Photovoltaic Systems Engineering

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Reference for this lecture:

Photovoltaic Systems Engineering Third Edition CRC

Roger Messenger, Jerry Ventre

PV System Design Examples

Module and Fan

PV Fan with Battery backup

PV-Powered Water Pumping System

PV-Powered Parking Lot Lighting Systems

A Cathodic Protection System

A Portable Highway Advisory Sign

A Critical Need Refrigerator System

PV System Design Procedures

Determination of average daily PV system loads

Battery selection procedure

Array sizing and tilt procedure

PV System Design Procedures

Determination of average daily PV system loads

1. Identify all loads to be connected to the PV system(dc and ac.

2. Determine average daily Ah for each load according to operating hours data.

3. Add up the Ah for the dc loads, being sure all are at the same voltage.

4. If there is a require for dc-dc converter, then the converter input Ah for these loads needs to account.

5. For ac loads, the dc input current to the inverter must be determined.

6. Add the Ah for the dc loads to the Ah for the ac loads, then divide by the wire efficiency factor and the battery efficiency factor to obtain the corrected average daily Ah for the total load.

7. The total ac load power will determine the required size of the inverter.

PV System Design Procedures

Battery selection procedure:

1. Determine the number of days storage required, depending on whether the load will be noncritical or critical.

2. Determine the amount of storage required in Ah.

3. Determine the allowable level of discharge.

4. Check to see whether a temperature correction factor is required.

5. Check to see whether the rate of charge exceeds the rate specified by the battery manufacturer.

6. Divide the final corrected battery capacity by the capacity of the chosen battery.

PV System Design Procedures

Array sizing and tilt procedure

1. Determine the design current for each month of the year.(Ah/psh)

2. Determine the worst-case (highest monthly) design current for each tilt angle.

3. For a fixed mount, select the tilt angle that results in the lowest worst case design current.

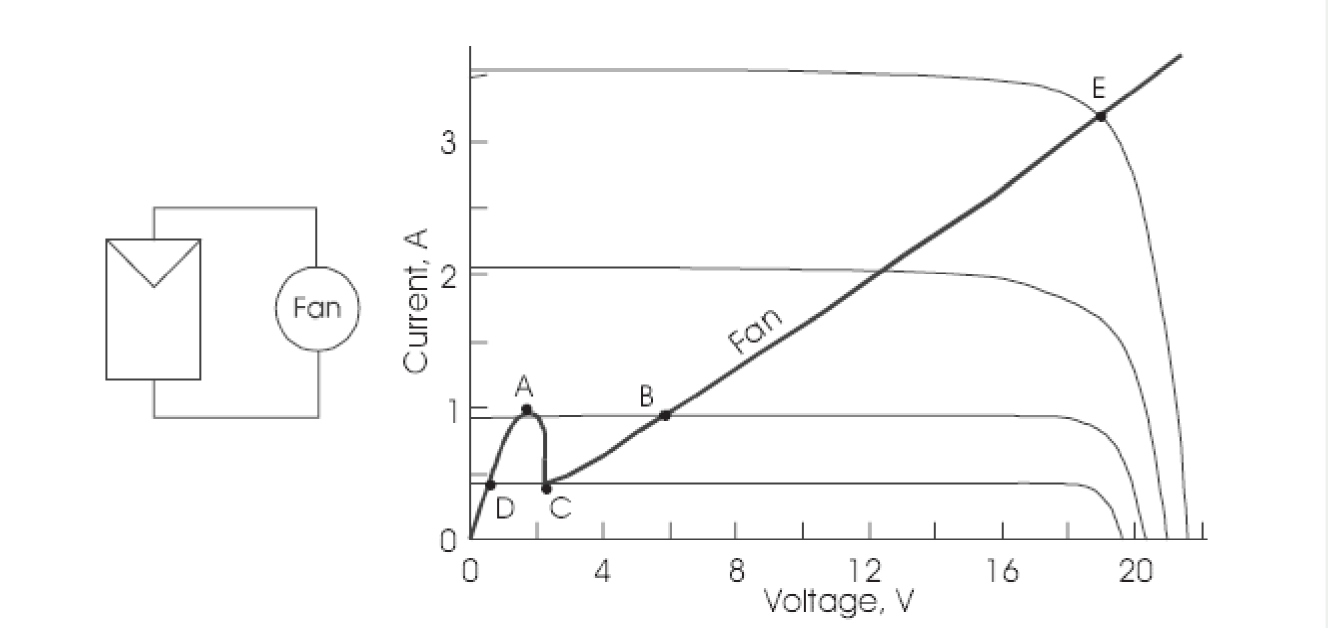
4. If tracking mounts are considered, then determine the design current for one- and two-axis trackers.

5. Determine the derated array current by dividing the design current by the module derating factor.

6. Determine the number of modules in parallel by dividing the derated array current by the rated module current.

7. Determine the number of modules in series by dividing the nominal system voltage by the lowest anticipated module voltage of a module supplying power to the system.

Module and Fan



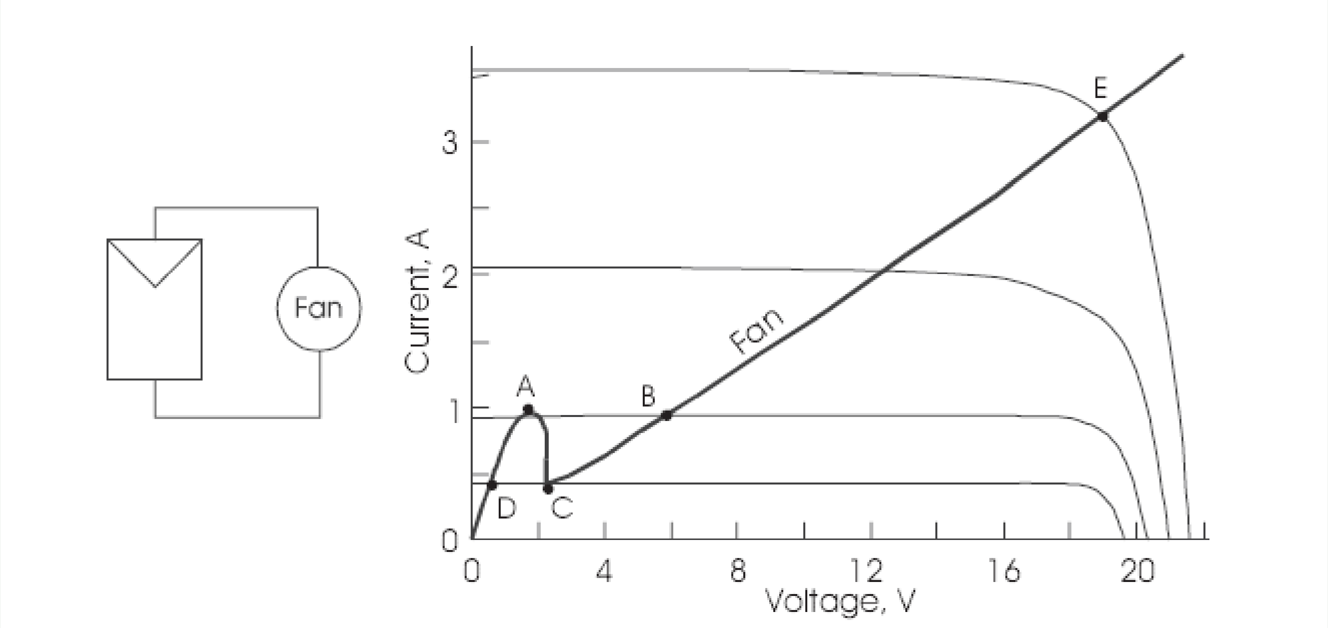
As irradiance increase: O → D → A → C→ B → E

As irradiance decrease: E → B → C→ D → O

If there is no concern for the exact quality of air the design becomes nearly trivial.

Larger modules will cost more but deliver more air of lower irradiance.

