MANUAL CALCULATION OF IRRADIATION DATA

$$\frac{\bar{H}}{\bar{H}_a} = a + b \times \frac{\bar{n}}{\bar{N}}$$

a, b = LOCATION CONSTANT ← GIVEN IN TABLE

$\bar{n}$ = MONTHLY AVERAGE DAILY SUNSHINE HOUR ← FROM TABLE

$\bar{N}$ = MONTHLY AVERAGE MAXIMUM POSSIBLE DAILY SUNSHINE HOUR

$$\bar{N} = \frac{2}{15} \cos^{-1}(-\tan\phi \cdot \tan\delta)$$

$\bar{H}$ = MONTHLY AVERAGE DAILY IRRADIATION DATA ON HORIZONTAL PLANE $\{MJ/m^2\}$

$\bar{H}_a$ = EXTRATERRESTRIAL IRRADIATION ON HORIZONTAL PLANE $\{MJ/m^2\}$

$$\omega_s = \cos^{-1}(-\tan$$

n = DAY NUMBER

$$H_a = \frac{24 \times 3600 \times G_{sc}}{\pi \times 10^6}\left[1 + 0.033\cos\left\{\frac{360 \times n}{365}\right\} \times \cos\phi \cos\delta \sin\omega_s + \frac{2\pi\,\omega_s}{360} \sin\phi \sin\delta\right]$$

G_{sc} = SOLAR CONSTANT $1367\ W/m^2$

ϕ = LATITUDE ANGLE OF A LOCATION

ω_s = SUNSET HOUR ANGLE

δ = DECLINATION ANGLE OF SUN

N CONSTANT ← GIVEN IN TABLE

Y AVERAGE DAILY SUNSHINE HOUR ← FROM TABLE

Y AVERAGE MAXIMUM POSSIBLE DAILY SUNSHINE HOUR

$$\bar{N} = \frac{2}{15}\cos^{-1}(-\tan\phi \cdot \tan\delta)$$

NUMBER

$$\omega_s = \cos^{-1}(-\tan\phi \cdot \tan\delta)$$

$$s\delta \sin\omega s + \frac{2\pi\,\omega s}{360} \sin\phi \sin\delta \Big]$$

ϕ = LATITUDE ANGLE OF A LOCATION

δ = DECLINATION ANGLE OF SUN

pb

CALCULATE MONTHLY DAILY AVERAGE TOTAL IRRADIATION ON HORIZONTAL SURFACE FOR JANUARY 17 IN BRISBANE

DATA

$a = 0.42$, $b = 0.22$ $\bar{n} = 7.5$

LATITUDE ANGLE OF BRISBANE $= -27.5$ ← $\phi = -27.5$

DECLINATION ANGLE OF SUN $= -20.9$ ← $\delta = -20.9$

$\bar{H} = ?$

$$\omega_s = \cos^{-1}(-\tan\phi \tan\delta)$$

$$= \cos^{-1}\left[-\tan(-27.5) \times \tan(-20.9)\right]$$

$$= 101.47$$

JAN 17 → $n = 17$ $\quad q_{sc} = 1367$

$$\bar{H}_a = \frac{24 \times 3600 \times G_{sc}}{\pi \times 10^6} \left[1 + 0.33 \cos\left(\frac{360n}{365}\right) \times \left[\cos\phi \cos\delta \sin\omega_s\right] + \frac{2\pi\,\omega_s}{360} \sin\phi \sin\delta \right]$$

$$= \frac{24 \times 3600 \times 1367}{3.1416 \times 10^6} \left[1 + 0.33 \cos\left(\frac{360 \times 17}{365}\right) \times \left[\cos(-27.5)\cos(-20.9) \sin 101.47\right] + \frac{2 \times 3.1416 \times 101.47}{360} \times \sin(-27.5) \times \sin(-20.9) \right]$$

$$= 42.81\ mJ/m^2$$

$$\bar{N} = \frac{2}{15} \cos^{-1}\left(-\tan\phi \times \tan\delta\right)$$

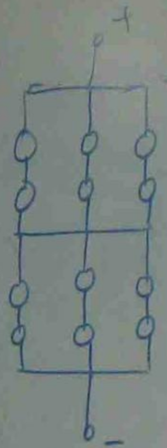
$$= \frac{2}{15} \cos^{-1}\left(-\tan(-27.5) \times \tan(-20.9)\right)$$

