circuit to supply stiff quasi-sinusoidal six-step current output of a second SCR-bridge's inverter and an overexcited synchronous machine.

5. **Cycloconverter or matrix converter (MC)**

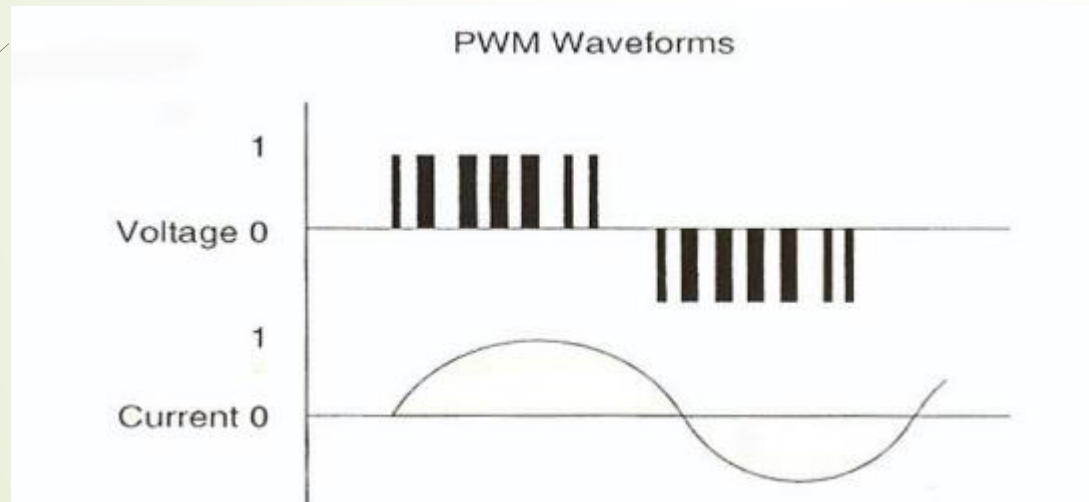
Cyclo converters and MCs are AC-AC converters that have no intermediate DC link for energy storage.

6 **Doubly fed slip recovery system**

A doubly fed slip recovery system feeds rectified slip power to a smoothing reactor to supply power to the AC supply network via an inverter, the speed of the motor being controlled by adjusting the DC current.

Pulse Width Modulation

- Pulse-width modulation (PWM), or pulse-duration modulation (PDM), is a commonly used technique for controlling power to electrical devices.



waveforms.



VFD Motor Selection issues

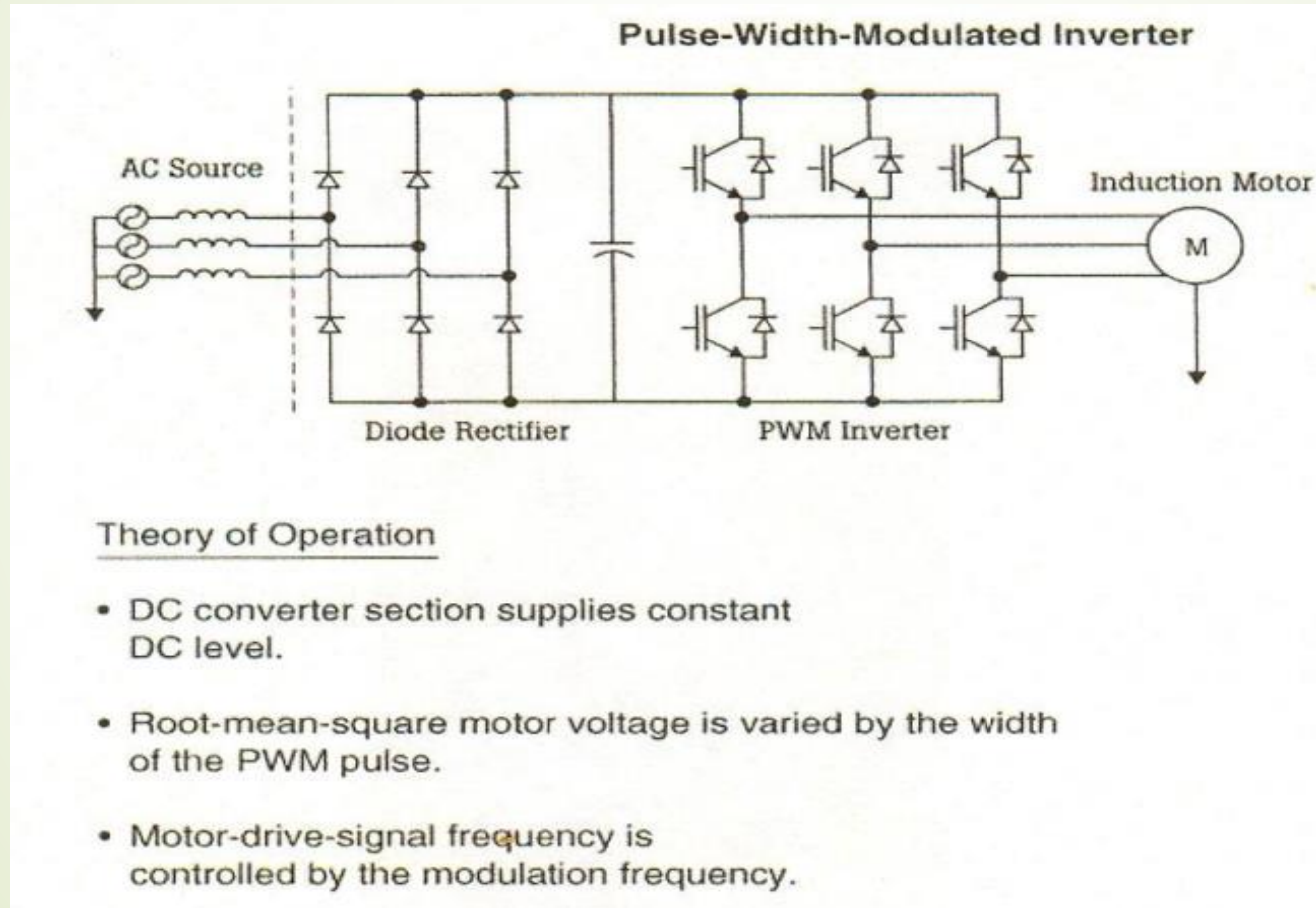
- The switching of insulated-gate bipolar transistors (IGBTs) to accomplish PWM on the output of a VFD creates voltage spikes on the line out to the motor.
 - These spikes are amplified over distance and, in time, break down the insulation of a motor, shortening the motor's life.
 - For VFD applications, Class F or higher insulation should be selected when possible.
- 



