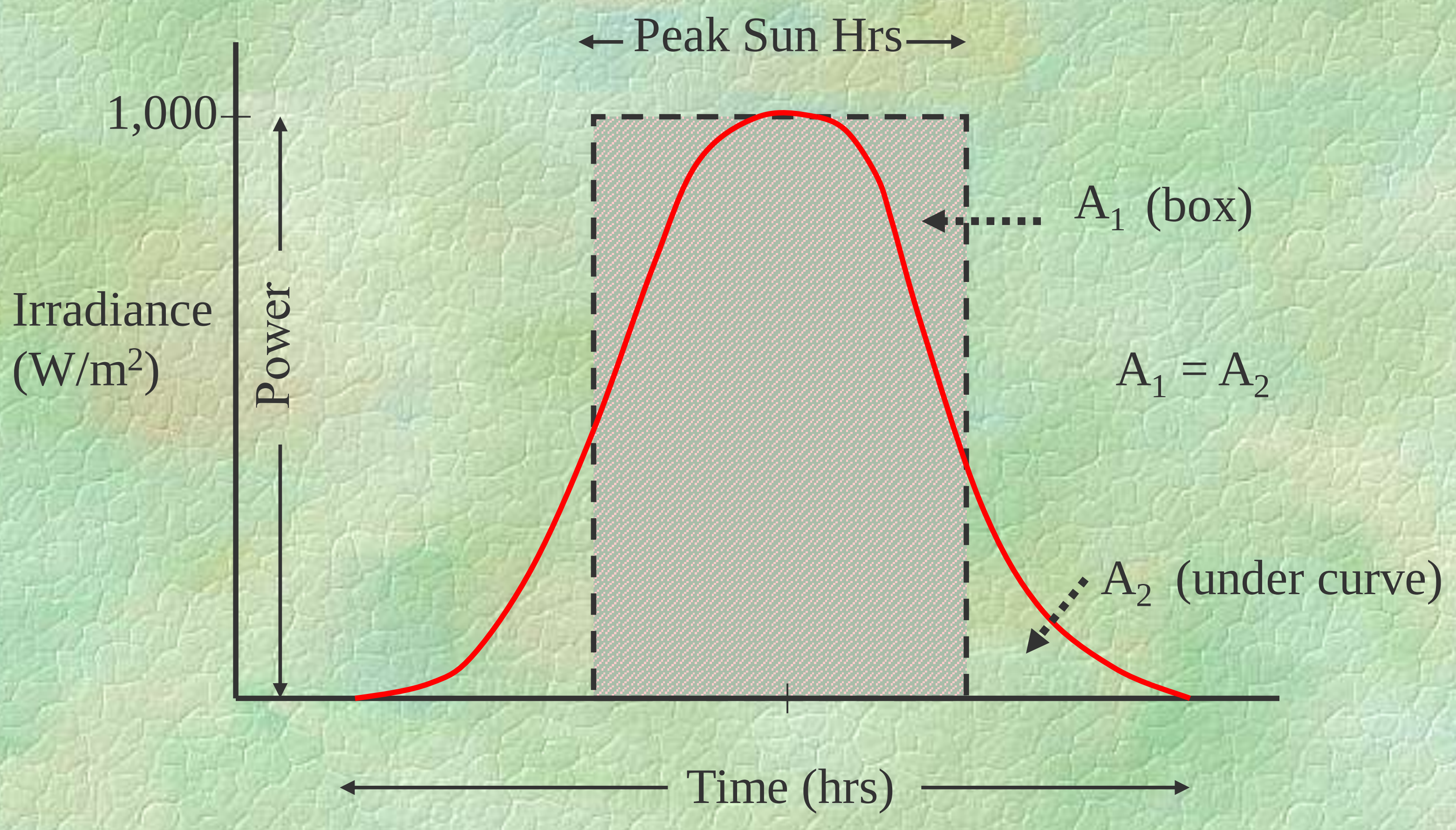
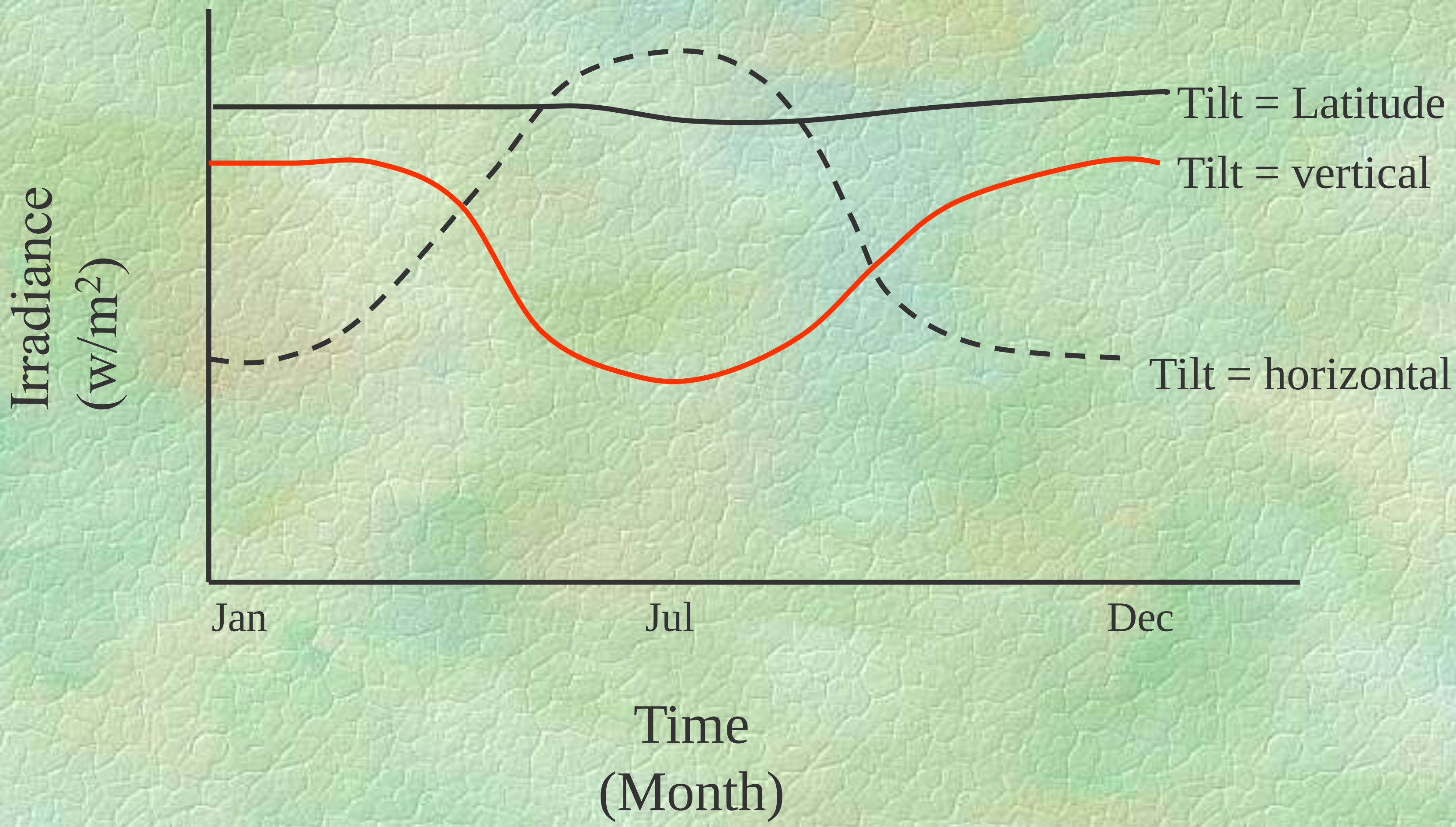
PV System Performance and Sizing

