Course Project: Implementation of MPPT in a CubeSat Electrical Power System Using STM32 and LabVIEW-based PIL Testing

AE 501: Virtual Instrumentation for Aerospace Engineers

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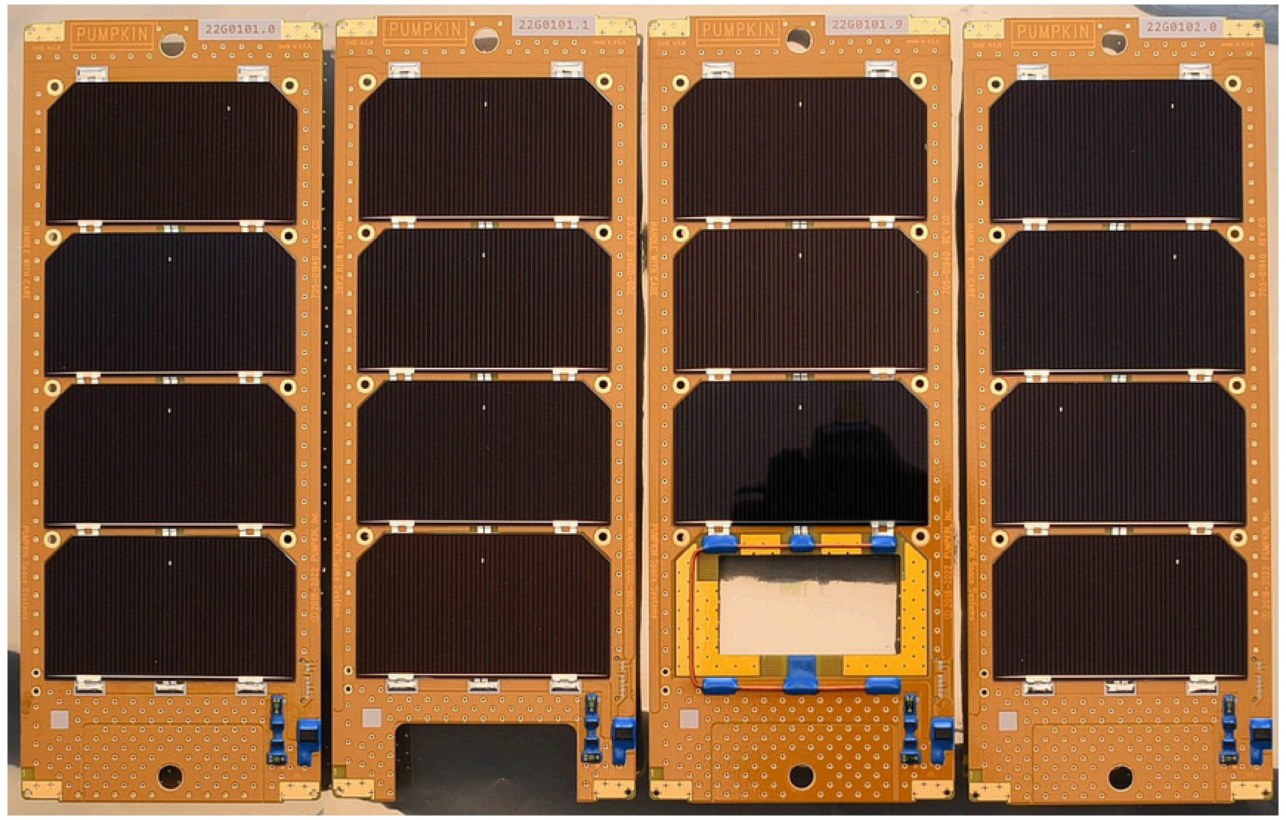
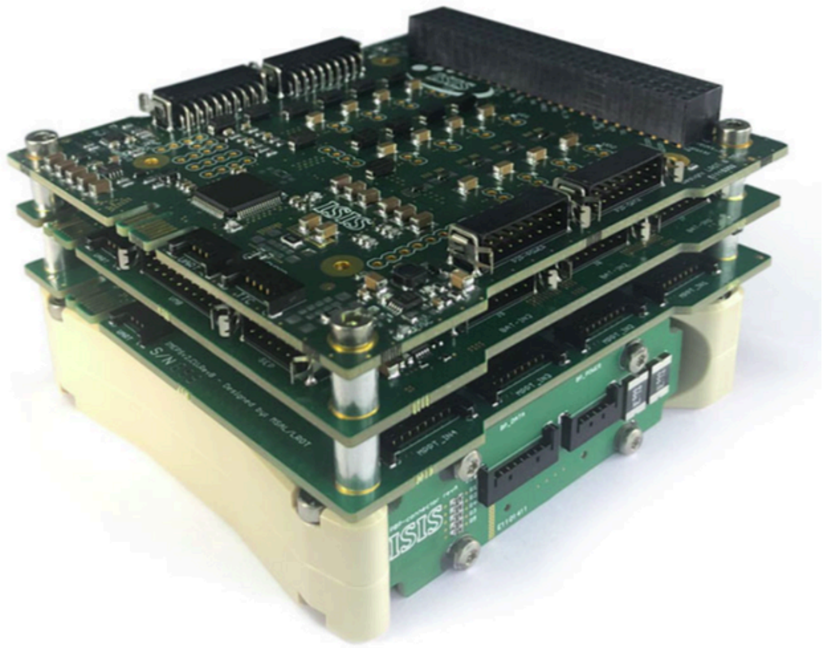
Electrical Power System (EPS): The Lifeline of a CubeSat