VFD Motor Selection issues Cont..

- In constant power applications, for higher torque, the speed would be low.
 - Reduced speed may affect the cooling of the motor windings for high torque applications.
 - When a VFD applies high-frequency pulses to a motor, the parasitic capacitance between stator and rotor generates voltage on the motor shaft. This creates discharge arcing and shaft current, which may damage the shaft and bearing surfaces.
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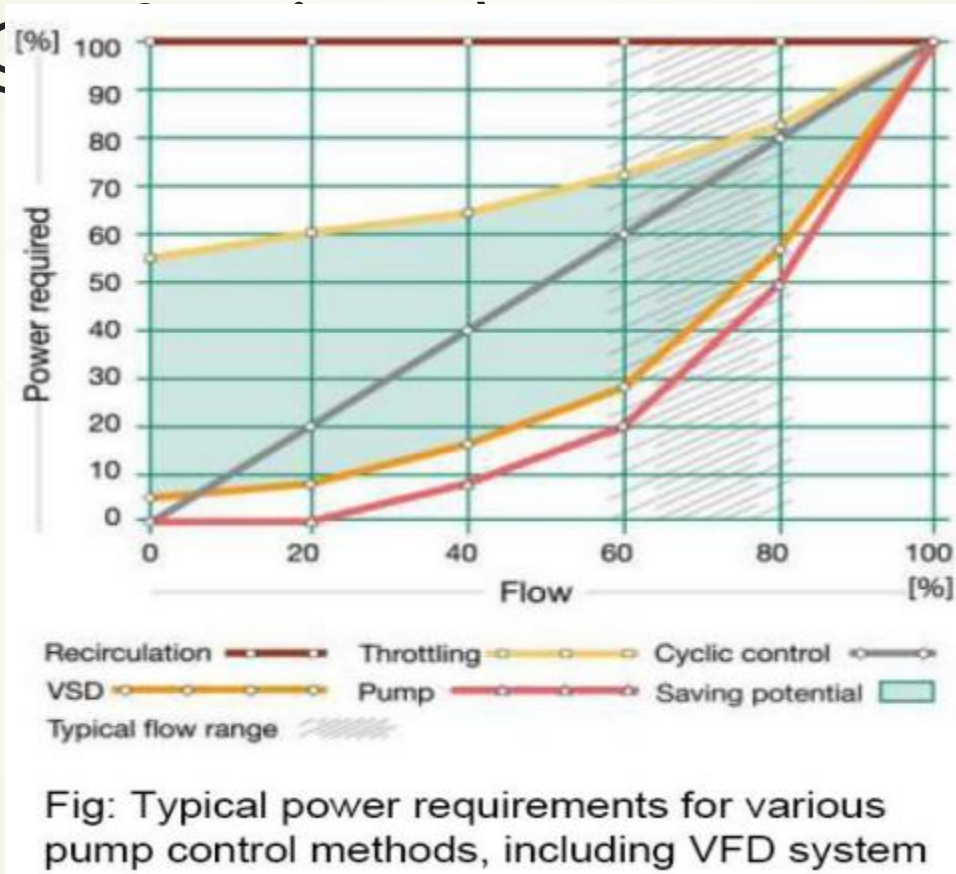
Sample PWM-Equivalent Circuit





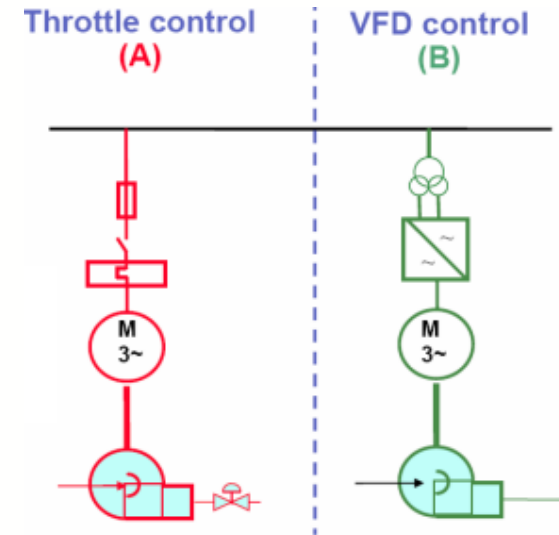
Application in Power Plants

VFD APPLICATION TO CEP/ID fan (for Energy)



- Variable speed control is the most energy efficient control method

How VFD Saves Energy ?



