Author: Engr Muhammad Nasir Jamal

Design of Solar Pumping Unit

Selecting Pump, Inverter, & Solar Power

By

Engr Muhammad Nasir Jamal
(Gold Medalist)

CEO & Director,
Eminent Engineering Pvt Ltd

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16-Mar-20 Author: Engr Muhammad Nasir Jamal

Who am I

- CEO and Director, Eminent Engineering Pvt Ltd,
- Working in Different Sectors of HEIS (since 2005), Like
  - Project Management
  - Marketing, Designing, Installation, After Sales Services
  - Manufacturing of HEIS Components, especially Filters
- Consultant for HEIS and Water Courses, NesPak
- Master Trainer on HEIS at:
  - Food and Agriculture Organization of United Nations, (FAO)
  - On Farm Water Management (OFWM), Govt. of Punjab
  - On Farm Water Management (OFWM), Govt. of KPK
  - UET, Peshawar
  - University of Peshawar, Center of Excellence in Geology
  - Angro Chemicals, HEIS Division
- PhD Scholar, Soil and Water Engineering (Agri Engg)

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What are We……

TWO BUSINESS DIVISION

- High Efficiency Irrigation System (HEIS)
- Solar Electric System

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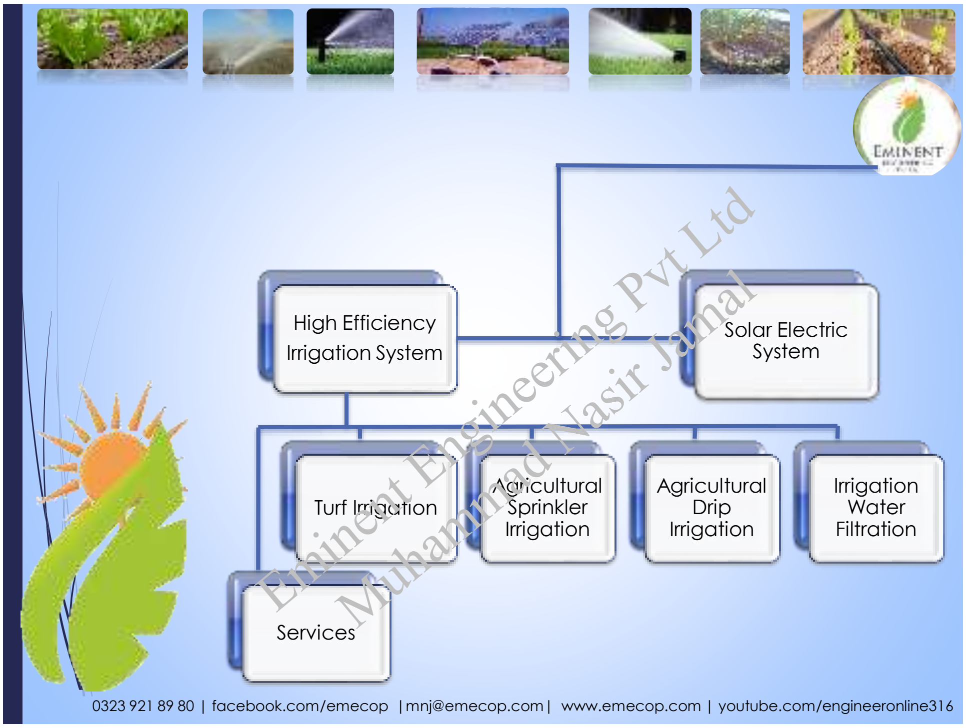

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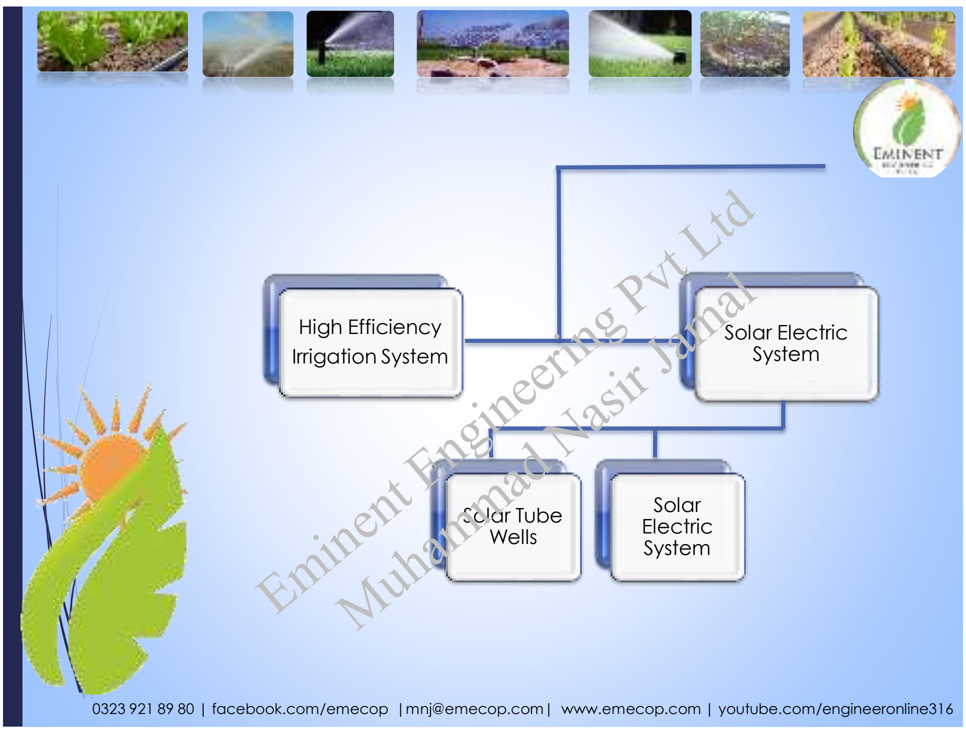

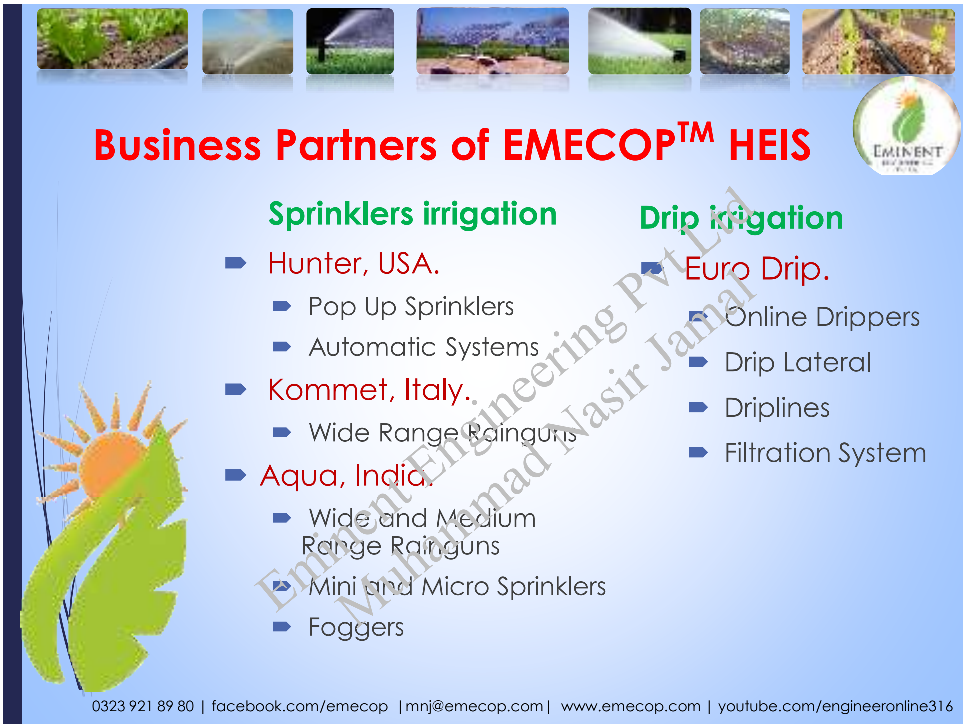

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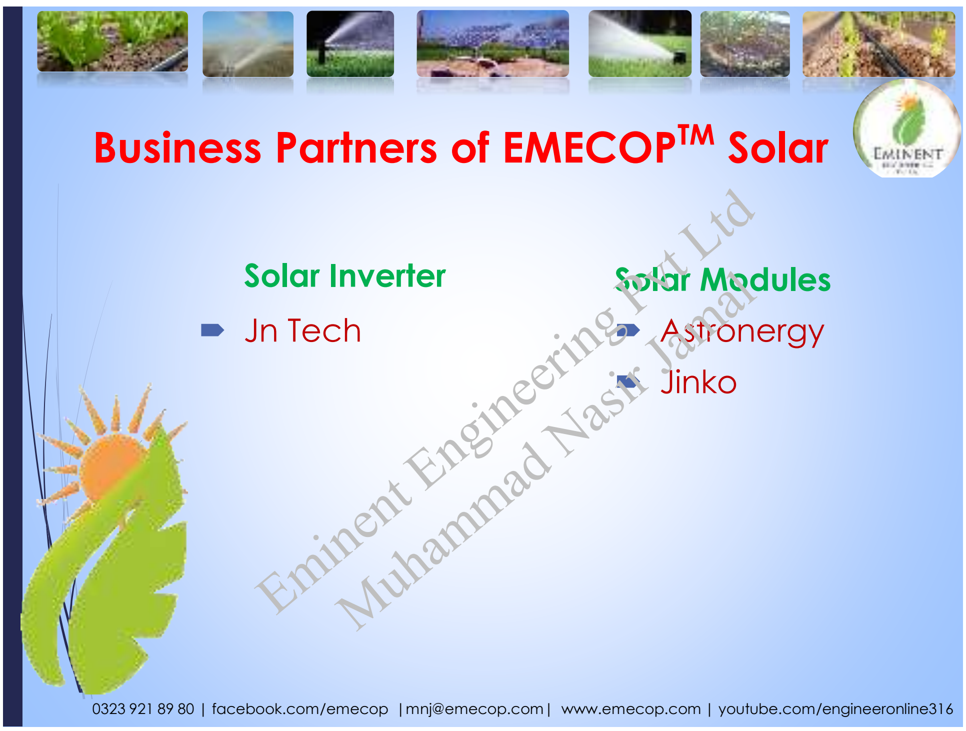

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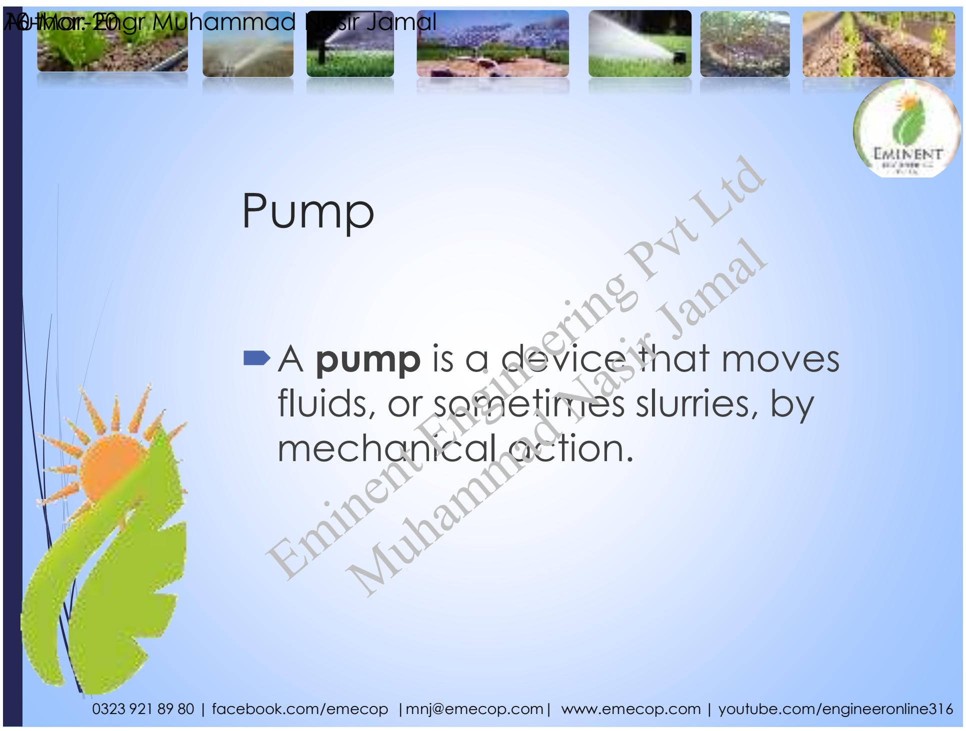

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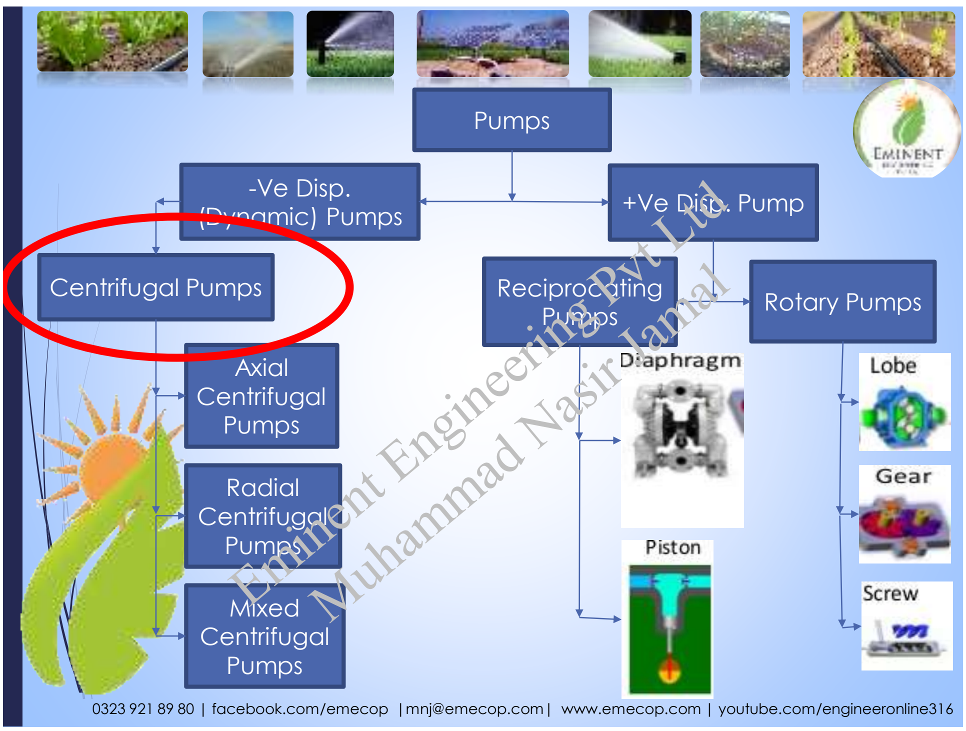

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Types of Pump

- Positive Displacement Pumps
  - Deliver same Discharge with every Stroke/rpm.
  - Maintain constant flow
    - A positive displacement pump makes a fluid move by trapping a fixed amount and forcing (displacing) that trapped volume into the discharge pipe.
    - Piston Pump
- Negative Displacement Pumps
  - Deliver variable flow with every stroke/rpm
  - Maintain constant head
    - Centrifugal Pumps

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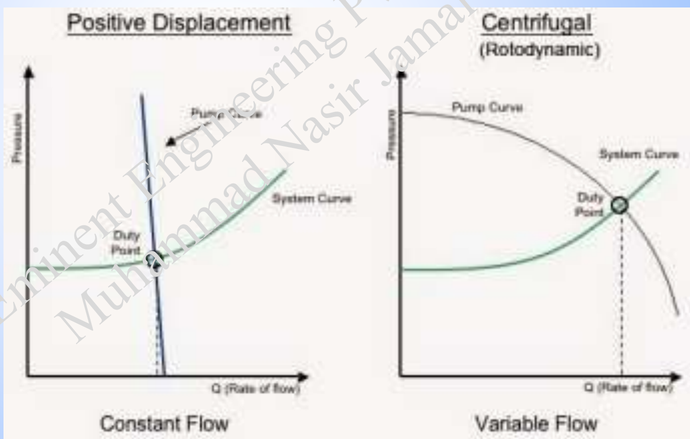
Negative Displacement Pumps

All Axial and Centrifugal Pumps

Comparison of -ve and +ve Displacement Pumps Performance Curve



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Practical Difference Between Dynamic (-ve) and (-ve) Displacement Pumps

- **is how they operate under closed valve conditions.**
  - Positive displacement pumps physically displace fluid
    - Closing a valve downstream of a positive displacement pump produces a continual pressure build up
    - That can cause mechanical failure of pipeline or pump.
  - Dynamic pumps differ in that they can be safely operated under closed valve conditions (for short periods of time).

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Centrifugal Pumps

- Roto dynamic pump
- Most often associated with the radial-flow type.
- Impeller rotates to increase fluid pressure & flow rate
- Most common type for moving liquids in piping system.
- Fluid enters the pump impeller along or near to rotating axis
- Impeller accelerates fluid radially outward or axially into diffuser or volute and then to piping system.
- However, this term can be used to describe all impeller type rotodynamic pumps including the radial, axial and mixed-flow variations.

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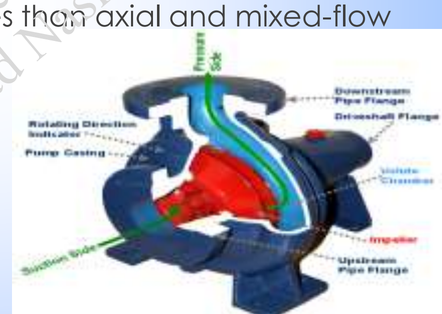
- **Radial-flow pumps**
  - Often simply referred to as centrifugal pumps.
  - The fluid enters along the axial plane, is accelerated by the impeller and exits at right angles to the shaft(radially).
  - Radial-flow pumps operate at higher pressures and lower flow rates than axial and mixed-flow pumps.