Insolation (kWhrs/m²/day)



Energy = Power x Time

Module Tilt Angle vs. Season



Solar on new Capitol Building Projects Leading to BIPV in Commercial Buildings

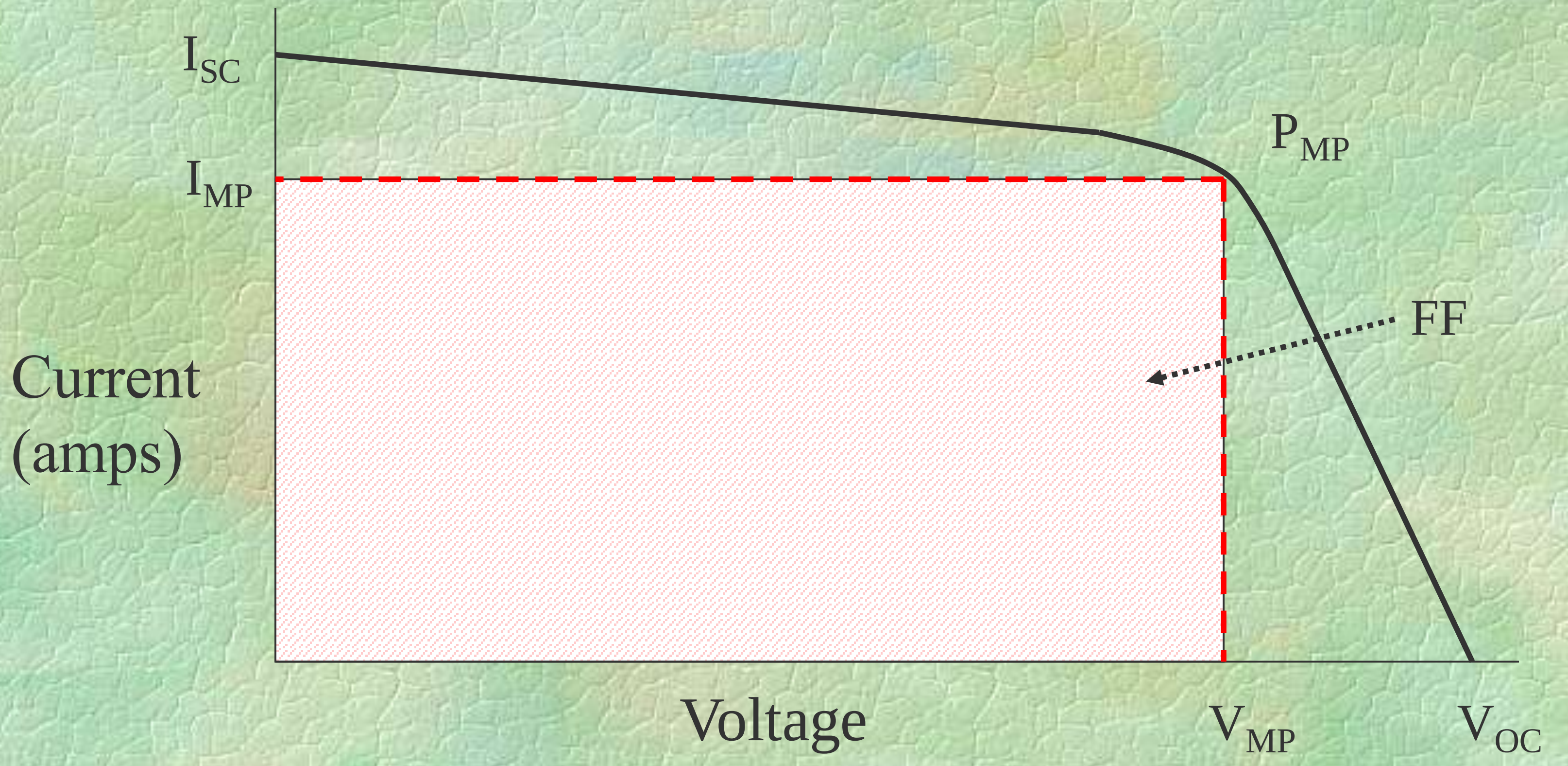
East End Office Complex 24 kW BIPV Curtain Wall

