EFFICIENCY OF THE SOLAR ARRAY AT MAXIMUM POWER OUTPUT

$$\boxed{\eta_{mp} = \eta_r \left[1 - c_i \left(T_c - T_r \right) \right]}$$

η_{mp} = ARRAY EFFICIENCY AT MAXIMUM POWER OUTPUT

η_r = ARRAY EFFICIENCY

c_i = MAXIMUM POWER COEFFICIENT OF VARIATION WITH TEMPERATURE

T_r = REFERENCE TEMPRATURE

T_c = CURRENT TEMPERATURE

ph. LATITUDE 30° N REFERENCE TEMPERATURE = 25°C

L = 5000

PoA = 4.3

AREA of PANEL

TYPICAL AMBIENT TEMPERATURE = 10°C

ARRAY OPERATES AT APPROXIMATELY 20°C ABOVE THE AMBIENT TEMPERATURE

DAILY IRRIDATION = 5000 kWH

SD = 1

INSOLATION (PoA) = 4.3 kWh/m²

/AREA

$\eta_{mppt} = 85\%$, $\eta_{bat} = 95\%$ DF = 0.9, $C_i = 0.005$

$T_r = 25°C$

CALCULATE TOTAL AREA OF SOLAR PANELS.

$\eta_r = 10$

$\eta_{out} = 70\% \Rightarrow 0.7$

$\eta_{in} =$

$=$

$\eta_{mp} =$

$=$

$\eta_{in} = 9.75$

FERENCE TEMPERATURE = 25°C

= 10°C

MATELY 20°C ABOVE THE AMBIENT

KWH

KWh/m²

95% DF = 0.9 , $C_i = 0.005$

of SOLAR PANELS.

$\eta_r = 10$

$\eta_{OUT} = 70\% \Rightarrow 0.7$

L = 5000

POA = 4.3

SD = 1

$$\text{AREA of SOLAR PANEL} = \frac{L / \text{sec}}{POA \times \eta_{im} \times \eta_{OUT}}$$

LOAD EFFICIENCY

$$\eta_{im} = \eta_{mp} \times \eta_{bat} \times \eta_{mppT} \times DF \times SD$$

$$= \eta_{mp} \times 0.95 \times 0.85 \times 0.9 \times 1$$

$$\eta_{mp} = \eta_r \left[1 - C_i (T_c - T_r) \right]$$

$$= 10 \left[1 - 0.005 (10 + 20 - 25) \right]$$

$$= 9.75\%$$

$$\eta_{in} = 9.75 \times 0.95 \times 0.85 \times 0.9 \times 1 = 0.071$$

L/sec

LOAD EFFICIENCY

$\eta_{in} \times \eta_{OUT}$

$\times$ DF $\times$ SD

η_{MPPT}

0.85 $\times$ 0.9 $\times$ 1

$-T_r)]$

$+20-25)]$

$\times 1 = 0.071$

AREA of SOLAR PANEL $= \dfrac{5000}{4.3 \times 0.071 \times 0.7 \times 3600 \text{ sec}}$

$= 6.49 \text{ m}^2$

SYSTEM DESIGN FOR PV POWERED WATER PUMPING

INSOLATION DATA MANIPULATION

I_s = MAXIMUM DAILY LIGHT INTENSITY

β = INCLINATION ANGLE

α = NOON TIME LATITUDE of SUN FOR THE MONTH

I_{st} = LIGHT INCIDENT

SUNNY DAY

$I_{st} =$

A

CLOUDY

I_{st}

HOUR

I_{st}

3600 sec.

PUMPING

THE MONTH

SUNNY DAY

$$I_{st} = 1.35 \times 0.7 \left[\text{AIR MASS} \times 0.678 \right] \times \underbrace{1.1}_{\text{DIFFUSION}} \sin(\alpha + \beta)$$

$$\text{AIR MASS} = \frac{1}{\sin \alpha}$$

CLOUDY DAY

$$I_{st} = 1.35 \times 0.7 \times \text{AIR MASS} \times 0.578 \times 0.2$$

HOUR OF SUNSHINE AT LIGHT INTENSITY I_{SA}

$$I_{SA} = \frac{\sum x_i m_i I_{st}}{\sum x_i m_i}$$

X_i = % of SUNNY DAY

Y_i = % of CLOUDY DAY

m_i = NO. OF DAYS IN PARTICULAR MONTH

E_i (HOURS O[F] SUNSHIN[E] PER DA[Y]

E_{mi} (HOUR[S] SU[N]... PER ...

