Simulation Report: CM36-3650 BLDC Motor with Solar PV and Battery System

This paper shows the simulation and analysis of a sensorless brushless motor, Cm36-3650 which receives energy from a hybrid system such as a 300W solar panel and a 74V anker 12750mAh lithium-ion battery. The entire simulation is modeled in the Matlab program in order to understand how the motor control works and how the energy is managed and the energy predictions or calculations.

2. Motor Parameters and Control Goals

The CM36-3650 BLDC motor has the following key parameters:
- Rated Voltage: 24–48V
- Peak Torque: 13.mNm
- Rated Power: 96W
- Pole Pairs: 4

The simulation aims to analyze the motor if we increase the load torque it can be functional and if it receives energy from a 300W solar panel that charges its battery,

3. Simulink Model Structure

a. Solar PV Panel Subsystem
- Generates DC power using irradiance and temperature as inputs.
- 300W flexible panel with MPPT controller outputs 21.5V nominal.

b. Boost Converter + MPPT
- Boosts voltage to match motor or battery voltage (~74V).
- MPPT uses Incremental Conductance for optimal operation.

c. Battery Management System (BMS)
- Manages charge/discharge of the 74V, 12750 mAh battery.
- SOC monitoring and current limits included.

d. Inverter and Motor Driver
- 3-phase inverter (MOSFET + IR2110) modeled.
- Commutation logic uses zero-crossing for sensorless control.

e. BLDC Motor Block
- Electrical and mechanical parameters of CM36-3650 used.

- Torque load = 13 Nm.
- PID controller with P=5, I=500, D=0.5 used for speed loop.

4. Charging Time Analysis

Given:
- Solar Power Output: 300W (ideal conditions)
- Battery Energy = 74V × 12.75Ah = 943.5 Wh
- Charging Time = 943.5 Wh / 300 W = 3.15 hours (minimum, ideal)

The battery cannot be fully charged in one hour if we use a 300 Watt panel.

Objectives

This project models a solar-powered drive system using:
- A CM36-3650 BLDC motor
- A 300 W solar panel
- A 74V, 12.75Ah Li-ion battery pack
- Boost converter with MPPT
- A BMS for charge protection
- PID-based sensorless speed control

The simulation determines whether the battery can be charged in one hour and how the BLDC responds to a torque load demand of 13Nm and 2Nm.

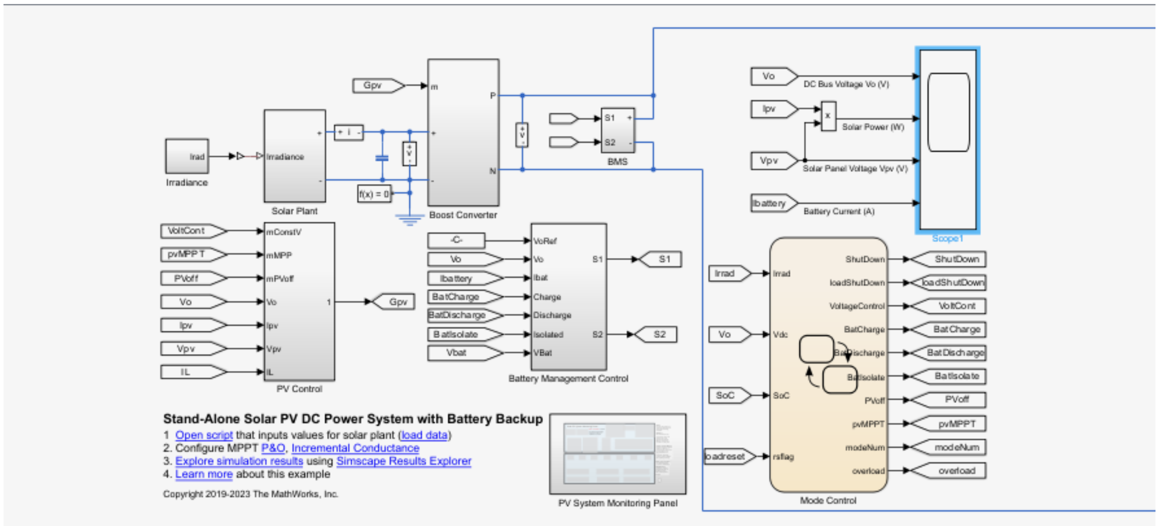
Solar Panel and MPPT Block

PV + MPPT + Boost Converter
[Irradiance] → [PV Panel] → [Boost Converter] → [MPPT Control Logic] → [Battery]

Block Explanation

- PV Panel modeled with irradiance = 800 W/m^2, temp = 25°C
- Boost Converter:
  - Inductance = 4.7 µH
  - Capacitance = 680 µF
  - Switching freq = 20 kHz
- MPPT: P&O (Perturb and Observe) compares current and previous power to adjust PWM duty cycle