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Surface Centrifugal Pumps

- Not Submerged in Water.
- Normally kept at surface
- Some time kept underground in ditch (above water table)

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- Surface Centrifugal Pumps are Classified as
  - Mono Block
    - Pump and motor is on same shaft (No Coupler).

- Surface Centrifugal Pumps are Classified as
  - Bare Shaft
    - Connected with motor of engine with coupler or pully belt




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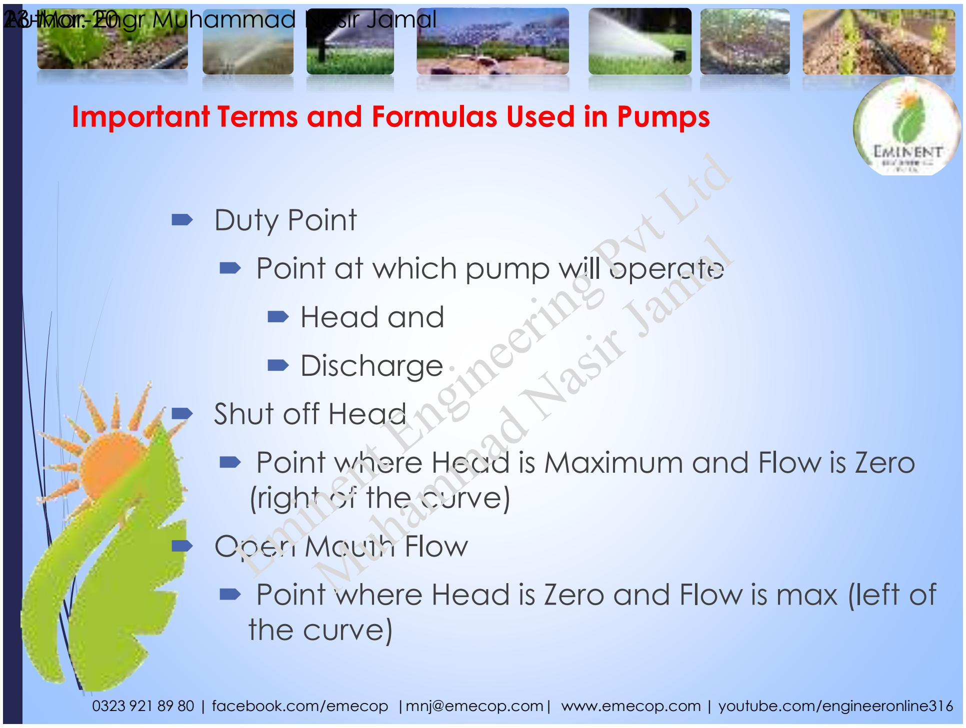
Pumps

Submersible Turbine Centrifugal Pumps

- Submerge Turbine Centrifugal Pumps
  - Motor and pump are coupled together and set is kept submerged in water.
  - Submergence is necessary.
  - Multi Stage pumps are used to provide required head.

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Efficiency

- Defined as the ratio of the power imparted on the fluid by the pump in relation to the power supplied to drive the pump.
- Its value is not fixed for a given pump,
- **Efficiency is a function of the discharge and therefore also operating head.**
- For centrifugal pumps, the efficiency tends to increase with flow rate up to a point midway through the operating range (peak efficiency) and then declines as flow rates rise further.

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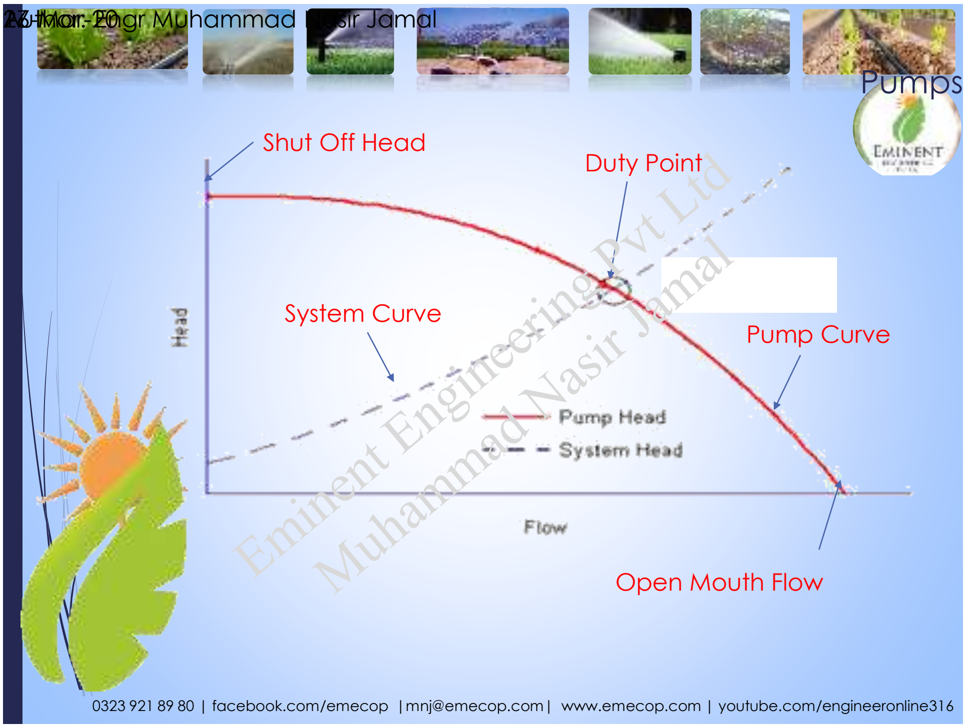
- Pump performance data such as this is usually supplied by the manufacturer before pump selection.
- Pump efficiencies tend to decline over time due to wear(e.g. increasing clearances as impellers reduce in size).
- When a system design includes a centrifugal pump, an important issue in its design is matching the *head loss-flow characteristic* with the pump so that it operates at or close to the BEP.
- Pump efficiency is an important aspect



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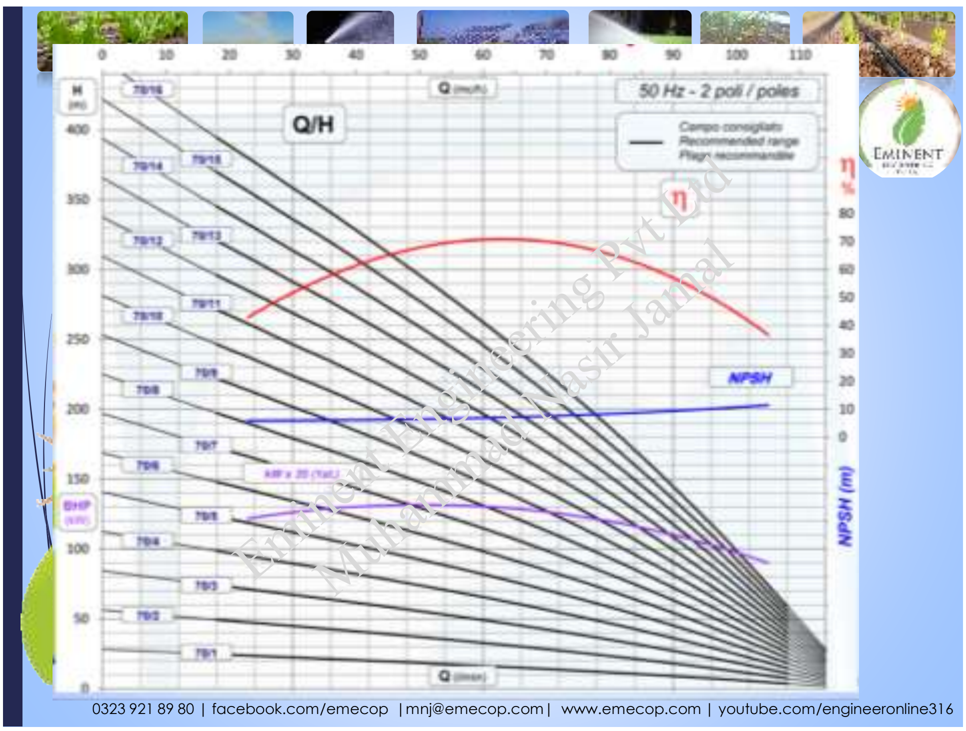

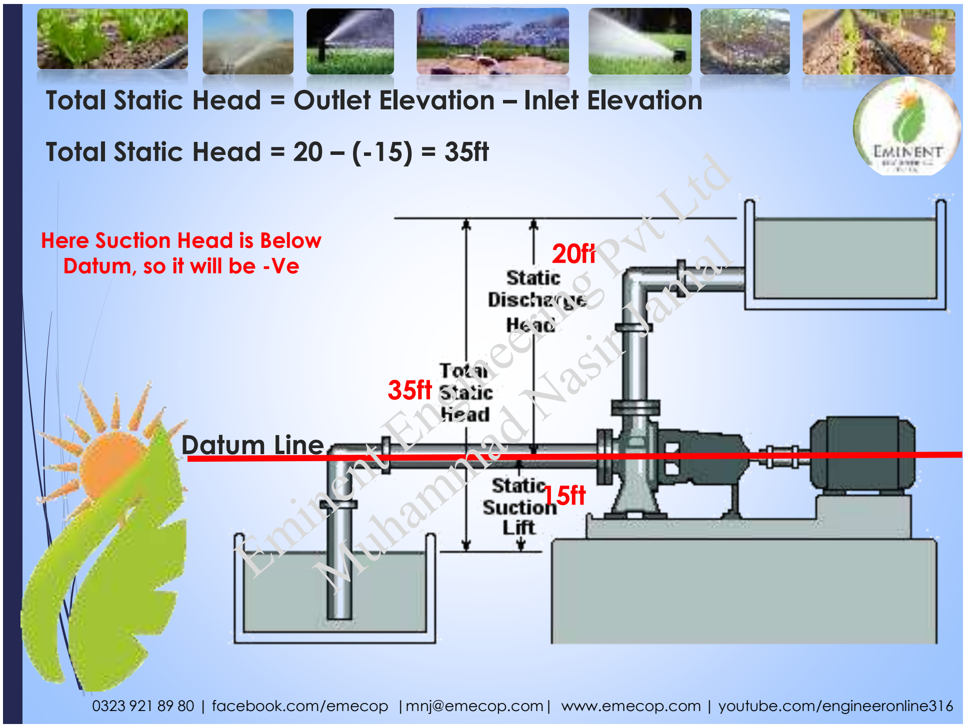

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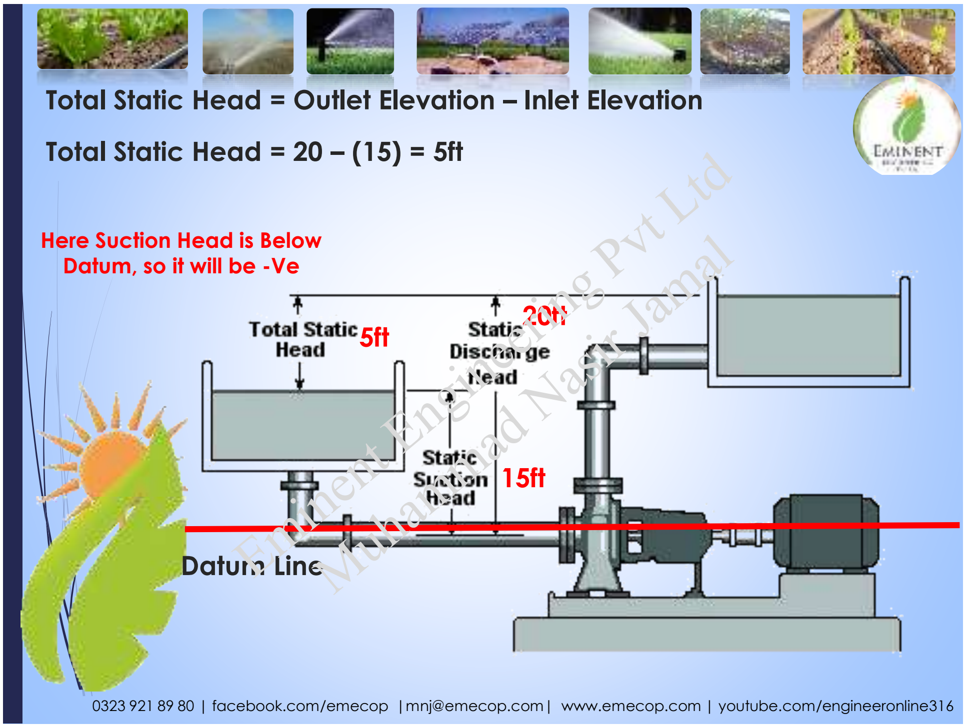

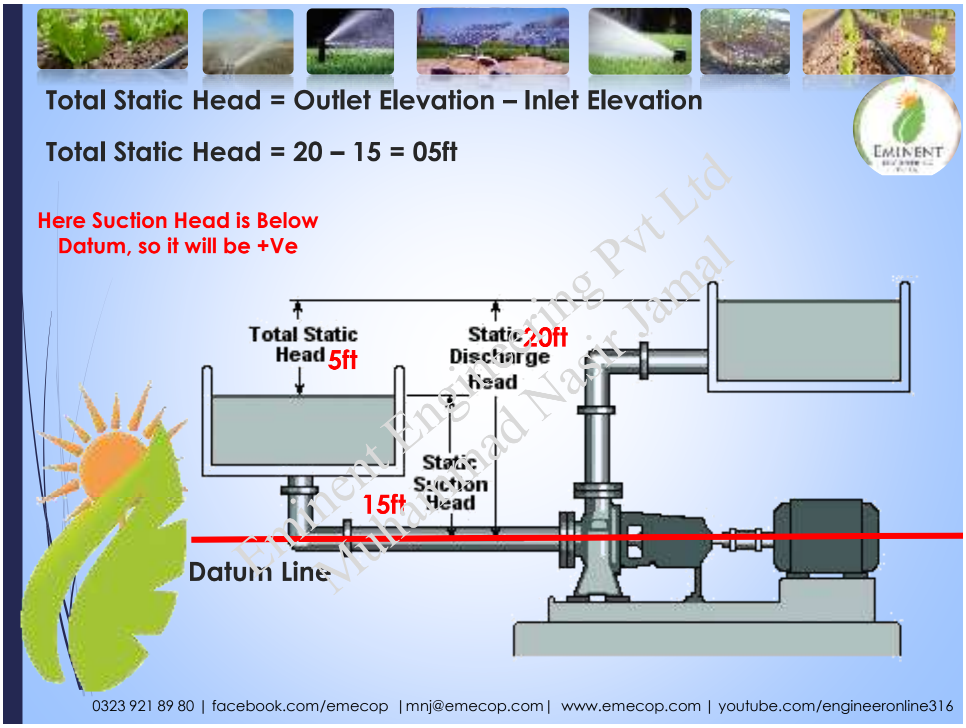

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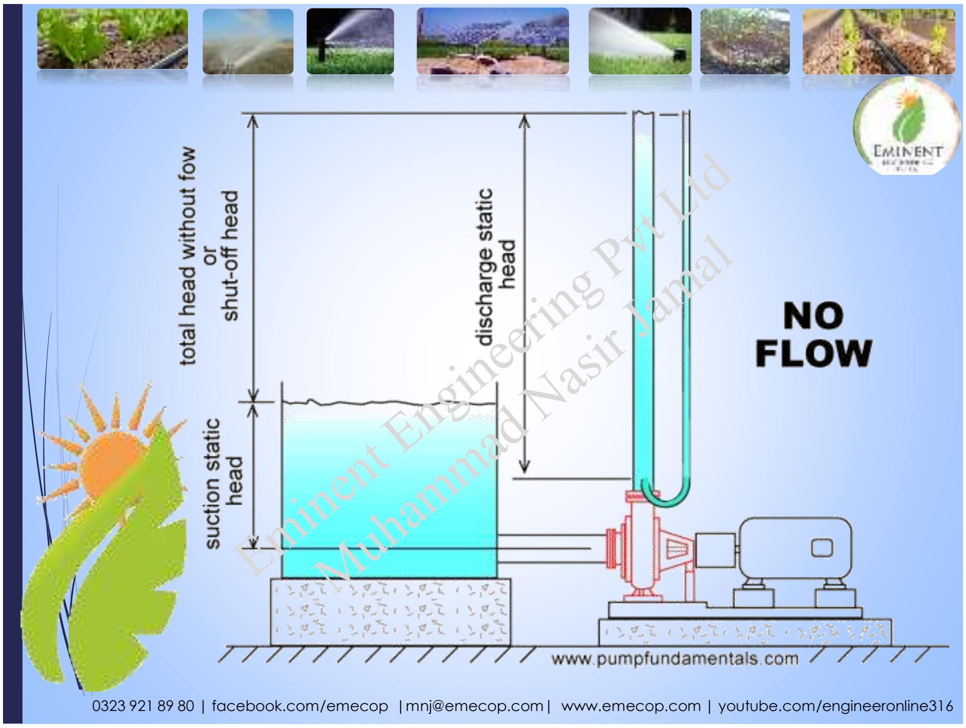