ANNUAL ...

HOU[RS]

$$E_i \left(\text{HOURS OF SUNSHINE PER DAY}\right) = \frac{6.76\, N_i \times I_{st}}{I_{SA}}$$

$$E_{mi} \left(\text{HOURS OF SUNSHINE PER MONTH}\right) = X_i \times M_i \times E_i$$

ANNUAL SUNSHING HOUR $E_y = \sum_{i=1}^{12} E_{mi}$

ARTICULAR

P.V MODULE CHARACTERISTICS

EACH CELL

V_{oc} AT 25°C = 600mV

F_F (FILL FACTOR) = 75%

V_{mp} (25°C) = 475 mV

V_{mp} (45°C) = 430 mV

I_{mp}/I_{sc} = 0.95

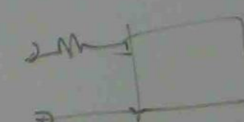
$$V = \frac{nKT}{q} \ln\left(I_L - \frac{1}{I_c}\right) - I R_s$$

$K = 1.4 \times 10^{-23}$ BOLTZAMAN's CONSTANT

$I_c =$

$= 2$

$R_s =$



V = TERMINAL VOLTAGE

I = CURRENT

I_L = LIGHT GENERATED CURRENT

I_c = DARK CURRENT

n = IDEALTY FACTOR $n = 1.3$

R_s = RESISTANCE OF SOLAR PANEL

$q = 1.6 \times 10^{-19}$ COULOMB

$$I_c = \frac{I_L}{e^{\frac{q V_{oc}}{mKT}}}$$

$$= 2.17 \times 10^{-7} I_L \text{ AT } 45^\circ C$$

3

$$R_s = \frac{1}{40 I_{sc}}$$

I_{sc} = SHORT CIRCUIT CURRENT

$$I_L = L \times I_{sc}$$

$L = 1 \longrightarrow 100 mW/cm^2$

$L = 0.5 \longrightarrow 80 mW/cm^2$

$$V = 0.361 \ln\left[L \times I_{sc} - \frac{1}{2.17 \times 10^{-7} I_{sc}} - \frac{1}{40 I_{sc}} \right]$$

$T = 318 K$

1 SINGLE MODULE (36 CELLS) = $V_{mp} = 15.5 V$

2 ———— 72 ———— = 31 V

3 ———— 108 ———— = 45.5 V

4 ———— 144 ———— = 52 V

L_{mp} (LIGHT INTENSITY) = $0.8 I_{SA}$

$$I_{mp} = I_m \times \frac{100}{0.8 I_{SA}}$$

THIS CURRENT IS REQUIRED FROM SOLAR PANEL

MOTOR CURRENT

P.V MODULE CHARACTERISTICS

EACH CELL

V_{oc} AT 25°C = 600 mV

F_f (FILL FACTOR) = 75%

V_{mp} (25°C) = 475 mV

V_{mp} (45°C) = 430 mV

I_{mp} / I_{sc} = 0.95

$K = 1.4 \times 10^{-23}$

BOLTZMAN'S CONSTANT

$$V = \frac{nKT}{q} \ln\left(I_L - \frac{1}{I_c}\right) - I R_s$$

V = TERMINAL VOLTAGE

I = CURRENT

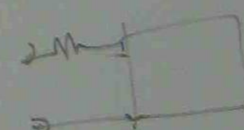
I_L = LIGHT GENERATED CURRENT

I_c = DARK CURRENT

n = IDEALITY FACTOR n = 1.3

R_s = RESISTANCE OF SOLAR PANEL

$q = 1.6 \times 10^{-19}$ COULOMB



I_c =

= 2.