$$\text{Power (P)} = k H \times Q = 10 \times 10 = 100$$

$$P_{(A)} = 12 \times 7 = 84$$

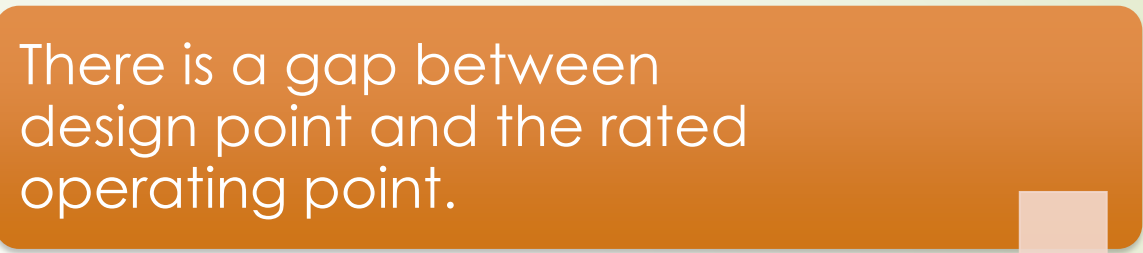
$$P_{(B)} = 7 \times 7 = 49$$

$$P_{(saved)} = 35 \text{ (42\%!)}$$



CEP/ID Fan

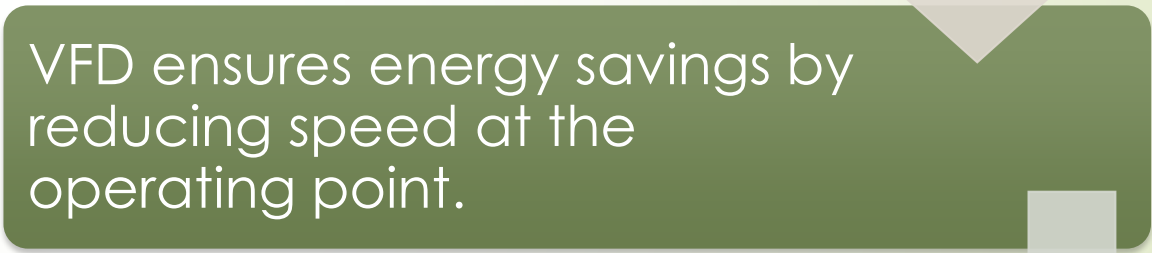
There is a gap between design point and the rated operating point.



Design margins are to take care of extreme operating conditions.



VFD ensures energy savings by reducing speed at the operating point.



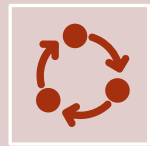
Margin to take care of operation at 47.5Hz. is not needed





VFD APPLICATION IN COMPRESSOR

VFD in Compressors



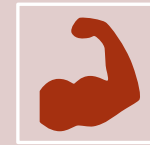
Instead of loading and unloading in a cyclic manner, the compressor is start/stop as per desired duty requirement to maintain the set pressure.



System saves energy as the motor does not run in idle mode.



VFD in compressor allows frequent start/stop of motor as per duty requirement.



Lower maintenance of the system due to smooth start.



Coal Conveyors

Coal conveyors are subjected to frequent start/stop.

Idle running of motor during stop by disengaging the hydraulic coupling causes energy loss.

Only 2 starts/hour are permissible.

Conveyors have to be designed to start while fully loaded, i.e. high torque.

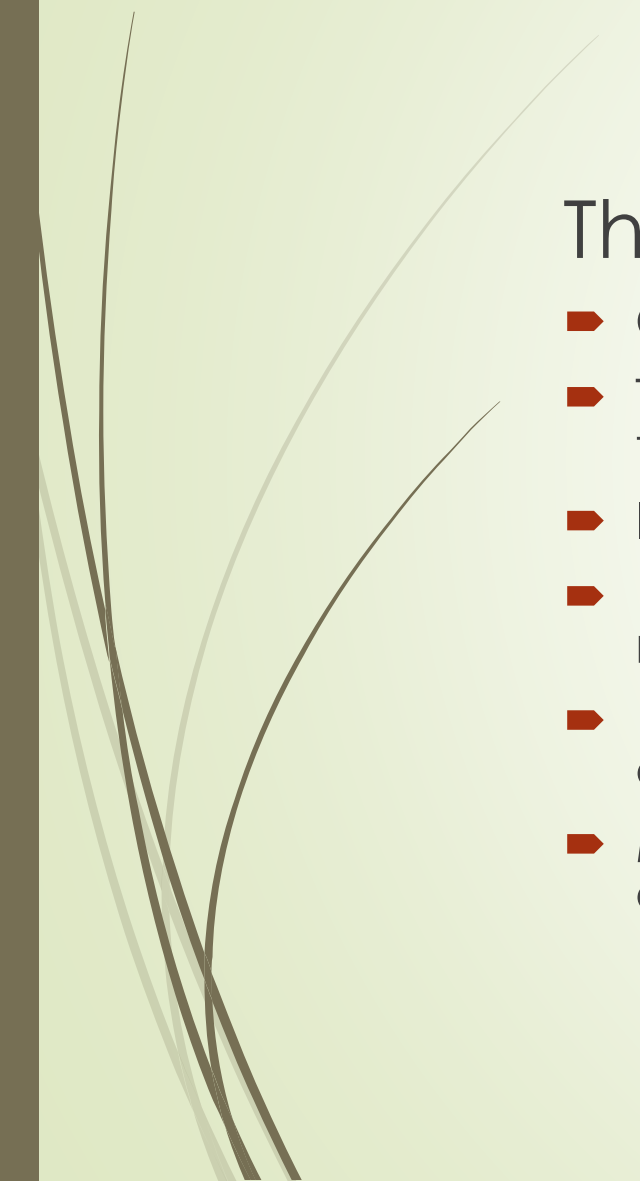
Generally, motors are run at part load.