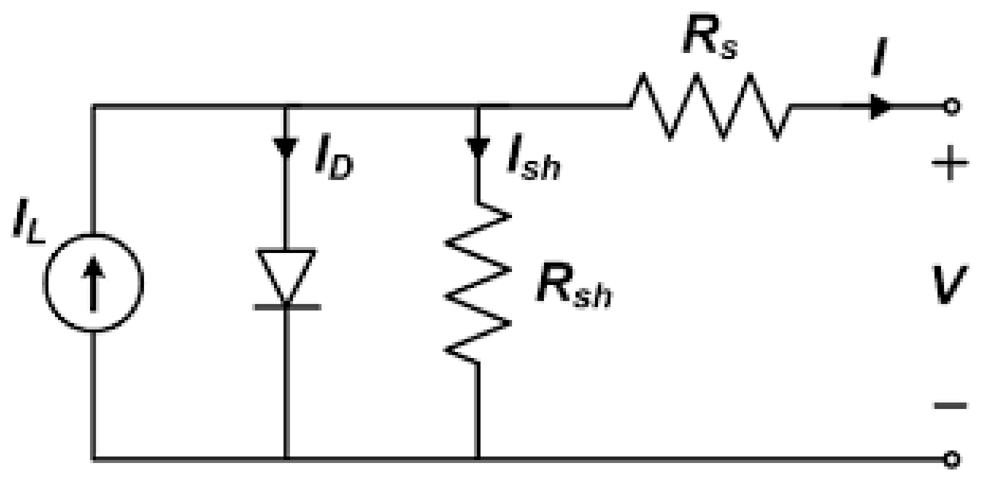




The EPS is crucial in CubeSats as it manages limited power within tight size and weight constraints, ensuring efficient energy use and reliable operation of all subsystems.

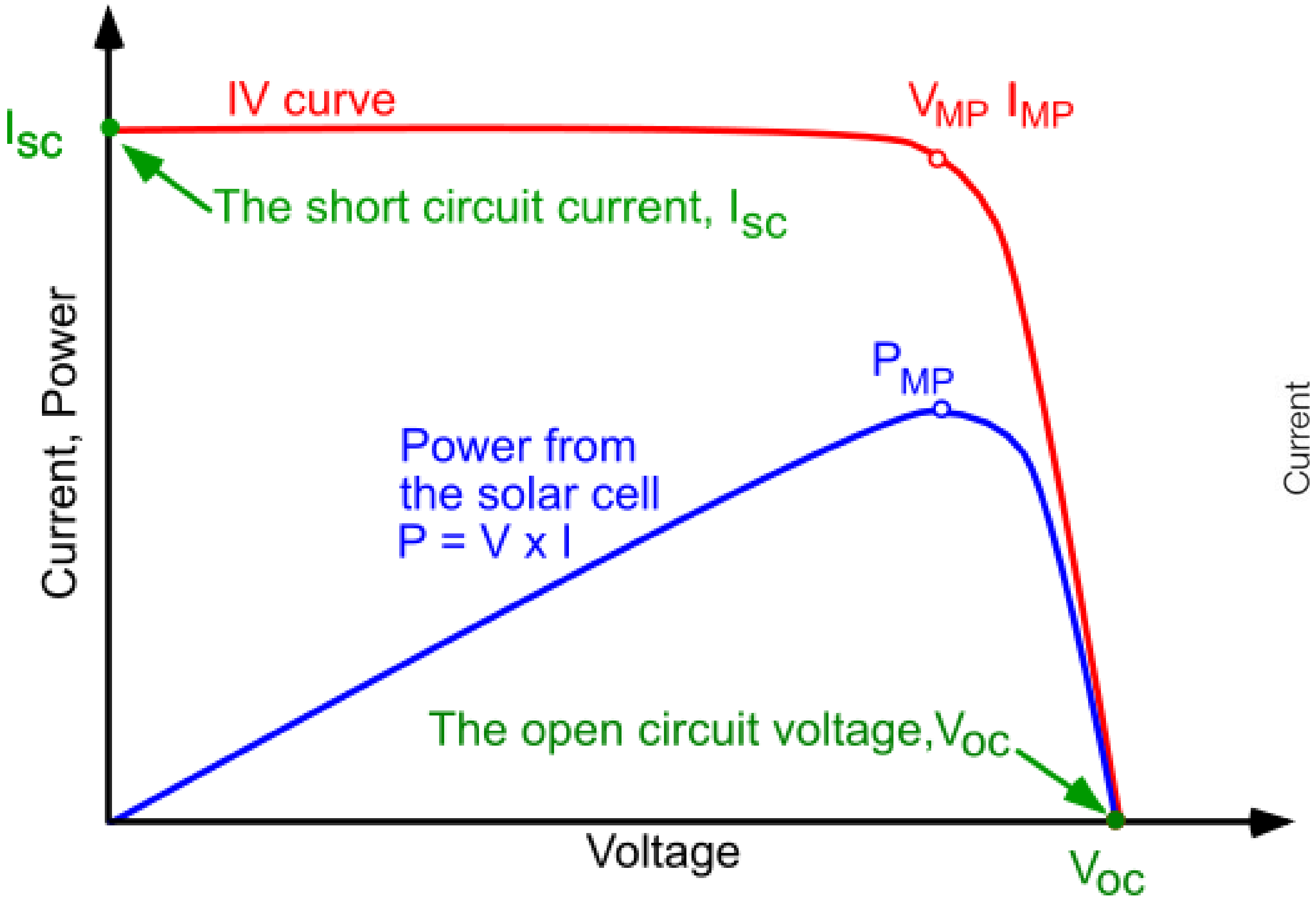
- Powers all satellite subsystems: ADCS, OBC, Communications, Payload, etc.
- Limited surface area for solar panels → **low power budget**
- Must ensure autonomous, reliable, and efficient power regulation
- Failure of EPS = complete mission loss