R_s =

$$I_o = \frac{I_L}{e^{\frac{q V_{oc}}{mkT}}}$$

$$= 2.17 \times 10^{-7} I_L$$ AT 45°C

$$R_s = \frac{1}{40 I_{sc}}$$

I_{sc} = SHORT CIRCUIT CURRENT

$$I_L = L \times I_{sc}$$

$L = 1 \longrightarrow 100 \, mW/cm^2$

$L = 0.5 \longrightarrow 50 \, mW/cm^2$

$$V = 0.361 \ln \left\{ L \times I_{sc} - \frac{1}{2.17 \times 10^{-7} I_{sc}} - \frac{1}{40 I_{sc}} \right\}$$

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$$I_{mp} = I_m \times \frac{100}{0.8 I_{SA}}$$

THIS CURRENT IS REQUIRED FROM SOLAR PANEL

MOTOR CURRENT

$$V = 0.361 \ln\left[L \times I_{sc} - \frac{1}{2.17\times10^{-7} I_{sc}} - \frac{1}{40 I_{sc}} \right]^{-1}$$

$T = 318\ K$

1 SINGLE MODULE (36 CELLS) = $V_{mp} = 15.5\ V$

2 —— 72 —— = 31 V

3 —— 108 —— = 45.5 V

4 —— 144 —— = 52 V

mw/cm²

mw/cm²

L_{mp} (LIGHT INTENSITY) = $0.8\ I_{SA}$

$$I_{mp} = I_m \times \frac{100}{0.8\ I_{SA}}$$

THIS CURRENT IS REQUIRED FROM SOLAR PANEL

MOTOR CURRENT

C

6% LOSS DUE TO DUST

10% LOSS FOR DEGRADING OF SOLAR PANEL

10% LOSS FOR COMBINED TOLERANCE

26% COMBINED REDUCTION → ∴ DERATING FACTOR = 74%

ACTUAL SHORT CIRCUIT CURRENT = $0.74 \times \frac{I}{100} \times I_{sc}$

I = mw/cm² IRRADIATION

MODULE SHORT CKT CURRENT

COMPARE → No. of PARALLEL PATHS.

40 I_{sc}

15.5 V

31 V

45.5 V

52 V

6% LOSS DUE TO DUST

10% LOSS FOR DEGRADING OF SOLAR PANEL

10% LOSS FOR COMBINED TOLERENCE

26% COMBINED REDUCTION → ∴ DERATING FACTOR = 74%

ACTUAL SHORT CIRCUIT CURRENT = $0.74 \times \frac{I}{100} \times I_{sc}$

I_{sc} ← MODULE SHORT CKT CURRENT

$I = mW/cm^2$

IRRIDATION

COMPARE → NO. OF PARALLEL PATHS.

ph. DESIGN A DIRE[...]

CIRCUITRY) F[...]

LATITUDE = 37[...]

TOTAL SUN

ACCORDING

Pb DESIGN A DIRECTLY COUPLED PUMPING SYSTEM (NO. OF BATTERIES OR POWER CONDITIONING CIRCUITRY) FOR IRRIGATION PURPOSE

LATITUDE = 37.25 2.5 million LITRE OF WATER IS REQUIRED

TOTAL SUN SHINE HOURS = 533. WATER HEAD = 9m

ACCORDING TO PUMP DATA

1 L/s	9m HEAD	2700 RPM	200WATT
1.2 L/s	9m HEAD	2700 RPM	210 WATT
1.3 L/s	9m HEAD	2700 rpm	230 WATT

$$I_m = \left(\frac{T + 0.0674}{0.136}\right)$$

$$V_{mp} = \left(\frac{N + 69.2\, I_m + 16.6}{70.4}\right)$$

$$I_{sc} = \frac{I_{mp}}{\text{DERATING FACTOR}}$$

$$\text{PUMPING RATE} = \frac{\text{LITRE}}{\text{TOTAL SUNSHINE HOUR} \times 3600} = \frac{2.5 \times 10^6}{533 \times 3600} = 1.3\ L/s.$$

1.3 L/s → 9m HEAD → 2700 RPM − 230 W

$$P = \frac{2\pi T N}{60}$$

$$230 = \frac{2 \times 3.1416 \times T \times 2700}{60}$$

$$T = 0.814\ \text{N-m}$$

$$I_m = \frac{0.814 + 0.674}{0.136} = 6.48\ A$$

$$V_{mp} = \frac{2700 + 69.2 \times 6.48 + 16.6}{70.4} = 45V$$

$$I_{mp} = \frac{I_m \times 100}{0.8\ I_{SA}} = \frac{6.48 \times 100}{0.8 \times 1000} = 8.2\ \text{Amp}$$

$$I_{sc} = \frac{I_{mp}}{\text{DERATING}} = \frac{8.2}{0.74} = 11.8\ \text{Amp}$$

ph

MONTH	n	S	D	S_{15}	R_{15}
DECEMBER	73.6	6.76	214	695	912
JANUARY	736	6.29	216	656	866

$N_i = 1.4$ $I_{st} = 103$ FOR DECEMBER

$N_i = 1.4$ $I_{st} = 102$ FOR JANUARY

CALCULATE
NO. OF SUNSHINE
HOUR FOR DECEMBER.