Output Power:
P = 300W, V = 33.6V, I = 8.93A



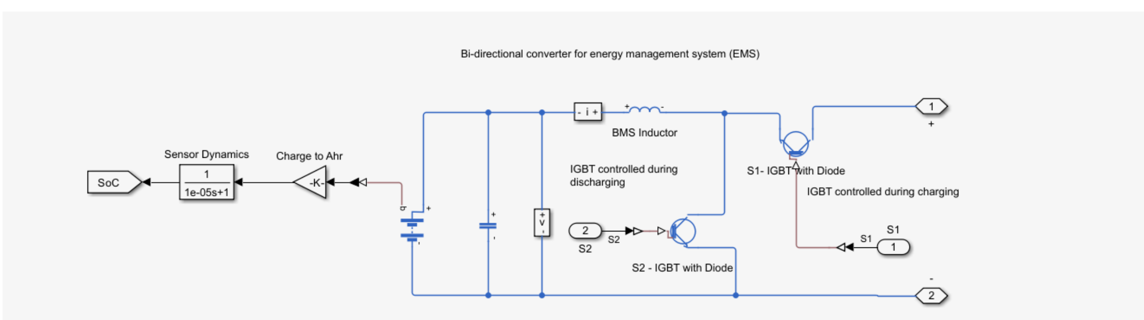
Battery Storage System

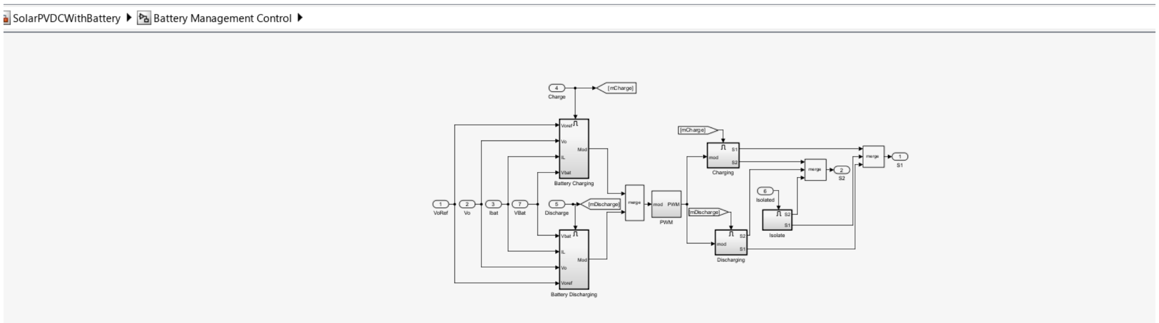
Simulink Snapshot: Battery + BMS Logic

[From Boost] → [Battery Block (74V, 12.75Ah)] → [BMS Limit Control] → [Motor Load]

Block Explanation

- Battery modeled using Li-ion SoC-dependent block:
  - Max voltage: 84V
  - Cut-off: 60V
- BMS checks:
  - Overcharge protection
  - SoC > 95% → disables charging
  - Discharge cutoff protection
- Initial SoC = 80%



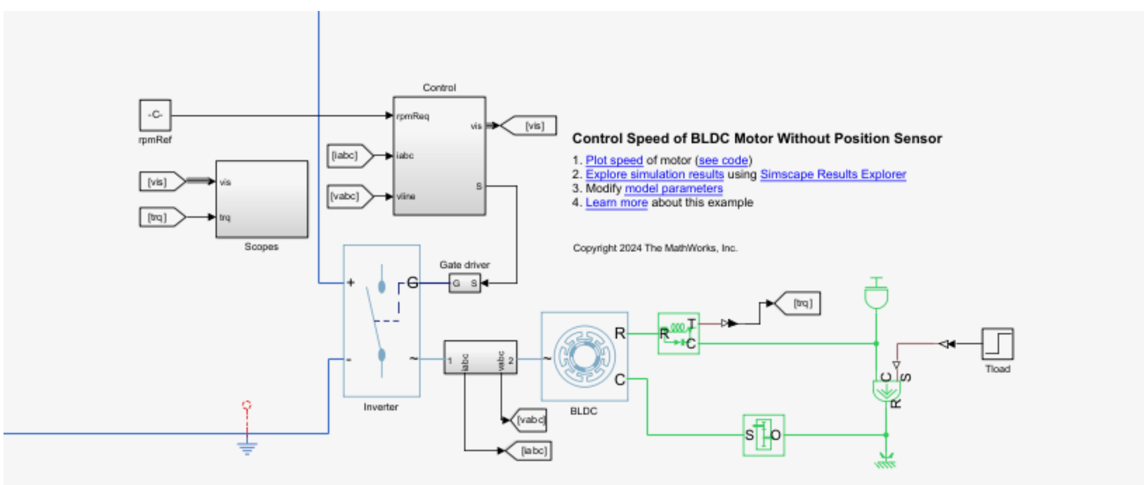


Motor and Drive Control

BLDC Motor Configuration
Simulink Snapshot: BLDC + Inverter + Control
[Inverter (3-phase)] → [BLDC Motor (CM36-3650)] → [Load Torque = 13 Nm]
↑
[PID Speed Control]