SMUD

PVDT

Building Integrated PV System

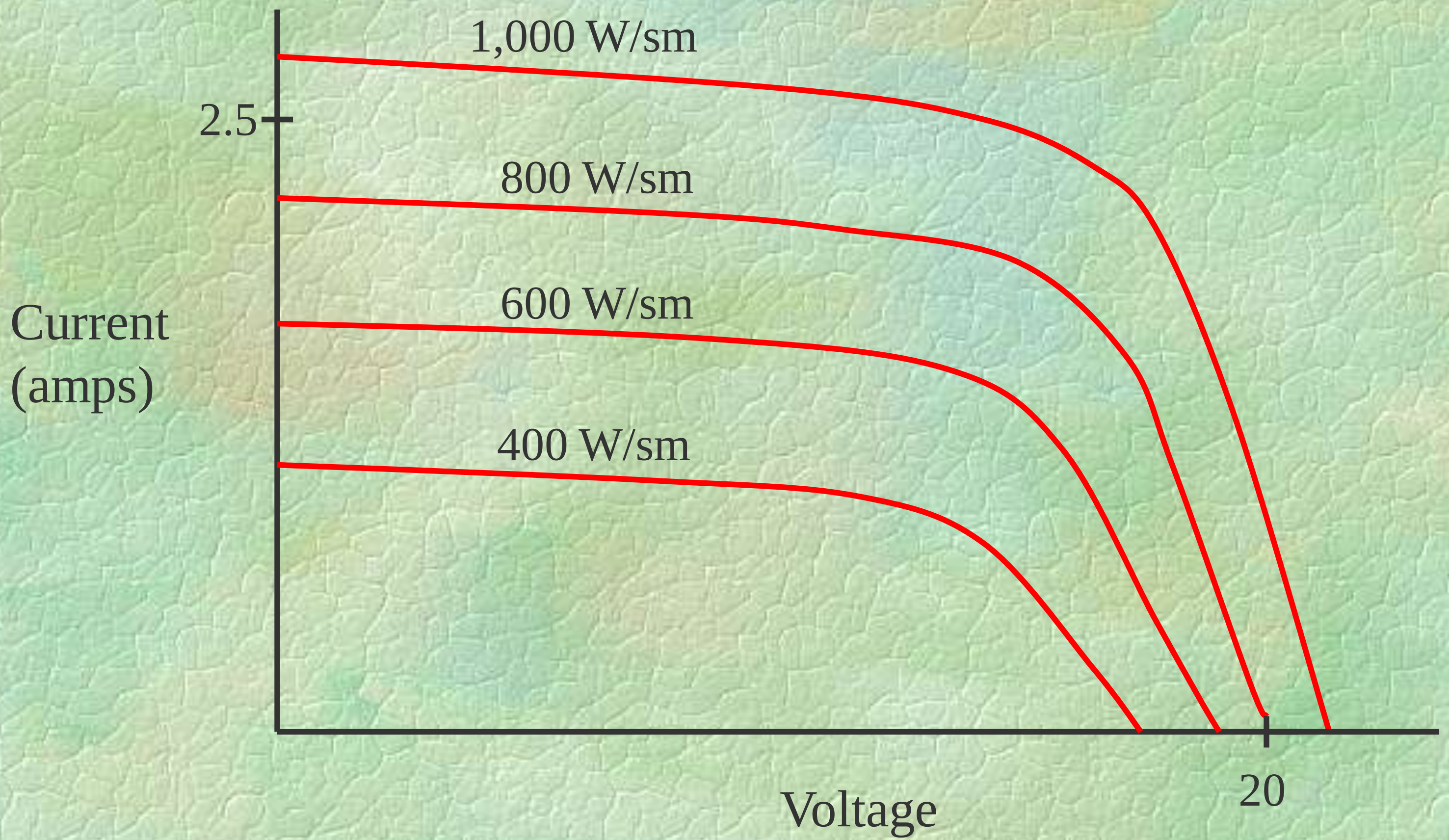
Typical PV Module Performance: I-V Curve