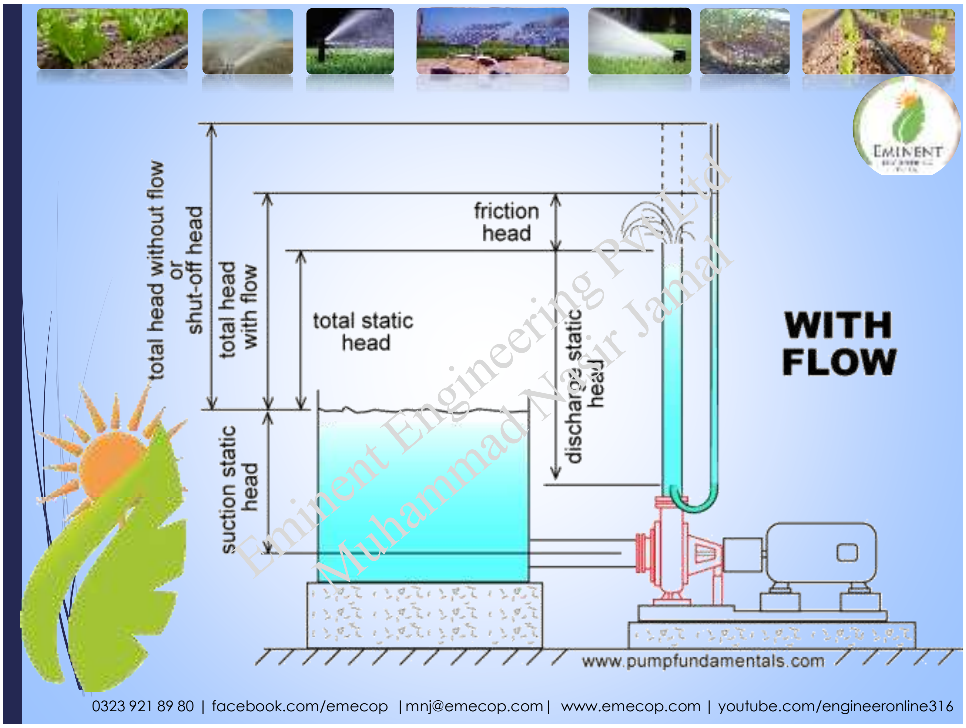

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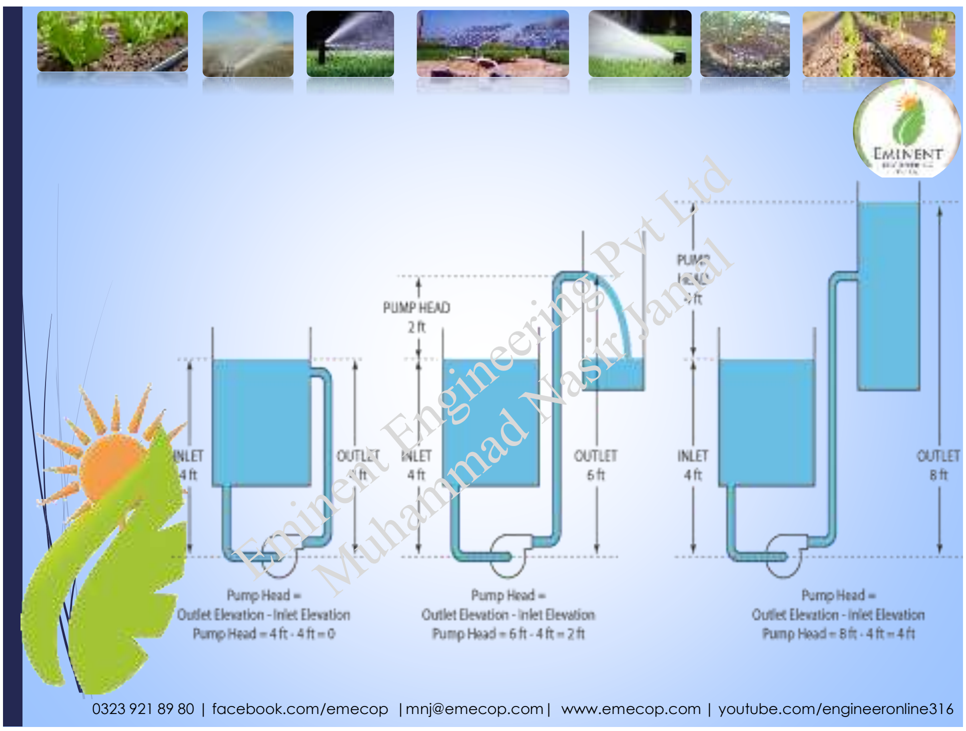

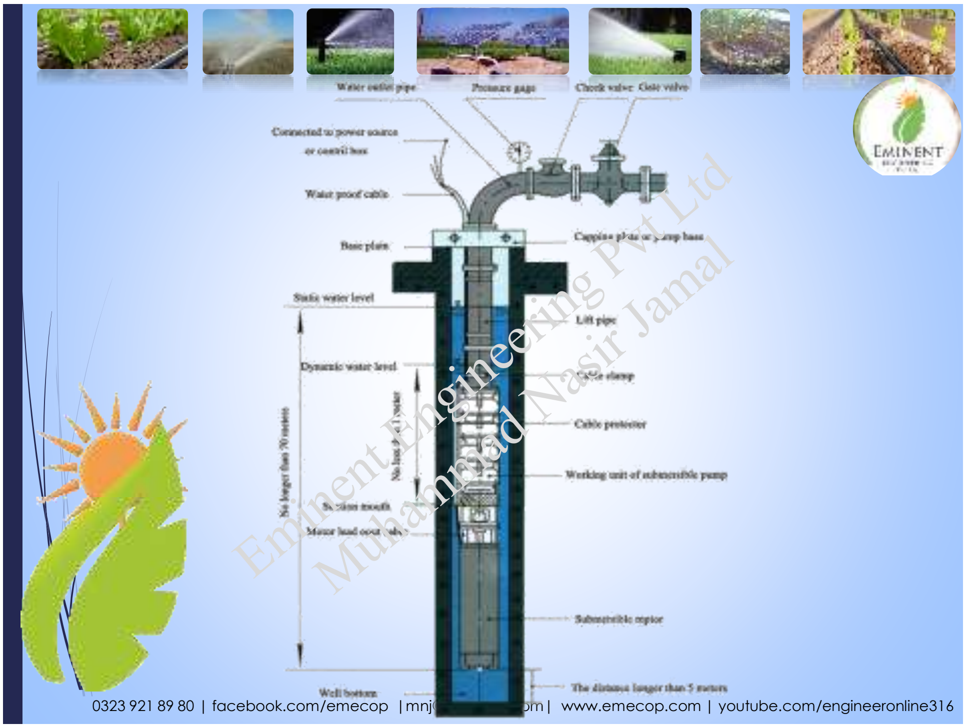

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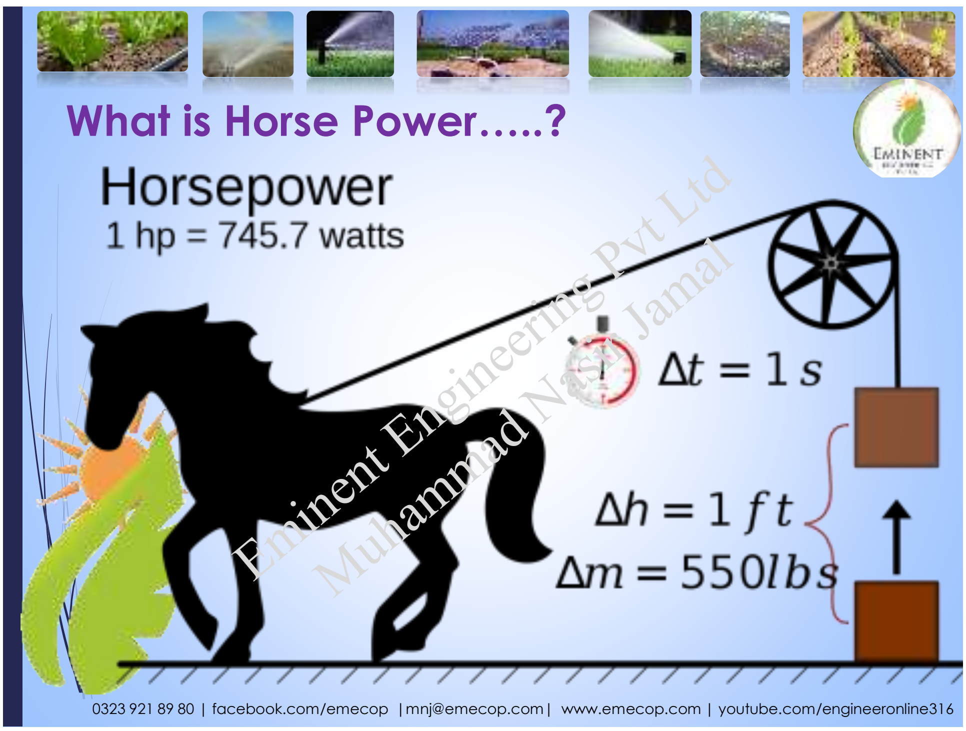

Horsepower

- Defined by James Watt:
  - The amount of work a horse can do in one second.
  - One horsepower = 746 Watts

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Calculating Water HP (Matric Units)

Is the minimum HP required to lift the water.

Its Given By = $\dfrac{H \times Q \times SG}{3{,}960}$

H = pump head in feet
Q = flow in gallons per minute (gpm)
SG = the specific gravity of the fluid being pumped

Calculating Pump HP (Matric Units)

$$= \frac{\text{Water HP}}{\text{Eff}} = \quad BHP = \frac{H \times Q \times SG}{3{,}960 \times eff}$$

Where:

BHP = brake horsepower

H = pump head in feet

Q = flow in gallons per minute (gpm)

SG = the specific gravity of the fluid being pumped

eff = the pump's efficiency

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Calculating Pump HP (SI Units)

$$P = \frac{(Q)(H)(SG)}{367(\eta)}$$

P = power, kW

H = head, m

Q = flow, m^3/hr

SG = specific gravity

η = pump efficiency, decimal

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Calculating Pump HP

$$P = \frac{(Q)(H)(SG)}{75\,(\eta)}$$

P = Power, HP
H= Head, m
Q = Flow, LPS
SG =Specific Gravity
η = Pump Efficiency, Decimal

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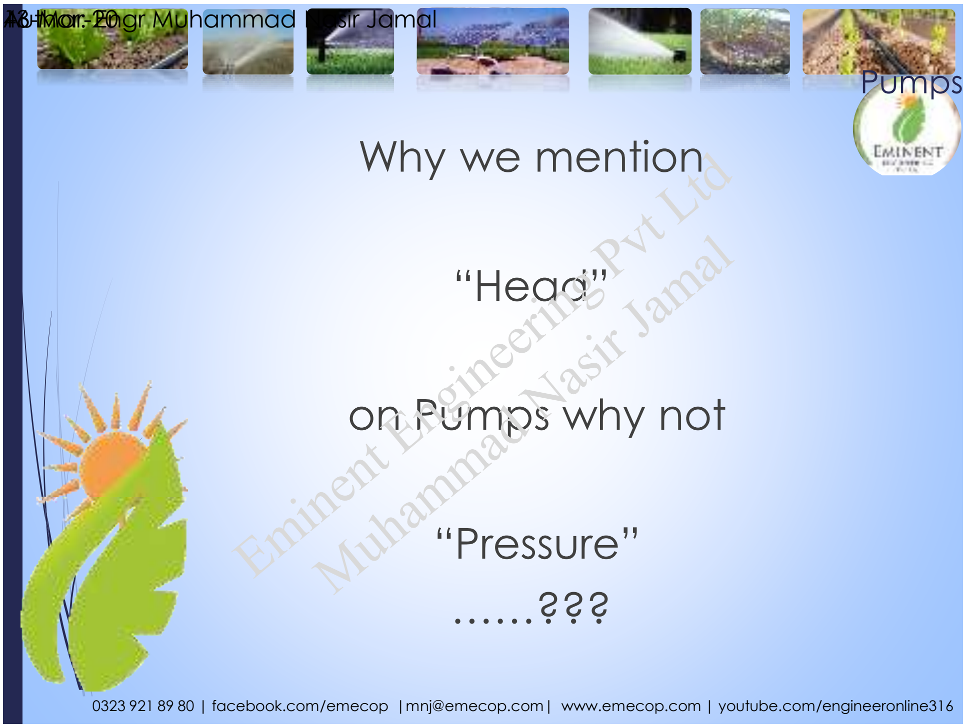
Calculating Motor HP (Matric Units)

$$EHp = \frac{brake\,horsepower}{motor\,efficiency}$$

EHp = Motor Horse Power



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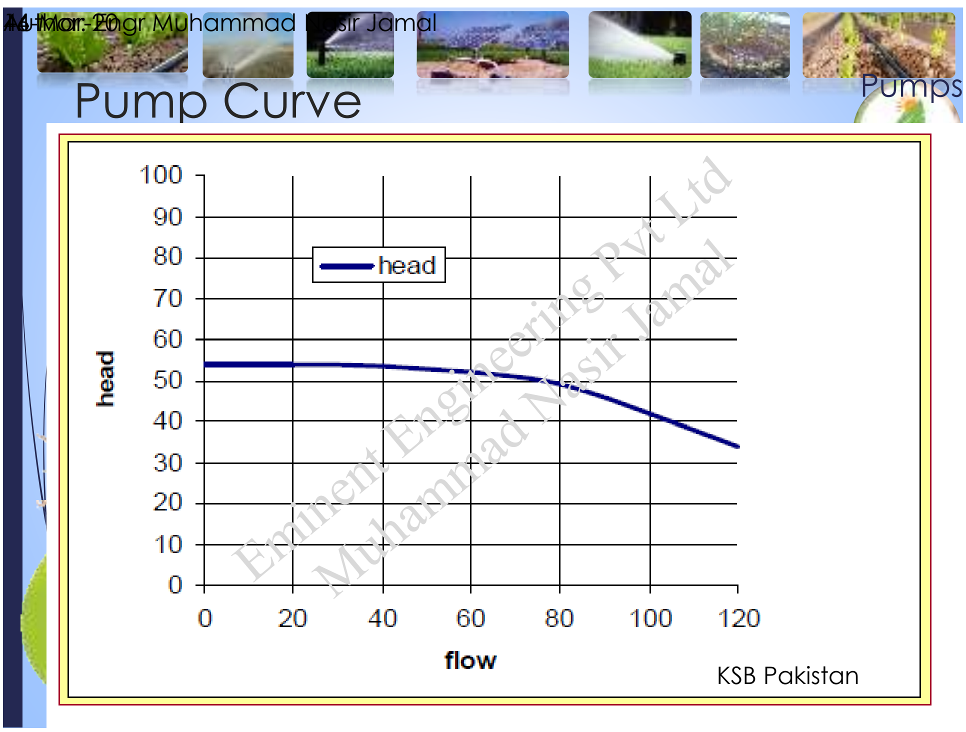

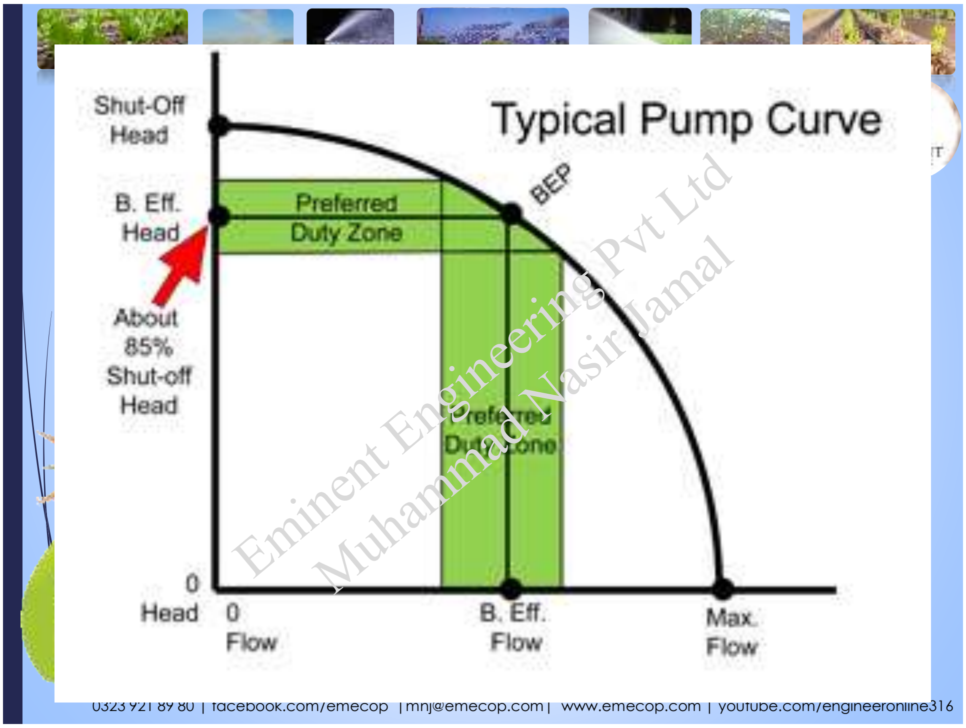

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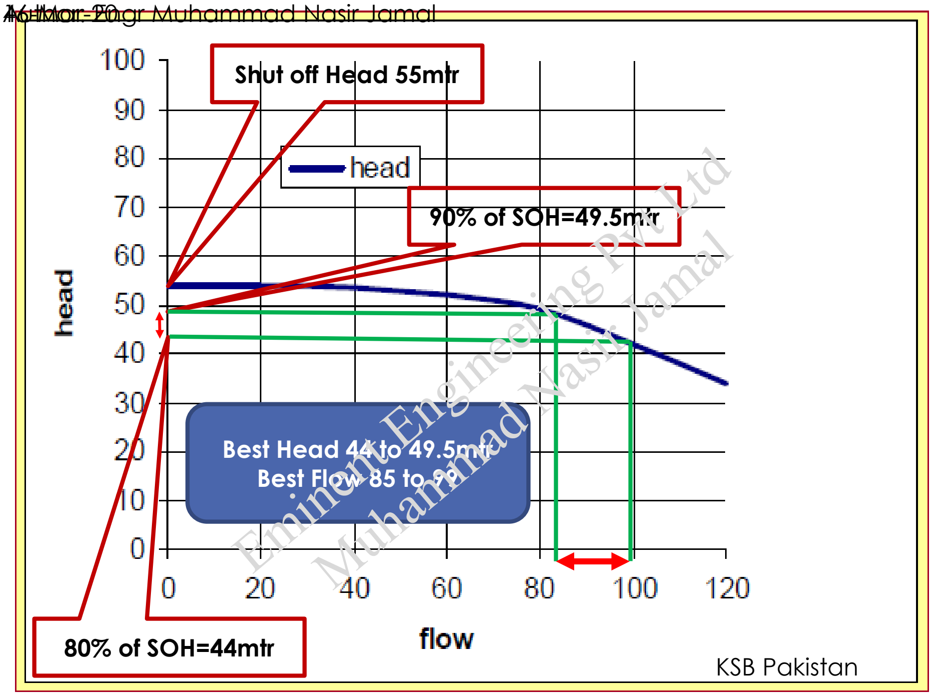