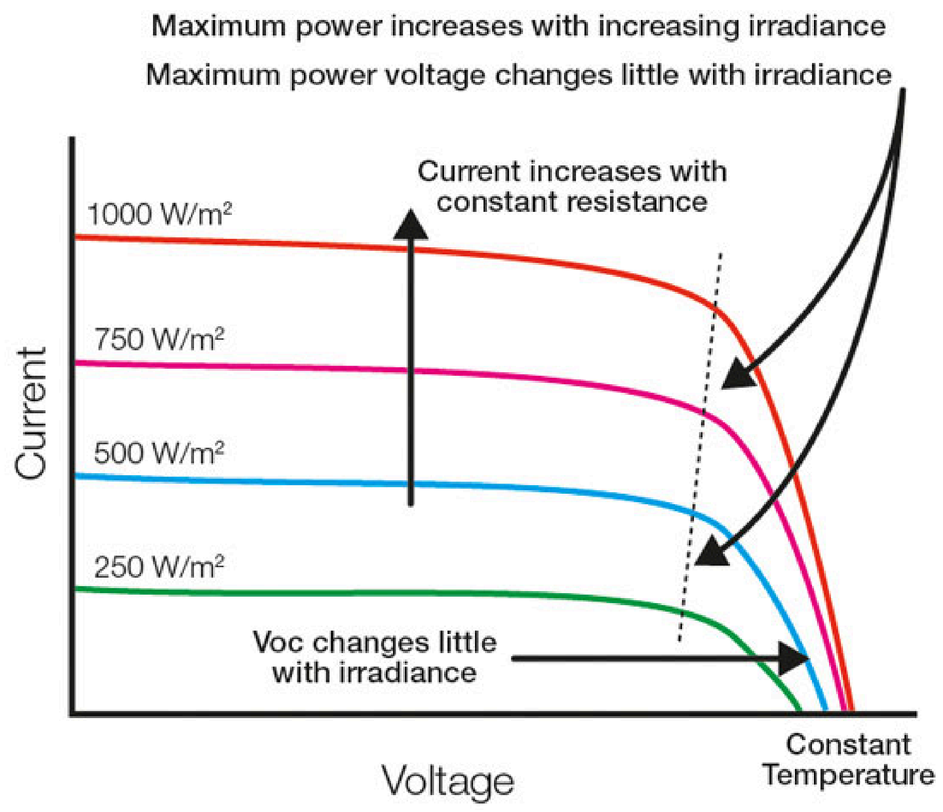
Solar Cells

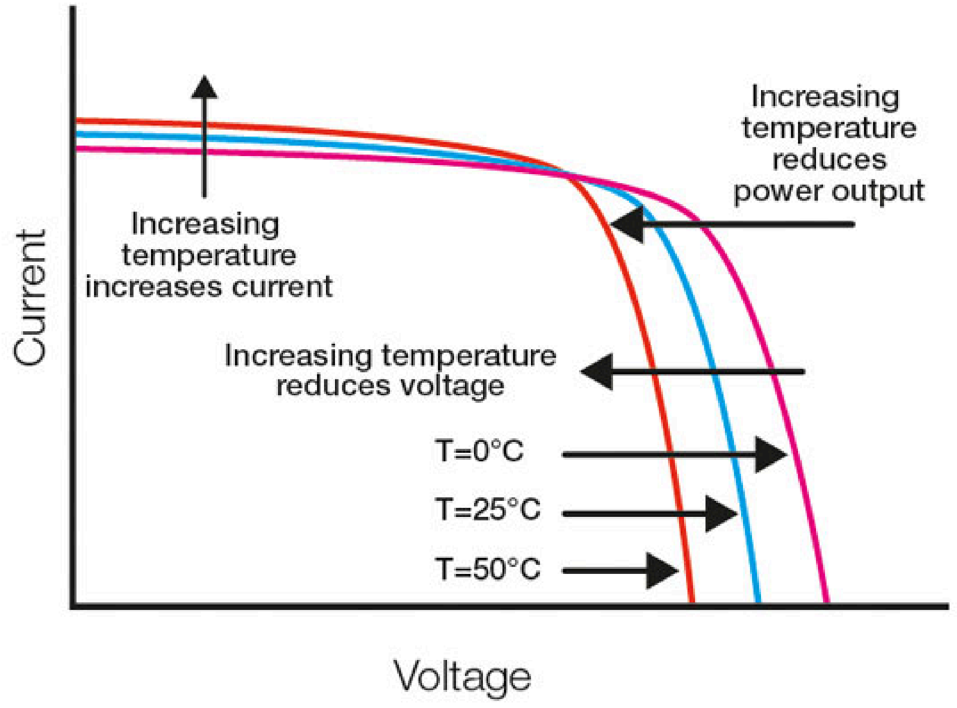


Solar cell I-V characteristics are nonlinear and vary with:

- Temperature
- Illumination angle
- Degradation over time

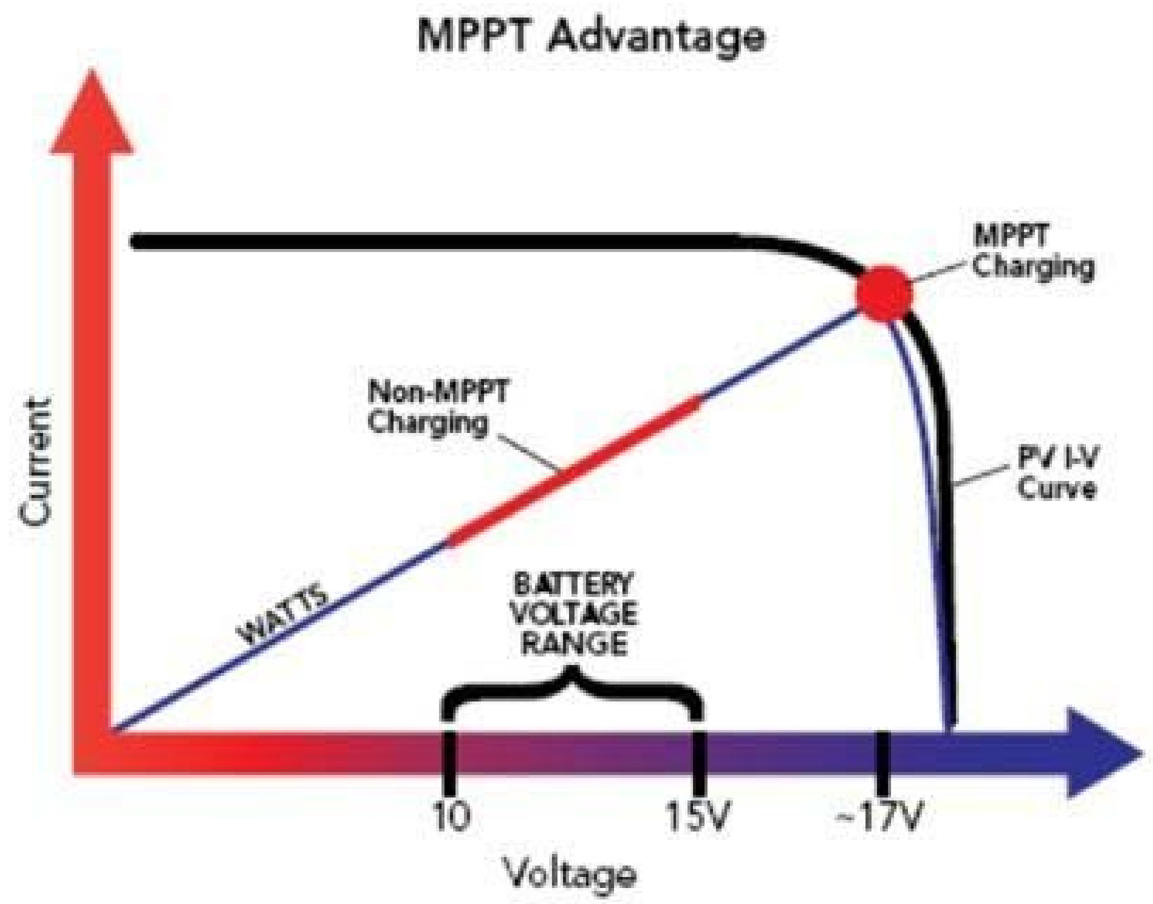


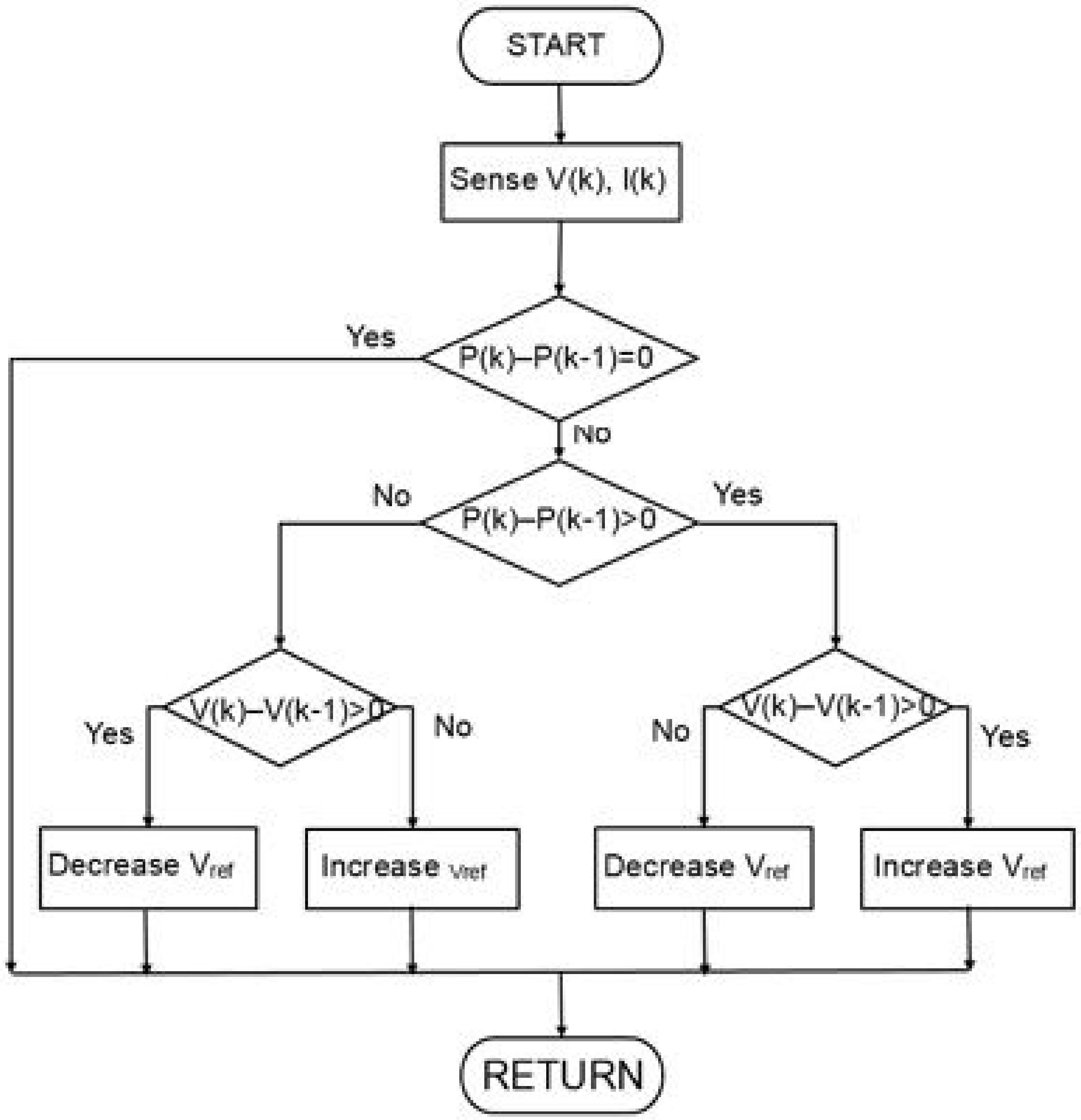




Maximum Power Point Tracking (MPPT)

MPPT is a control technique used in power converters to dynamically adjust their operating point so that the solar panels always deliver the maximum possible power, regardless of environmental conditions