Module and Fan



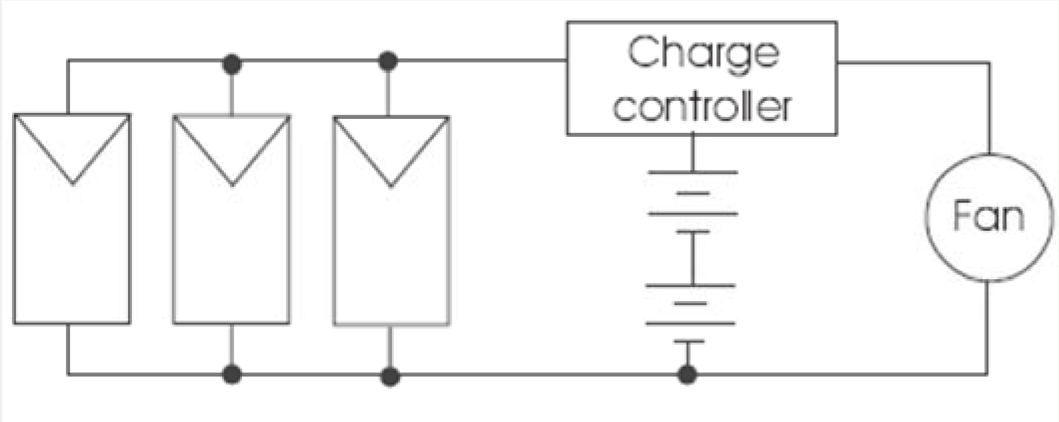
Using maximum power tracking or MPT leads to:

Start at lower irradiance level.

Greater air flow.

Example 1: PV Fan with Battery Backup

What happen in low irradiance level or night or cloudy days?



24 W

Better working independent to irradiance level.

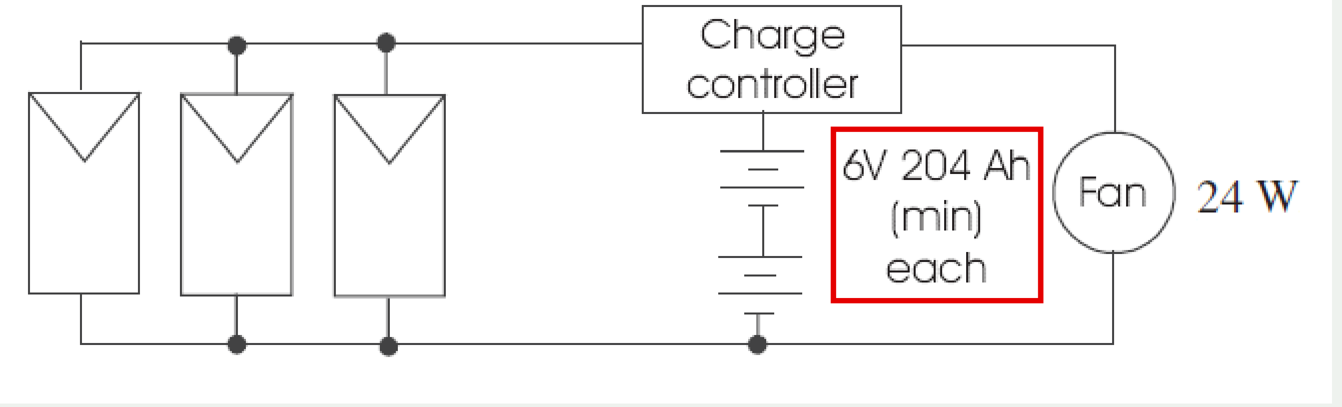
Continuous working.

Better quality of air.

Design procedure ?

Let fan power 24 W

Example 1: PV Fan with Battery Backup



24 W during a day → 24×24 = 576 Wh

Using 12 V batteries → 576/12 = 48 Ah

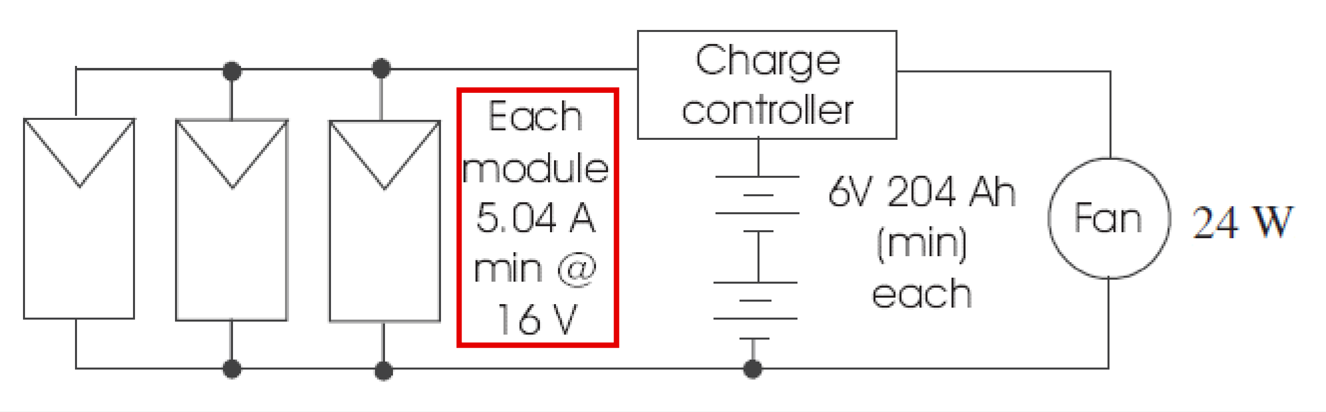
Batteries efficiency → 48/0.9 = 53.3 Ah

Wiring efficiency → 53.3/0.98 = 54.4 Ah

Let three day with no sun → 54.4 × 3 = 163 Ah

Let 20% deep of discharge → 163/0.80 = 204 Ah

Example 1: PV Fan with Battery Backup



Lets specify the PV power needs.

Suppose 4 hours of full sun is available in the worst case.

We need 54.4 Ah during a day.

Let 10% degradation of module (dust or temperature)

$$54.4 / 0.9 = 60.4 \text{ Ah}$$

Let three module each → $60.4 / (3 \times 4) = 5.04$ A

Example 2: PV-Powered Water Pumping System

LPD: Liter per day(pumping requirement)

h: Effective pumping high(m) → $h = h_0/\eta_{pipe}$

Potential Energy:

$$W_p = g.LPD.h$$

PT: Pumping time

PTF: Pumping time factor (Extra facility i.e. MPT)

η_p: Efficiency of pump

Pump HP:

$$HP = \frac{W_p}{\eta_p}\frac{1}{3600.PT.PTF.746} = \frac{g}{3600\times 746}\frac{LPD.h}{PT.PTF.\eta_p}$$

Example 2: PV-Powered Water Pumping System

Pump HP:

$$Hp = \frac{W_p}{\eta}\frac{1}{3600.PT.746} = \frac{g}{3600\times 746}\frac{LPD.h}{PT.PTF.\eta}$$

Design requirement:

$$LPD = 7600, \quad h_0 = 60\,m, \quad PT = 6\,\text{hours}$$

HP pump requirement:

$$HP = \frac{9.8}{3600\times 746}\frac{7600\times 60/0.95}{PT.PTF.\eta} = 1.17$$

- Use 1 Hp pump with 1.25 service factor
- Use 1.5 Hp pump

Example 2: PV-Powered Water Pumping System

$$HP = \frac{9.8}{3600 \times 746} \frac{7600 \times 60 / 0.95}{PT.PTF.\eta} = 1.17$$

Use $1\,Hp$ pump with 1.25 service factor

Cell requirement: (Suppose 10% degradation factor)

$$1.17\,HP \times 746 \times 1.1 = 960\,W$$

$$\rightarrow 19 \times 50\,W \quad Module$$

(Let PFT=1.25)

$$\rightarrow \frac{19 \times 50\,W}{1.25} = 15\,Module$$

Dilemma: A MPT or 4 more Module?

Example 2: PV-Powered Water Pumping System

Alternative design approach:

$$LPD = 7600, \quad h_0 = 60\,m, \quad PT = 6\,\text{hours}$$

Pumping characteristics of a typical dc submersible pump.

Lift, ft	GPM	Pump Current	Pump Voltage	PV watts
150	6.4	6.00	90	675
150	12	8.95	120	1340
175	6.2	5.56	90	625
175	13.7	8.82	120	1320
200	7.6	6.64	105	875
200	11.0	8.42	120	1260
250	6.4	7.76	120	1164

$$LPD = 7600 \;\rightarrow\; GPM = \frac{7600}{3.785 \times 6 \times 60} = 5.58$$

$$h_0 = 60\,m = 197' \;\rightarrow\; h = h_0 / .95 = 207'$$

$$\frac{W}{GPM} = \frac{207-200}{250-200}\left(\frac{1164}{6.4} - \frac{875}{7.6}\right) + \frac{875}{7.6} = 125$$

$$PV\ watts = 698\,W$$

Example 2: PV-Powered Water Pumping System

$PV\ watts = 698W$

Pumping characteristics of a typical dc submersible pump.