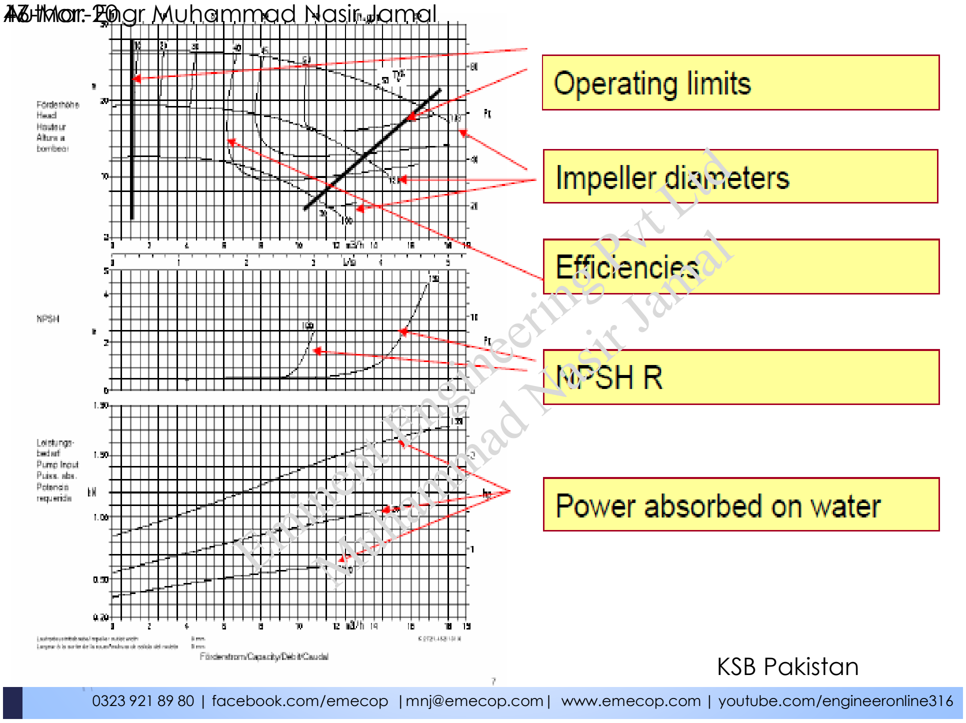

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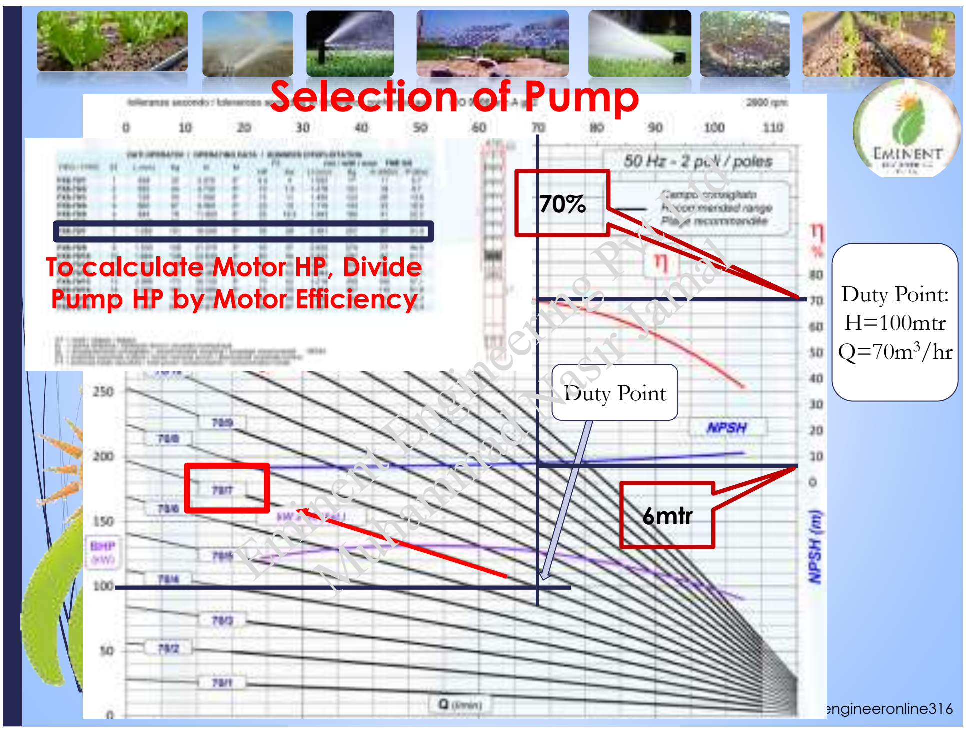

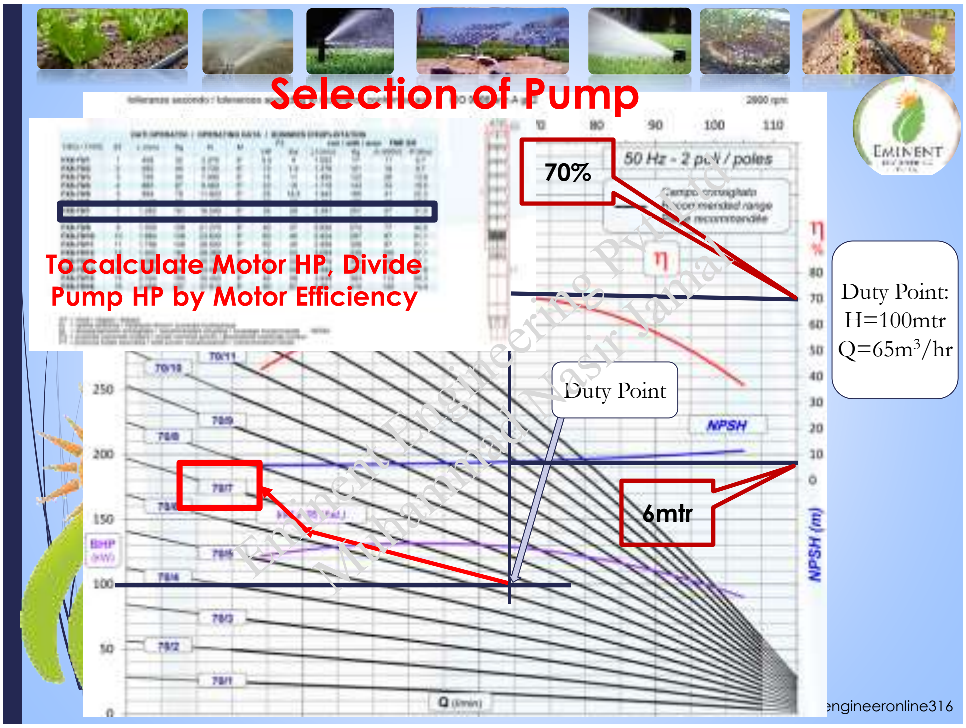

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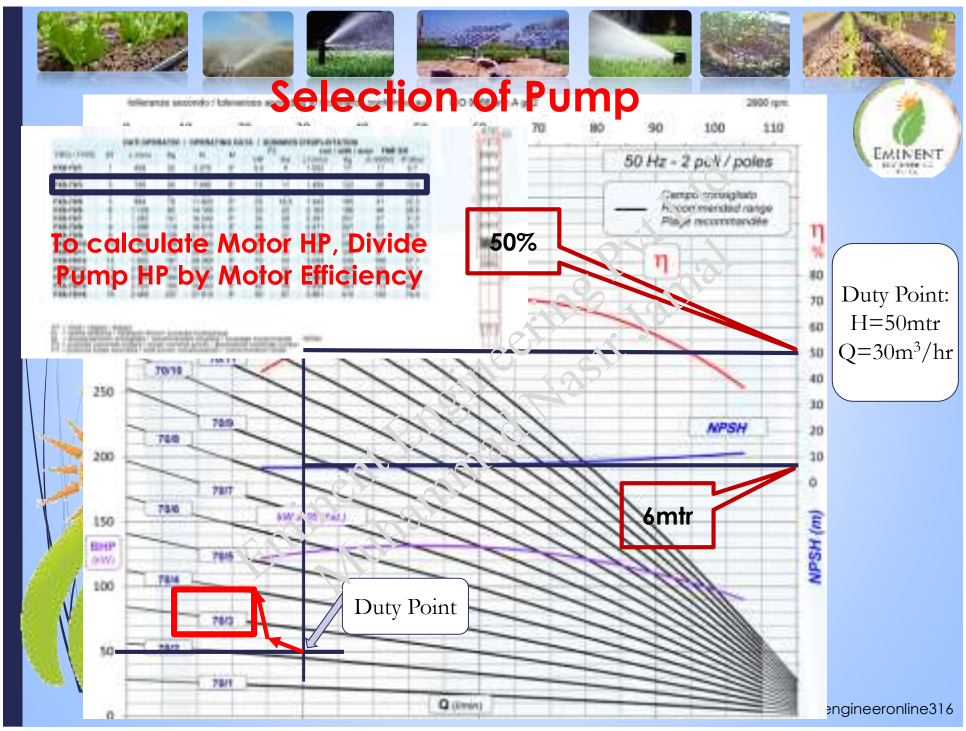

HP of Motor

1. There is Difference between Motor Actual HP and Rated HP
2. Rated HP is Power Available on Motor Shaft
3. Actual HP is the Power Need to be Given to Motor
4. Actual HP depends upon Efficiency of Motor
5. The More Efficient Motor will have LESS Difference in Rated and Actual HP and Vice Versa

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HP of Motor

1. Pump Curves Gives Us Input Power of Pump
2. We have to Select Motor which Output (Rated) HP is Equal to Pump Input HP
3. We Need to Calculate Motor Input HP (In case of Solar System)

⚠ Ignoring Last Step will result in System Failure

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Affinity Law

(Q1/ Q2) = (N1/N2) = (D1/D2)

(H1/H2) = $(N1/N2)^2$ = $(D1/D2)^2$

(HP1/HP2) = $(N1/N2)^3$ = $(D1/D2)^3$

Pump speed	1450 rpm		2900 rpm	
Flow	50	m3/h	100	m3/h
Head	50	m	200	m
Power	9	kW	72	kW

Standard Test Conditions (STC)

- STC is the set of criteria that a solar panel is tested at.
  - Since voltage and current change based on temperature and intensity of light
  - So all solar panels are tested to the same standard test conditions.
- This includes
  - the cells' temperature of 25°C
  - light intensity of 1000 watts per square meter, (sun at noon)
  - Atmospheric density of 1.5, (Sun's angle directly perpendicular to the solar panel at sea level)

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Normal Operating Cell Temperature (NOCT)

- The Conditions at Which Panel is Tested rarely Exist in Field, especially :

S.No	Parameter	STC	NOCT
1	Cell Temp	25 Deg. C	Up to 50 Deg. C
2	Light Intensity	1000 w/m^2	800 w/m^2

Light Intensity and Temperature influence Voltage and Current.

Open Circuit Voltage (Voc)

- How many volts the solar panel outputs with no load on it.
- It is the maximum voltage that the solar panel can produce under standard test conditions
- This is the number to use when determining how many solar panels you can wire in series going into your inverter

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Short Circuit Current (Isc)

- Is how many amps the solar panels are producing when the plus and minus of the panels wires are directly connected to each other.
- This is the highest current the solar panels will produce under standard test conditions.
- When determining how many amps a connected device can handle, like a solar charge controller or inverter, the Isc is used

Maximum Power Point (Pmax)

- The Pmax is the combination of the volts and amps results in the highest wattage (Volts x Amps = Watts).
- Maximum Power Point Tracking (MPPT) inverter tries to keep the volts and amps at this point to maximize the power output.

Maximum Power Point Voltage, Rated Voltage (Vmp)

- The voltage when the power output is the greatest/Max

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Maximum Power Point Current, Rated Current (Imp)

- Current (amps) when the power output is the greatest.

Nominal Voltage

- Nominal voltage is a category
- For example, a nominal 12V solar panel has a Voc of about 22V and a Vmp of about 17V. It is used to charge a 12V battery (which is actually around 14V).

Temperature Coefficient of Power (Pmp)

- This indicates how strongly the PV array power output depends on the cell temperature, meaning the surface temperature of the PV array.
- It is a negative number because power output decreases with increasing cell temperature.
- Manufacturers of PV modules usually provide this coefficient in their product brochures,

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Temperature Coefficient of Voltage (Voc)

- This indicates how strongly the PV array Vmp output depends on the cell temperature, meaning the surface temperature of the PV array.
- It is a negative number because Vmp output decreases with increasing cell temperature.
- Manufacturers of PV modules usually provide this coefficient in their product brochures,

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Module Efficiency

The photovoltaic (PV) efficiency at standard test conditions is the efficiency with which the PV array converts sunlight into electricity at its maximum power point under standard test conditions.

$$\eta_{mp,STC} = \frac{Y_{PV}}{A_{PV}\, G_{T,STC}}$$

$\eta_{mp,STC}$	= the efficiency of the PV module under standard test conditions [%]
Y_{PV}	= the rated power output of the PV module under standard test conditions [kW]
A_{PV}	= the surface area of the PV module [m^2]
$G_{T,STC}$	= the radiation at standard test conditions [1 kW/m^2]

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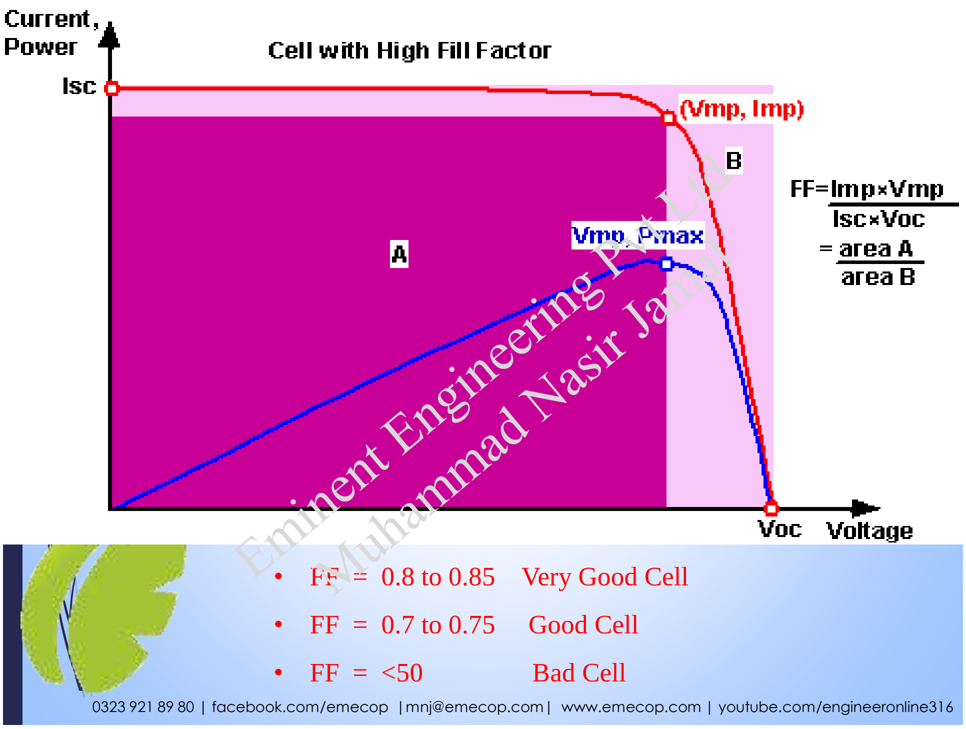
Fill Factor

- The short-circuit current and the open-circuit voltage are the maximum current and voltage respectively from a solar cell.
- At these operating points, the power from the solar cell is zero.
- The "fill factor", is a parameter which, in conjunction with V_{oc} and I_{sc}, determines the maximum power from a solar cell.
- The FF is defined as the ratio of the maximum power from the solar cell to the product of V_{oc} and I_{sc}



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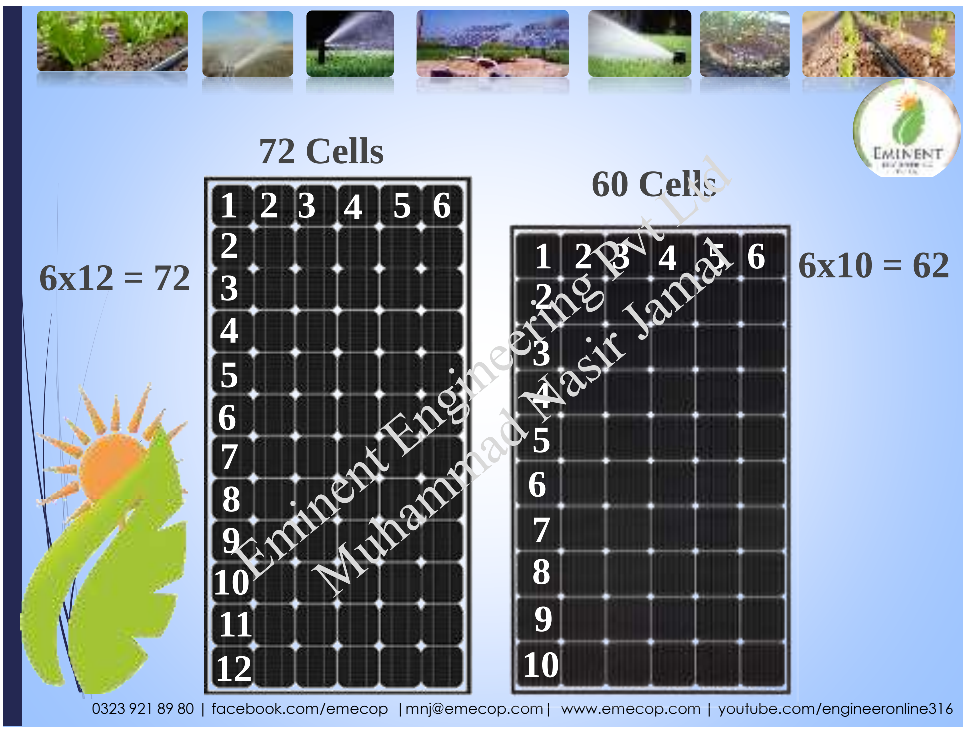