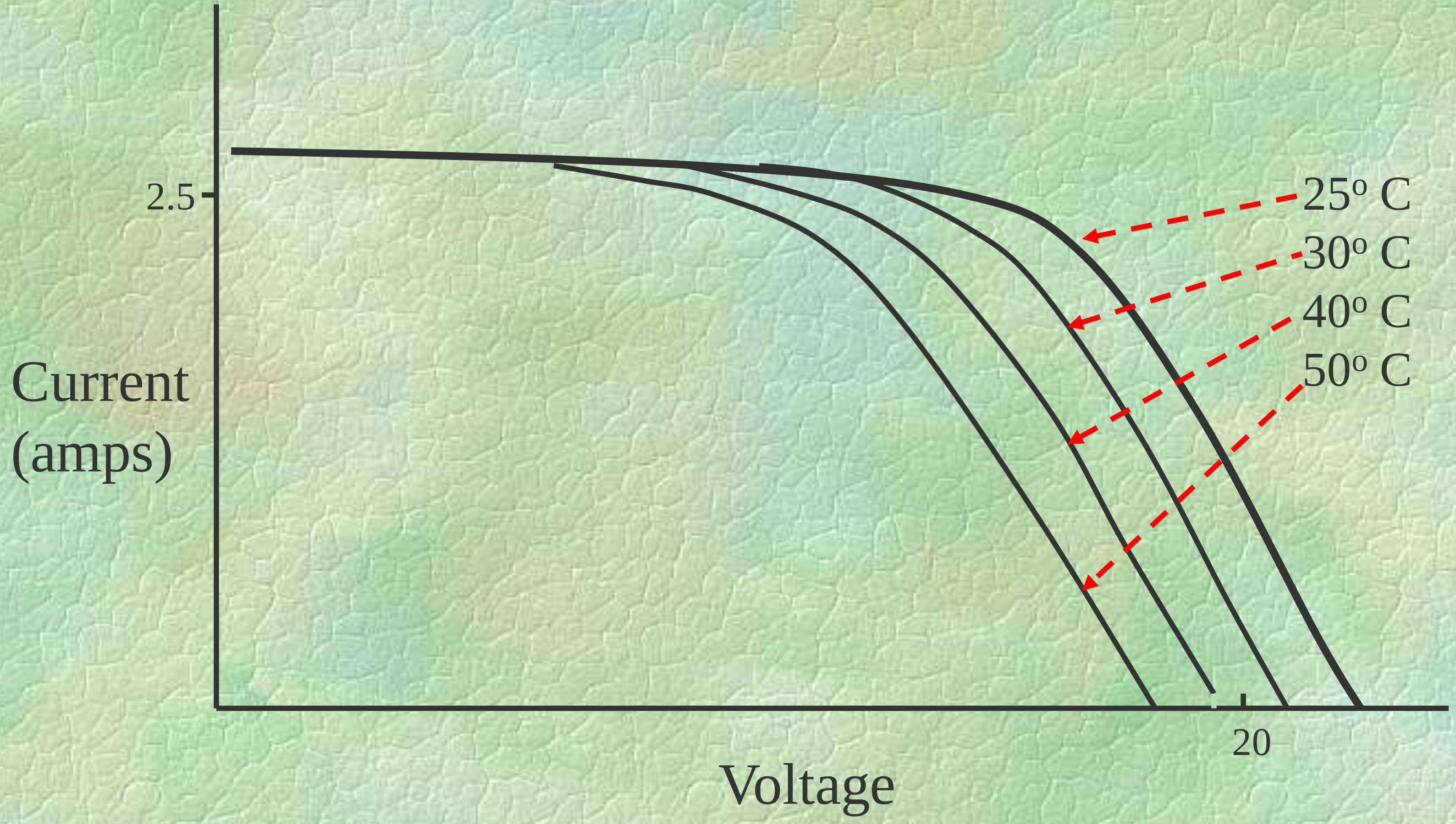
V_{OC} = open circuit voltage
I_{SC} = short circuit current
P_{MP} = maximum power