$$= 13.3$$

$$\bar{H} = \bar{H}_a \left(a + b \frac{\bar{n}}{\bar{N}} \right)$$

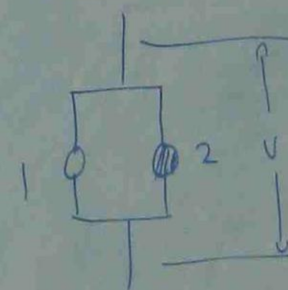
$$= 42.81 \left(0.42 + 0.22 \times \frac{7.5}{13.3} \right)$$

$$= 23.3\ mJ/m^2$$

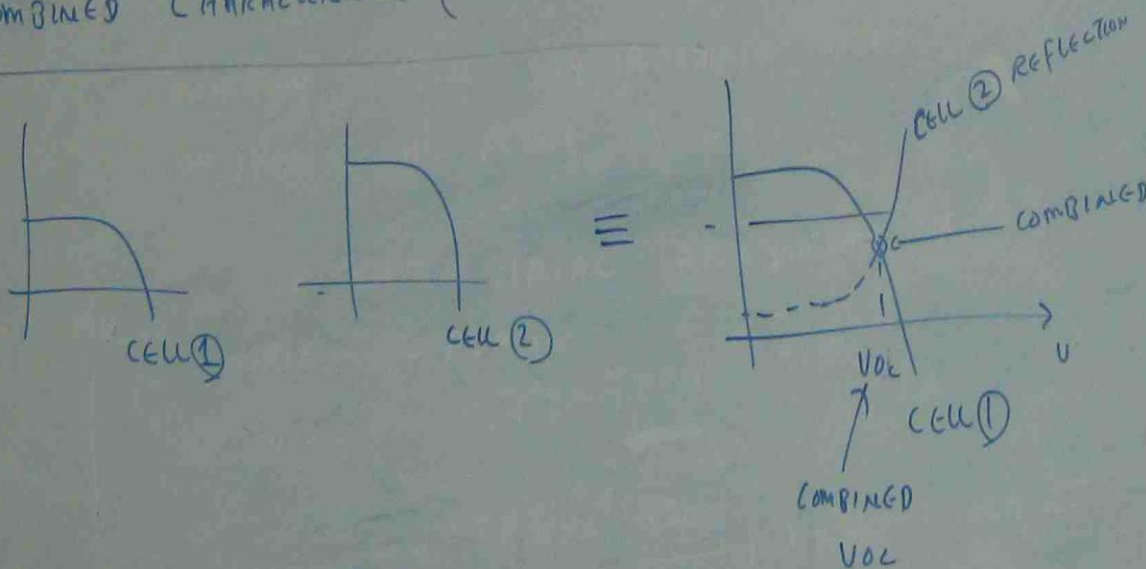


3 PARALLEL STRINGS
2 SERIES BLOCKS
2 CELLS PER SUBSTRING

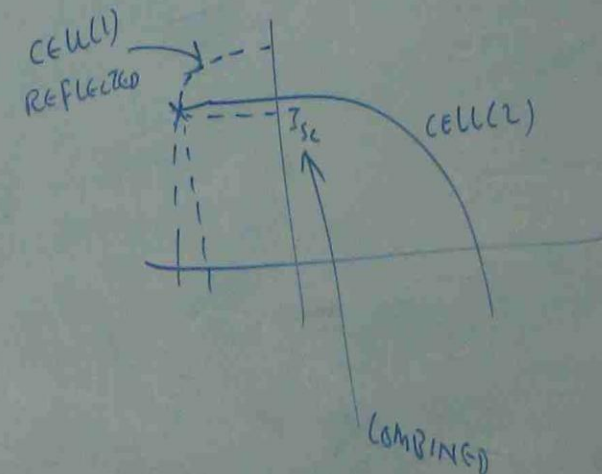
MIS MATCHED CELL (IV)



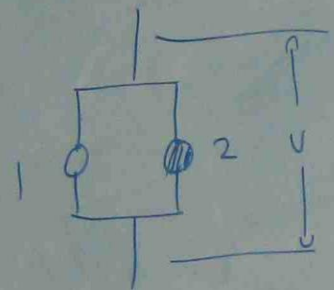
COMBINED CHARACTERISTICS (OPEN CIRCUIT)