$$\text{SUNDAY } kWh/m^2 = 6.76\, N_i \times I_{st}$$

$$\text{CLOUDY DAY } kWh/m^2 = 6.76\, N_i\, I_{ci}$$

$$I_{ci} = 9.3$$

$$(X_2 + Y_2) = 1$$

SUN SHINE HOUR = $E_i = \dfrac{6.76 \; N_i \; I_{st}}{I_{SA}}$

$$I_{SA} = \frac{\Sigma\, x_i\, m_i\, I_{st}}{\Sigma\, x_i\, m_i}$$

DECEMBER

$$R_{1S} = X_1 \times S_1 \times N_1 \times I_{st_1} + Y_1 \times S_1 \times N_1 \times I_{c_1}$$

$$912 = X_1 \times 6.76 \times 1.4 \times 103 + Y_1 \times 6.76 \times 1.4 \times 9.3$$

$$912 = 975\, X_1 + 89\, Y_1 \quad \text{—— (1)}$$

UNDERSTOOD $\boxed{1 = X_1 + Y_1 \quad \text{—— (2)}}$

$$(2) \times 89 \Rightarrow \quad 89 = 89\, X_1 + 89\, Y_1$$

$$912 = 975\, X_1 + 89\, Y_1$$

$$(89 - 912) = (89 - 975)\, X_1$$

$$X_1 = 0.93$$

$$\therefore Y_1 = 1 - X_1 = 1 - 0.93 = 0.07$$

$$\boxed{I_{SA} = \frac{\Sigma\, x_i\, m_i\, I_{st}}{\Sigma\, x_i\, m_i} =}$$

$R_{15} = X_2 S_2 N_2 \times I_{St} + Y_2 S_2 N_2 I_{St}$

$866 = X_2 \times 6.29 \times 1.4 \times 102 + Y_2 \times 6.29 \times 1.4 \times 9.3$

$866 = 895 X_2 + 89 Y_2$

$\boxed{1 = X_2 + Y_2}$

SOLVE $X_2 = 0.89$ $Y_2 = 0.11$

$$I_{SA} = \frac{0.93 \times 31 \times 103 + 0.89 \times 31 \times 102}{0.93 \times 31 + 0.89 \times 31}$$

$= 103 \ mW/cm^2$

$$E_i = \frac{6.76 \times 1.4 \times 10^3}{I_{SA}} = \frac{6.76 \times 1.4 \times 10^3}{103} = 9.5$$

Pb. DESIGN A DIRECTLY ...

CIRCUITRY) FOR ...

LATITUDE = 37.25 ...

TOTAL SUN SH...

ACCORDING TO ...

SUN SHINE HOUR $= E_i \times M_i \times X_1$

$= 9.5 \times 31 \times 0.93$

$= 274 \ hr$

$I_m =$

V_m

Pb/ DESIGN A DIRECTLY COUPLED PUMPING SYSTEM (NO. OF BATTERIES OR POWER CONDITIONING CIRCUITRY) FOR IRRIGATION PURPOSE

LATITUDE = 37.25 2.5 MILLION LITRE OF WATER IS REQUIRED

TOTAL SUN SHINE HOURS = 533. WATER HEAD = 9m

ACCORDING TO PUMP DATA

1 L/s	9m HEAD	2700 RPM	200 WATT
1.2 L/s	9m HEAD	2300 RPM	210 WATT
1.3 L/s	9m HEAD	2700 rpm	230 WATT

HINE $= E_i \times M_i \times X_1$

$= 95 \times 31 \times 0.93$

$= 274\ \mathrm{hr}$

$$I_m = \frac{(T + 0.0674)}{0.136}$$

$$V_{mp} = \frac{(N + 69.2\, I_m + 16.6)}{90.4}$$

$$I_{sc} = \frac{I_{mp}}{\text{DERATING FACTOR}}$$

$$\text{PUMPING RATE} = \frac{\text{LITRE}}{\text{TOTAL SUNSHINE HOUR} \times 3600} = \frac{2.5 \times 10^6}{533 \times 3600} = 1.3\ L/s$$