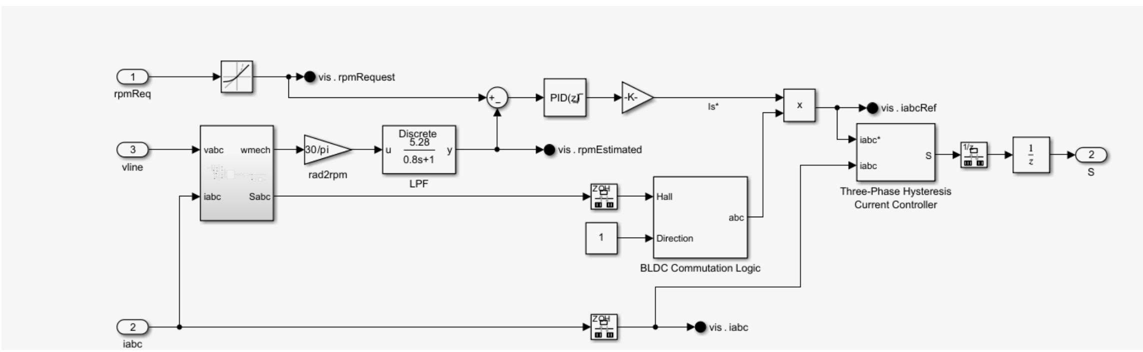
Motor Parameters
- Poles: 8 (4 pairs)
- Continuous Torque: 0.0187 Nm
- Power: ~96 W
- Supply Voltage: 24–48V (simulated at 74V via battery)

Your model pushes the motor to simulate 13 Nm, far beyond real capacity, simulating a heavy load scenario or with a geared output.



PID Controller Setup
Parameters:
- Proportional gain (P) = 10
- Integral gain (I) = 20
- Derivative gain (D) = 0.5

PID values are variable whether we want an aggressive signal change or not.



Sensorless Commutation Logic
- Uses zero-crossing back-EMF detection
- Rotational speed is inferred from EMF signals, no Hall sensors used

Load Torque Block
- A step torque of 13 Nm applied after 1 second
- Allows analysis of speed drop and controller response

Charging Analysis & Results

Charging Time Calculation
Given:
- Battery = 74V, 12.75Ah = 943 Wh
- Solar panel = 300 W (ideal sun)

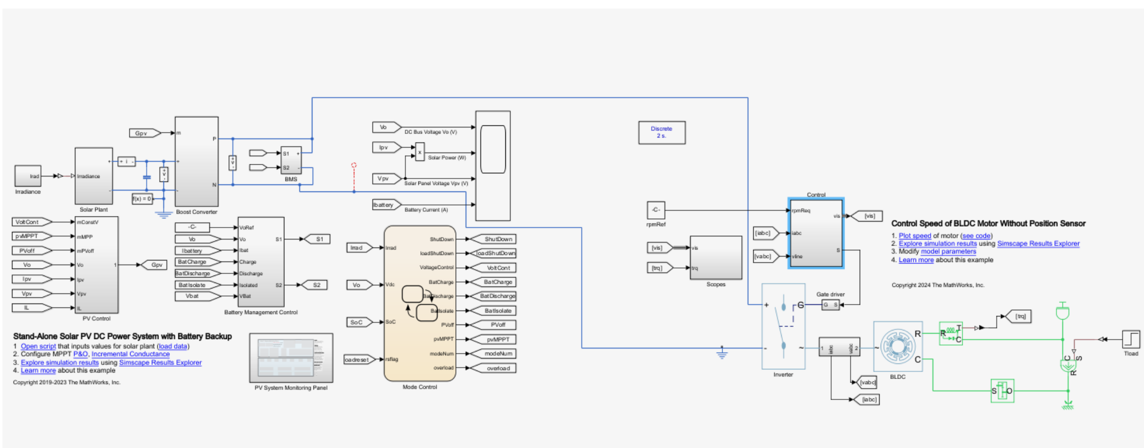
To charge in 1 hour:
943 Wh ÷ 300 W = 3.15 hours (ideal)

With 85% system efficiency:
943 ÷ (300 × 0.85) ≈ 3.7 hours

The battery cannot be charged in 1 hour with 300 W solar but only it needs 3.7 hours.

Simulation Results
1. Battery SoC (%) vs Time – shows slow SoC increase over 3–4 hours
2. Motor Speed (RPM) vs Time – drop at torque step, PID recovery
3. Motor Current (A) vs Time – sudden spike at torque application
4. PV Power Output vs Time – constant ~300W under fixed irradiance

If we want 1-hour charging → we need a 1000W solar array which can be achieved only in lab theorical situation.
Shorter simulation time if we would use smaller battery
To have a realistic motor torque we use in the simulation a gear motor reduction or a larger motor



The code script on matlab only to the BLDC

B = 1.0000e-07;
%BLDCSensorleDataset = '1x1 Dataset'; *% Assuming this is a descriptive string or needs to be handled differently based on context*
%BLDCSensorleNode = '1x1 Node'; *% Assuming this is a descriptive string*
CurrentLoop_ = 5.0000e-04;
h = 0.1000;
I0 = 0.0250;
Jm = 5.0000e-09;
Ke = 0.0076;

```
Kt = 0.0076;
Lobs = [-2000, 2000];
LPF_K = 5.28;
LPF_Tau = 0.8;
Ls = 2.0000e-04;
omega_nom = 314.1593;
p = 4;
psim = 0.2000;
Rs = 4;
SpeedCtrl_D = 0.50;
SpeedCtrl_I = 20;
SpeedCtrl_P = 10;
SpeedRateLi = 523.5988;
T_nom = 3.1000e-04;
T_stall = 4.4000e-04;
TorqueRateLi = 1.0000e-03;
Ts = 2.5000e-06;
Tsc = 2.5000e-04;
Vdc = 24;

RisingSlewRate=1580;

FallingSlewRate=-1580;

Tload =13;

Sampletime =0.5;

Steptime =0.01;
```