VFD can provide ideal solution for Conveyors.



REELING DRUM APPLICATION cont....

The present scheme

- Cables reeling drum provided with brake motor
 - The brake motor stops and holds the drum, as and when the paddle-feeder or stacker-reclaimer stops moving
 - It protects the cable from slackness.
 - The brake is released on restart and motor rotates the drum to maintain safe tension in the cable.
 - The motor with conical rotor with spring loaded brake and brake-shoe arrangement are prone to high maintenance.
 - Many times causes unreeling of cable resulting in snapping or damage of it.
- 

REELING DRUM APPLICATION

VFD Alternative Scheme

- The arrangement is an innovative solution of brake motor.
- The VFD maintains constant torque on the cable reeling drum continuously even at zero speed (i.e. stop condition).
- This constant torque maintains safe tension on the cable.
- Power consumption at zero speed is equal to no load and part consumption during movements, as and when the drum rotates



VFD APPLICATION IN BOILER AREA

Axial blade pitch control and VFD control give the same level of efficiency in power consumption at part load operations.

- VFD control for PA fan, ID fan, Coal Feeder and Fuel Oil motors can be implemented for old 210MW units.
- VFD control for ID fans, Coal Feeder and Fuel Oil motors can be implemented for old 500 MW units.
- New units should have VFD for coal feeder speed control as against eddy current clutch control.
- Sipat-I coal feeder motors already have VFD controls



VFD APPLICATION TO BFP (for smooth start)

Advantages of Using VFD

Increased motor life due to the lower thermal and mechanical stressed in view of the absence of starting inrush currents and reduced speed operation.



No limitation on the number of starts.



No contribution to fault current.



One VFD can be used to start all the MDBFPs.



One more VFD can be kept as standby

VFD APPLICATION TO BFP – 4 UNITS

	OPTION-A	OPTION-B	OPTION-C
	2 x50% TD+ 1x50%MD(hydraulic coupling)	2 x50% TD+ 1x50%MD (VFD)	3x50% MDBFP (VFD)
VFDs	0	2 (1+1standby)	9 (8+1standby)
Turbines	8	8	0
Motor	4	4	12
Hydraulic couplings	4	0	0
Flexibility of layout	Negative	Negative	Positive
Space requirement	Negative	Negative	Positive
Maintenance	Negative	Negative	Positive
Startup time	Negative	Positive	Positive
Motor startup	Negative	Positive	Positive
Supply side Harmonics	Neutral	Neutral	Neutral
System Cost	Low	High	Neutral

VFD solution may be cheaper than the conventional one with other advantages as bonus.



BFP for 660MW Units- OPTION-B

- The BFP motor rating for 660MW (2x50% TDBFP+1x50% MDBFP) unit is 18MW and thus causes high electrical and mechanical stress on the system during starting.
 - Instead of 1x50%, it was proposed to use 2x30% rating BFP for 660 & 800 MW units. However, with VFD it can be retained as 1x50%.
 - The size of each VFD for 18MW motor shall be approximately 5MVA equal to no load MVA rating.
- 

Advantages of Using VFD with OPTION-C

BFPs can be placed at 0.0 M El.

Saving in Plant Cost due to lowering of De-aerator Elevation.

Absence of Associated Steam and Condensate piping.

Flexibility of Layout and Space Saving.

Absence of voltage dip problems.

This option is ruled out now because new CERC regulation permits only 2% additional aux. power on account of BFP, whereas BFP power consumption will be 4% in supercritical unit.

- Siemens quote for VFD of 300kW Air Compressor motor:

Rs. 4 million

- Siemens quote for VFD of 4000kW ID Fan induction motor:

Rs. 45 million

- ABB quote for VFD of 4000kW ID Fan induction motor:

Rs. 28.8 million

- Expected Price of VFD of 10MW rating along with motor

Rs. 80 millions

PRICE OF VFD
for BFP Motors
cont.



VFD WITH REMOTE RF CONTROL FOR EOT CRANES

USE:

1. LIFTING / LOWERING LOADS
2. CARRYING LOADS ALONG /ACROSS THE RAILS

MOTORS :