$1.3\ L/s \rightarrow 9\text{m HEAD} \rightarrow 2700\ \text{RPM} - 230\text{W}$

$$P = \frac{2\pi T N}{60}$$

$$230 = \frac{2 \times 3.1416 \times T \times 2700}{60}$$

$T = 0.814$ N-m

$$V_{mp} = \frac{2700 + 69.2 \times 6.48 + 16.6}{90.4} = 35\text{V}$$

$$I_{mp} = \frac{I_m \times 100}{0.8\, I_{st}} = \frac{6.48 \times 100}{0.8 \times 1000} = 8.2\ \text{Amp}$$

$$I_{sc} = \frac{I_{mp}}{\text{DERATING}} = \frac{8.2}{0.74} = 11.5\ \text{Amp}$$

$$I_m = \frac{0.814 + 0.674}{0.136} = 6.48\ \text{A}$$

I_{SH}

4×9.3

pb/ DESIGN A DIRECTLY COUPLED PUMPING SYSTEM (NO. OF BATTERIES OR POWER CONDITIONING CIRCUITRY) FOR IRRIGATION PURPOSE

LATITUDE = 37.25   2.5 MILLION LITRE OF WATER IS REQUIRED

TOTAL SUN SHINE HOURS = 533.   WATER HEAD = 9 m

ACCORDING TO PUMP DATA

1 L/s	9 m HEAD	2700 RPM
1.2 L/s	9 m HEAD	2900 RPM
1.3 L/s	9 m HEAD	...00 rpm

SUN SHINE HOUR $= E_i \times M_i \times X_1$

$= 9.5 \times 31 \times 0.93$

$= 274$ hr

2

$$I_m = \left(\frac{T + 0.0674}{0.136}\right)$$

$$V_{mp} = \left(\frac{N + 64.2\, I_m + 16.6}{70.4}\right)$$

$$I_{sc} = \frac{I_{mp}}{\text{DERATING FACTOR}}$$

PUMPING RATE = $\frac{\text{LI...}}{\text{TOTAL S...}}$

1.3 L/s $\longrightarrow$ 9 m HEAD ...

$$P = \frac{2\pi T N}{60}$$

$$230 = \frac{2 \times 3.1416 \times T \times 2...}{60}$$

$T = 0.814$ N-m

9.5

$$I_m = \frac{0.814 + 0.674}{0.136} = 6.48\text{ A}$$

TLY COUPLED PUMPING SYSTEM (NO. OF BATTERIES OR POWER CONDITIONING

R IRRIGATION PURPOSE

2S 2.5 MILLION LITRE OF WATER IS REQUIRED

INE HOURS= 533. WATER HEAD= 9m

PUMP DATA

1 L/s	9m HEAD	2700 RPM	200 WATT
1.2 L/s	9m HEAD	2700 RPM	210 WATT
1.3 L/s	9m HEAD	2700 rpm	230 WATT

$$= \left(\frac{T + 0.0674}{0.136}\right)$$

$$p = \left(\frac{N + 69.2\, I_m + 16.6}{70.4}\right)$$

$$I_{sc} = \frac{I_{mp}}{\text{DERATING FACTOR}}$$

$$\text{PUMPING RATE} = \frac{\text{LITRE}}{\text{TOTAL SUNSHINE HOUR} \times 3600} = \frac{2.5 \times 10^6}{533 \times 3600} = 1.3\ L/s.$$

$1.3\ L/s \rightarrow 9\,m\ \text{HEAD} \rightarrow 2700\ \text{RPM} - 230\,W$

$$P = \frac{2\pi T N}{60}$$

$$230 = \frac{2 \times 3.1416 \times T \times 2700}{60}$$

$$T = 0.814\ N\text{-}m$$

$$I_m = \frac{0.814 + 0.674}{0.136} = 6.48\,A$$

$$V_{mp} = \frac{2700 + 69.2 \times 6.48 + 16.6}{70.4} = 45V$$

$$I_{mp} = \frac{I_m \times 100}{0.8\, I_{SA}} = \frac{6.48 \times 100}{0.8 \times 1000} = 8.2\ Amp$$

$$I_{sc} = \frac{I_{mp}}{\text{DERATING}} = \frac{8.2}{0.74} = 11.6\ Amp.$$