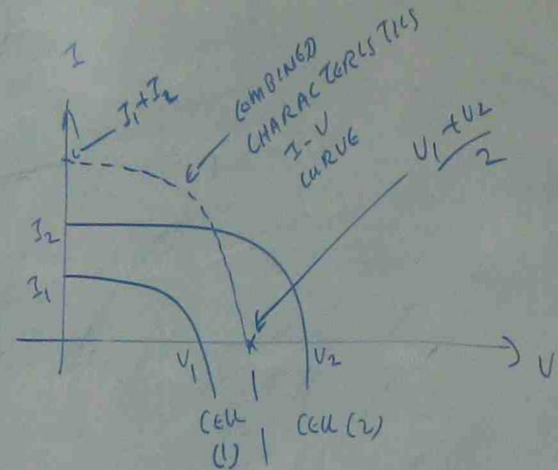


COMBINED SHORT CIRCUIT

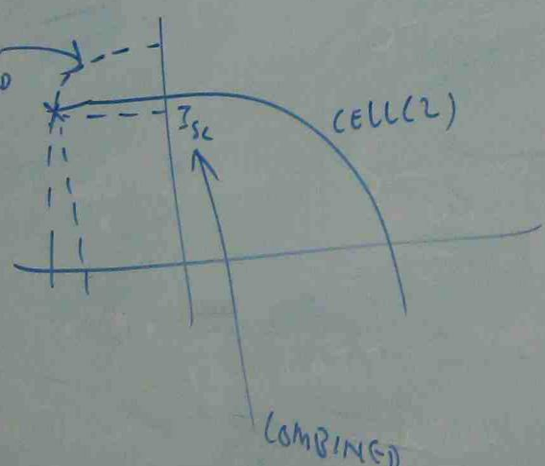


MIS MATCHED CELL (IV)



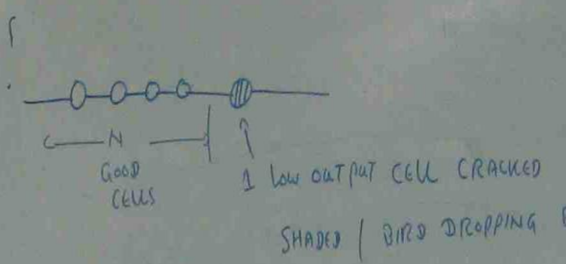


COMBINED SHORT CIRCUIT CHARACTERISTICS



HOT SPOT HEATING

MISMATCHED CELL WITH IN A MODULE CAN RESULT IN SOME CELL GENERATING AND SOME DISSIPATING POWER. IN THE WORST CASE, THE WHOLE OUTPUT OF GOOD CELLS CAN BE DISSIPATED IN BAD CELL ON SHORT CIRCUIT.

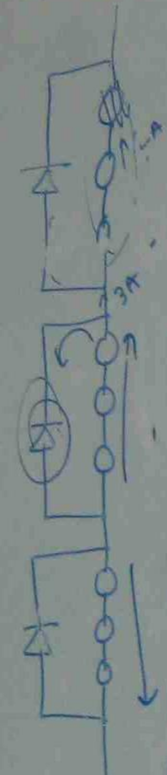


DISSIPATION OF POWER IN POOR CELL CAN CAUSE THE BREAK DOWN IN LOCALISED REGION OF THE CELL P-N JUNCTION.

AN ENORMOUS POWER DISSIPATION IN SMALL AREA CAUSES LOCAL OVER HEATING (OR) HOT SPOT AND AS RESULT, GLASS CRACKING (OR) MELTING OF SOLDER CAN HAPPEN.

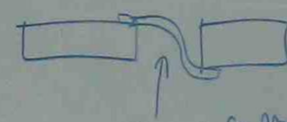
CAUSE

REA



ONE SOLUTION TO THE PROBLEM OF MISMATCHED CELL AND HOT SPOT IS TO ADD BY PASS DIODE TO THE CIRCUIT.

NOT ALL COMMERCIAL MODULES INCLUDE BY PASS DIODE. IF THEY DO NOT, CARE MUST BE TAKEN TO ENSURE THAT THE MODULES ARE NOT SHORT CIRCUITED FOR LONG PERIOD AND IT IS NOT BE SHADED BY SURROUNDING STRUCTURES (OR) ADJACENT ARRAYS.



ELECTRICAL INSULATION

CLASS (A) ⟶ 50V SYSTEM VOLTAGE

CLASS (B) ⟶ 50 ⟶ 1000V

EFFICIENCY LIMIT LOSSES & MEASUREMENT

ESSENTIAL PARAMETERS

OPEN CIRCUIT VOLTAGE (V_{OC})

SHORT CIRCUIT CURRENT (I_{SC})