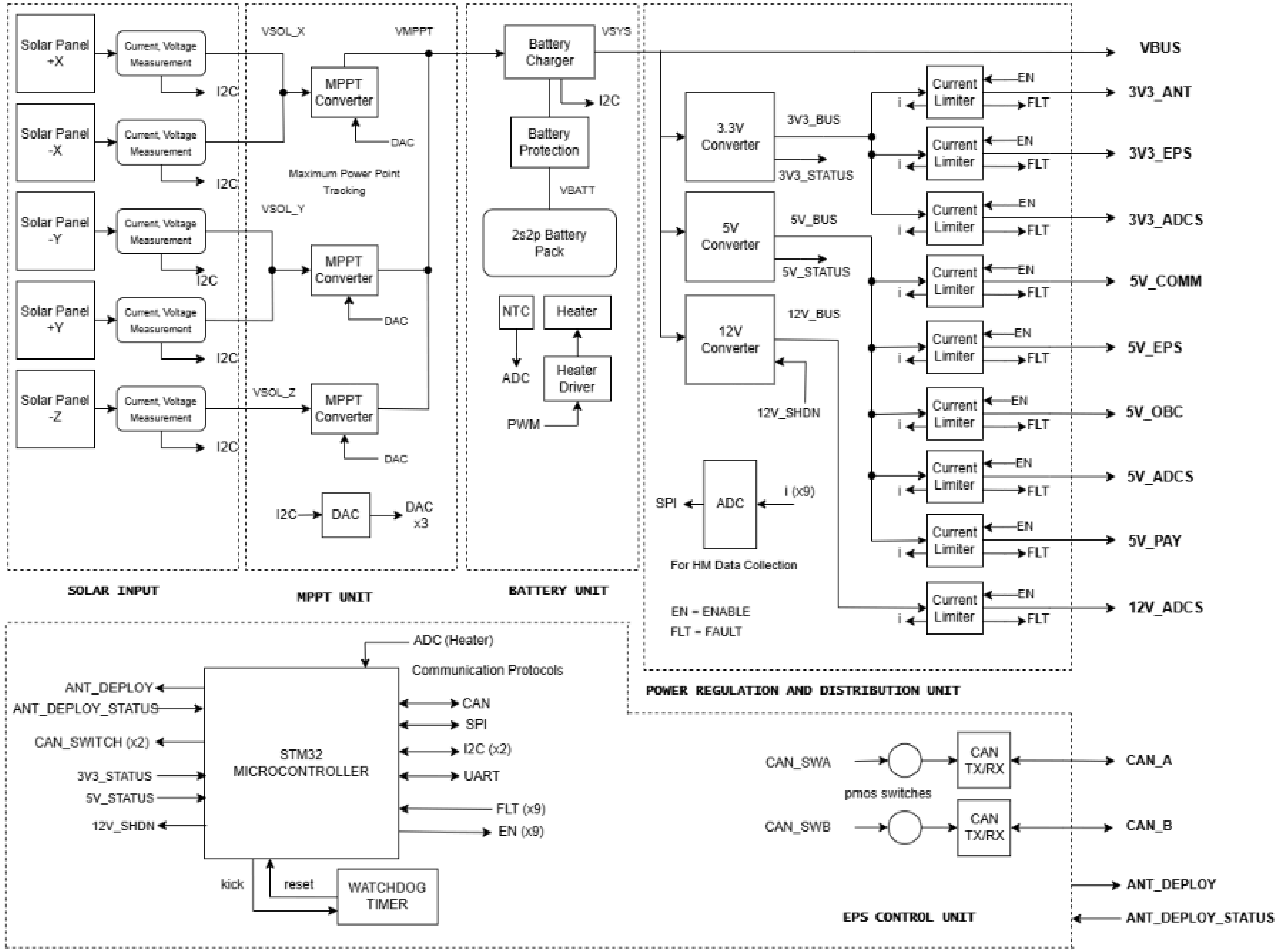


Our Problem

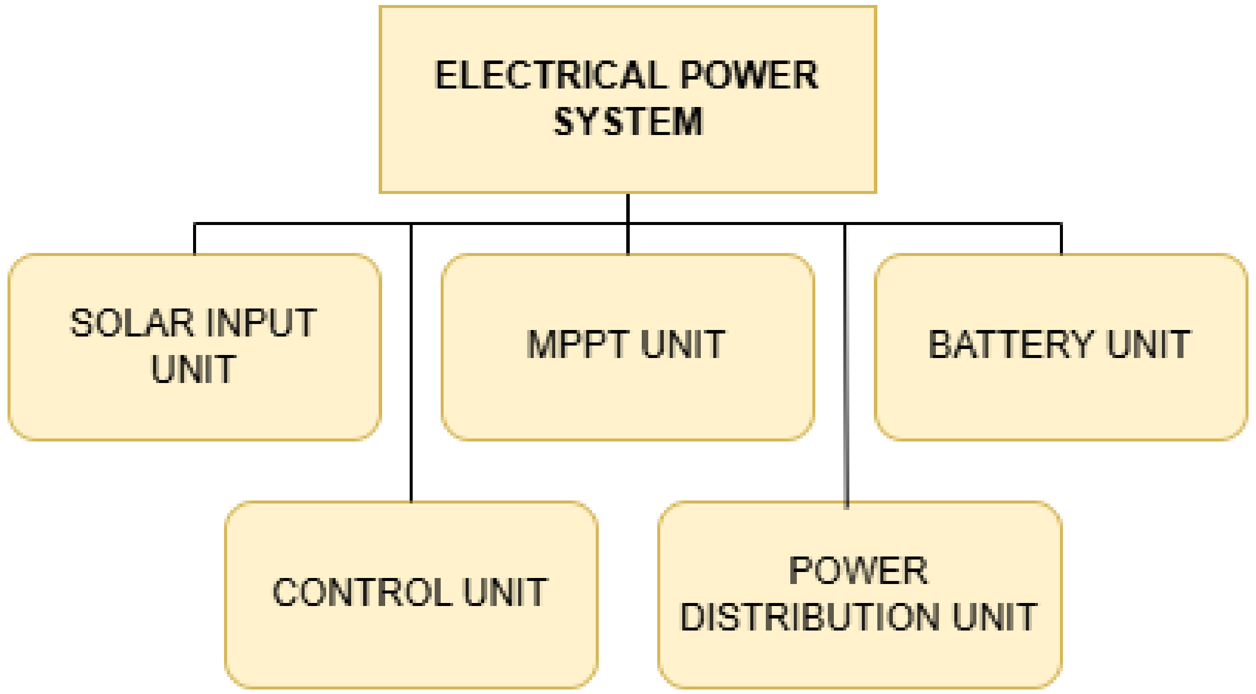
The EPS is crucial in CubeSats as it manages limited power within tight size and weight constraints, ensuring efficient energy use and reliable operation of all subsystems.Orbital conditions cause **rapid fluctuations in solar irradiance and temperature**, significantly affecting power output. The **Maximum Power Point Tracking (MPPT)** algorithm optimizes energy extraction from solar arrays under these dynamic conditions. Testing MPPT algorithms directly onboard a satellite introduces **significant risks** and **high costs**, necessitating reliable ground-based testing methods.

Processor-In-the-Loop Simulation (PILS) offers a solution by **virtually simulating** orbital conditions or utilizing real sensor data, enabling thorough and cost-effective validation of EPS systems without the risks of physical deployment.