Lift, ft	GPM	Pump Current	Pump Voltage	PV watts
150	6.4	6.00	90	675
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175	13.7	8.82	120	1320
200	7.6	6.64	105	875
200	11.0	8.42	120	1260
250	6.4	7.76	120	1164

PV voltage:

$$\begin{cases} 120 \rightarrow 1260 \\ 105 \rightarrow 875 \end{cases} \Rightarrow \quad 698\ W \rightarrow 98.1\ V$$

PV current:

$$698\ W / 98.1\ V \rightarrow 7.12\,A$$

Another option:

Smaller pump(working all day), more PV+ Battery storage

Example 3: A PV-Powered Parking LOT Lighting System

Clearly we need battery storage.

Determination of illumination level.

Illumination level unit: Lumen of ft-candle

Illumination engineering society publishes guidelines for illumination levels for various spaces.

Parking lot lighting needs approximately 1 f-c (security).

A desk for normal work needs approximately 50 f-c.

Direct sun light provides about 10,000 f-c.

Example 3: A PV-Powered Parking LOT Lighting System

Approximate luminous efficacy for several light sources.

Source	Luminous Efficacy, l/w	Lamp Lifetime, hr
25 W incandescent	8.6	2500
100 W incandescent	17.1	750
100 W long-life incandescent	16.0	1125
50 W quartz incandescent	19.0	2000
T-8 fluorescent	75–100	12,000–24,000+
Compact fluorescent	27–80	6,000–10,000
Metal halide	80–115	10,000–20,000
High-pressure sodium	90–140	10,000–24,000+
3.6 W LED array	~130	100,000+

Example 3: A PV-Powered Parking LOT Lighting System

Lumens calculation.

$$\text{Lumens} = \frac{FC.A}{CU.MF.RCR}$$

FC: desired illumination in f-c.

A: Area in ft^2.

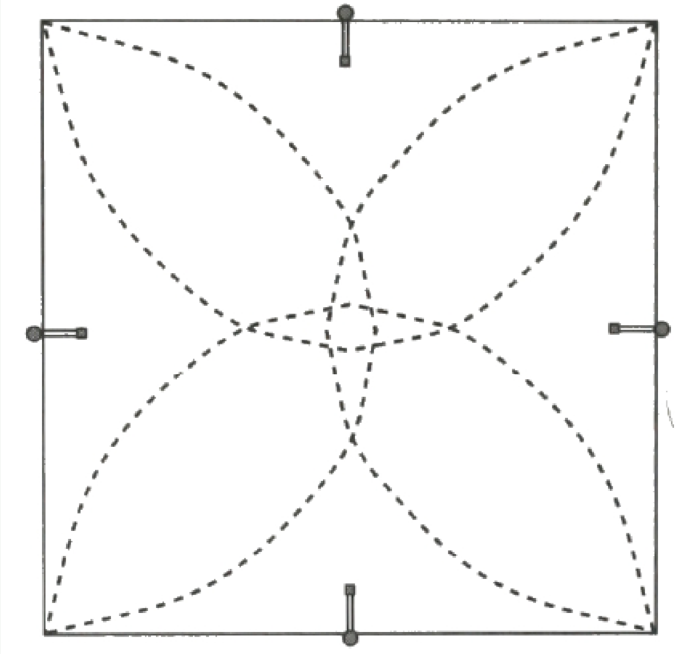
CU: The amount of light emerged from the fixture.

MF: Accounts for dirt on the lamp, lens and reflector.

RCR: Room cavity ratio, depends on the room size, color, floor color and room contents.

Example 3: A PV-Powered Parking LOT Lighting System

Let a parking of 160×160 ft and we need a 2 f-c illumination.



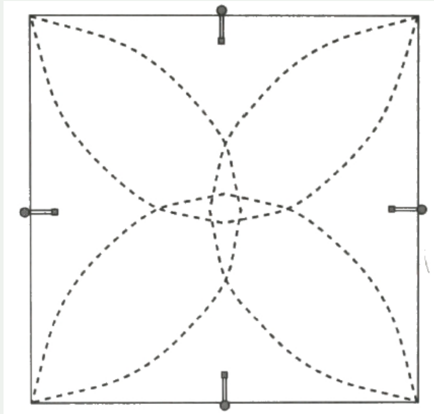
Let CU=0.8 and MF=0.9 and RCR=1.

So total needed lumens is:

$$\text{Lumens} = \frac{2\times160\times160}{0.8\times0.9\times1} = 71{,}111$$

Example 3: A PV-Powered Parking LOT Lighting System

Determination of lamp wattage and daily load



$$\text{Lumens} = \frac{2\times160\times160}{0.8\times0.9\times1} = 71{,}111$$

Lumens of each lamp:

$$\text{Lumens/lamp} = 71{,}111/4 = 17{,}778$$

Metal halide	80–115	10,000–20,000

$$\Rightarrow 175\ \text{W lamp is ok.}$$

$$\text{Balast Usage} \quad \Rightarrow 175\ \text{W}/0.9 = 200\ \text{W}$$

Example 3: A PV-Powered Parking LOT Lighting System

Now we must consider the worst case need during the year.

Suppose night time is 13 hours in the winter and 9 hours in the summer.

$$\text{Winner Energy Consumption} = 200 \times 13 = 2600\,Wh$$

$$\text{Summer Energy Consumption} = 200 \times 9 = 1800\,Wh$$

Determination of Battery storage requirements

Suppose two days of storage needed so:

$$\text{Battery } Ah = \frac{2 \times 2600\,Wh}{0.98 \times 0.8 \times 24} = 276\ Ah$$

We assume 24 V battery with 80% depth of dischareg.

Example 3: A PV-Powered Parking LOT Lighting System

Determination of PV cell requirements

Suppose 4 hours of full sun is available in the worst case.

Suppose 6 hours of full sun is available in the best condition.

$$PV\ \ watts = \frac{2600\,Wh}{0.98 \times 0.9 \times 4} = 737\ \ W \ \ \rightarrow\ \ 750\ W$$

Winter situation:

$$\text{Load}\quad 13 \times 200 = 2600\,W\,, \qquad \text{Generation} = 750 \times 4 = 3000\ \text{W}$$

Summer situation:

$$\text{Load}\quad 9 \times 200 = 1800\,W\,, \qquad \text{Generation} = 750 \times 6 = 4500\ \text{W}$$

Example 3: A PV-Powered Parking LOT Lighting System

Winter situation:

Load $13 \times 200 = 2600W$, Generation $= 750 \times 4 = 3000$ W

Summer situation:

Load $9 \times 200 = 1800W$, Generation $= 750 \times 6 = 4500$ W

A. Turn off lights during nights in winter.

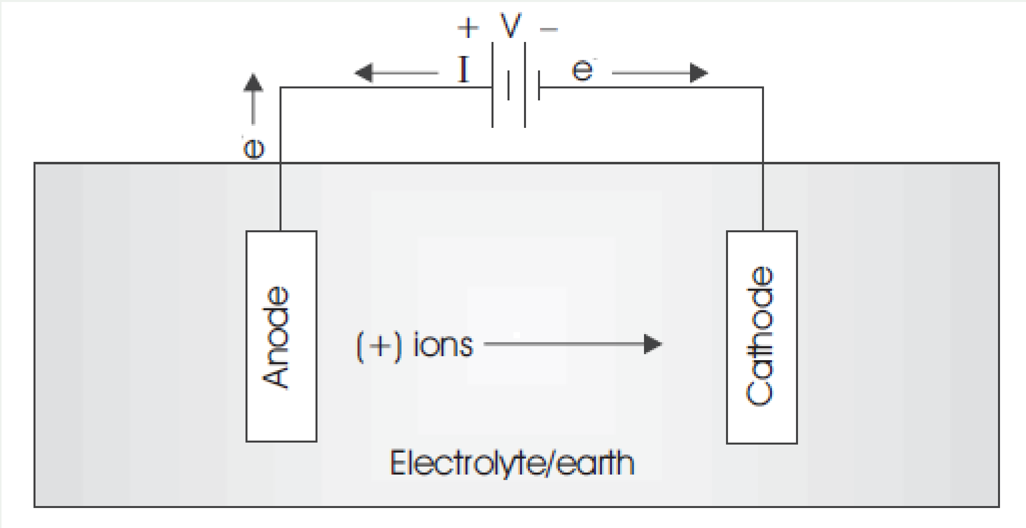
B. Use charge controller.

