Introduction to solar PV energy
- Dimensioning -

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The power of the sun - G

- Global Irradiation 0.29-0.4 um
- Instantaneous value (Power) W/m²

Units

- Energy: Wh/m²
- Energy: J/m²
- Solar Peak Hours

Conversions

- 1 wh = 3600 J

Irradiance (W) vs Irradiation (Wh)
Irradiance and irradiation values stand for area densities, i.e. no subscripts are used to indicate the surface area. All symbols refer to horizontal planes; for a tilted plane, the slope $\beta$ and the plane azimuth (Alpha) are added in brackets.

- Subscript 0 stands for extraterrestrial or astronomical.
- Subscript h stands for hourly and subscript d for daily.
A nearly constant 1.36 kilowatts per square meter (the solar constant) of solar radiant power impinges on the earth's outer atmosphere.

Approximately 70% of this extraterrestrial radiation makes it through our atmosphere on a clear day.

Irradiance at ground level regularly exceeds 1,000 w/m². In some mountain areas, readings over 1,200 w/m² are often recorded.
Type of systems

- Grid-Intertied solar-electric system: on grid
- Grid-Intertied solar-electric system with battery backup
- Off-Grid solar-electric system with battery backup (Telcenter A)
- Grid-Intertied solar-electric system with battery and generator backup (Telecenter B)
Type of load

- AC load
- DC load
- Direct pump (no batteries)
Components (I)

- PV
- PV Mounts
- Array PV - DC Disconnect
- Charge Controller (Regulator)
- Battery
Components (II)

- System Meter
- Main DC Disconnect
- Inverter
- AC Breaker Panel (AC Disconnect)
- Kwh meter (Utility Meter)
PV Panel

- $I_{sc}$
- $V_{oc}$
- $I_{pmax}, V_{pmax}$ (Maximum Power)
- Voltage is enforced by the battery
- Form Factor ($P_{max}/I_{sc}.V_{sc}$) 0.7-0.8
PV Panel

- Performance: $P_{\text{max}}/P_{\text{sun}} \sim 10\%-13\%$
- Normalized conditions: $1\text{kW/m}^2$ sea level 25°C
- Wp (Peak Power)
Testing the panels

- Testing the panels (annex)
PV Panel

- Operation:
  - $I_{pmax}$, $V_{max}$
  - Efficiency Lost: Pmax – 5%

- Array
  - Same panels
  - Serial = We add V
  - Parallel = We get more I
Battery

- Serial elements: 2 V
- Models: 12 V, 24 V and 48 V
- Car batteries vs Deep Cycle Batteries
  - 1.2 to 1.28 (add water)
Deep Cycle Batteries

- Nickel-Cadmium (vs) Lead-Acid
- Maintenance vs Cost
Sun and Battery Cycles

- Daily
- Seasons
- Weather
Battery Status

- Over charged
  - Gas, oxidation of positive electrode
  - Reduces acid stratification
  - Controlled 2.35 – 2.4 V
  - Role of regulator

- Over discharged
  - Lower limit 1.85
  - PbSo4 Lead Sulfate
Battery Parameters

- Vn Nominal Voltage
- Cn Nominal Capacity Ah, Wh
- C100
- SOC vs DOD
- DOD 70% and life of the battery
- Cusable = Cn * MDR (maximum discharge rate)
Temp and Batteries

- Capacity 1%/C
- Low temperatures – Battery charge to avoid freeze (reduce the max. discharge rate)
Loads

- Role of low power devices
- Energy Demands
  - Estimation
  - Forecasting
- User Habits
Regulator

- Cuts at 2.45 V (battery state)
- Maximum current (at least 20% more than the PV)
- Operating tension
Regulator

- Serial (can disconnect) vs Shunt (NO!)
- Charge Controller
  - Senses Temp of Batteries Battery Temperature Compensation (BTC)
  - Can lower the V of the panels to increase the I
  - PWM (Pulse Width Modulation)
  - Measures and cuts (LVD) Low voltage disconnect
  - Maximum Power Point Tracking
Inverter

- Converter DC/AC
- DC/DC (pumps, to start them)
- Sin wave vs modified sin wave
- Be Careful not all equipment can handle a modified sin wave inverter!
- Protection (sc)
- Efficiency
Inverter Parameters

- Protection (against sc)
- Efficiency > 70%
Method: Worse month
- Reliable: how many days without sun?
  - Autonomy days (N)
  - Nominal Voltage?
    - More than 3 KW  = 48 V
Worse Month

- What is the worse month?
- We need to know the energy demands (DC + AC) and the energy available
- What PV array angle is optimal?
Orientation

- Towards the equator
- Tolerance of 20 degrees (alpha)

Angle (β):
- $|L| + 10 = \text{winter}$
- $|L| = 0$
- $|L| - 10 = \text{summer}$

- Angle > 20 degrees (dust)
Daily or monthly average energy at angle B

\[ G(B) = f(G(0)) \]

\[ f(B) = AG(0) + B(G(0))^2 \]

- A depends on \( r=0.2 \) and \( \beta \)
- B depends on Latitude and \( \beta \)
- We can always use a simulation tool to get the values!
Imax (Loads)

- $Et = E(AC) + E(DC)$ (Ah) (electric charge)
- Ah/day - Ah/period
- $G(B) = \text{kWh/m}^2 \text{ day}$
- $Imax = \frac{Et}{G(B)}$
- Example
  - Nigeria = 3.5 – 4 kWh.m2 day
  - Et = 100 Ah
  - $Imax = 25 \text{ A/Kw} * \text{ m2}$
Number of par. panels?

- \( N_{pp} = \frac{I_{max}}{I_{pmax}} \)

- Example
  - \( 25 \text{ A/kw.m}^2 / 5 \text{ A/kw.m}^2 = 5 \text{ Units} \)
Capacity of Battery?

- Normally measure in Ah (electric charge)
- Serie vs Parallel
- Example:
  - C100 = 200 Ah
  - Usable = 200 Ah x discharge depth (70%) = 140 Ah
- Dimensioning
  - Capacity = N. Et (Ah) * 1.2
Regulator and Inverter Power

- **Regulator**
  - 20% Imax x Npp

- **Inverter**
  - Performance at 70% of the load
Multi-variable system
Simulation: Worst month
Set pre-conditions first
Measure your load
  Are they any possible energy savings?
Be careful with the units!