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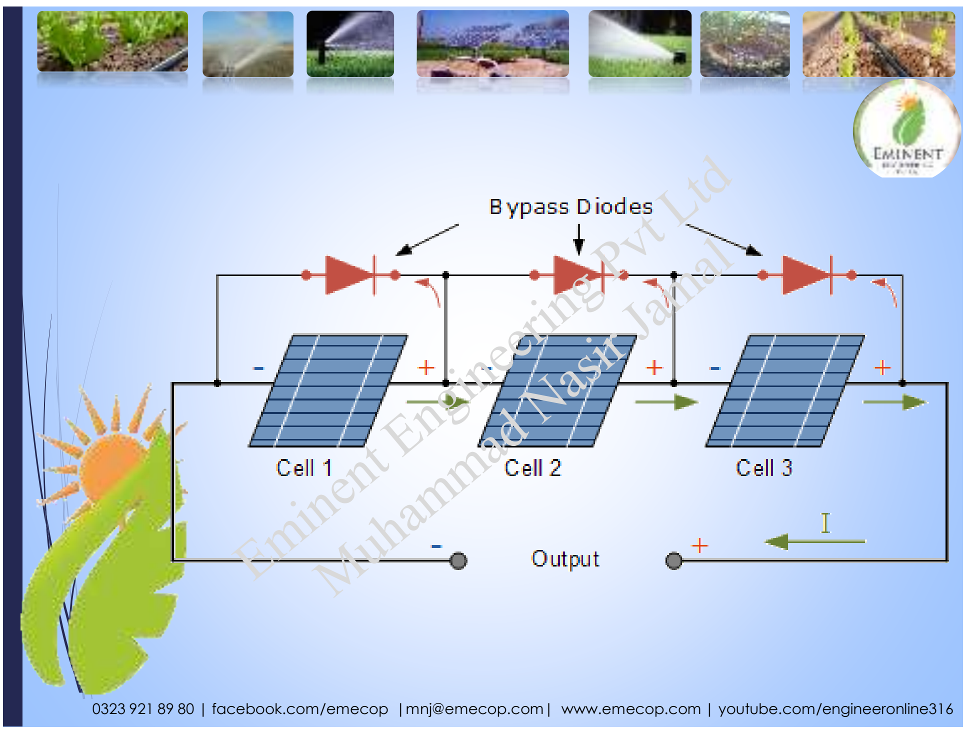

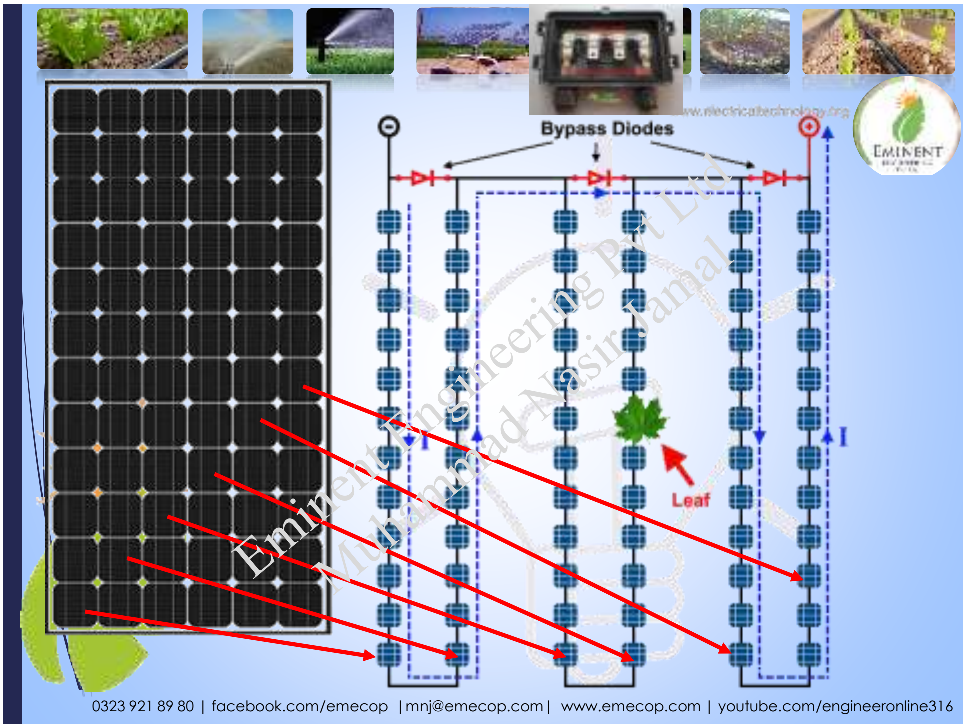

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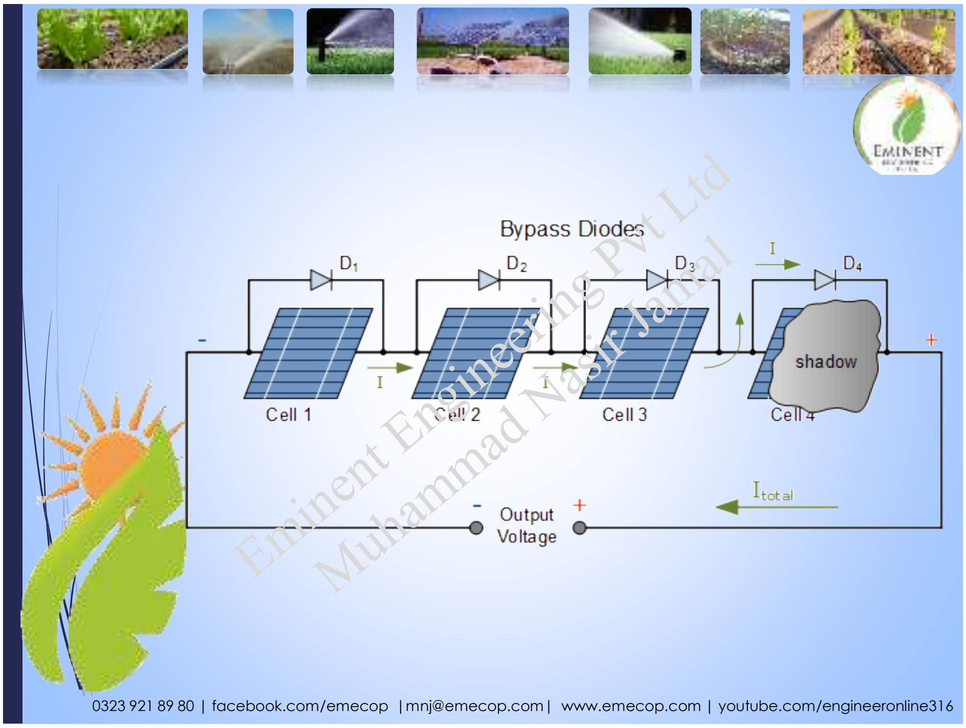


Air Mass (AM)

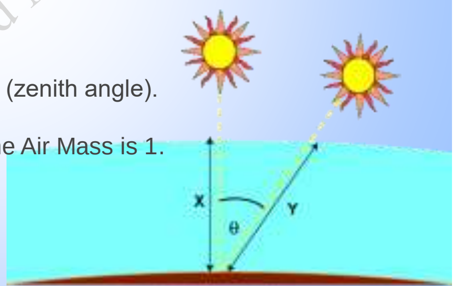
- It's the path length which light takes through the atmosphere normalized to the shortest possible path length (that is, when the sun is directly overhead).
- The Air Mass quantifies the reduction in the power of light as it passes through the atmosphere and is absorbed by air and dust.
- The Air Mass is defined as:

AM=1/cos(θ)

where θ is the angle from the vertical (zenith angle).

When the sun is directly overhead, the Air Mass is 1.

For AM=1.5, Angle is 48.89Deg.



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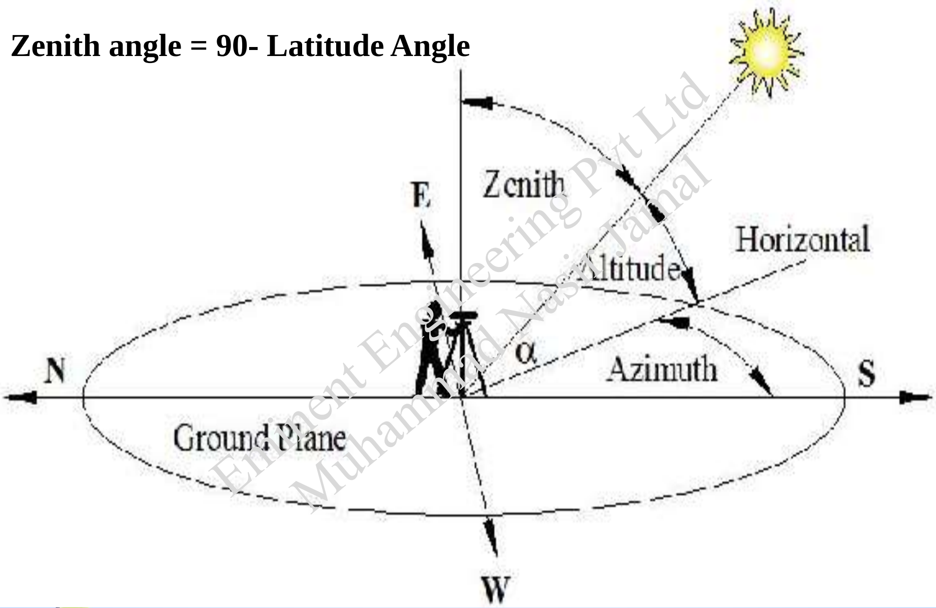
Zenith angle = 90- Latitude Angle



ELECTRICAL SPECIFICATIONS

STC rated output (P_{mpp})*	310 Wp	315 Wp	320 Wp	325 Wp	330 Wp
Rated voltage (V_{mpp}) at STC			37.02 V		
Rated current (I_{mpp}) at STC			8.65 A		
Open circuit voltage (V_{oc}) at STC			45.45 V		
Short circuit current (I_{sc}) at STC			9.25 A		
Module efficiency			16.5%		
Rated output (P_{mpp}) at NOCT			223.5 Wp		
Rated voltage (V_{mpp}) at NOCT			33.80 V		
Rated current (I_{mpp}) at NOCT			6.61 A		
Open circuit voltage (V_{oc}) at NOCT			41.70 V		
Short circuit current (I_{sc}) at NOCT			7.15 A		
Temperature coefficient (P_{mpp})			- 0.408%/°C		
Temperature coefficient (I_{sc})			+0.050%/°C		
Temperature coefficient (V_{oc})			- 0.311%/°C		
Normal operating cell temperature (NOCT)			46±2°C		
Maximum system voltage (IEC/UL)			$1000V_{DC}$ or $1500V_{DC}$		
Number of diodes			3		
Junction box IP rating			IP 67		
Maximum series fuse rating			15 A		

* Measurement tolerance +/- 3%

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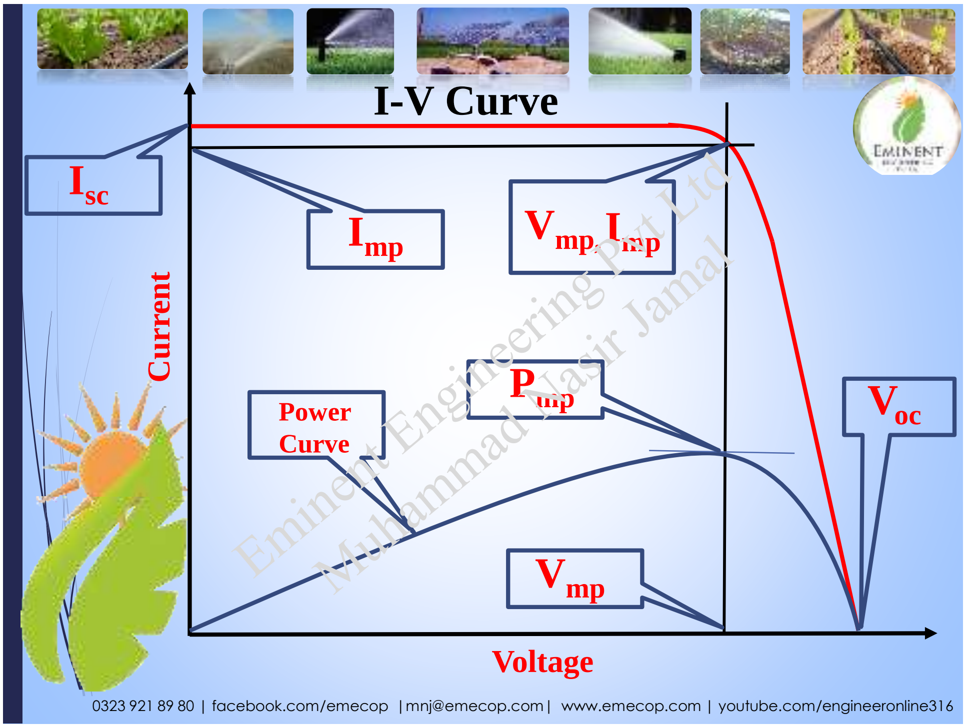

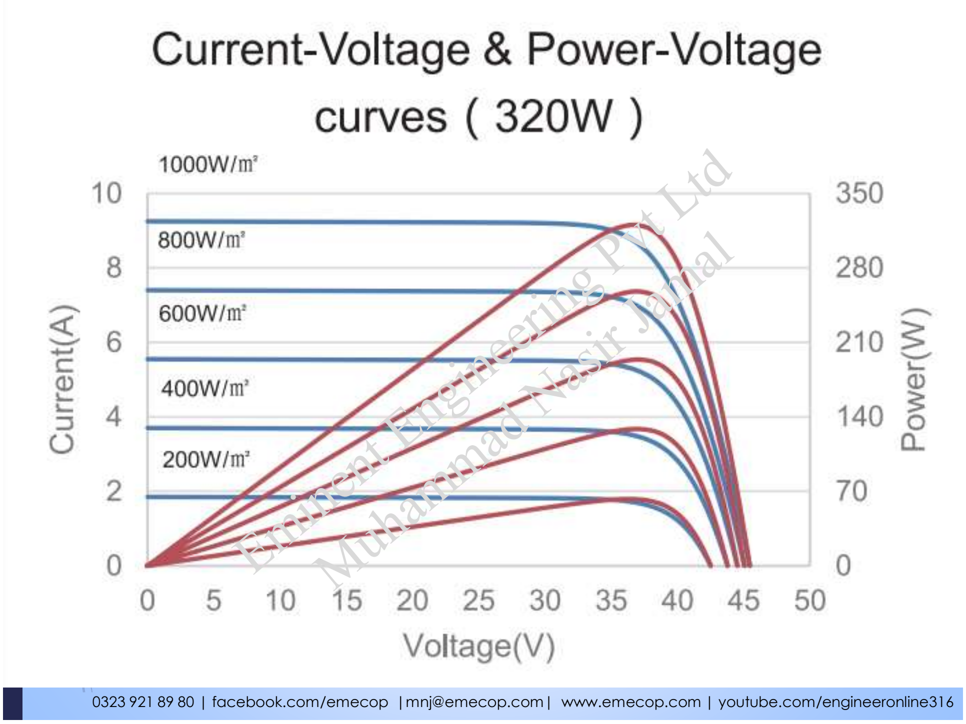

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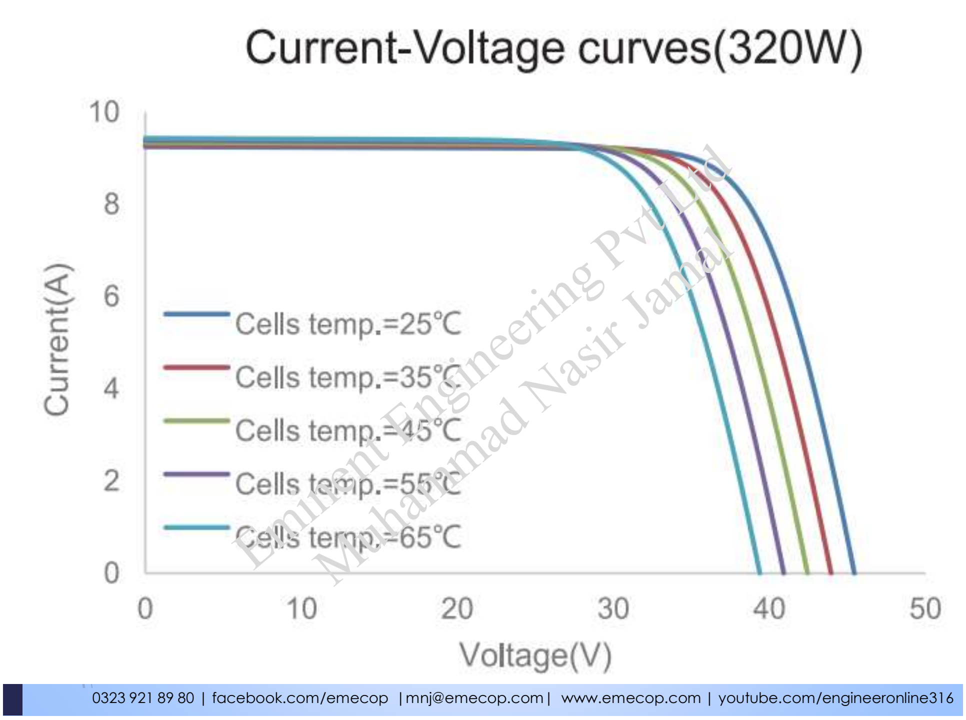