V_{MP} = maximum power voltage
I_{MP} = maximum power current
FF = Fill Factor

Effect of Decreased Irradiance on I-V Curves



Effect of Cell Temperature on Silicon I-V Curve



Extreme effects of Shading on c-Si Modules

% of One Cell Shaded	% Loss of Power
0	0
25	25
50	50
75	66
100	75
3 Cells Shaded	93

Bypass diodes reduce the effect of shading by allowing current to bypass shaded cells and modules.

Effect of Orientation on Annual Electricity Production

	PV Panel Tilt Angle From Horizontal (Degrees)					
Direction	0 (Flat)	15 (3:12)	30 (7:12)	45 (12:12)	60	90 Vertical
South	89%	97%	100%	97%	88%	56%
SSE,SSW	89%	97%	99%	96%	87%	57%
SE,SW	89%	95%	96%	93%	85%	59%
ESE,WSW	89%	92%	91%	87%	79%	57%
E,W	89%	88%	84%	78%	70%	51%

Typical System Losses

Type	Loss (%)
Wiring	2 - 3
Module Mismatch	2
Nameplate Variance	3
Inverter	5
Soiling	0 - 8
Orientation (a)	0 - 15
Total	12 - 36

(a) Includes tilt and shading

Design Considerations: Matching the User's needs and situation with a solution

- Factors driving design solutions:
  - Lowest cost option?
  - Most energy?
  - Utility rate structure
  - Available area
  - Roof vs. ground
  - Building integrated, carport
  - Shading

Design Considerations: Matching the User's needs and situation with a solution

- Weather – temperature, insolation
  - Environmental or site constraints
  - Distance to interconnection
  - Aesthetics
  - In-house O&M capability

PV System Performance: Example

Location: Honolulu, Hawaii, Lat: 21.33 deg

PV module peak rating: 80 watts STC
69.2 watts PTC

Avg annual insolation: 5.4 - 5.7 kWh/m^2/day

Avg daily peak solar hours: 5.4 - 5.7 hrs/day

60 modules washed once per year

15% tilt (roof pitch 3 on 12)

Southeast orientation

No shading

Electricity cost: 13 cents/kWh

PV System Performance: The Simplistic Method

Energy = (5.5 hrs/day) x (365 days/yr) x (80 watts/module) x (60 modules) / (1000 watts/kW) = 9,636 kWh/yr

Energy Savings @ 13 cents/kWh = $1,253/yr

PV System Performance: Reality

Energy = (5.5 hrs/day) x (365 days/yr) x (69.2 watts/module PTC) x (60 modules) x (0.86)(inverter, wiring, mismatch losses) x (0.96)(soiling losses) x (0.94)(orientation losses) / (1000 watts/kW) = 6,469 kWh/yr

Energy savings @ 13 cents/kWh = $841/yr

Difference = 32%

PV System Performance: So What Now?