1. MAIN HOIST/ CREEP MOTOR
2. AUXILIARY HOIST / CREEP MOTOR
3. CROSS TRAVEL / CREEP MOTOR
4. LONG TRAVEL / CREEP MOTOR

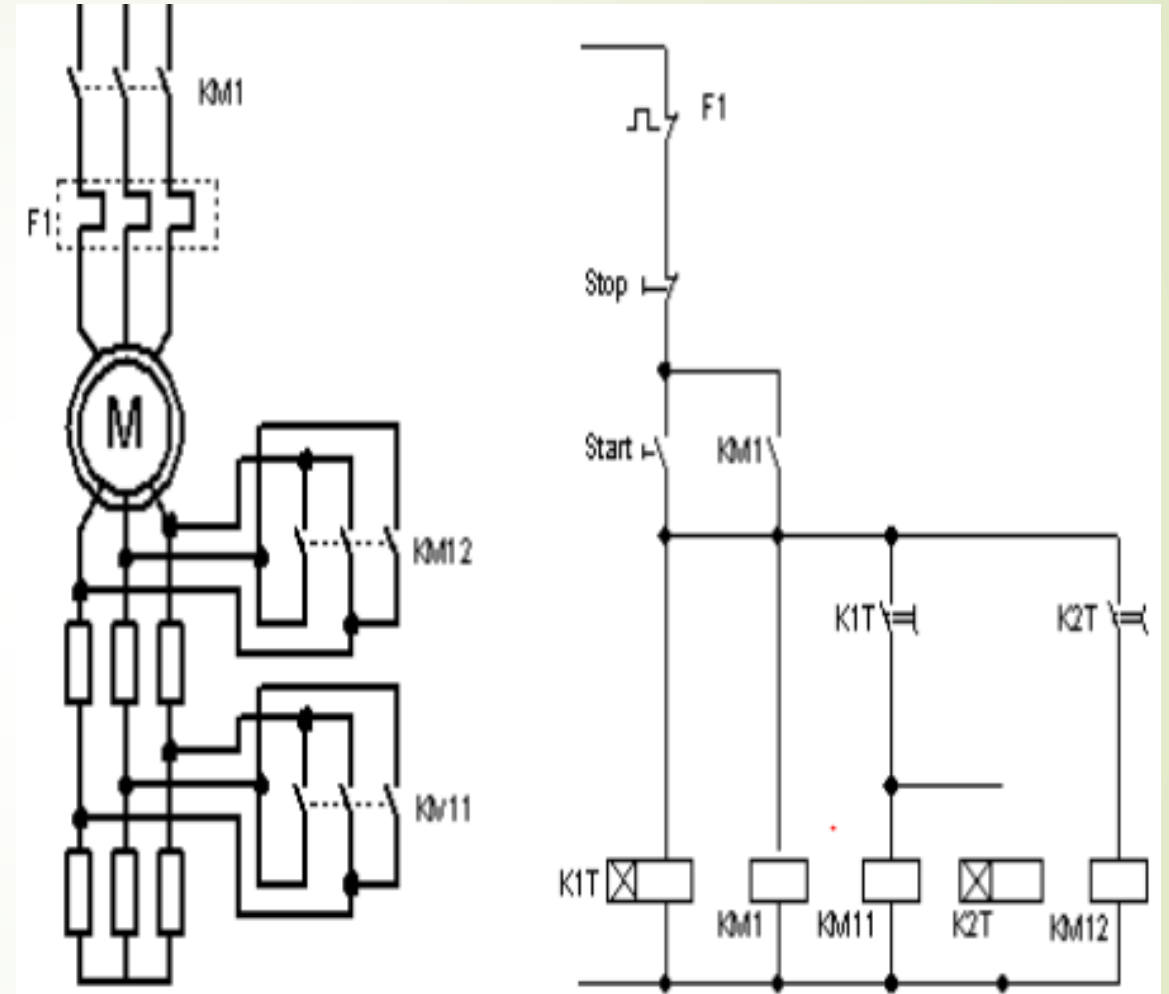
RANGE OF EOT CRANES IN NTPC:

(7.5 T – 105 T



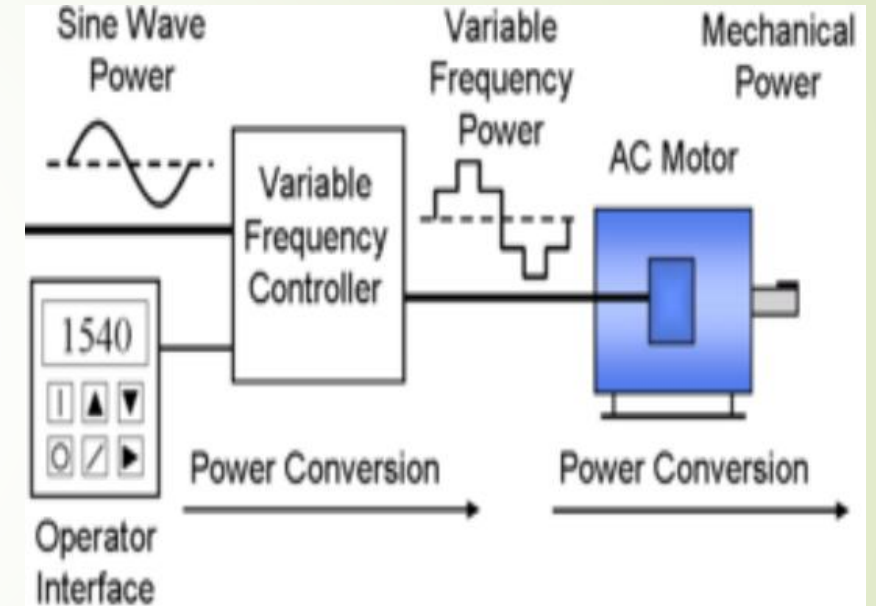
CONVENTIONAL PRACTICE

- SLIP-RING INDUCTION MOTOR EMPLOYING RESISTANCE CUT-IN/ CUT-OUT FOR SPEED CONTROL .
- CABIN /PENDENT CONTROL.



VFD SYSTEM

- Squirrel Cage Induction Motor in place of Slip Ring Induction Motor.
- Speed Control by variable Voltage Variable frequency drives.
- Radio Remote Frequency control unit.



COMPONENTS & WORKING PHILOSOPHY

- Variable Frequency Drives
- Radio frequency Remote Controller
 - ❖ Transmitter unit
 - ❖ Encoder
 - ❖ Receiver
 - ❖ Decoder
 - ❖ Interface panel
 - ❖ Coupling system
 - ❖ Control gear
 - ❖ Battery



SALIENT FEATURES

VFD SYSTEM

SQ.CAGE INDUCTION MOTOR WITH VPI INSULATION AND INSULATED NDE BEARING.