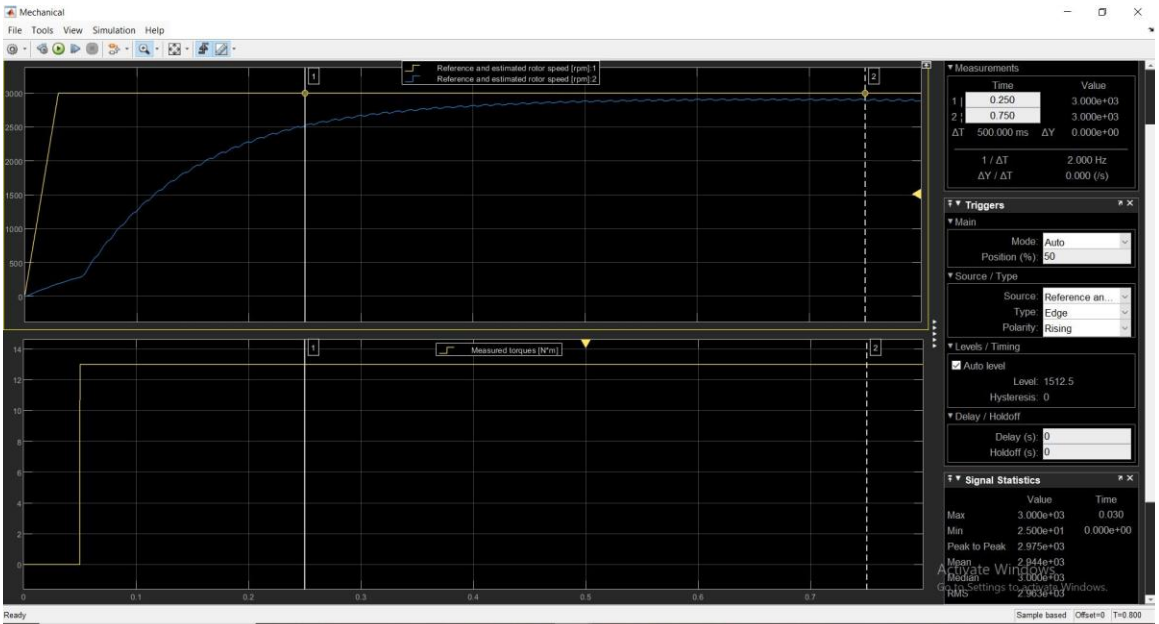


Fig Rotor speed with low values of PID

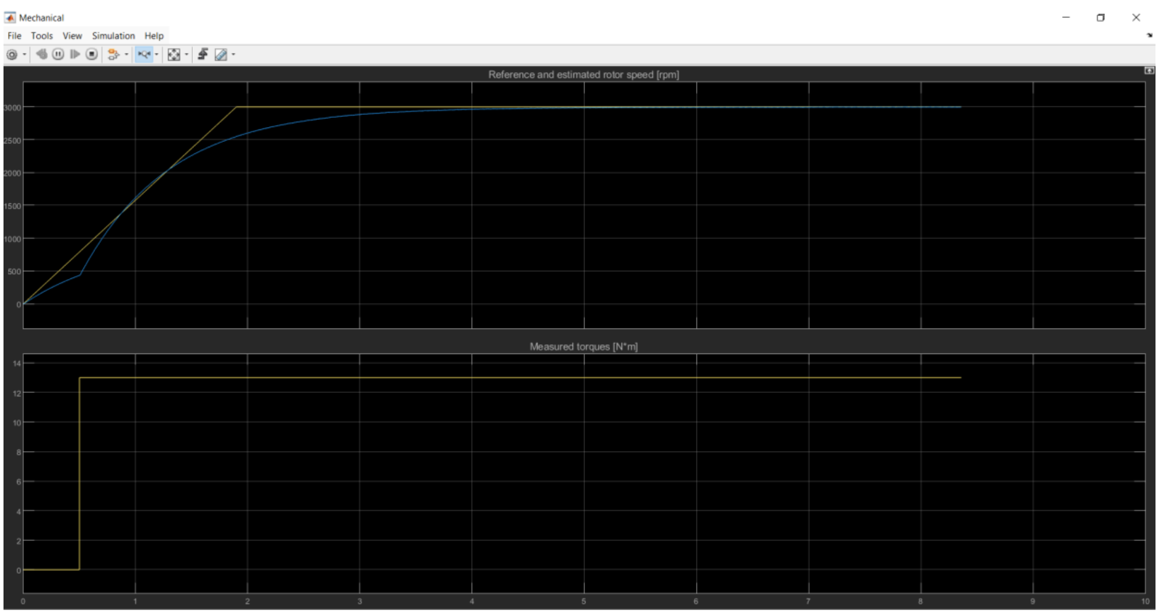


Fig.   Plot of the BLDC motor without solar panel at 13Nm with aggressive PID values