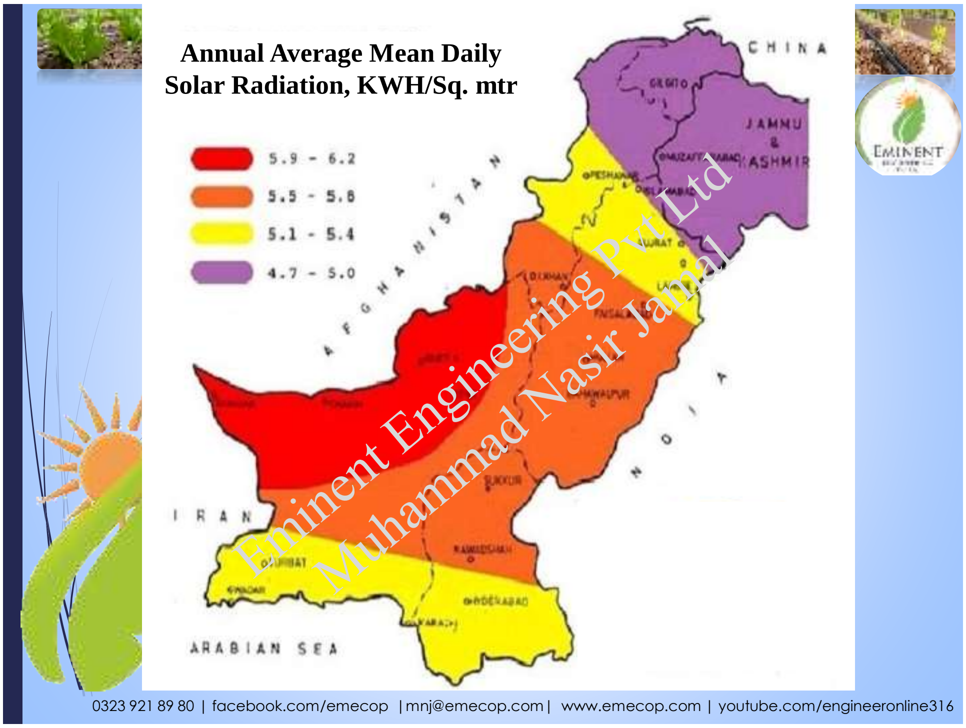

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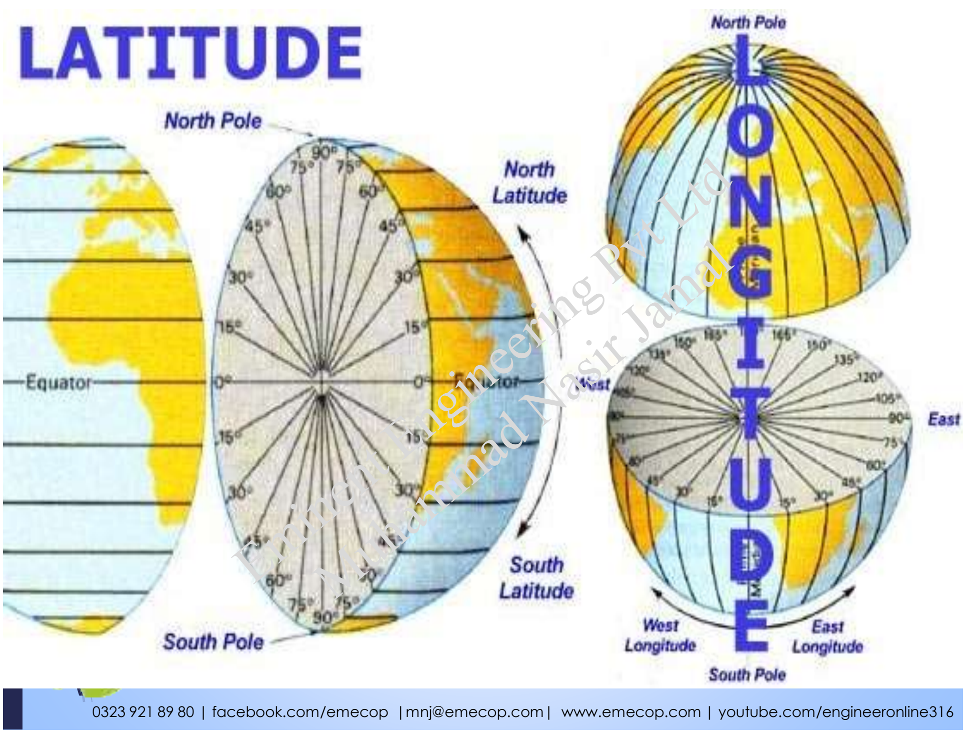

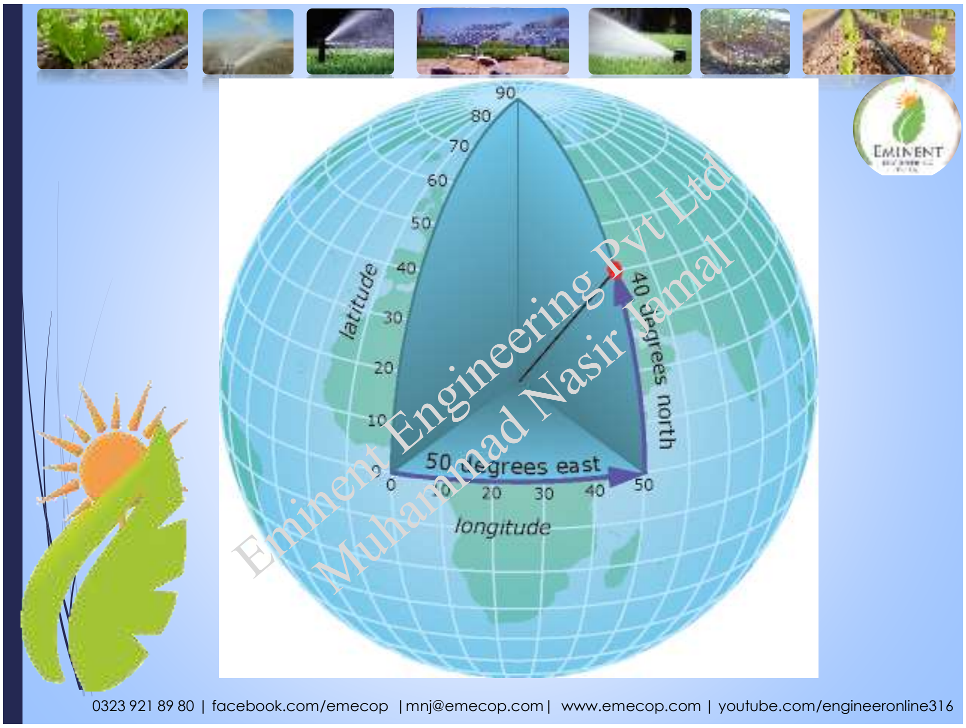

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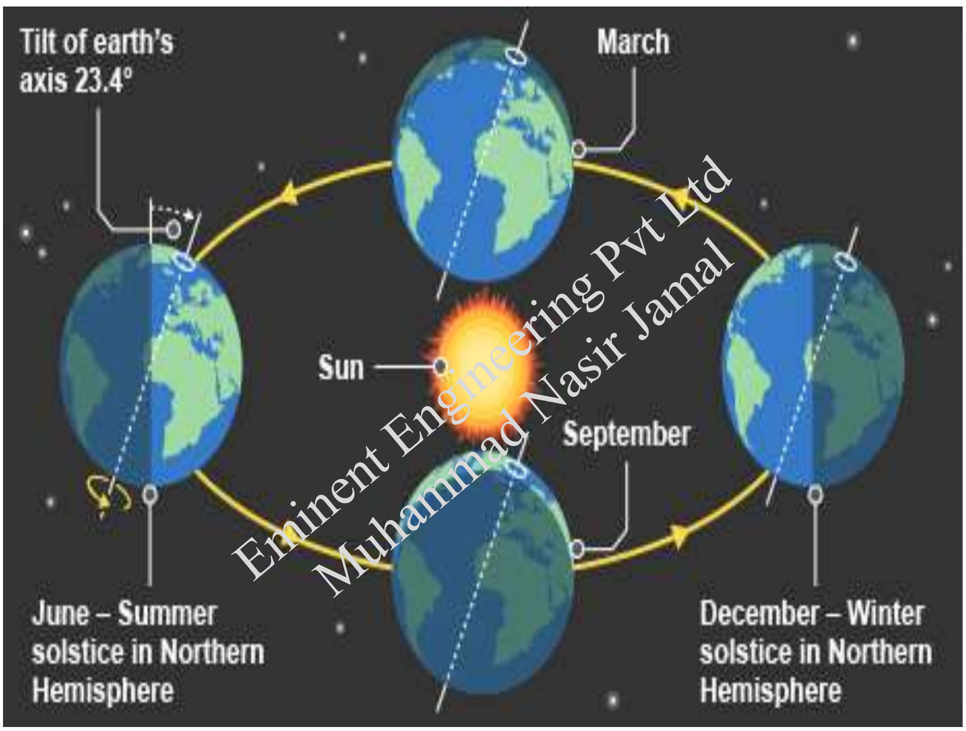

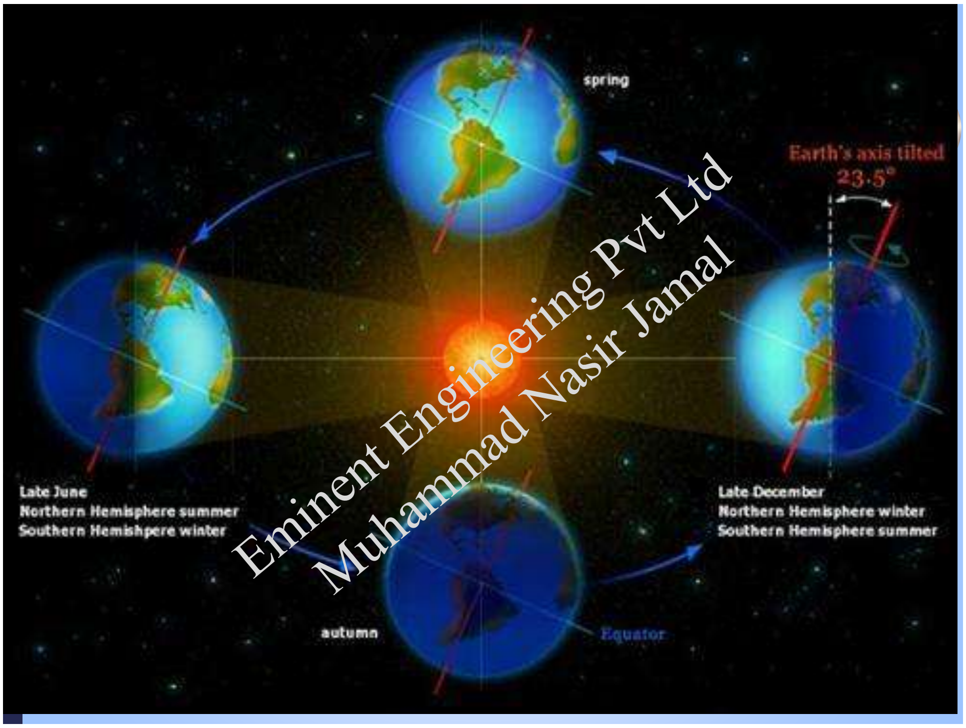

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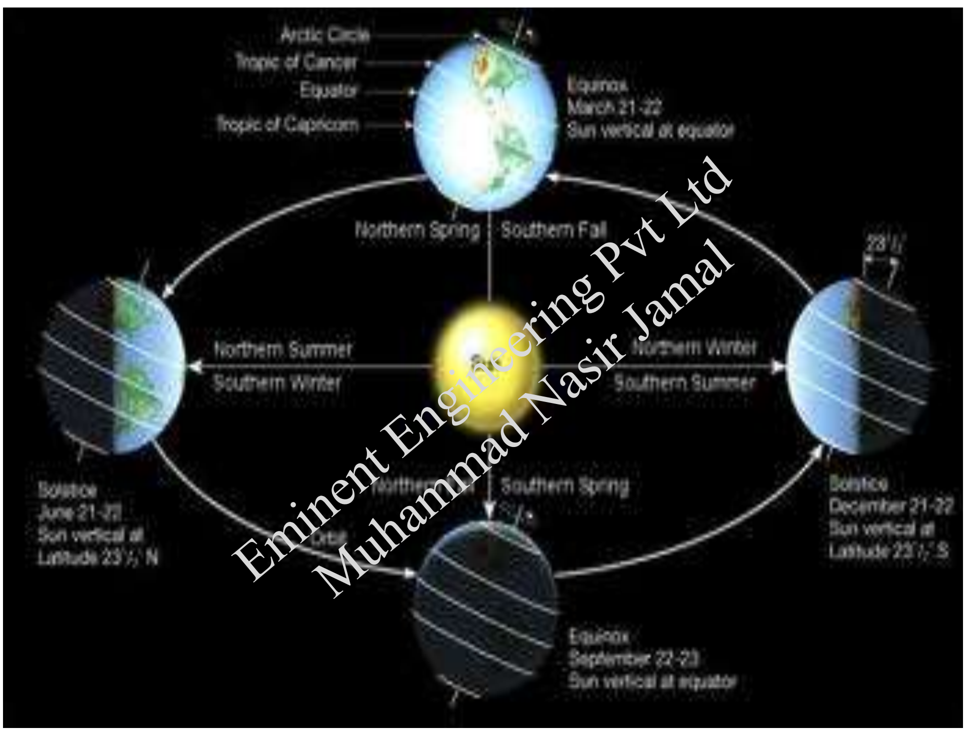

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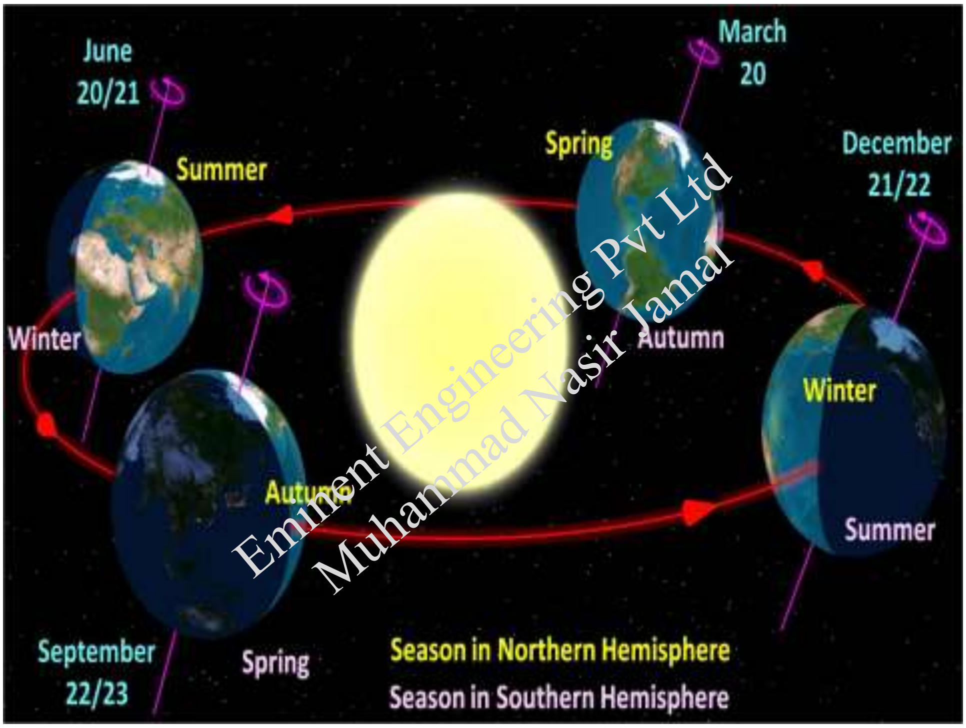

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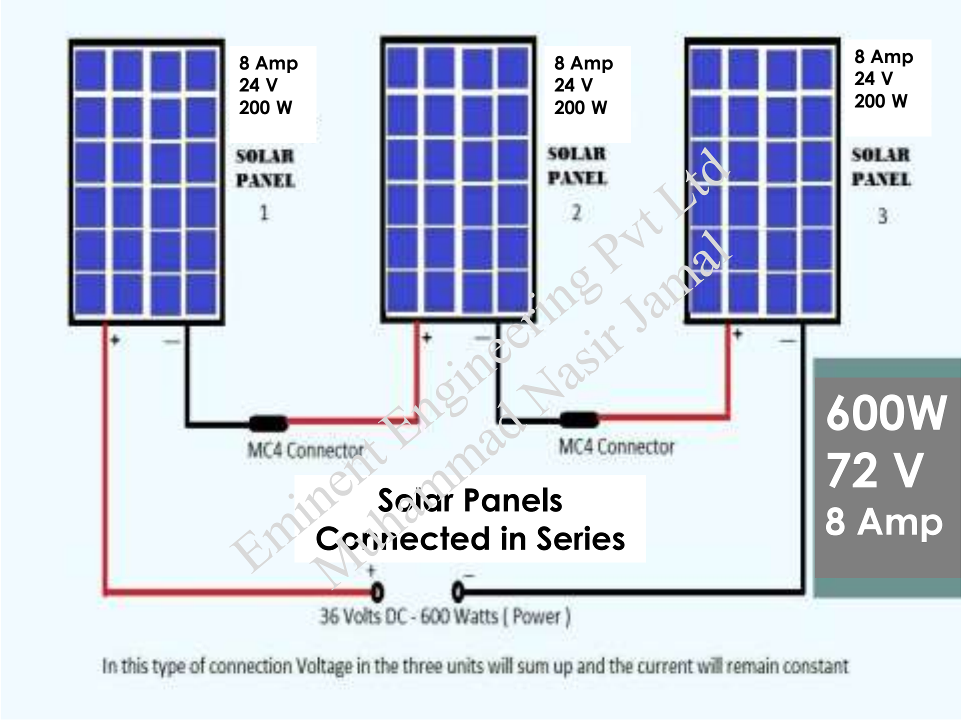