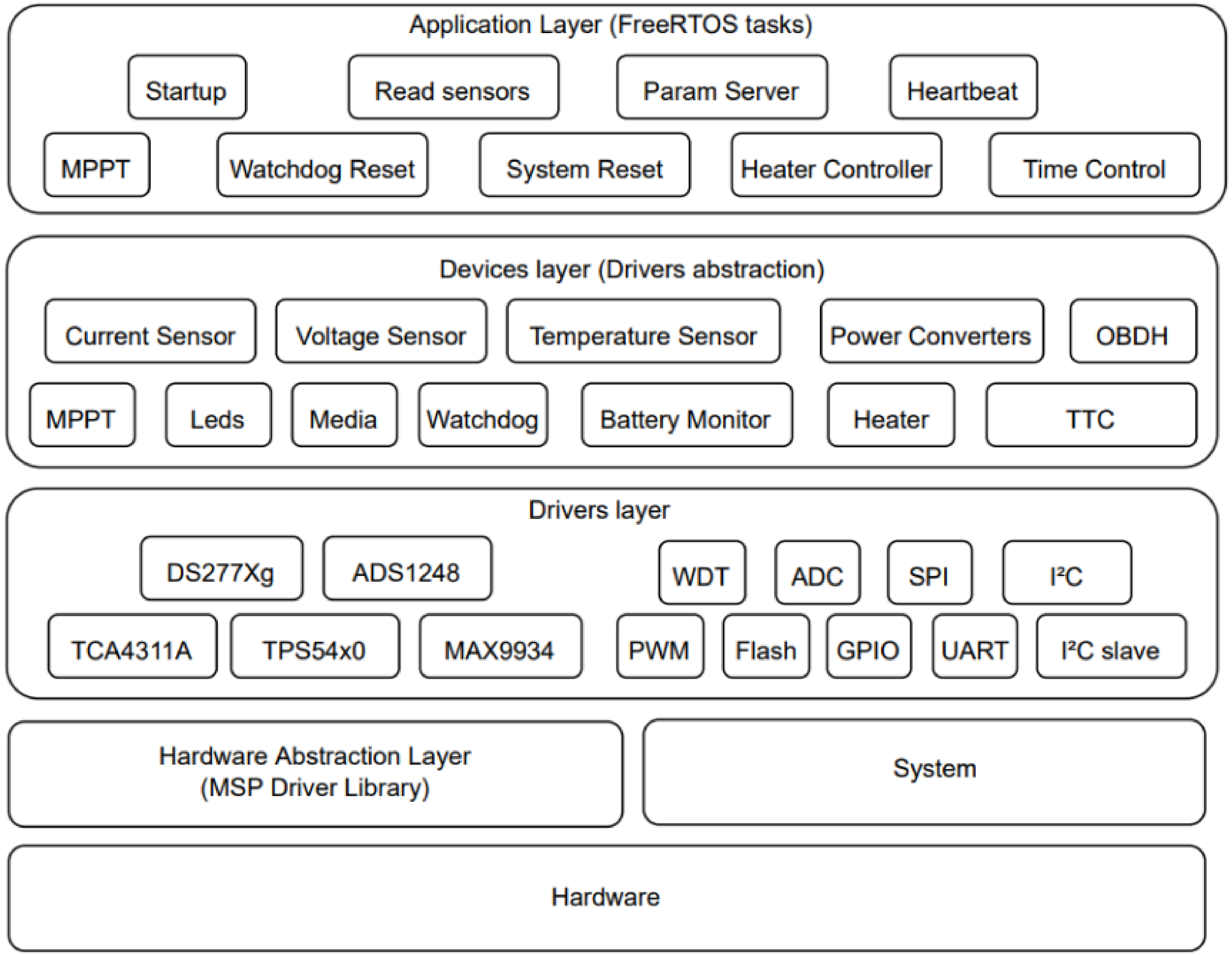
Hardware Architecture



ELECTRICAL POWER SYSTEM ARCHITECTURE

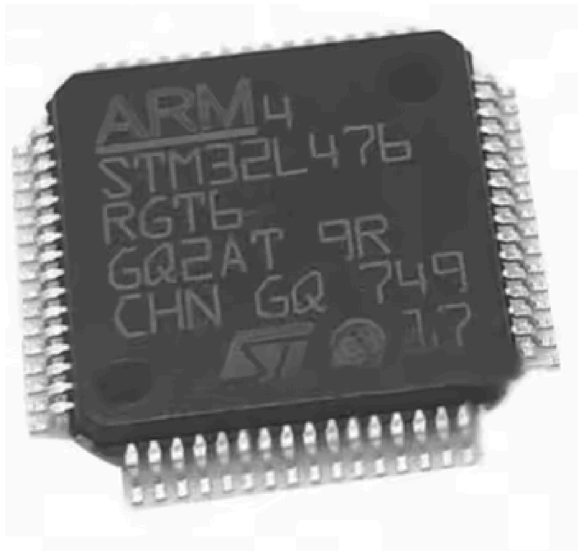


EPS Control Unit

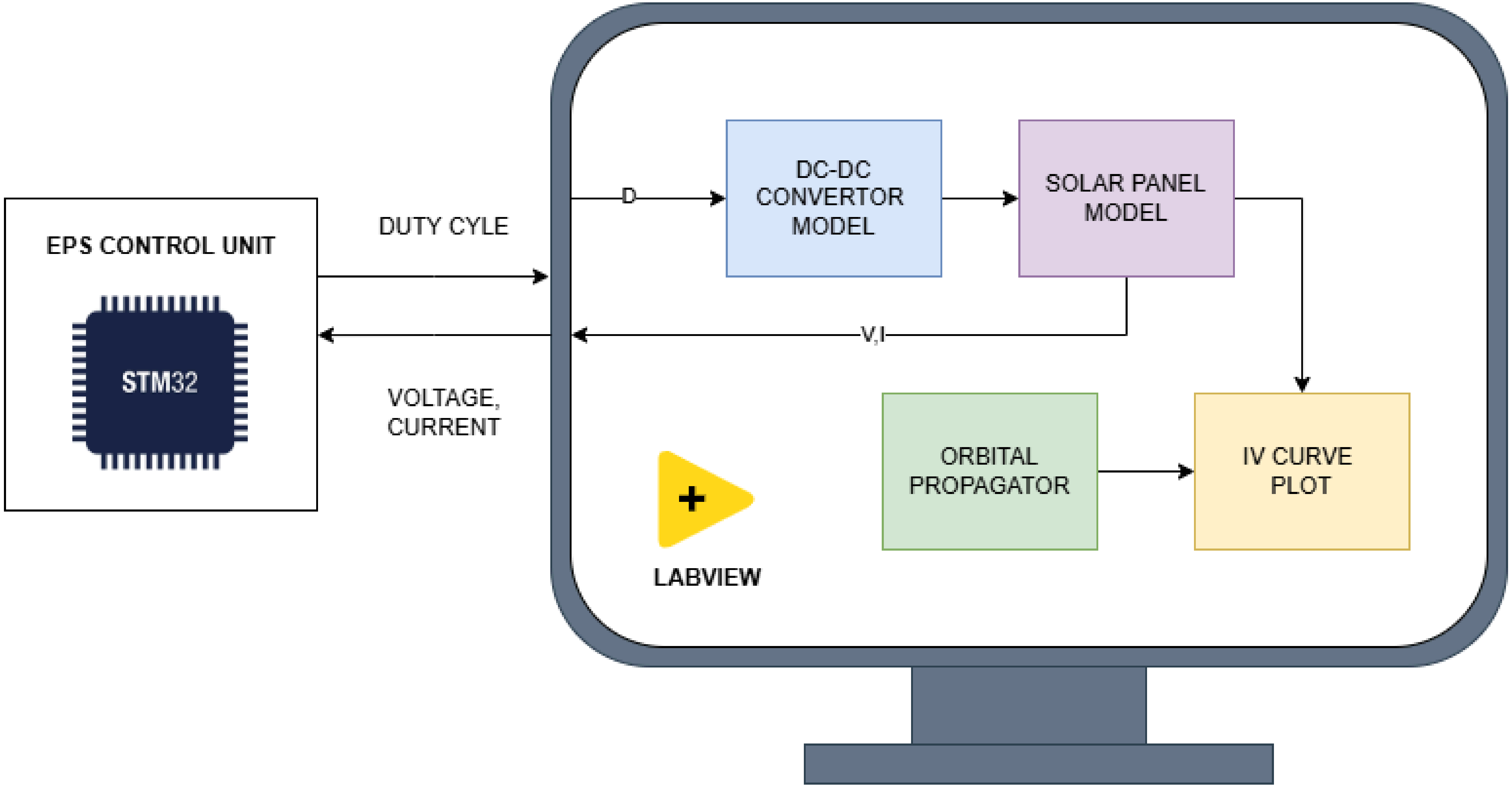


STM32L4767VET6 microcontroller
Embedded programming in C/C++
FreeRTOS real time operating system
Watchdog timer, RTC, CAN Transceiver,
I2C Buffer and other components

Flight software modified for PILS to take sensor reading from serial port instead of INA232 and send duty cycle back to Labview model



PILS ARCHITECTURE



Calculations

Array Generations for Graph

- VOLTAGE ARRAY

$$V_i = \frac{V_{oc}}{N-1} \times i \quad \text{for } i = 0 \text{ to } N-1$$

Where:

- `N` = number of voltage points (e.g., 100)
- `i` = current index in the For Loop

Automatically handled in labview using **ramp pattern.vi**

Calculations

Array Generations for Graph

- CURRENT CALCULATION

- Case 1: For $V \leq V_{mp}$

$$I(V) = I_{sc} + \left(\frac{I_{mp} - I_{sc}}{V_{mp}} \right) \cdot V$$

- Case 2: For $V > V_{mp}$

$$I(V) = I_{mp} + \left(\frac{0 - I_{mp}}{V_{oc} - V_{mp}} \right) \cdot (V - V_{mp})$$

- POWER CALCULATION

$$P(V) = V \cdot I(V)$$

Calculations

Orbital Solar Panel Simulation

- ASSUMPTIONS & GIVEN VALUES

Parameter	Value	Explanation
G_STC	1367 W/m^2	Solar constant (irradiance at standard test conditions)
T_STC	301 K	Cell temperature at STC
β (Beta angle)	0°	Orbit normal is perpendicular to sun vector (simplifies θ calculation)
T_base	260 K	Base satellite cell temperature in shadow
ΔT (rise at full sunlight)	40 K	Estimated heating from full irradiance