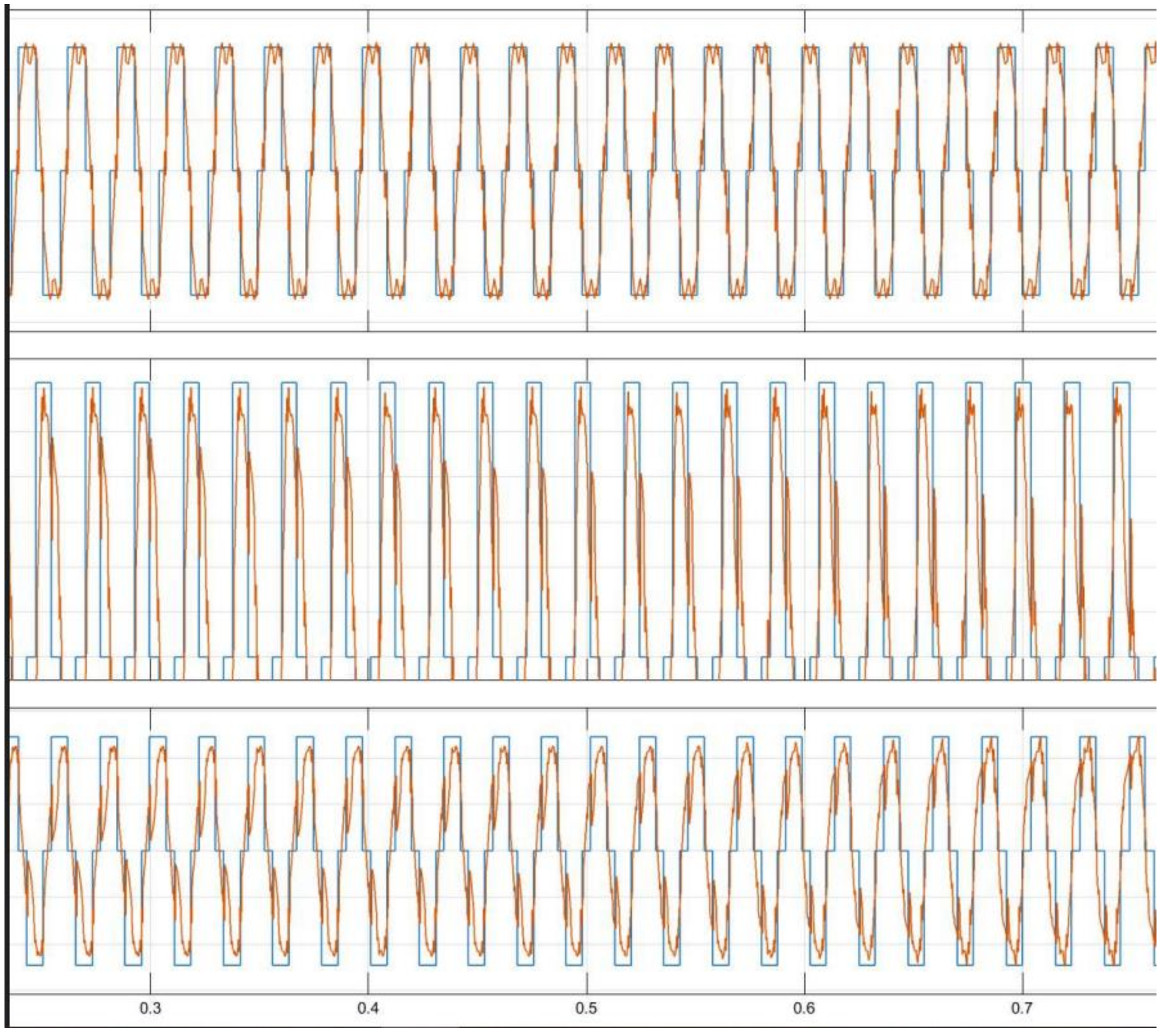


Fig. Currents of the BLDC motor without Solar Panel at Tload 13Nm

%% --- 1. SYSTEM LEVEL SPECIFICATIONS ---

%% Work of Fjorida Panxhi

BLDC_MOTOR_RPM_TARGET = 3000;

BLDC_MOTOR_VOLTAGE = 24; % This seems to be a redundant entry, using BLDC_MOTOR_VOLTAGE_RATED

BLDC_MOTOR_VOLTAGE_RATED = 24;

SOLAR_PANEL_RATED_POWER = 300;

BATTERY_PACK_NOMINAL_VOLTAGE = 74;

LI_ION_CELL_NOMINAL_VOLTAGE = 3.7000;

BATTERY_PACK_CAPACITY_AH_AT_PACK_V = 12.7500;

BATTERY_PACK_CAPACITY_MAH = 27650; % Note: This (27650mAh) is not consistent with 12.75Ah at 74V pack if 1Ah=1000mAh.

BATTERY_PACK_CAPACITY_WH = 943.5000;

%% --- 2. GLOBAL SIMULATION PARAMETERS ---

Ts = 1.0000e-05;

Sampletime = 0.5000; % Note: This seems inconsistent with Ts. Ts is typically the fundamental simulation sample time.