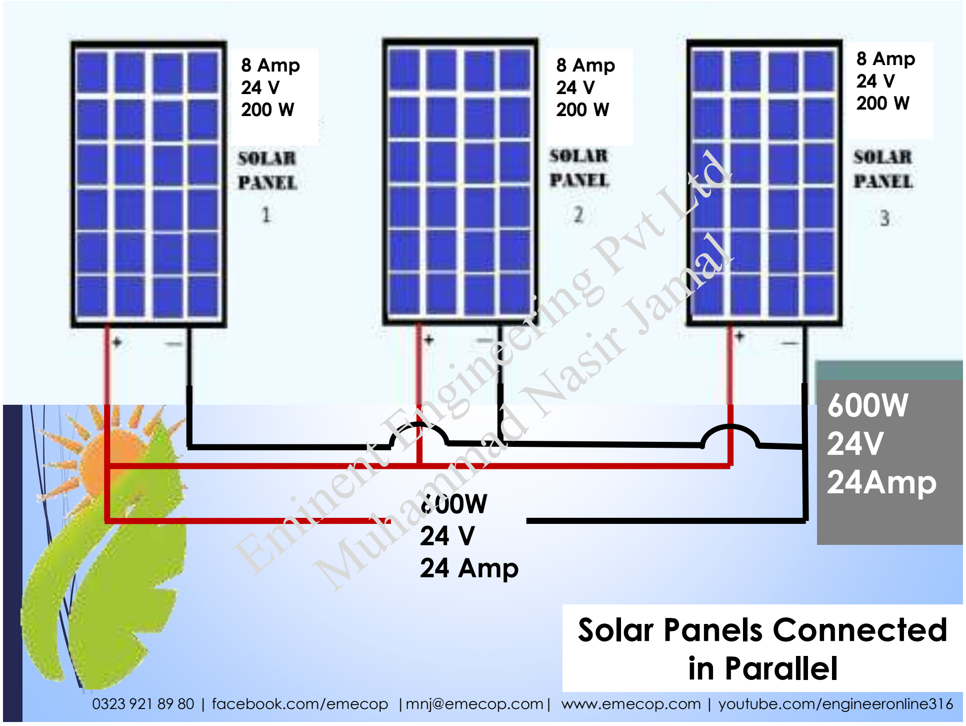

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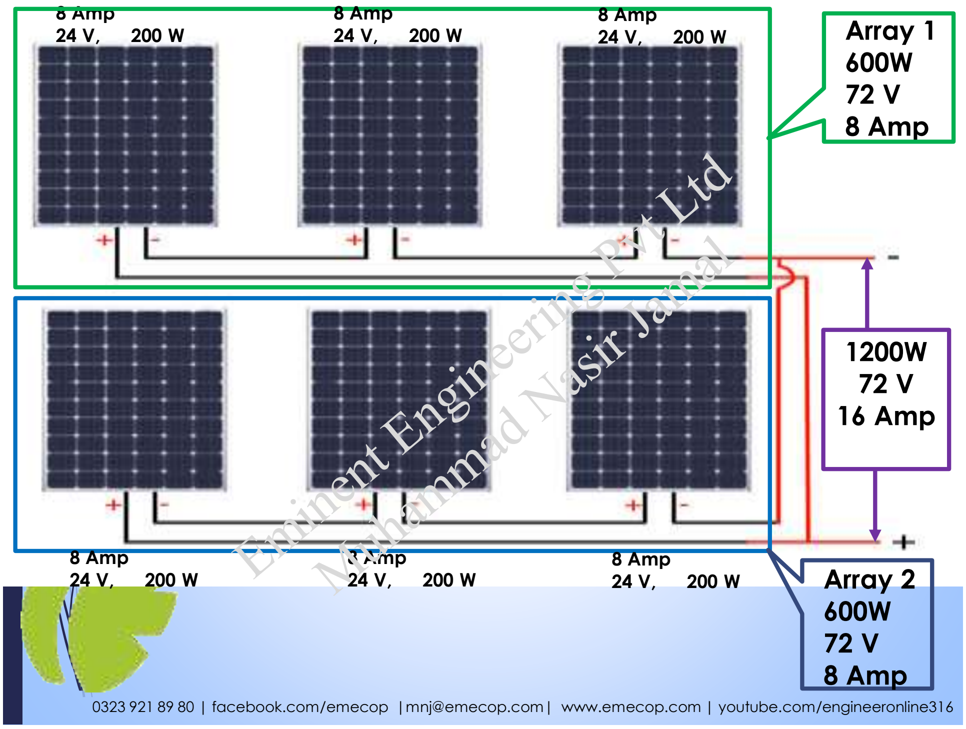
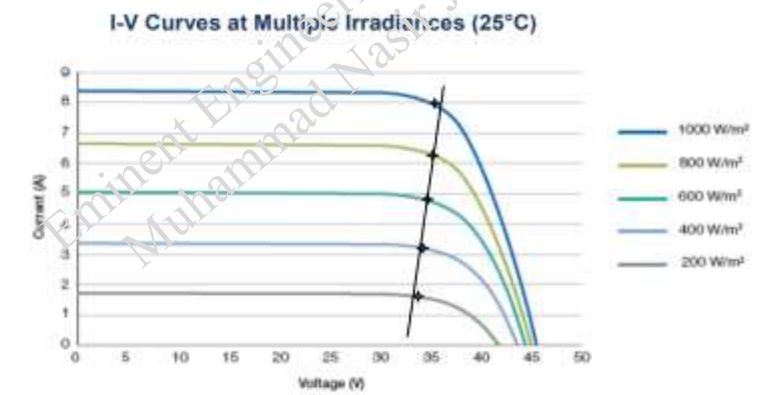


MPPT Pump (VFD) Inverters

Power = Voltage x Current.

Voltage = Constant, Current Increases. ……. Power Increases

Voltage = Increases, Current = Constant……… Power Increases



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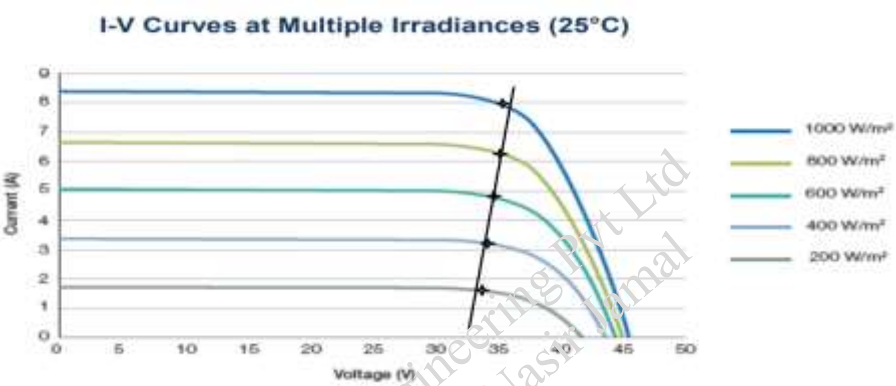

- From the graph, when the sun gives 1000 W/m^2, the Voc is around 45.5 V and Isc is about 8.3 A (amperes).
- In this case, with Voc = 45.5 V and zero current, the power We get is:

  P = Voc x I = 45.5 x 0 = 0 W (watts)
- Now with Isc = 8.3 A and zero voltage, the power We get is:

  P = V x Isc = 0 x 8.3 = 0 W

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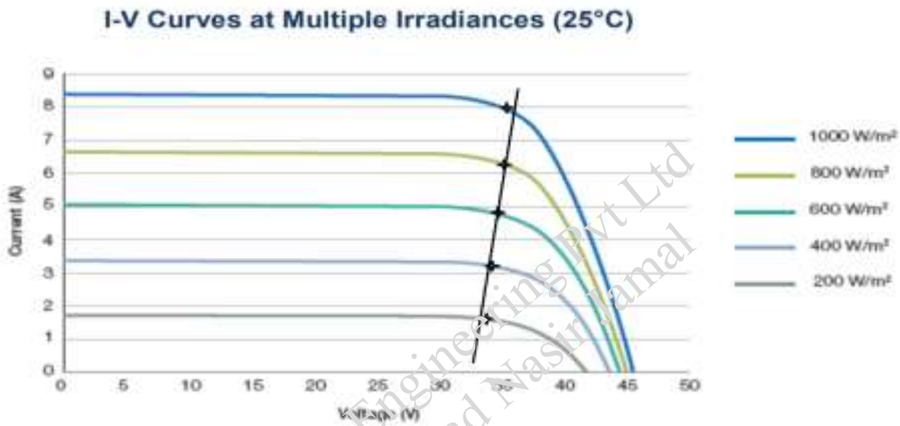

At 1000W/Sq mtr			
S.No	Voltage	Current	Power
1	45	1	45
2	42	6	252
3	34	8.2	278.8
4	36 (Vmp)	8 (Imp)	288 (Pmp)

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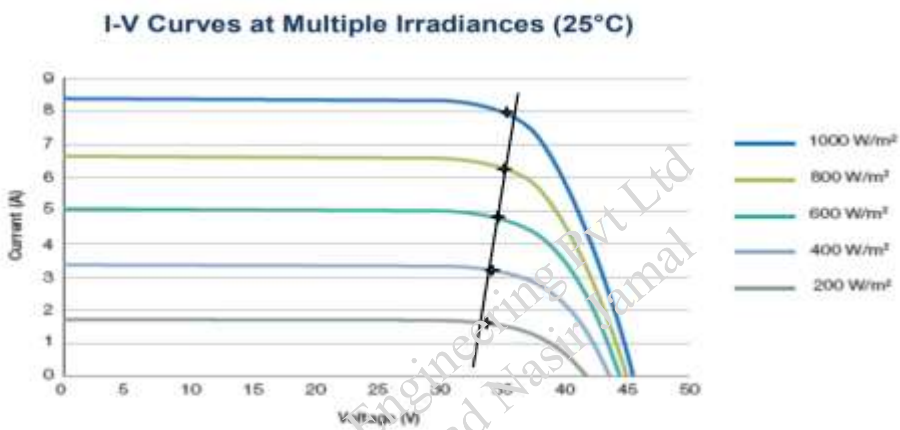

At 800W/Sq mtr			
S.No	Voltage	Current	Power
1	45	1	45
2	42	6	252
3	34	8.2	278.8
4	36 (Vmp)	8 (Imp)	288 (Pmp)

Jn Tech Pump (VFD) Inverters

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Model	JNP1K1L	JNP1K5L	JNP2K2L	JNP3KL	JNP3K7L	JNP4KL	JNP2K2H	JNP3KH	JNP3K7H	JNP4KH	JNP5K5H	JNP7K5H
d.c. Input												
d.c. Max. Input Voltage	450Vdc					750Vdc	880Vdc					
Recommended MPPT Voltage	150~400Vdc					[illegible]	460~850Vdc					
d.c. Max. Input Current	8A	10A	14.6A	21A	24.6A	15A	5A	6.9A	9A	9A	12A	16.3A
Max. MPPT Efficiency	99%											
Number of String	1	1	2	2	2	2	2	2	2	2	2	3
a.c. Output												
Max. Motor Output Power	1.1kW	1.5kW	2.2kW	3kW	3.7kW	4kW	2.2kW	3kW	3.7kW	4kW	5.5kW	7.5kW
Rated Output Voltage	220~240Vac,t[illegible] phase						380~460Vac,three phase					
Output Frequency Range	0~50/60Hz											

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Model	JNP11KH	JNP15KH	JNP18KSH	JNP22KH	JNP30KH	JNP37KH	JNP45KH	JNP55KH	JNP75KH	JNP90KH	JNP110KH
d.c. Input											
d.c. Max. Input Voltage	880Vdc										
Recommended MPPT Voltage	460~850Vdc										
d.c. Max. Intput Current	24.4A	33.3A	41.1A	49A	67A	82A	100A	[illegible]	166A	205A	251A
Max. MPPT Efficiency	[illegible]										
Number of String	3	3	3	1	1	1	1	1	1	1	1
a.c. Output											
Max. Motor Output Power	11kW	15kW	18.5kW	22kW	30kW	37kW	45kW	55kW	75kW	90kW	110kW
Rated Output Voltage	380~460Vac,three phase										
Output Frequency Range	0~50/60Hz										
Rated Output Current	21A	29A	36A	42A	57A	71A	86A	104A	142A	171A	209A

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Design Steps for Level 1 (At STC):

1. Note down the specifications, i.e. Voc, Vmp at STC of Solar Module
2. Note down the specifications, i.e. Max. Input Voltage, Recommended MPPT Voltage range of Inverter
3. Select Nos. of Solar Modules to be connected in Series, while taking care of :
   - Voc (STC) of all panels connected in series < Max. Input Voltage of Inverter
   - Vmp (STC) of all panels connected in series shall be within Recommended MPPT voltage range of Inverter

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Design Steps for Level 2 (At NOCT):

1. Note down the specifications, i.e. Voc, Vmp at NOCT of Solar Module
2. Note down the specifications, i.e. Max. Input Voltage, Recommended MPPT Voltage range of Inverter
3. Select Nos. of Solar Modules to be connected in Series, while taking care of :
   - Voc (NOCT) of all panels connected in series < Max. Input Voltage of Inverter
   - Vmp (NOCT) of all panels connected in series shall be within Recommended MPPT voltage range of Inverter

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Calculating Data at NOCT (48 Deg. C)

1. Note down the following specifications from Solar Module Data

ELECTRICAL SPECIFICATIONS					
STC rated output (P_{mpp})*	310 Wp	315 Wp	320 Wp	325 Wp	330 Wp
Rated voltage (V_{mpp}) at STC	36.91 V	36.99 V	37.02 V	37.11 V	37.15 V
Rated current (I_{mpp}) at STC	8.40 A	8.53 A	8.65 A	8.77 A	8.89 A
Open circuit voltage (V_{oc}) at STC	45.15 V	45.30 V	45.[illegible] V	45.67 V	45.86 V
Short circuit current (I_{sc}) at STC	8.92 A	9.04 A	9.25 A	9.48 A	9.52 A
Module efficiency	16.0%	16.3%	16.5%	16.8%	17.1%
Rated output (P_{mpp}) at NOCT	216.5 Wp	220.0 Wp	223.5 Wp	226.9 Wp	230.4 Wp
Rated voltage (V_{mpp}) at NOCT	33.7[illegible] V	[illegible] V	33.80 V	33.86 V	33.92 V
Rated current (I_{mpp}) at NOCT	6.42 A	6.52 A	6.61 A	6.70 A	6.79 A
Open circuit voltage (V_{oc}) at NOCT	[illegible]1.43 V	41.57 V	41.70 V	41.91 V	42.08 V
Short circuit current (I_{sc}) at NOCT	6.90 A	6.99 A	7.15 A	7.33 A	7.37 A
Temperature coefficient (P_{mpp})	TC_{pm} - 0.408%/°C				
Temperature coefficient (I_{sc})	TC_{Isc} +0.050%/°C				
Temperature coefficient (V_{oc})	TC_{Voc} - 0.311%/°C				
Normal operating cell temperature (NOCT)	46±2°C				
Maximum system voltage (IEC/UL)	$1000V_{DC}$ or $1500V_{DC}$				
Number of diodes	3				
Junction box IP rating	IP 67				
Maximum series fuse rating	15 A				

* Measurement tolerance +/- 3%

Final Level:

1. Two main conditions:
   - Max. voltage range of inverter
   - MPPT Voltage range of inverter

   MUST be satisfied both at STC and NOCT

2. Wattage of Solar >= HP of Motor

If Both of above conditions are satisfied, Design will work in field.

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Design Example:

- Motor HP = 7.5
- Available Solar Module = 320W (Astronergy)
- Inverter, Jn Tech, 7.5KW

Solar Module Model Name:	Astronergy, 320W, Poly 72 Cells
Open Circuit Voltage –Voc (STC)	45.450
Maximum Power Voltage-Vmp (STC)	37.020
Open Circuit Voltage –Voc (NOCT)	41.7
Maximum Power Voltage-Vmp (NOCT)	33.8

Solar Inverter Model Name:	Jn Tec 7.5KW
Max. Input DC Voltage	880VDC
MPPT Voltage Range	460 - 850VDC

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Design Steps for Level 1 (At STC):

1. Motor HP 7.5HP
2. Motor KW 7.5*0.746 KW = 5.595KW
3. Solar Power Needed 5.595 * 1.35 = 7.55KW
4. Nos. of 320W Panels Needed 7.55*1000/320 = 23.6 = 24Nos.

5. Voc (STC) of 24 Panels connected in Series = 24*45.45

=1090.8V (Whereas Range is up to 880V)

6. Vmp (STC) of 24 Panels connected in Series = 24*37.02

= 888.48V (Whereas Range is 440 - 850V

So Both Voc and Vmp are not satisfied. So we have to have atleast 2 Arrays

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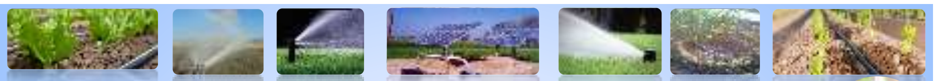

Design Steps for Level 1 (At STC): Second Try with 2 Array of 12 panels in each

1. Motor HP 7.5HP
2. Motor KW 7.5*0.746 KW = 5.595KW
3. Solar Power Needed 5.595 * 1.35 = 7.55KW
4. Nos. of 320W Panels Needed 7.55*1000/320 = 23.6 = 24Nos.