α_I	+0.0005 /K	Current temperature coefficient
β_V	-0.0022 V/K	Voltage temperature coefficient

Parameter	Value	Explanation
n	1.2	Diode ideality factor
k	1.380649×10−23 J/K	Boltzmann constant
q	1.602×10 −19 C	Charge of electron
Earth Radius (R_E)	6.371 x 10^6 m	
G (Gravitational Constant)	6.674 x 10^-11	
M (Earth Mass)	5.972 x 10^24	

Calculations

Orbital Solar Panel Simulation

- ORBITAL PERIOD

$$T = 2\pi\sqrt{\frac{(R_E + h)^3}{GM}}$$

- SATELLITE SUN ANGLE (θ) OVER TIME

$$\theta(t) = \left(\frac{360 \times t}{T}\right) \mod 360$$

$$\theta_{\text{rad}} = \theta_{\text{deg}} \times \frac{\pi}{180}$$

- PROJECTED SOLAR IRRADIANCE

Only valid when Sun is in view (i.e., $\theta \in [0°, 90°] \cup [270°, 360°]$):

$$G_{\text{eff}} = G_{\text{STC}} \times \cos(\theta_{\text{rad}})$$

Otherwise:

$$G_{\text{eff}} = 0 \quad \text{(Eclipse)}$$

Calculations

Orbital Solar Panel Simulation

- SOLAR CELL TEMPERATURE

$$T_{\text{cell}} = T_{\text{base}} + \Delta T \left(\frac{G_{\text{eff}}}{G_{\text{STC}}} \right)$$

- IV CHARACTERESTICS

$$I_{sc}(G,T) = I_{sc,\text{STC}} \times \left(\frac{G_{\text{eff}}}{G_{\text{STC}}} \right) [1 + \alpha_I (T_{\text{cell}} - T_{\text{STC}})]$$

$$V_{oc}(G,T) = V_{oc,\text{STC}} + \beta_V (T_{\text{cell}} - T_{\text{STC}}) + \frac{nkT_{\text{cell}}}{q} \ln \left(\frac{G_{\text{eff}}}{G_{\text{STC}}} \right)$$

$$I_{mp}(G,T) \approx I_{mp,\text{STC}} \times \frac{I_{sc}(G,T)}{I_{sc,\text{STC}}}$$

$$V_{mp}(G,T) \approx V_{mp,\text{STC}} \times \frac{V_{oc}(G,T)}{V_{oc,\text{STC}}}$$

Labview Program