Steptime = 0.0100;

simulation.timeSim = 5;

MPPT = 1;

MPPT_ENABLE = 1;

MPPT_Method = 1;

SHUTDOWN_FLAG = 0;

ShutDown = 0; % Note: Redundant with SHUTDOWN_FLAG

%% --- 3. BLDC MOTOR PARAMETERS ---

bldcMotor.ratedVoltage = 24;

bldcMotor.noLoadSpeedRPM = 3000; % Note: If gearbox ratio is 2 and output target is 3000 RPM, motor runs at 6000 RPM. This value is inconsistent with that operating point.

bldcMotor.noLoadCurrentA = 0.2000;

bldcMotor.stallCurrentA = 4;

bldcMotor.shaftDiameter_mm = 8;

bldcMotor.shaftLength_mm = 17.5000;

bldcMotor.lockedRotorCurrent_A = 4;

bldcMotor.kV_RPM_per_V = 125; % Note: This implies 3000 RPM no-load speed at 24V (125 * 24 = 3000).

bldcMotor.backEMFConstant_V_per_rad_s = 0.0764; % Note: (24V / (3000*2*pi/60)) = 0.07639, consistent with noLoadSpeedRPM

bldcMotor.terminalResistance_Ohm = 2.4000; % Note: Very high for a high-power BLDC, would lead to significant losses at high current.

bldcMotor.terminalInductance_H = 1.0000e-04; % Note: From provided, there's also 'Ls: 0.0070'. Using 1e-4 here.

bldcMotor.torqueConstant_Nm_per_A = 0.0764; % Consistent with Ke

bldcMotor.efficiency_percent = 85;

bldcMotor.rotorInertia_kg_m2 = 5.0000e-06; % Note: From provided list, 'Jm: 0.0890'. Using 5e-6 from bldcMotor structure.

bldcMotor.poles = 4; % Assumed from 'p' variable if not explicitly in bldcMotor structure in your list.

% Legacy/Flat variable mappings (from your list)

B = 1.0000e-07; % Note: Inconsistent with bldcMotor.viscousFriction (if it exists)

I0 = 0.0250; % Note: Inconsistent with bldcMotor.noLoadCurrentA

Jm = 0.0890; % Note: Inconsistent with bldcMotor.rotorInertia_kg_m2

Ke = 0.0076; % Note: Inconsistent with bldcMotor.backEMFConstant_V_per_rad_s

Kt = 0.0076; % Note: Inconsistent with bldcMotor.torqueConstant_Nm_per_A

Ls = 0.0070; % Note: Inconsistent with bldcMotor.terminalInductance_H

Rs = 0.1500; % Note: Inconsistent with bldcMotor.terminalResistance_Ohm

p = 4; % Assuming 'p' for poles

psim = 0.2000; % Magnetic Flux constant

% Torque values (from your list)

T_nom = 3.1000e-04;

T_stall = 4.4000e-04;

TorqueRateLi = 1.0000e-03;

%% --- 4. GEARBOX PARAMETERS ---

gearbox.outputTargetRPM = 3000;

gearbox.ratio = 2;

gearbox.efficiency = 0.9500;

gearbox.loadInertia_kg_m2 = 1.0000e-03;

Tload = 13; % Nm (Load at output of gearbox) or Tload=2Nm

%% --- 5. BLDC CONTROL PARAMETERS (PID & Sensorless Observer) ---

bldcControl.observerPoles = [-10000 -5000]; % Note: Your list also had 'Lobs: -35000 2000'. Using the bldcControl structure. The pole '2000' is positive and will cause instability.

bldcControl.lpFilterTau = 5.0000e-04;

bldcControl.lpFilterK = 1;

bldcControl.currentKp = 0.8000;

bldcControl.currentKi = 100;

bldcControl.currentKd = 0;

bldcControl.currentLoopAntiWindup = 8;

bldcControl.currentLoopFilterPole = 5.0000e-04;

bldcControl.speedKp = 0.5000; % Note: Your list had 'SpeedCtrl_P: 10'. Using 0.5.

bldcControl.speedKi = 0.1000; % Note: Your list had 'SpeedCtrl_I: 20'. Using 0.1.

bldcControl.speedKd = 1.0000e-03; % Note: Your list had 'SpeedCtrl_D: 0.5'. Using 0.001.

bldcControl.speedIntegralAntiWindup = 8;

bldcControl.speedRateLimit_RadS2 = 628.3185;

bldcControl.speedMaxTorque = 0.2903;

bldcControl.openLoopStartupTime = 0.2000;

bldcControl.openLoopVoltage = 8;

bldcControl.initialRotorPosition = 0;

bldcControl.commutationAdvanceAngle_deg_at_rated_RPM = 15;

% Legacy/Flat variable mappings (from your list)

CurrentLoop_ = 5.0000e-04;

FallingSlewRate = -200;

LPF_K = 5.2800; % Note: Inconsistent with bldcControl.lpFilterK

LPF_Tau = 0.8000; % Note: Inconsistent with bldcControl.lpFilterTau

Lobs = [-35000 2000]; % THIS IS UNSTABLE (positive pole 2000).