Bob Parkins Performance Rule No. 1:
PV system performance is ALWAYS site specific.

Bob Parkins Performance Rule No. 2:
If performance is important, specify PV output in AC (alternating current) at the load.

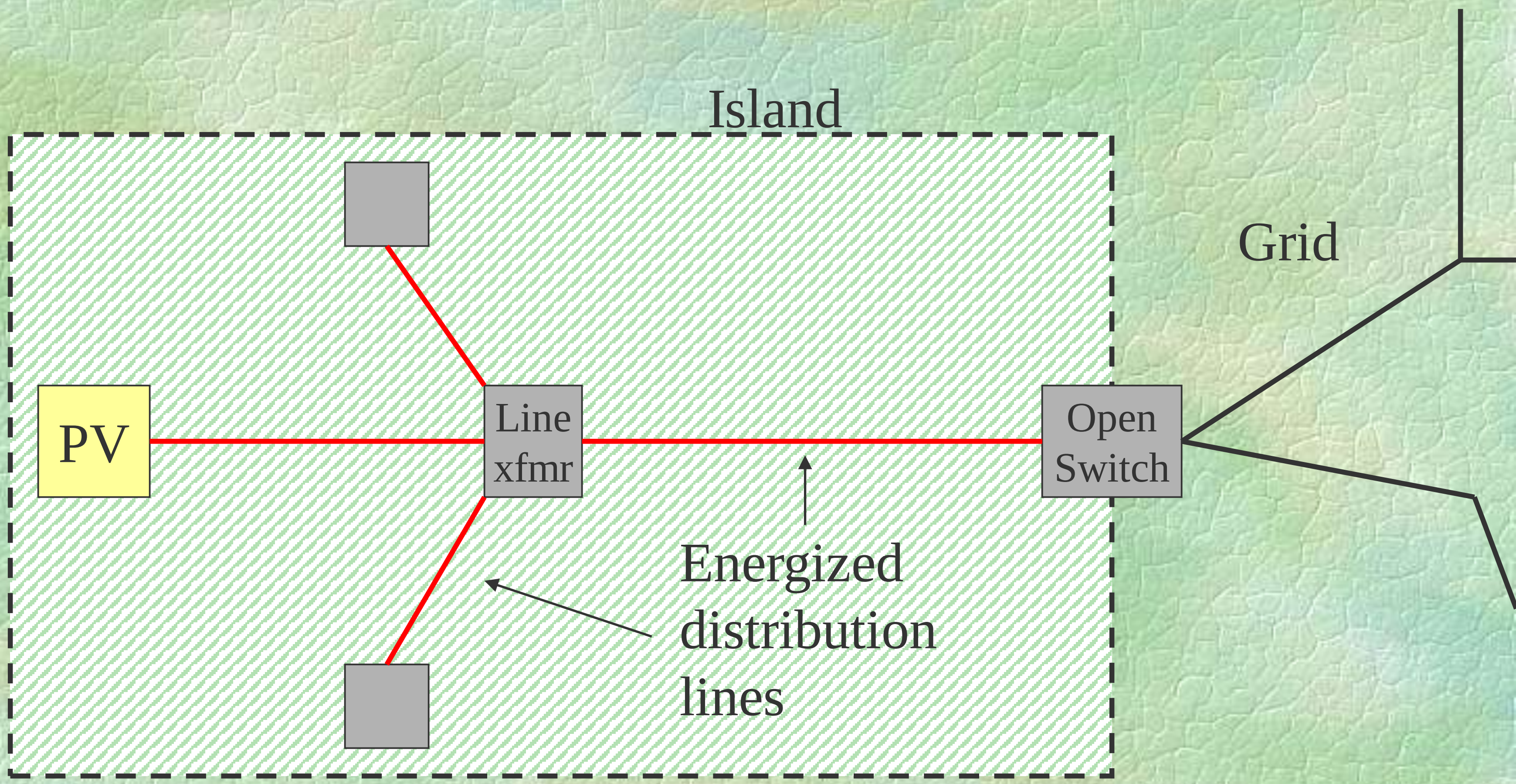
Grid-Interactive Inverters

Purpose: Using the grid as a reference, it converts Direct Current from a PV array to Alternating Current at what ever voltage and frequency presented to it by the utility.