FILL FACTOR (FF)

$$V_{OC} = \frac{kT}{q} \ln\left(\frac{I_L}{I_0} + 1\right)$$

$$I_0 = A\left(\frac{q D_e n_i^2}{L_e N_A} + \frac{q D_h}{L_h N_D}\right)$$

$$I_0 \simeq 1.5 \times 10^5 \, e^{\frac{E_g}{kT}}$$

$$E_g = hf$$

$$V_{oc} = \frac{KT}{q} \ln\left(\frac{I_L}{I_o} + 1\right)$$

$$I_o = A\left(\frac{q D_e n_i^2}{L_e N_A} + \frac{q D_h n_i^2}{L_h N_D}\right)$$

$$I_o \simeq 1.5 \times 10^{5}\, e^{\frac{E_g}{KT}} \; A/cm^2$$

$$E_g = h f$$

PV CELL INTERCONNECTION & MODULE FABRICATION

MAXIMUM VOLTAGE FROM SINGLE SILICON CELL = 600 mV

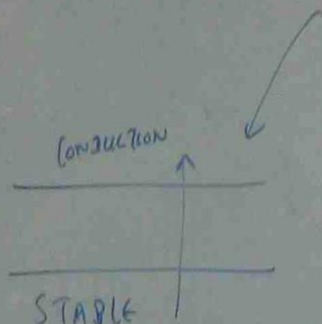
CELLS ARE CONNECTED IN SERIES TO OBTAIN THE DESIRED VOLTAGE

36 CELLS IN SERIES ARE USED FOR 12 V CHARGING SYSTEM

UNDER PEAK SUN LIGHT 100 mW/cm²

MAXIMUM CURRENT CAN BE DELIVERED BY CELL = 30 mA/cm²

EFFICIENCY LIMIT FOR BLACK BODY CELL



BLACK BODY SOLAR CELL IN EQUILIBRIUM EMITS PHOTONS. FOR PHOTONS OF ENERGY LARGER THAN BAND GAP, THE SOURCE OF THESE PHOTONS IS PREDOMINANTLY RECOMBINATION EVENTS IN SEMICONDUCTOR.

IN THERMAL EQUILIBRIUM, THESE EVENTS WILL BE BALANCED BY EQUAL GENERATION RATE.

EFFECT OF TEMPERATURE

THE SHORT CIRCUIT CURRENT OF SOLAR CELL IS NOT STRONGLY TEMPERATURE DEPENDANT.

THE RELATION BETWEEN SHORT CIRCUIT CURRENT & OPEN CIRCUIT VOLTAGE

$$I_{sc} = I_0 \left(e^{\frac{qV_{oc}}{kT}} - 1 \right)$$

$$\frac{dV_{oc}}{dT} = 2.3\ mV/C$$

...RRENT of SOLAR CELL IS NOT STRONGLY ...NT.

...N SHORT CIRCUIT CURRENT & OPEN CIRCUIT

$$\ldots o \left(e^{\frac{qV_{oc}}{kT}} - 1 \right)$$

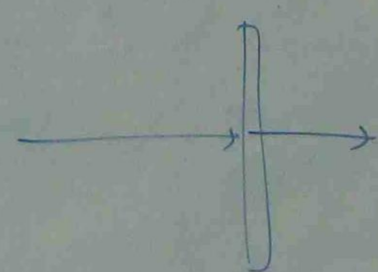
... 2-3 mV/°C

EFFICIENCY & LOSSES

SILICON IS QUITE REFLECTIVE. REFLECTION loss = 10%

ELECTRICAL CONTACT AT P & N REGION BLOCKS 5 → 15% OF INCOMING SUN LIGHT

IF THE CELL IS NOT THICK ENOUGH, SOME OF THE LIGHT OF APPROPRIATE ENERGY THAT DOES NOT GET COUPLES INTO THE CELL WILL PASS STRAIGHT OUT OF THE BACK



OPEN CIRCUIT VOLTAGE LOSSES

THE FUNDAMENTAL PROCESS DETERMINING V_{oc} IS RECOMBINATION IN SEMICONDUCTOR. THE LOWER THE RECOMBINATION IN SEMICONDUCTOR, THE HIGHER THE V_{oc}.

INTERACTION OF LIGHT WITH SEMICONDUCTOR

THE TRANSMITTED LIGHT CAN BE ABSORBED WITHIN THE SEMICONDUCTOR BY USING IT'S ENERGY TO EXCITE ELECTRON FROM OCCUPIED LOW ENERGY STATE TO UNOCCUPIED HIGH ENERGY STATE.

E_i = INITIAL STATE ENERGY

E_f = FINAL STATE ENERGY

h = PLANK CONSTANT

f = FREQUENCY OF LIGHT WAVE

THE TRANSMITTED LIGHT IS ATTENUATED AS IT PASSES THROUGH THE SEMICONDUCTOR.

$$E_f - E_i = hf$$

THE RATE OF ABSORPTION OF LIGHT IS PROPORTION TO INTENSITY OF FLUX OR PHOTON FOR A GIVEN WAVELENGTH

AS PHOTON ENERGY hf INCREASES, IT CREATES THE MOMENTUM AT WHICH TRANSITION OCCURS.