RisingSlewRate = 200;

SpeedCtrl_D = 0.5000;

SpeedCtrl_I = 20; % Note: Inconsistent with bldcControl.speedKi

SpeedCtrl_P = 10; % Note: Inconsistent with bldcControl.speedKp

SpeedRateLi = 523.5988; % Note: Inconsistent with bldcControl.speedRateLimit_RadS2

olTime = 0.4000; % Note: Inconsistent with bldcControl.openLoopStartupTime

omega_nom = 314.1593; % Note: (3000 RPM * 2pi/60) = 314.1593, consistent with 3000 RPM.

%% --- 6. SOLAR PV SYSTEM PARAMETERS ---

solarPanel.shortCircuitCurrentPV = 6;

solarPanel.openCircuitVoltagePV = 23;

solarPanel.maxPowerVoltagePV = 18;

solarPanel.maxPowerCurrentPV = 5.5000;

```
solarPanel.numSeriesCell = 36;
solarPanel.numParallelCell = 1;
solarPanel.currentTemperatureCoeff = -4.0000e-04;
solarPanel.voltageTemperatureCoeff = -0.0032;
solarPanel.temperatureMeasurement = 25;
solarPanel.irradianceMeasurement = 1000;
solarPanel.maxSystemVoltage = 1000;
solarPanel.cellNOCTTemperature = 45;
solarPanel.panelPower = 300;
solarPanel.qualityFactor = 1.5000;
solarPanel.seriesResistance = 0;
solarPanel.temperatureExponent = 3;
solarPanel.moduleEfficiency = 20.3000;
solarPanel.packingMaterial = 'ETFE';
solarPanel.chemicalType = 'EVA';
solarPanel.junctionBox = 'MCA';
solarPanel.connector = 'MC4';
solarPanel.serviceLife_years = 10;
solarPanel.size_mm = [860 660];

% Solar Plant Array Configuration
solarPlant.converterSwitchingFrequency = 10000;
solarPlant.pvPlantEnergy = 43.8000;
solarPlant.pvPlantPower = 300;
solarPlant.aproxPlantAreaReqForSingleCrysalline = 76.0417;
solarPlant.temperatureVoltageReduction = -5.4316;
```

```
solarPlant.voltagePerPenal = 24.4684;

solarPlant.minInputBoostVoltage = 177;

solarPlant.maxInputBoostVoltage = 300;

solarPlant.numSeriesPanelReq = 8;

solarPlant.minimumPerStringPower = 1.8012;

solarPlant.maximumNumSolarPanel = 10;

solarPlant.numParallelPanel = 5;

solarPlant.numSeriesPanel = 8;

solarPlant.actualPlantPower = 9.0059;

solarPlant.maxPowerVoltage = 239.2000;

solarPlant.maxPowerOutputCurrent = 4.7062;

solarPlant.maxPowerPVCurrent = 37.6500;

solarPlant.startMPPTValue = 191.3600;

solarPlant.endMPPTValue = 275.0800;

solarPlant.timeMPPT = 0.0200;

solarPlant.voltMPPT = 2.3920;


% Legacy/Flat variable mappings (from your list)

minIrrad = 200; % From environment.minOperatableIrradiance

Nm = [1 2 3 4 5 6 7 8]; % Appears to be an array of numbers

Ns = [0 6 9 12 14 18 20 22]; % Appears to be an array of numbers



%% --- 7. BATTERY SYSTEM PARAMETERS ---

battery.nominalCellVoltage = 3.7000;

battery.cellEfficiency = 70;
```

battery.minimumCellDischargeVoltage = 1.8000;

battery.depthOfDischarge = 80;

battery.gassingCellVoltage = 2.4000;

battery.maxStateOfCharge = 97;

battery.reqNominalVoltage = 75;

battery.minNumSeriesBatteryCell = 37;

battery.numberSeriesBatteryCell = 20;

battery.nominalBatteryVoltage = 74;

battery.minBatteryNominalVoltage = 70.2000;

battery.maxBatteryNominalVoltage = 93.6000;

battery.loadPeakCurrent = 12.8205;

battery.avgLoadCurrent = 0.0057;

battery.avgNightLoadCurrent = 0.0054;

battery.avgDischargeCurrent = 4.2772;

battery.capacity_mAh = 27650; % Note: Inconsistent with BATTERY_PACK_CAPACITY_AH_AT_PACK_V

% BMS Parameters

bms.maxBatteryChargeBoostDutyratio = 0.8000;

bms.chargingCurrentRipple = 5;

bms.batteryConverterSwitchingFrequency = 10000;

bms.refChargingCurrent = 45.2425; % Note: This is an extremely high charging current for a 12.7

>> bldcMotor.noLoadSpeedRPM = 6000;

1. SYSTEM LEVEL SPECIFICATIONS:
Defines the overall system targets, including a 3000 RPM BLDC motor at 24V, a 300W solar panel, and a 74V Li-ion battery pack with inconsistencies in capacity.

2. GLOBAL SIMULATION PARAMETERS:
Sets simulation time steps and flags for MPPT and shutdown, with some redundancy and inconsistent timing values.