Standards: IEEE 929
UL 1471

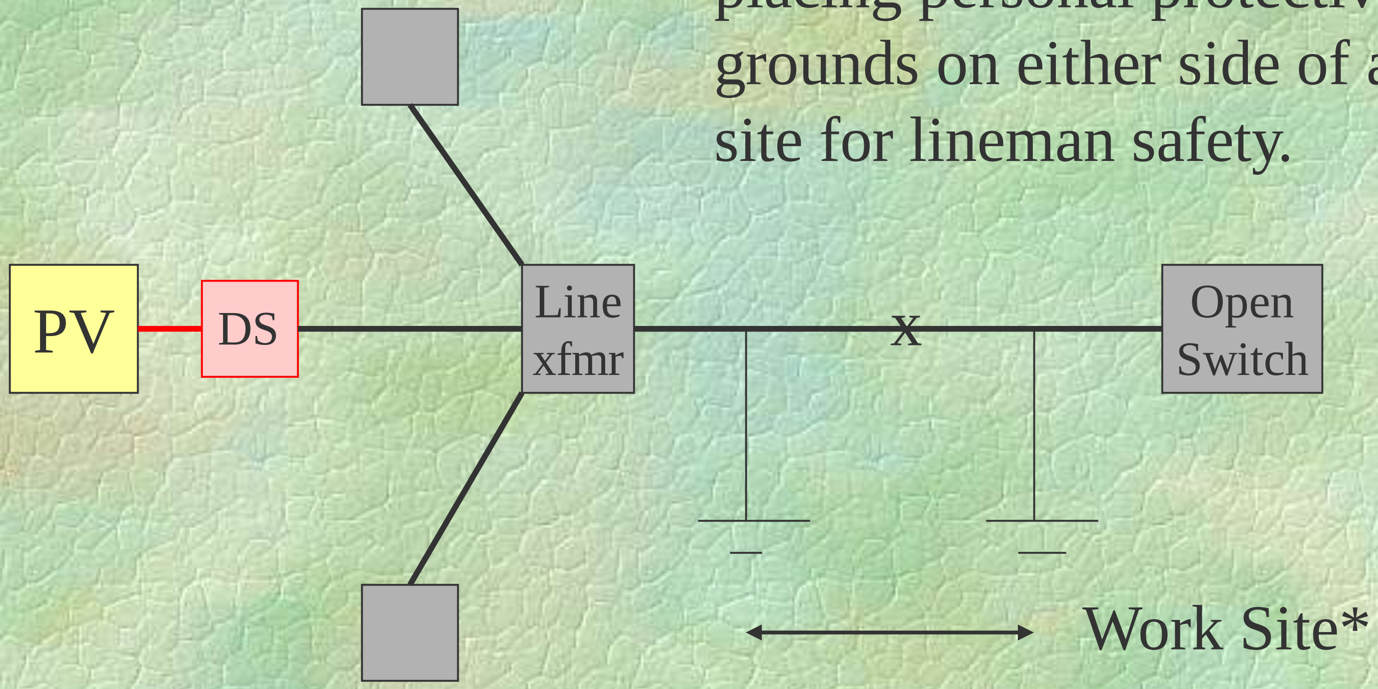
Method: a. Solid state switching
b. pulse width modulation
c. Self commutated (1 – 10 kHz) vs line commutated (60 Hz) – results in true sine wave quality

Islanding: Definition – When an isolated section of a distribution network continues to operate with its own generation, e.g. a PV system, when utility power is out. Back feed from the generation may inadvertently energize nearby lines, causing a potential safety hazard to linemen.