- ❖ CHOICE OF MOTION CONTROL FROM OPERATORS CABIN OR REMOTE CONTROLLER.
- ❖ STARTING TORQUE UPTO 400% WITH STARTING CURRENT LIMITED TO 150%.
- ❖ VFD CAPABLE OF WITHSTANDING UPTO 50° C.
- ❖ HARMONIC REDUCTION DEVICES.
- ❖ SPEED CONTROL WITH 6 PULSE DESIGN.
- ❖ PROTECTIONS: O/L , O/V , E/F , O/ S Ckt., I/P LOSS , LOAD LOSS, I/P TRANSIENT PROTECTION

SALIENT FEATURES CONTINUED.....

B) RADIO FREQUENCY REMOTE UNIT

- ❖ WIRELESS CONTROL WITH DOUBLE JOYSTIC MOVEMENT TYPE STEPPED CONTROL WITH SPRING RETURN
- ❖ TRANSMITTER & RECEIVER HAVE A UNIQUE FREQUENCY & ADDRESS CODE TO AVOID INTERFERENCE
- ❖ CAN COMMUNICATE UPTO 100 m DISTANCE.
- ❖ CRANE OPERATION IS LOCKED IN CASE OF COMMUNICATION FAILURE.
- ❖ CHOICE OF TANDEM/SLAVE/SINGLE OPERATION



TECHNICAL ADVANTAGES



VFD SYSTEM

- ❖ No slip ring related maintenance.
- ❖ Creep motor not required.
- ❖ Gear box not required.
- ❖ Electrical braking before mechanical breaking-break life is more.
- ❖ Online fault display- hence less down time.
- ❖ Starting current is less than dol starting.
- ❖ Smooth starting and stopping offers jerk less operation – longer life due to less mechanical fatigue.
- ❖ Wide speed range- step less speed control.
- ❖ 100% holding torque available at standstill.
- ❖ More energy efficient



TECHNICAL ADVANTAGES

RF CONTROL

- ❖ EASE IN HANDLING
- ❖ UNRESTRICTED OPERATOR MOBILITY
- ❖ NO ROUTINE MAINTENANCE REQUIRED
- ❖ WIRELESS OPERATION

COST ANALYSIS

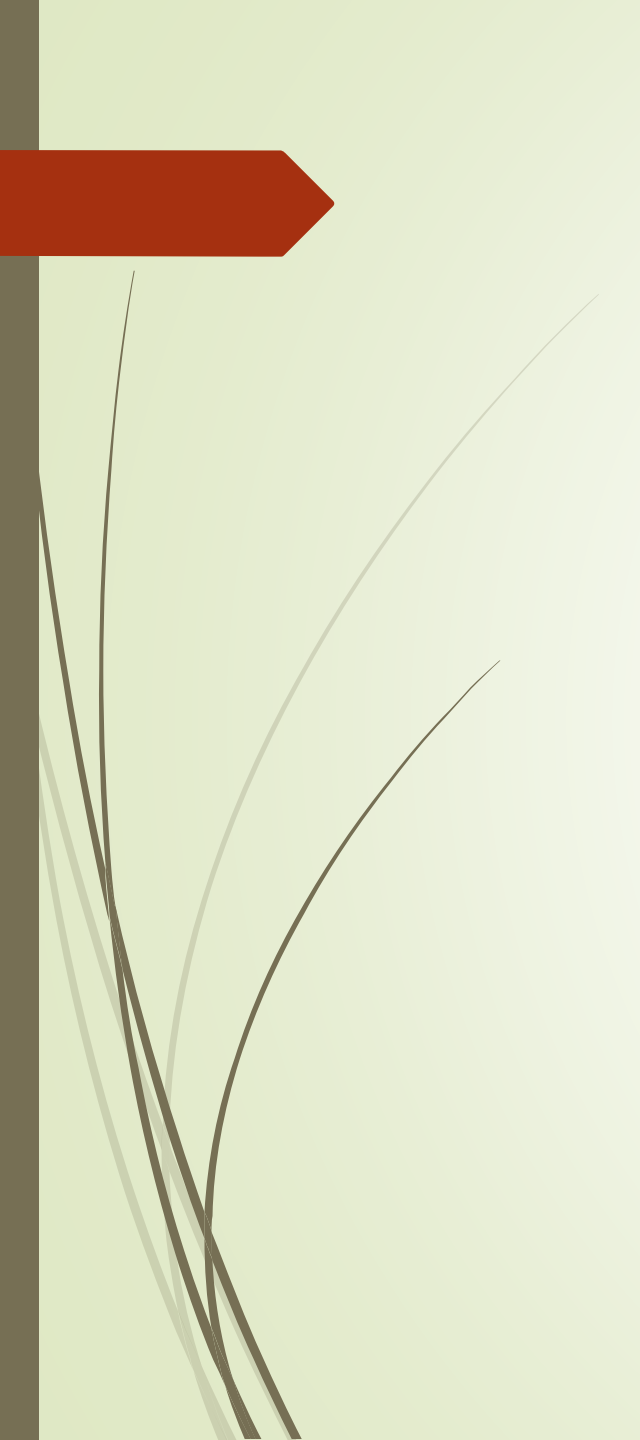
A) VFD SYSTEM IN 105T EOT CRANE IS COSTLIER BY Rs 1,39,750 ie 0.7% OF COST OF ONE EOT CRANE (Approx. 2 crore).

B) RF REMOTE CONTROLLER COSTS 1.15 Lacs WHICH IS 0.57% OF COST OF ONE EOT CRANE.

BOTTOM LINE:

- + B) COMBINED TOGETHER SUMS UP TO BE 1.27% COSTLIER THAN THE PRESENT SYSTEM.