C. Use more battery(longer than two days of reserve).

D. Tilting the array.

Example 4: A Cathodic Protection System

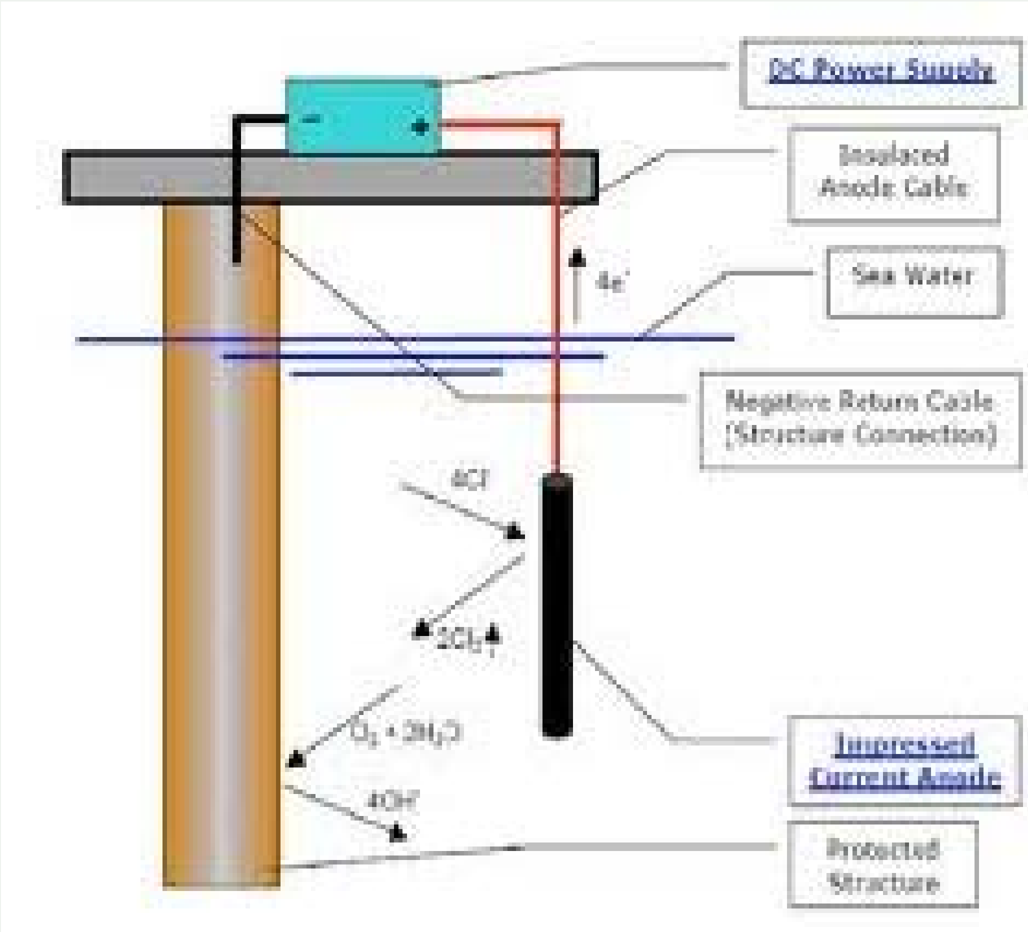
Mechanism of cathodic protection



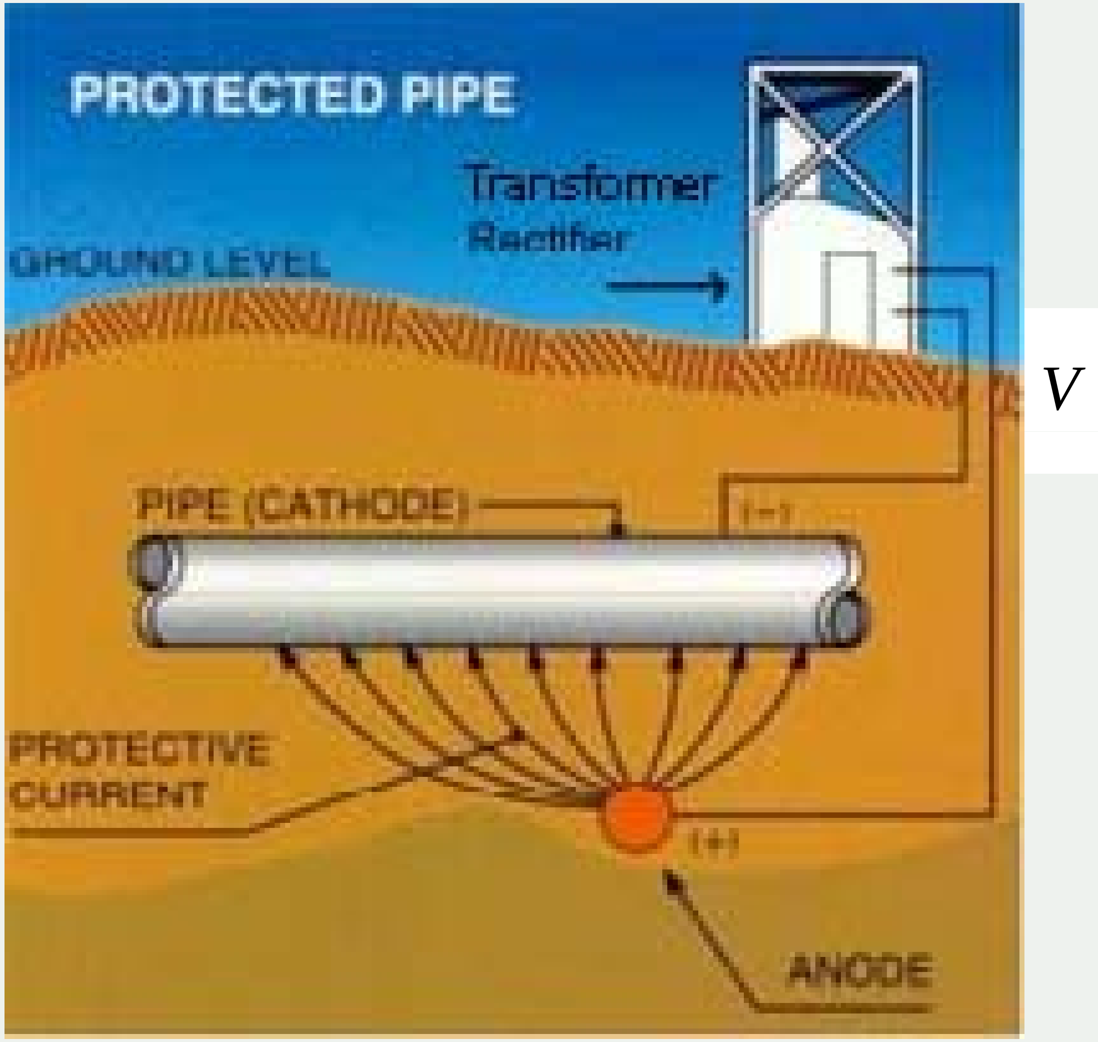
The U.S. government requires that any underground storage of toxic materials or petrochemicals have cathodic protection.

To prevent ion loss from cathode, different current densities are required for different materials, ranging from a fraction of mA/ft^2 to several mA/ft^2.