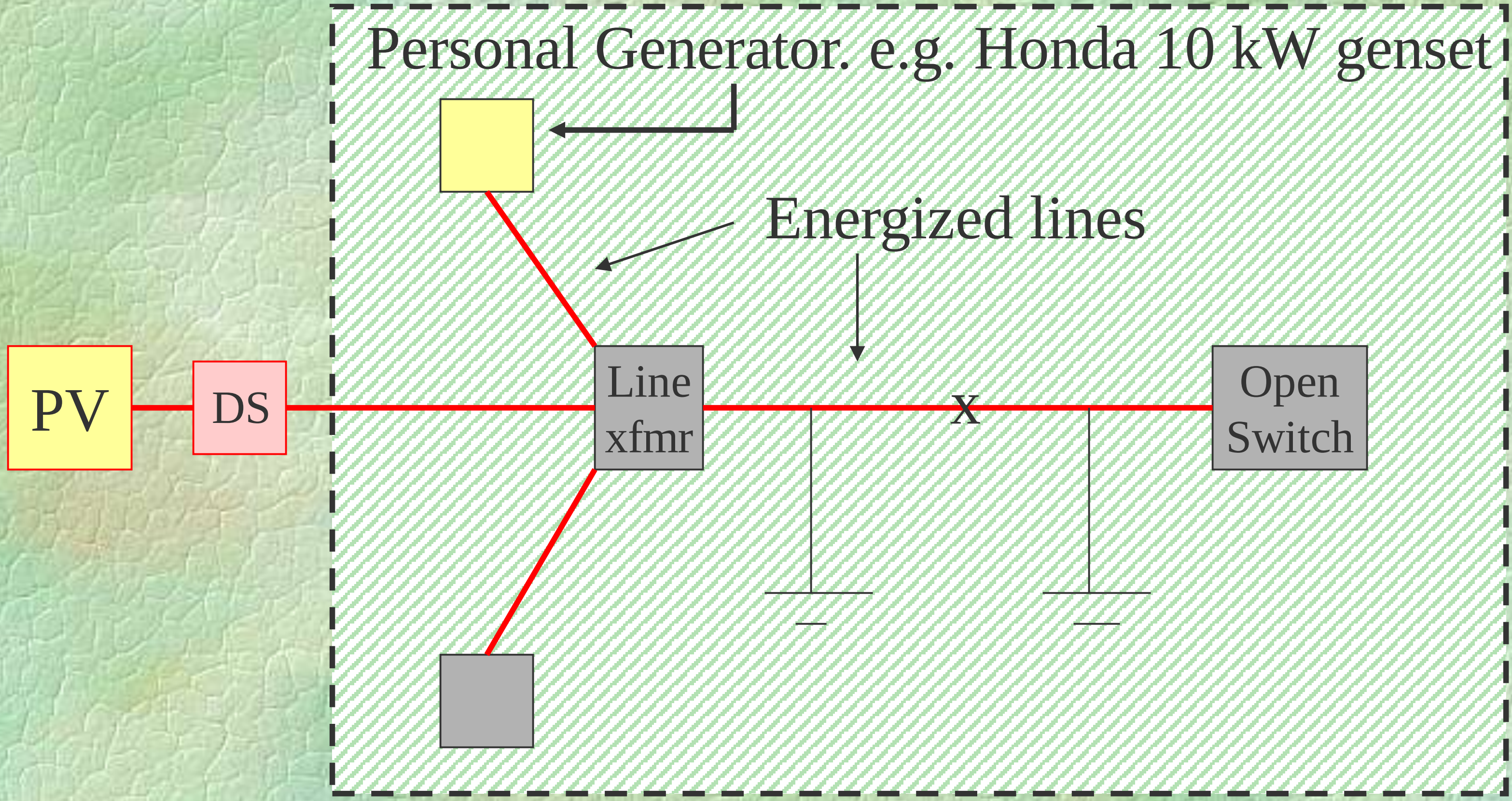
Early Anti-Islanding Practice

*IEEE 1001-1988 Sect 9 calls for testing conductors and placing personal protective grounds on either side of a work site for lineman safety.



DS = Manual, lockable disconnect switch, accessible by Utility linemen to isolate PV from the distribution network.

Inadvertent Islanding by Personal Generators



Other Sources of unwanted energization:

Inverters

UL 1471:

Protects against islanding by automatically disconnecting the inverter upon loss of grid power.

DISCONNECT SCHEME

Grid Voltage*	Max Trip Time
V < 50%	6 cycles
50% < V < 88%	120 cycles
88% < V < 106%	Normal Operation
106% < V < 137%	120 cycles
137% < V	2 cycles

* Referenced to normal 120 V service, per ANSI C84.1

Other Features of UL 1471 Qualified Inverters:

a. Power Factor: generally 0.95 - 1.0

b. Power Quality: True sine wave

c. Frequency: Disconnect within 6 cycles if frequency drifts beyond +/ 0.5 Hz.

d. Harmonics: <5%

e. Reconnect after grid restoration: 5 minutes

Inverters

Standard Configurations:

Residential: 120/240V, single phase.
1 to 5.0 kW

Commercial: 120/208V, 277/480V three phase.
10 kW and higher, usually with isolation xfmr.
Custom made units available in any voltage.

Costs: Residential: About $0.80 - $1.00/W
Commercial: larger units approach $0.50/W

Life Expectancy: generally 10+ years before rebuild or replacement.