The 1.27% extra cost is insignificant, in lieu of benefits on energy savings, reduction in manpower and low maintenance.



AIR CONDITIONING

Limitations of Centralized AC



Higher space requirement for installation of equipment. AC plant room is required.



Not suitable for frequent load variation.



Not efficient at part load operation.



Difficult to retrofit.



Operators' intervention is required to control/ vary inside conditions. Water Cooled systems although are very efficient, require large quantity of make-up water.



Limitations of Localized AC system

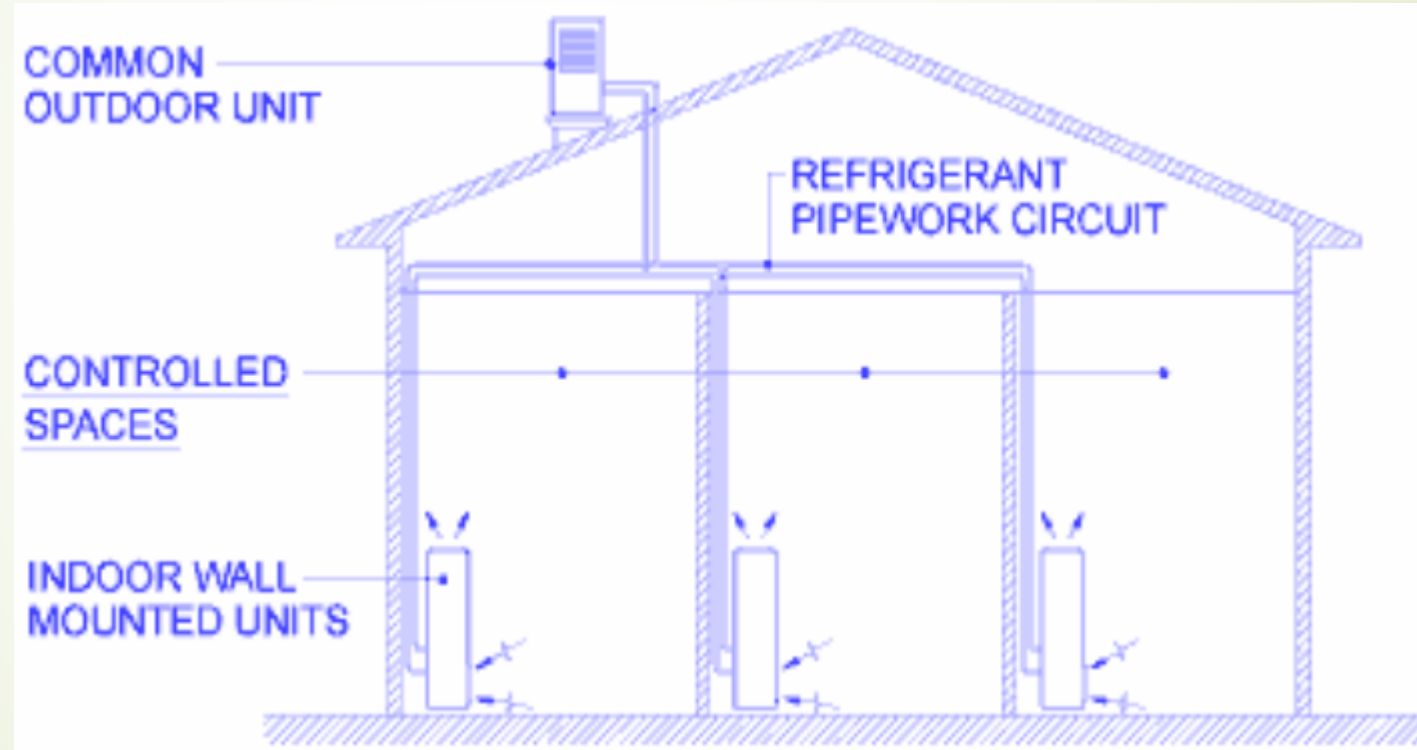
- ❖ Envisaged normally for small buildings.
 - ❖ Available upto 15 TR capacity as a single unit.
 - ❖ No humidity control.
 - ❖ No arrangement for fresh air supply.
 - ❖ Distance of outdoor unit can not be more than 10M.
 - ❖ Part load operation is not possible.
 - ❖ Noise in operation
- 

VRV (Variable Refrigerant Volume)

- ❖ Based on limitation of the above two systems a need was felt for an intermediate of the above two systems. VRV system has been developed to overcome the limitations imposed by centralized and localized systems.
- ❖ The Variable Refrigerant Volume (VRV) system is also Known as Variable refrigerant Flow (VRF) system.



Schematic diagram of VRV system



VRV (Variable Refrigerant Volume) System



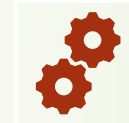
Similar to split type of air conditioning.



VRV comprises of no. of indoor units which share a common refrigerant circuit, served from a common outdoor unit comprises of multiple compressors of varying capacity.



The refrigerant flow is varied by using inverter controlled variable speed compressor to respond to changes in the cooling or heating requirement.