5. Voc (STC) of 12 Panels connected in Series = 12*45.45

=545.4 V (Within limits. Range is up to 880V)

6. Vmp (STC) of 12 Panels connected in Series = 12*37.02

= 444.24V (Just in Range. Range is 440 - 850V)

Although both conditions are marginaly satisfied. Lets accept the combination for a while.

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Design Steps for Level 1 (At NOCT):

1. Motor HP 7.5HP
2. Motor KW 7.5*0.746 KW = 5.595KW
3. Solar Power Needed 5.595 * 1.35 = 7.55KW
4. Nos. of 320W Panels Needed 7.55*1000/320 = 23.6 = 24Nos.

5. Voc (NOCT) of 12 Panels connected in Series = 12*41.7

=500.4V (Whereas Range is up to 880V)

6. Vmp (NOCT) of 12 Panels connected in Series = 12*33.8

= **405.6V** (Whereas Range is 440 - 850V)

Voc is Satisfied but Vmp are not satisfied. So we have to increase Nos. of panels in multiple of 2 (because Nos. of arrays are 2)

Design Steps for Level 1 (At NOCT): Panels / Array=14

1. Motor HP 7.5HP
2. Motor KW 7.5*0.746 KW = 5.595KW
3. Solar Power Needed 5.595 * 1.35 = 7.55KW
4. Nos. of 320W Panels Needed 7.55*1000/320 = 23.6 = 24Nos.
5. Voc (NOCT) of 12 Panels connected in Series = 14*41.7
   =583.8V (Whereas Range is up to 880V)
6. Vmp (NOCT) of 12 Panels connected in Series = 14*33.8
   = **473.2V** (Whereas Range is 440 - 850V)

Both Parameter are Satisfied at NOCT. Now Let See At STC as Well

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Design Steps for Level 1 (At STC): Second Try with 2 Array of 12 panels in each

1. Motor HP 7.5HP
2. Motor KW 7.5*0.746 KW = 5.595KW
3. Solar Power Needed 5.595 * 1.35 = 7.55KW
4. Nos. of 320W Panels Needed 7.55*1000/320 = 23.6 = 24Nos.
5. Voc (STC) of 12 Panels connected in Series = 14*45.45
   =636.3 V (Within limits. Range is up to 880V)
6. Vmp (STC) of 12 Panels connected in Series = 14*37.02
   = 518.28V (Just in Range. Range is 440 - 850V)

So at STC both parameters are satisfied as well

Final Design…

1. So We will use 28 Panels of 320W
2. Nos. of Array will be 2
3. Total Solar Power will be 28*320 = 8.960KW
4. We will use 3 Manual Trackers with capacity of 10 Panels each.
5. Inverter size will be 7.5KW

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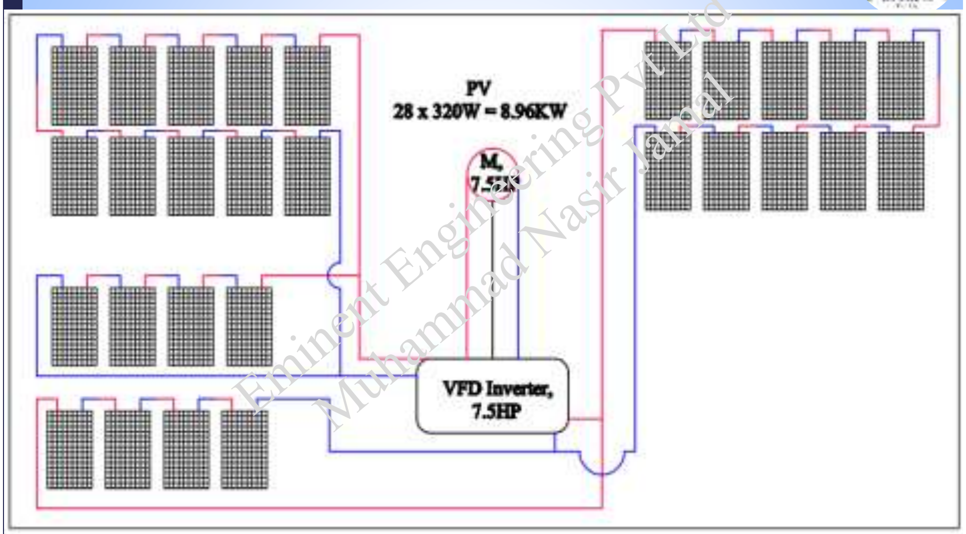

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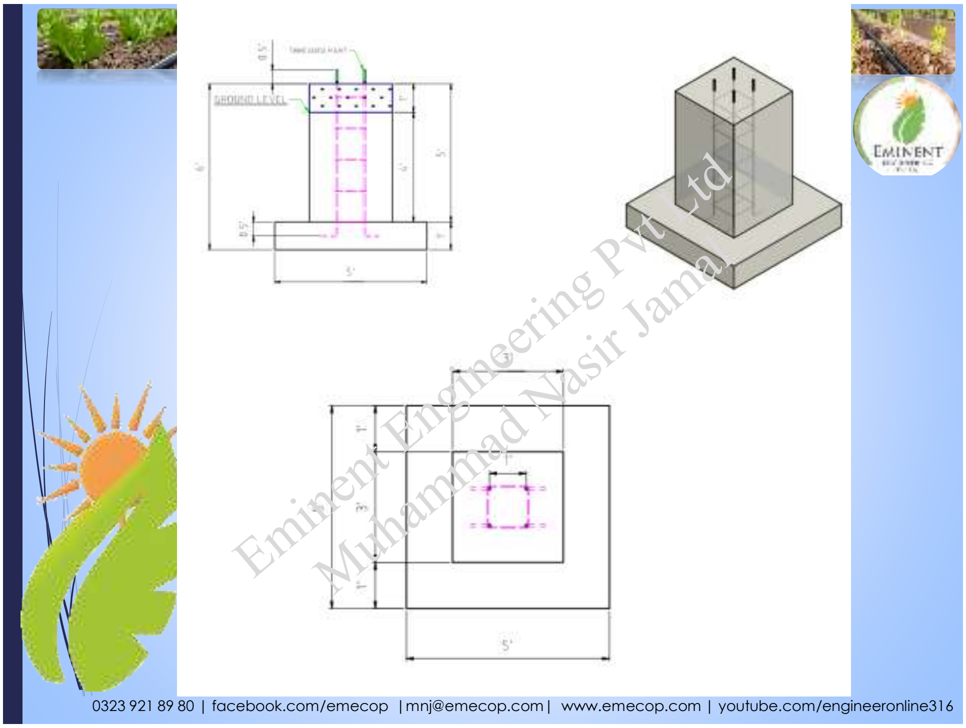

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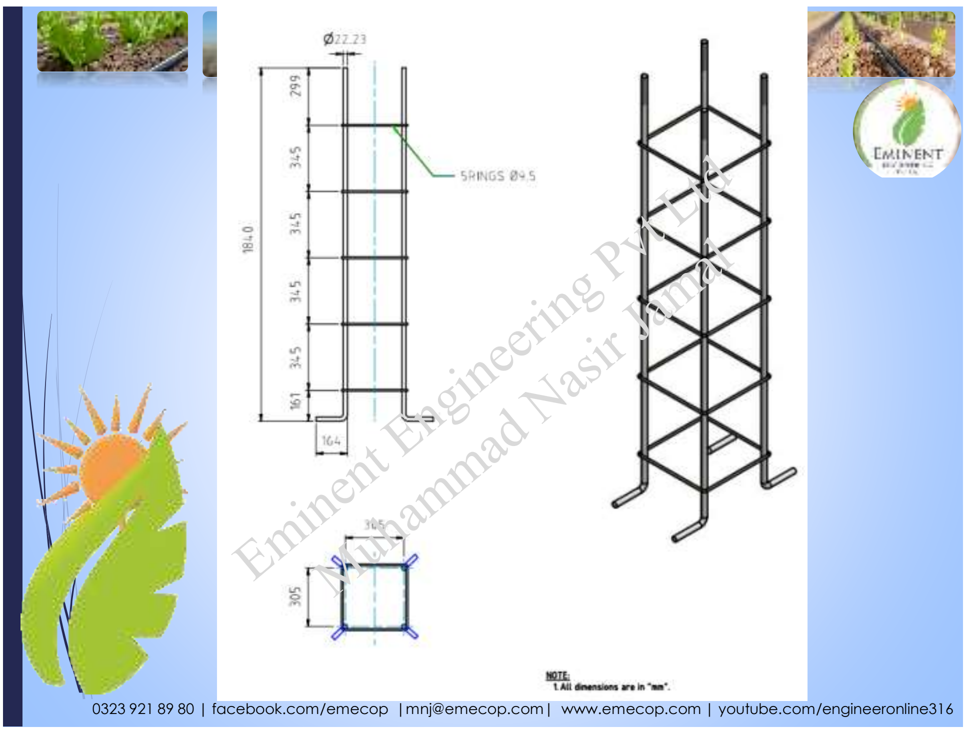

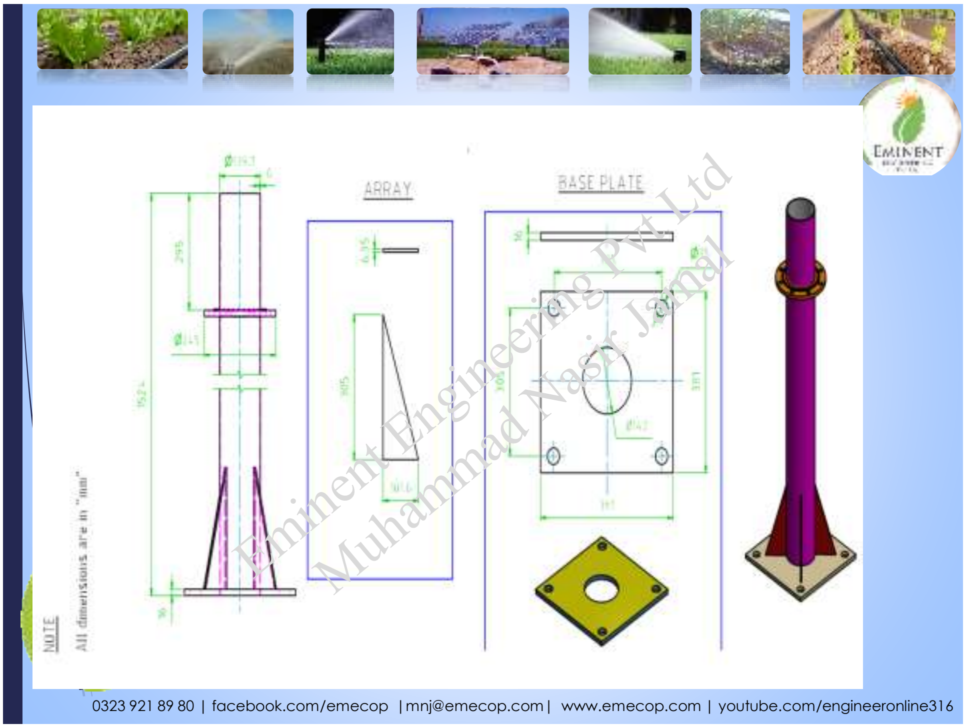

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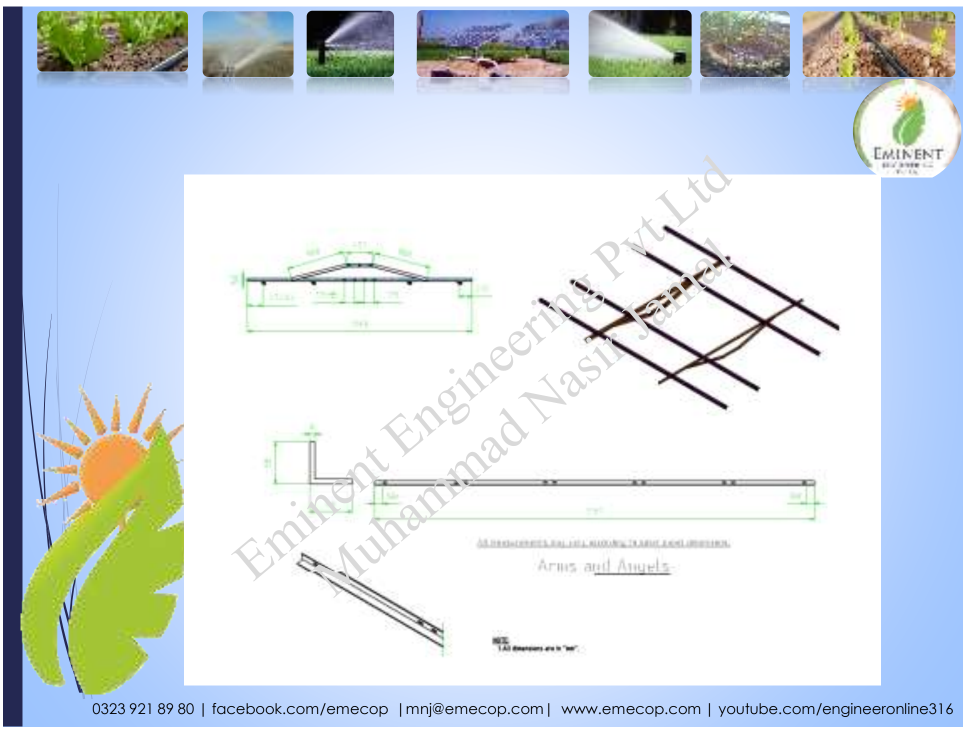

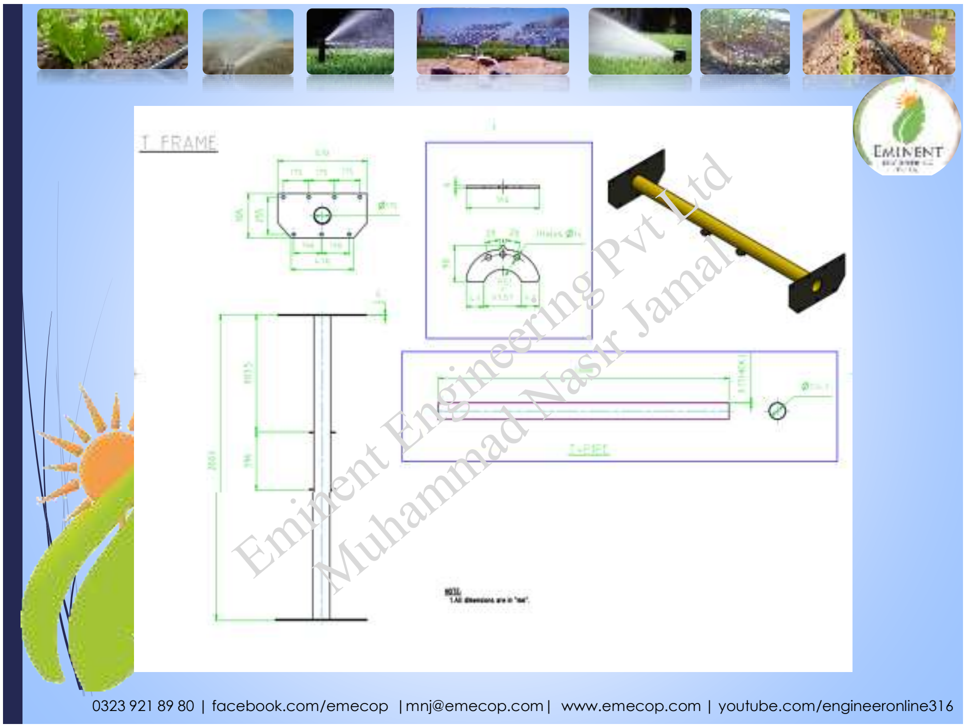

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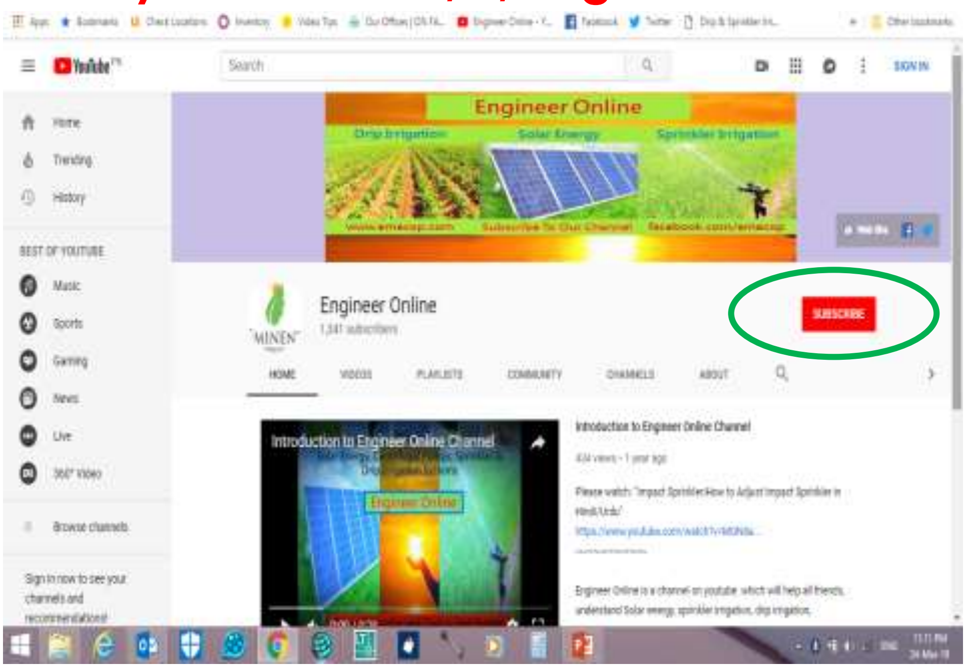

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Thank You...

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