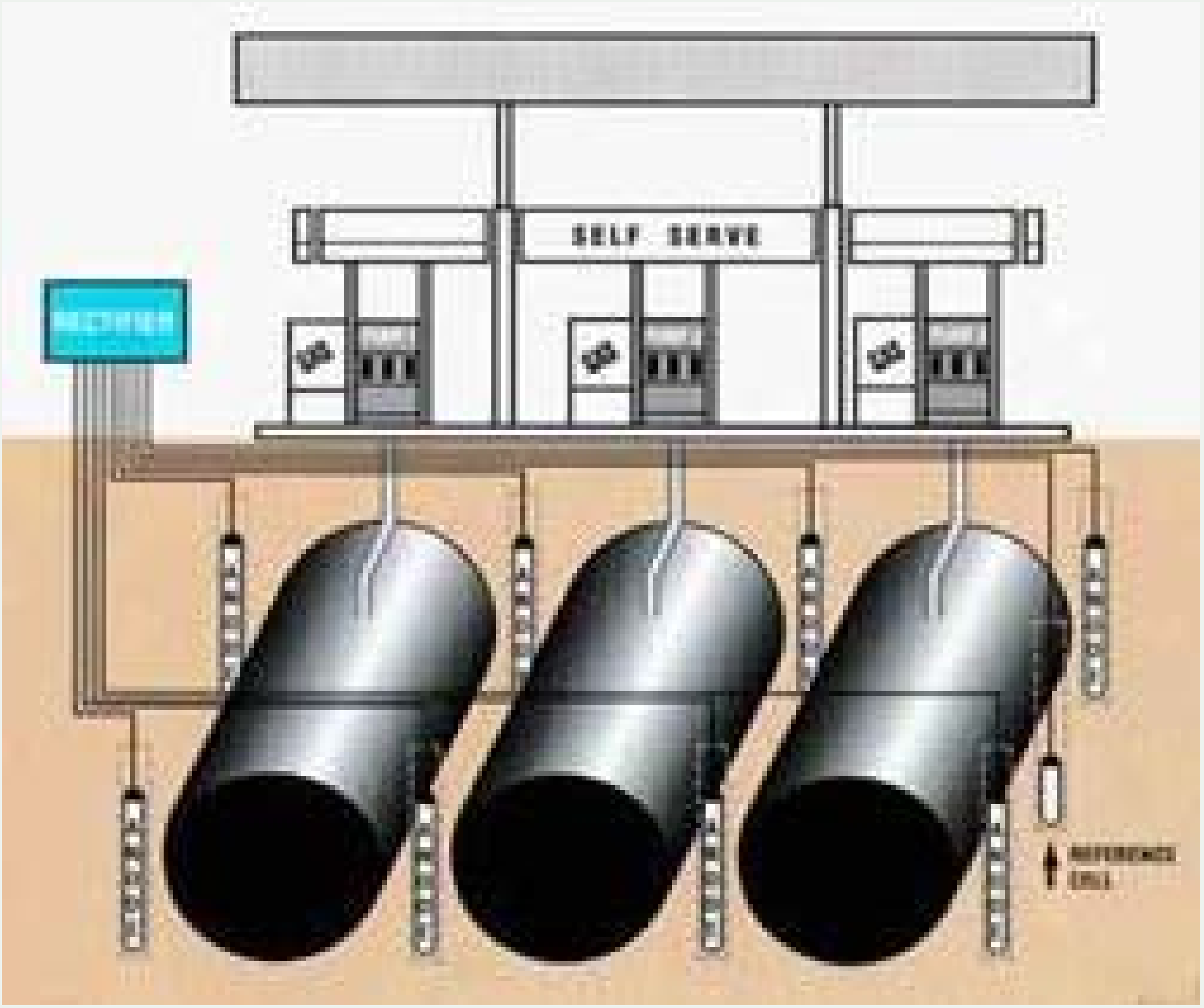
Example 4: A Cathodic Protection System



Example 4: A Cathodic Protection System



Example 4: A Cathodic Protection System



Example 4: A Cathodic Protection System

1- Determine system current needs. Small current,… and large,…

2- Choose the anode, typical anodes will carry a maximum current of 2A, so current is not limiting factor. Resistance between cathode and anode is more important issues.

Table 7.4 Anode Resistance to Ground in Standard 1000 Ω-cm Soil

Anode Diameter (in.)	Anode Length (ft)				
	4	5	6	7	8
3	5.0 Ω	4.3 Ω	3.7 Ω	3.3 Ω	3.0 Ω
4	4.7 Ω	4.0 Ω	3.5 Ω	3.1 Ω	2.8 Ω
6	4.1 Ω	3.5 Ω	3.1 Ω	2.8 Ω	2.5 Ω
8	3.7 Ω	3.2 Ω	2.9 Ω	2.6 Ω	2.3 Ω
10	3.5 Ω	3.0 Ω	2.7 Ω	2.4 Ω	2.2 Ω

3- Update the resistance by considering the actual soil.

Example 4: A Cathodic Protection System

Suppose we need cathodic protection for a 100 ft^2 still storage in a sandy soil.

- * Still storage need 1mA/ft^2 so we need 0.1 A for storage.
- * Suppose a 3in. Diameter, 5-ft long anode(4.3 Ω for 1000 Ω-cm soil).
- * Total resistance of sandy soil is 25×4.3=107.5 Ω
- * Required voltage is 107.5×0.1=10.5 V

$$\text{Daily use} = \frac{0.1 \times 24}{0.98 \times 0.9} = 2.72 \quad Ah$$

- * Let we consider 5 days as reserve so,

$$Battery\, need = \frac{2.72 \times 5}{0.8} = 17 \quad Ah$$

Example 4: A Cathodic Protection System

- Now suppose worst case daily peak sun hours be 4h.

- Cell current:

$$\text{Cell Current} = \frac{2.72}{4 \times 0.9} = 0.76 \quad A, \quad 12\ V$$

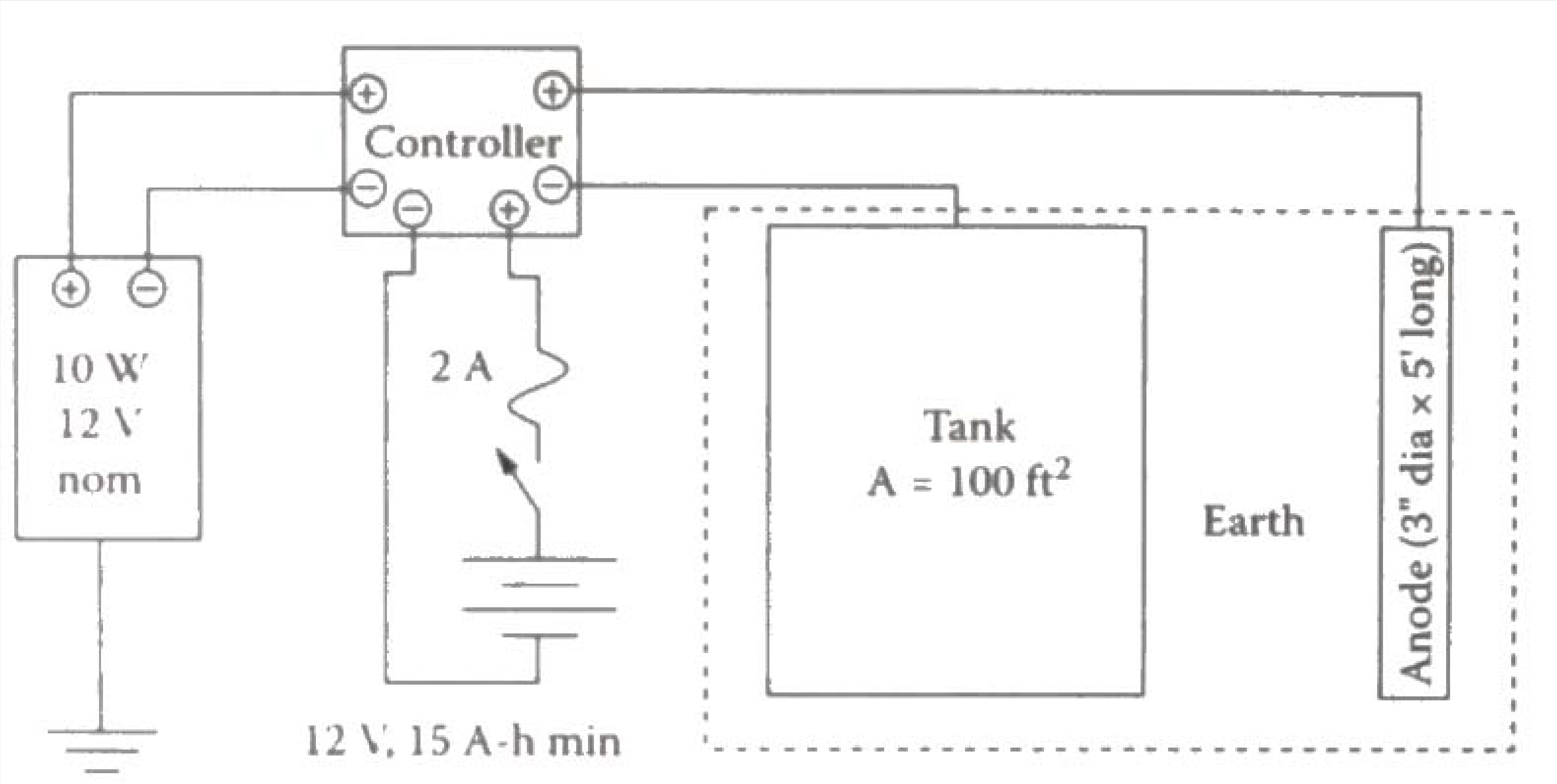
If current in summer situation is big so:

A. Use charge controller.

B. Use more battery(longer than 5 days of reserve).

C. Tilting the array.

Example 4: A Cathodic Protection System



Example 5: A Portable Highway Advisory Sign

Example 5: A Portable Highway Advisory Sign

A different method of design!

Suppose one use a PV on top of sign. 4 Module each 2×5 ft.