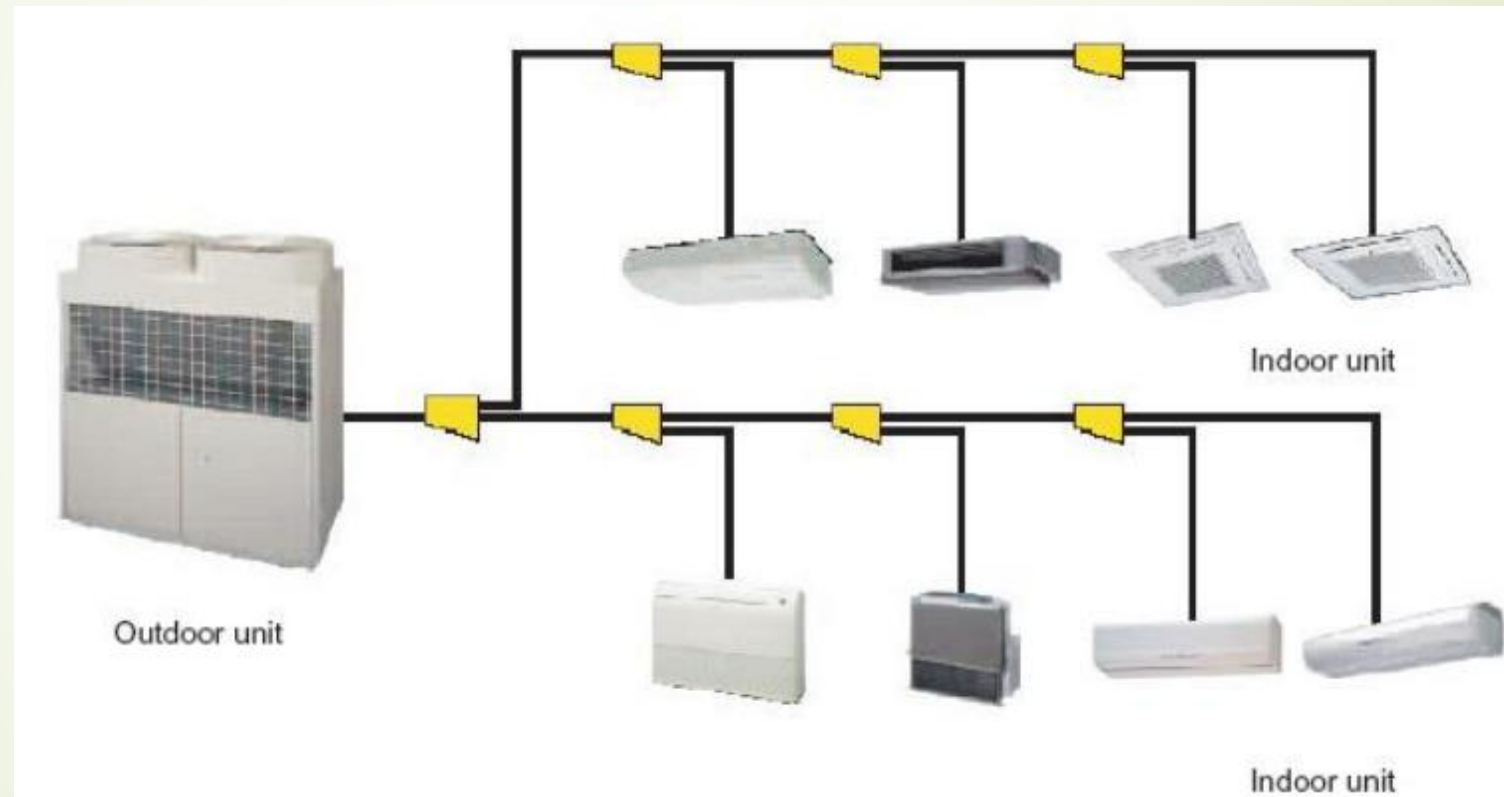


By the combination with the inverter compressor and the constant speed compressor, the comfortable room condition will be obtained by changing the compressor operation condition.



VRV conditions air for each room individually as per load requirement.

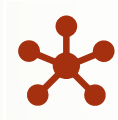
Layout of VRV system



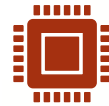
VRV/VRF



VRV system can work as centralised system.



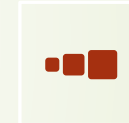
VRV system can work as localized system.



Operating cost of the system is minimized by use of variable refrigerant flow concept.



Make up water is not required.



VRV system can operate at part load.



Total Piping length from outdoor to indoor unit can be as maximum as 150M.

S.No.	Features	VRV System	Water cooled Chiller system	Benefits of VRF System
1.	Type of System	Completely Air-cooled system with three basic parts- Outdoor, indoor units & controllers	Water cooled system with many component chilling machines, AHUs, Cooling tower, Chilled Water pumps, Condensate water pumps, many types valves, Electricals & controls etc.	Minimum parts thus very simple VRF systems
2.	Energy Consumption	Overall 25%-35% power saving on average basis	Only efficient at certain load conditions	Constant saving by optimal running

S.No.	Features	VRV System	Water cooled Chiller system	Benefits of VRF System
3.	Distribution Piping Network	Smaller copper piping	Bigger MS piping	Shaft/ floor space not required
4.	Interiors, Ceiling height	Different type of Indoor options to fit into different construction, interiors	Only Ducted Systems possible.	Flexibility in layout.
5.	Standby Function	Inbuilt Standby - Multi tier	To be added at extra cost	Ensured Operation all Times

VRV/VRF (Comparison with chillers)

Conclusion

VFD Can be used in CEP for future projects for energy saving.

For All old stations, VFD can be installed in CEP based on techno-economics.

For Large size units, VFD in BFP Motor offers a number of advantages and can be considered in future.

VFD can be useful for conveyor motors, compressor and reeling drum motors.

Boiler Auxiliaries such as PA fan , ID fan ,Coal Feeder and Fuel Oil motors can be upgraded with VFD control, for old 210 MW and 500MW units.

New units of all sizes should have VFD for coal feeder speed control.

VFD is becoming popular for VRV air-conditioning , Hoists, Lifts and EOT Cranes



THANK YOU