Determine the available average power.

$$4\times 2\times 5(ft^2)\times 0.3048^2(m^2/ft^2)\times 1000(W/m^2)\times 0.18=669\ \ W$$

Since of degradation, MPPT and wiring during the sunlight

$$\text{Hourly Available power}=669\times 0.80\times 0.96\times 0.98=503\ \ W$$

Let a 12 V battery system so,

$$\text{Hourly Available Current}=503/12=41.9\ \ A$$

Example 5: A Portable Highway Advisory Sign

$$\text{Hourly Available Current} = 503/12 = 41.9\ \ A$$

Available average monthly irradiance for the region(PSH) in the horizontal position is:

	Jan	Feb	Mar	Apr	May	Jun
Peak sun (h)	2.6	3.4	4.5	5.7	6.2	6.4
	Jul	Aug	Sep	Oct	Nov	Dec
Peak sun (h)	6.2	5.7	4.8	4.1	2.9	2.4

Battery need(suppose 80% deep charge and 5 days of storage):

$$\text{Battery Ah} = 41.9 \times 2.4 \times 5 / 0.8 = 628\ \ Ah$$

Example 5: A Portable Highway Advisory Sign

Available power for each hour of the day at different month(90% efficiency of battery storage).

$$\text{Hourly Available power} =$$
$$\text{Hourly Available power at sunlight} \times PSH \times 0.9/24 =$$
$$PSH \times 503 \times 0.9/24 = PSH \times 18.87$$

	Jan	Feb	Mar	Apr	May	Jun
Peak sun (h)	2.6	3.4	4.5	5.7	6.2	6.4
Avg power (W)	49	64	85	107	117	120
	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Peak sun (h)	6.2	5.7	4.8	4.1	2.9	2.4
Avg power (W)	117	107	90	77	55	45

Example 5: A Portable Highway Advisory Sign

With a microcontroller in the system, it is straightforward to program the user of the average power that will be used to implement any particular program.

If the system is not programmed to use maximum available power, then the controller needs to have the capability to disconnect the PV array from batteries.

Example 6: A Critical-need Refrigeration System

Refrigeration for medication.

We need 99% availability.

The refrigerator is a 10.12 ft^3 unit with high energy efficiency.

The refrigerator is rated as 171 kWh/yr or 0.47 kWh/day.

The refrigerator is *ac* and use an inverter with 94% efficiency.

Suppose that it use only 6 hours a day so 470/6=78 W

So, a 300-500 W inverter is ok. Larger one are not good since of reduction in efficiency.

Load of refrigerator in one day is: 470/0.94/0.98=510 Wh/day

Example 6: A Critical-need Refrigeration System

Battery Sizing

$$Ah = (dailyAh)\frac{days}{D_T D_{ch} D_{deep}}$$

Days: Days of autonomy.

D_T: Temperature derating factor.

$$D_T = \frac{C}{C_{80^\circ F}} = 0.00575T + 0.54 \qquad 20 < T < 80^\circ F$$

D_{ch}: Charge discharge derating factor.

D_{deep}: Depth of discharge.

Example 6: A Critical-need Refrigeration System

Battery Sizing

Load of refrigerator in one day is: 470/0.94/0.98=510 Wh/day

$$Ah = 510/12 = 42.5\ Ah \xrightarrow[\text{wiring}]{\text{Ch \& Dis}} 42.5/0.88 = 48.3\ Ah$$

$$\xrightarrow[\text{discharge}]{\text{deep of}} 48.3/0.8 = 60.4\ Ah$$

Critical days of reserve:

In July PSH=3.93 at lattitude+15°, 3.71 at latitude and 3.36 at latitude-15°

$$D_{crit} = (0.2976 \times 3.93^2) - (4.7262 \times 3.93) + 24 = 10\ days$$

$$Battery\ need = 60.4 \times 10 = 604\ Ah\ \ at\ \ 12\ V\ \ at\ \ C/240\ rate$$

Example 6: A Critical-need Refrigeration System

Array Sizing with MPPT:

$$\xrightarrow[\text{wiring}]{\text{Ch \& Dis}} 42.5/0.88 = 48.3\ Ah \qquad \rightarrow 48.3 \times 12 = 580\ Wh$$

Since of degradation and efficiency of MPPT

$$\text{Array watts} = \frac{580}{0.85 \times 0.9 \times 3.93} = 192\ W \qquad \rightarrow 4 \times 50 = 200\ W$$

Array Sizing without MPPT:

$$\xrightarrow[\text{wiring}]{\text{Ch \& Dis}} 42.5/0.88 = 48.3\ Ah \qquad \xrightarrow[\text{array}]{\text{each}} 48.3/3.93 = 12.45\ A$$

Since of degradation

$$12.45/0.9 = 13.8\ A \qquad \rightarrow 2 \times (21.8V, 7.99\ A, 17.2V and\ 7.15\ A)$$

$$\rightarrow 2 \times 123 = 246\ W$$

Example 6: A Critical-need Refrigeration System

Tracking array mount

Critical days of reserve: In July PSH=5.14

$$D_{crit} = (0.2976 \times 5.14^2) - (4.7262 \times 5.14) + 24 = 7.57 \ days$$

$$Battery \ need = 60.4 \times 7.57 = 457 \ Ah \ \ at \ \ 12 \ V \ \ at \ C/120 \ rate$$

Array Sizing with MPPT: $\xrightarrow[wiring]{\text{Ch \& Dis}} 42.5/0.88 = 48.3 \ Ah \rightarrow 48.3 \times 12 = 580 \ Wh$

Since of degradation and efficiency of MPPT

$$\text{Array watts} = \frac{580}{0.85 \times 0.9 \times 5.14} = 147 \ W$$

$$\rightarrow 3 \times 50 = 150 \ W$$

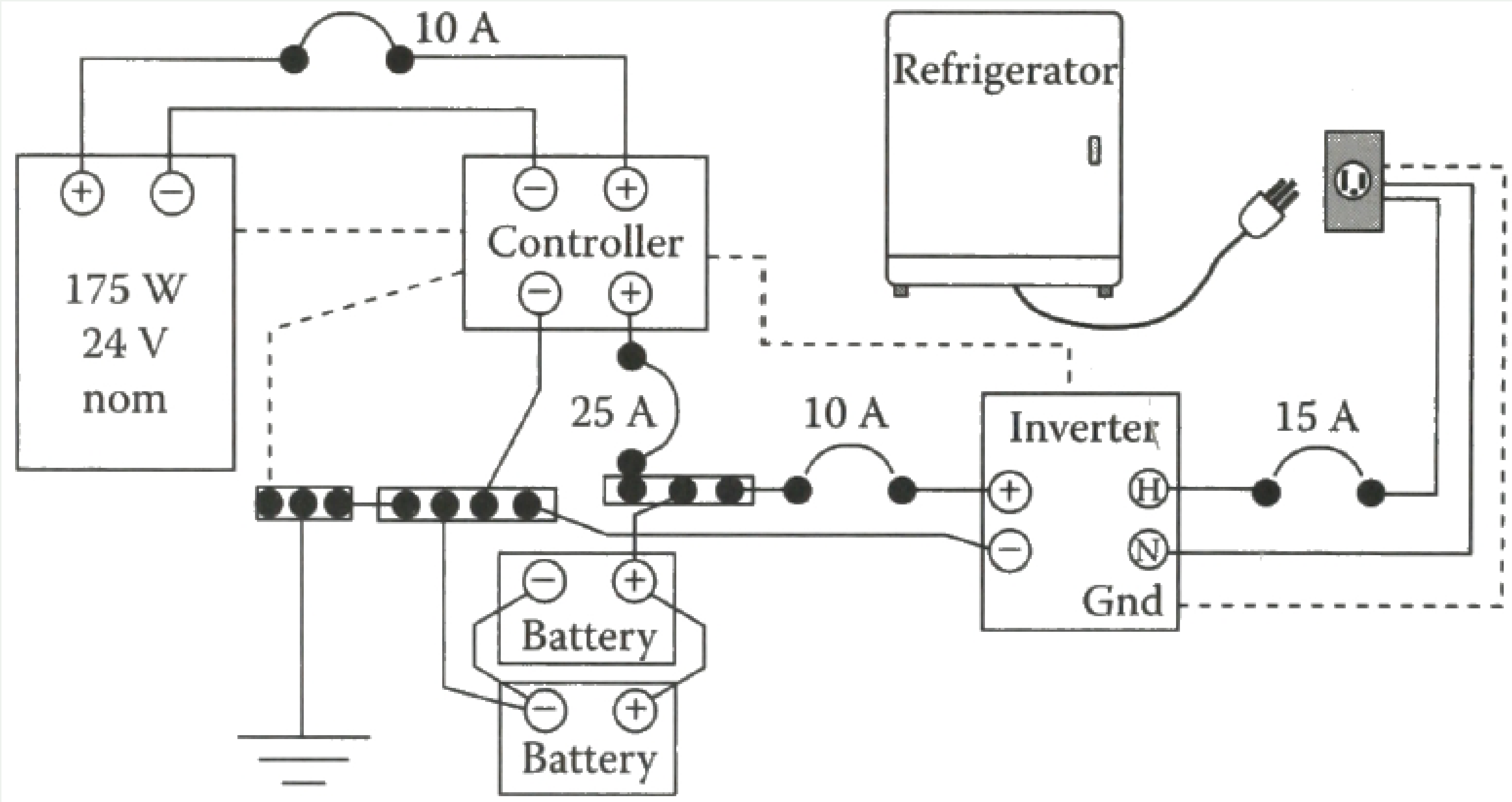
Array Sizing without MPPT $\xrightarrow[wiring]{\text{Ch \& Dis}} 42.5/0.88 = 48.3 \ \xrightarrow[array]{\text{each}} 48.3/5.14 = 9.39 \ A$

Since of degradation

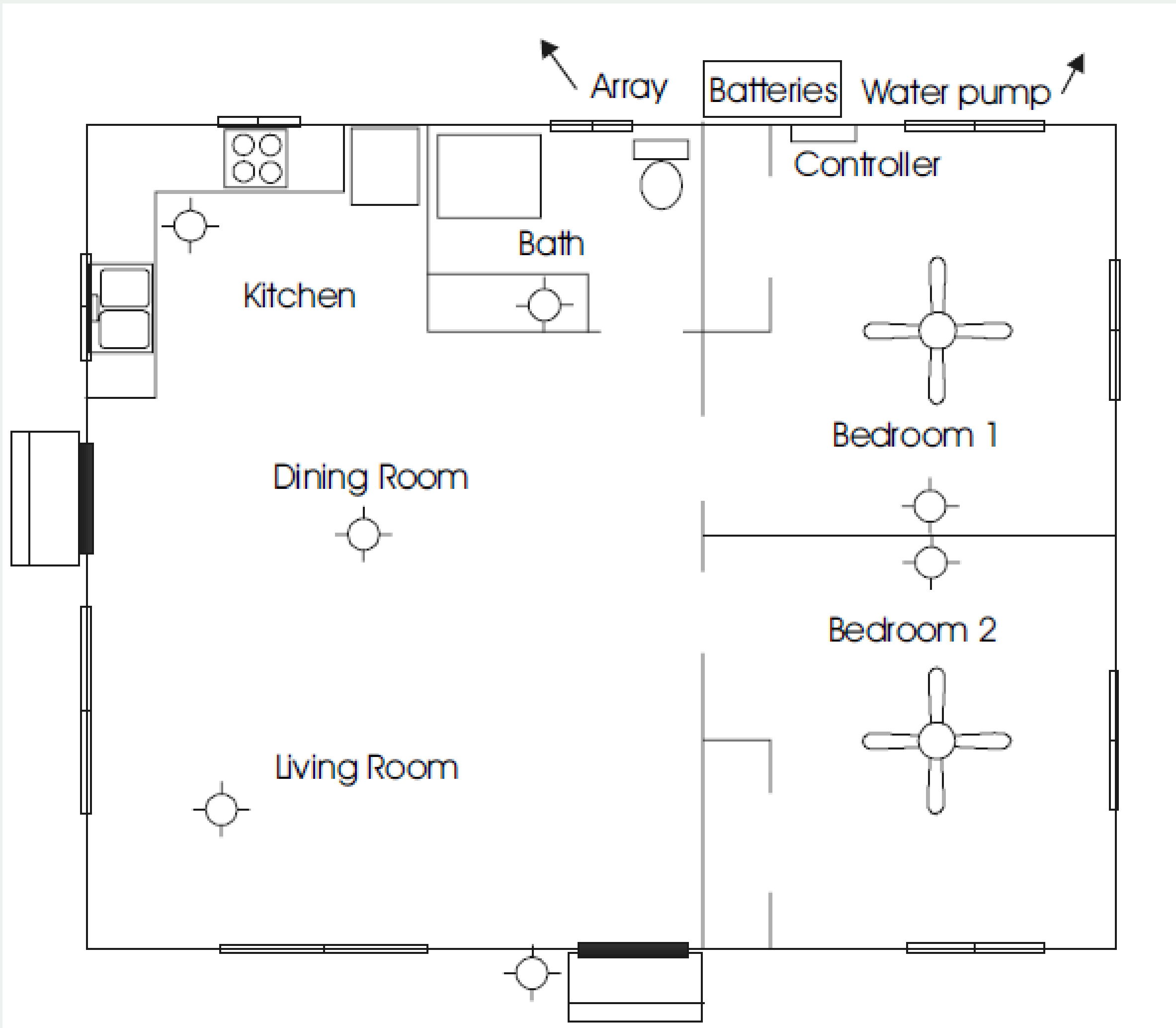
$$9.39/0.9 = 10.4 \ A$$

$$\rightarrow 1 \times (11.05 \ A, 16.7 \ A) \approx 200 \ W$$

Example 6: A Critical-need Refrigeration System



Example 7: A PV-powered Mountain Cabin



Example 7: A PV-powered Mountain Cabin

Cabin used for weekends (three days).

A 200-ft-deep well be located 30ft from the cabin.

Refrigerator is rated 306 kWh/yr or 0.84 kWh/day

Assume 6 h of compressor operation per day so power is 140 W

Assume 150 liter of water per person, so 4×150=600 liter/day.

We need a 600 liter storage for water or 3×600=1800 liter/week.

Let storage be 10ft above to preserve the pressure and consider 5% piping losses so h=210×1.05=220.5 ft.

One pump, that will operate on dc and ac will pump 4.4 LPM at a head of 225 ft, using 115 W, so its efficiency is around 37%.

Example 7: A PV-powered Mountain Cabin

600 L/ 4.4 LPM=136 min so a 600 liter storage is ok.

Energy needed for water pumping is:

$$Energy_{pump} = 115 \times 136 / 60 = 261 \;\; Wh / day$$

Example 7: A PV-powered Mountain Cabin

Summary of Monthly Variation in Weekly Ah Loads for Mountain Cabin

			Nov-Feb		Mar		Apr,Oct		May, Sep		Jul, Jul, Aug	
Load	Watts	Day/week	h/week	Ah/week	h/week	Ah/week	h/week	Ah/week	h/week	Ah/week	h/week	Ah/week
Kit light	32	3	12	8	10.5	7.0	10.5	7.0	9.0	6.0	7.5	5.0
BR1 light	17	3	6	2.1	4.5	1.6	4.5	1.6	3.0	1.1	3.0	1.1
BR2 light	17	3	3	1.1	3	1.1	3.0	1.1	3.0	1.1	3.0	1.1
LR light	17	3	15	5.3	12	4.3	9.0	3.2	6.0	2.1	6.0	2.1
Outdoor light	17	3	1.5	0.5	1.5	0.5	1.5	0.5	1.5	0.5	1.5	0.5
DR light	32	3	12	8	9	6.0	7.5	5.0	6.0	4.0	4.5	3.0
Bath light	17	3	6	2.1	6	2.1	5.0	1.8	4.0	1.4	3.0	1.1
Refrigerator	152	7	35	111	38.5	121.9	38.5	121.9	42.0	133.0	45.5	144.1
Water pupm	125	7	5.5	14.3	6	15.6	6.5	16.9	7.0	18.2	8.0	20.8
BR1 fan	32	3	0	0	0	0.0	3.0	2.0	8.0	5.3	24.0	16.0
BR2 fan	32	3	0	0	0	0.0	3.0	2.0	8.0	5.3	24.0	16.0
Receptacles	2500	3	2	104	1.75	91.1	1.5	78.1	1.3	65.1	1.0	52.1
	2990			256		251		241		243		263

Inverter size ?? 3000 W

Battery size ?? Array size and tilt ??

Example 7: A PV-powered Mountain Cabin

Battery size

The charge and discharge derating factors will both be unity.

Corrected Weekly Ah Loads for Cabin Accounted for wire(2%) and Battery(10%) losses

Nov,Dec,Jan, Feb	Mar	Apr, Oct	May, Sep	Jun, July,Aug
290	284	273	275	298

Determination of system battery capacity requiremnents

Month	Jan, Feb	Mar	Apr	May	Jun,Jul,Aug	Sep	Oct	Nov	Dec
Ah/Week	290	284	273	275	298	275	273	290	290
Temp Derate	0.8	0.85	0.9	0.95	1	0.95	0.9	0.85	0.8
Discharge depth	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Total cap req	453	418	379	362	373	362	379	426	453

Eight 12 V, 244 Ah, 8-years lifetime sealed lead-acid battery.

Example 7: A PV-powered Mountain Cabin

Determination of optimum design current and array tilt angle.

Denver , Colorado

Month	Corr Load Ah/wk	Latitude-15 °		Latitude		Latitude+15°	
		Hr/day	A	Hr/day	A	Hr/day	A
Jan	290	4.32	9.6	5.07	8.2	5.51	7.5
Feb	290	4.94	8.4	5.54	7.5	5.81	7.1
Mar	284	6.42	6.3	6.80	6.0	6.80	6.0
Apr	273	6.69	5.8	6.65	5.9	6.24	6.3
May	275	7.07	5.6	6.69	5.9	5.97	6.6
Jun	298	7.22	5.9	6.67	6.4	5.78	7.4
Jul	298	7.32	5.8	6.84	6.2	6.01	7.1
Aug	298	6.84	6.2	6.66	6.4	6.13	6.9
Sep	275	6.78	5.8	7.02	5.6	6.85	5.7
Oct	273	5.92	6.6	6.53	6.0	6.75	5.8
Nov	290	4.37	9.5	5.05	8.2	5.43	7.6
Dec	290	4.05	10.2	4.81	8.6	5.28	7.8
Design current for tilt			**10.2**		**8.6**		**7.8**
Optimum design current							**7.8**

Fixed tilt.

Adjustable tilt.

Example 7: A PV-powered Mountain Cabin

Optimization of Array by Seasonal Tilt Adjustment

Mo	Jan	Feb	Mar	Apr	May	Jun
Tilt	+15	+15	+15	−15	−15	−15
A	7.5	7.1	6.0	5.8	5.6	5.9
Mo	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Tilt	−15	−15	lat	+15	+15	+15
A	5.8	6.2	5.6	5.8	7.6	7.8

Fixed tilt or adjustable tilt?

→ Fixed tilt is ok. →10% for degradation → 8.7 A needed.

Adjustable tilt → More excess energy in summer.

Example 7: A PV-powered Mountain Cabin

So 8.7 A module needed.

Thus, four modules in a parallel combination of 2 series groups with I_{mp}=8.92 A, V_{mp}=69.6 V is ok(620 W).

Now if one use MPPT with a battery charger at 54 V , then

$$\text{Required power} = 54 \times 8.7 / (0.98 \times 0.97) = 494 \; W$$

Another possible module is 4×130 W (in series) with V_{mp}=17.6, I_{mp}=7.39 A, V_{oc}=21.9 and I_{sc}=8.02 A

4×155 W- 4×130 W =100 W saving.

Saving cost is around 100×4 \$/W=400 \$.

Example 7: A PV-powered Mountain Cabin

Now suppose we choose:

4×130 W (in series) with V_{mp}=17.6, I_{mp}=7.39 A, V_{oc}=21.9 and I_{sc}=8.02 A

$$\text{Produced Current} = 0.9 \times 520 \times 0.96 / 54 = 8.32 \;\; A$$

Average Weekly Excess Ah produced by the selected array for the cabin:

	Month	Jan	Feb	Mar	Apr	May	Jun
Ah/day	Available	8.32	8.32	8.32	8.32	8.32	8.32
Ah/day	Needed	7.5	7.1	6	6.3	6.6	7.4
h	PSH	5.51	5.81	6.8	6.24	5.97	5.78
Ah/week	Excess	32	50	110	88	72	37

Month	Jul	Aug	Sep	Oct	Nov	Dec
Available	8.32	8.32	8.32	8.32	8.32	8.32
Needed	7.1	6.9	5.7	5.8	7.6	7.8
PSH	6.01	6.13	6.85	6.75	5.43	5.28
Excess	51	61	126	119	27	19

Example 7: A PV-powered Mountain Cabin

Average Weekly Excess Ah produced by the selected array for the cabin:

Month	Jan	Feb	Mar	Apr	May	Jun
Available	8.32	8.32	8.32	8.32	8.32	8.32
Needed	7.5	7.1	6	6.3	6.6	7.4
PSH	5.51	5.81	6.8	6.24	5.97	5.78
Excess	32	50	110	88	72	37

Month	Jul	Aug	Sep	Oct	Nov	Dec
Available	8.32	8.32	8.32	8.32	8.32	8.32
Needed	7.1	6.9	5.7	5.8	7.6	7.8
PSH	6.01	6.13	6.85	6.75	5.43	5.28
Excess	51	61	126	119	27	19

What to do with all this extra energy.

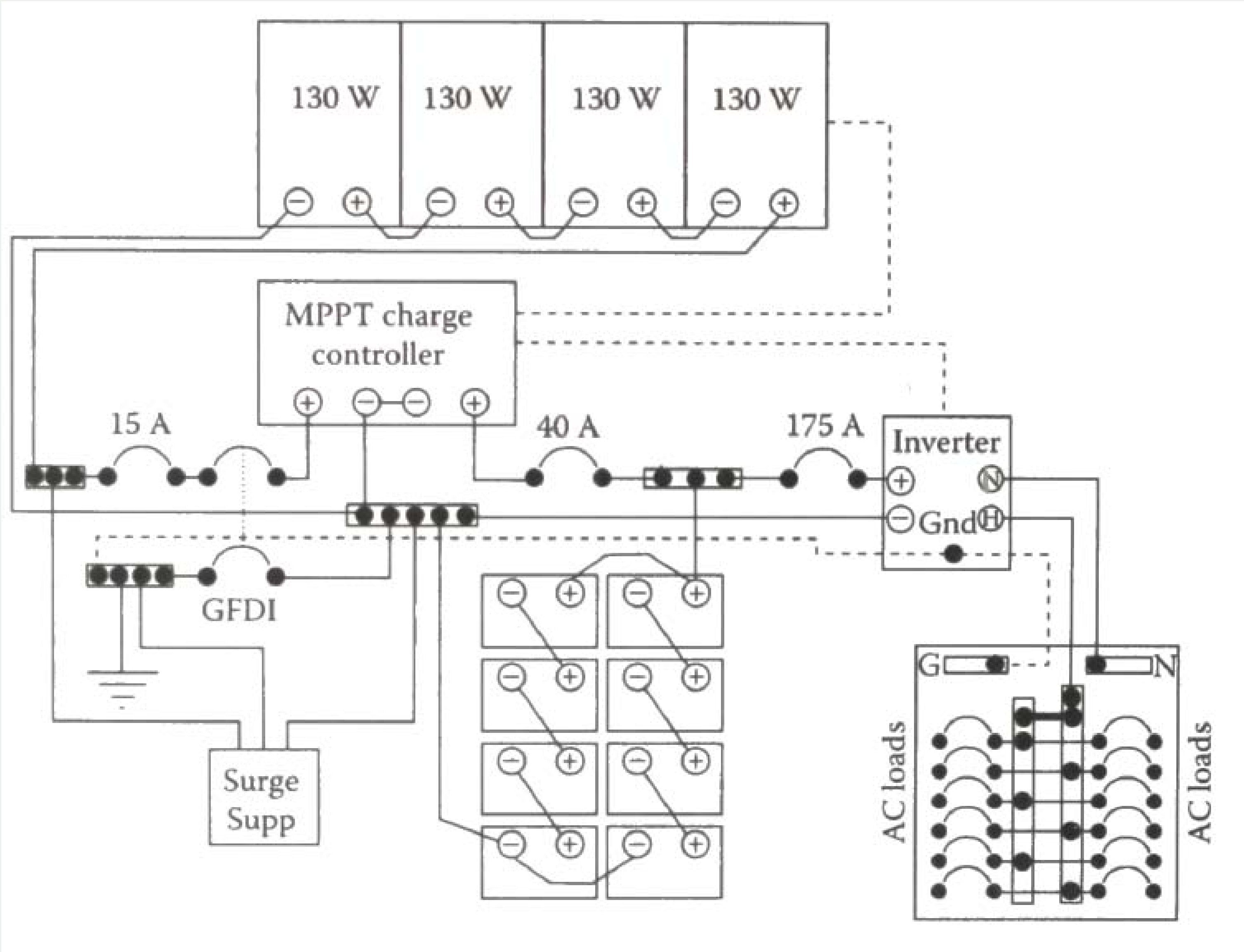
The fan might be run longer.

Heat some water.

Pump more water.

Stay more in the cabin.

Example 7: A PV-powered Mountain Cabin



Biggest PV power plant in Iran(43.2 kw)

18(216/12) Arrays (2400 W) each 7.5 MT totally 136 MT.

Biggest PV power plant in Iran

18 Tracker each 6.5 MT, total 117MT

Biggest PV power plant in Iran

6 inverter each 7KW
each 7MT
totally 42 MT

Arrays : 136 MT
Inverters: 42 MT
Trackers: 117 MT
Foundation: 25 MT

Total: 320 MT

Biggest PV power plant in Iran

E total 10817 kWh
h total 3030

E today 2.05 kWh
Mode MPP

Pac 4198 W
Vpv 422 V