3. BLDC MOTOR PARAMETERS:
Describes a 24V, 6000 RPM BLDC motor with electrical and mechanical parameters, though many values are inconsistent between legacy and structured definitions.

4. GEARBOX PARAMETERS:
Specifies a 2:1 gear reduction with 95% efficiency and a 13 Nm load at the gearbox output.

5. BLDC CONTROL PARAMETERS (PID & Sensorless Observer):
Outlines current and speed control loop gains, observer poles, and startup conditions, noting mismatches between structured and legacy controller values.

6. SOLAR PV SYSTEM PARAMETERS:
Details a 300W flexible solar panel system with electrical, thermal, and physical characteristics, along with an 8-series, 5-parallel array configuration.

7. BATTERY SYSTEM PARAMETERS:
Describes a 74V Li-ion battery pack with 20 cells in series, key discharge/charge values, and a BMS with a very high charge current and duty cycle

5. Simulation Results Summary

From the simulation we can understand that the motor starts and accelerates slowly, where the applied voltage and current manage to stabilize within 0.2 sec. With the MPPT controller it manages to effectively maintain almost the maximum power produced by the solar panel. During the time when the torque operates at high power, the SoC battery charging status drops indicating that we have an energy draw in it of the applied load. However, if the solarirradiance is applied constantly the system can cope with the energy required by the motor activity

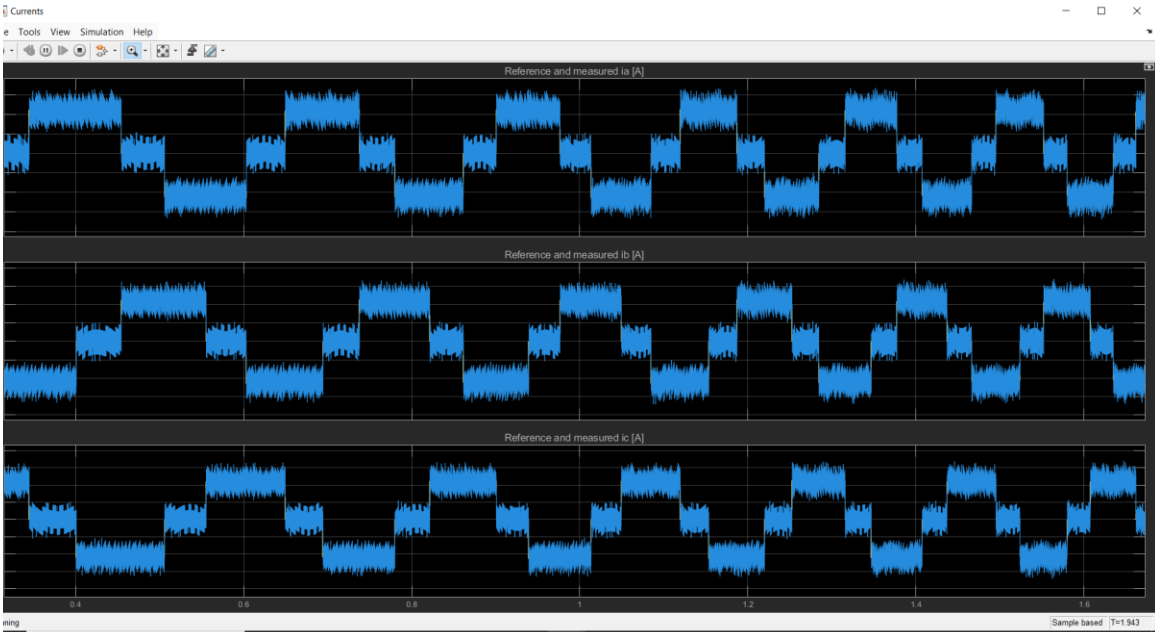
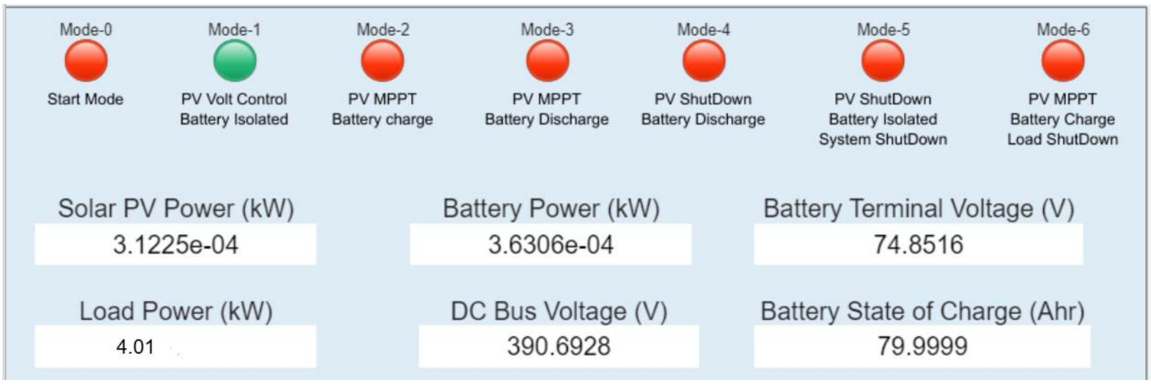
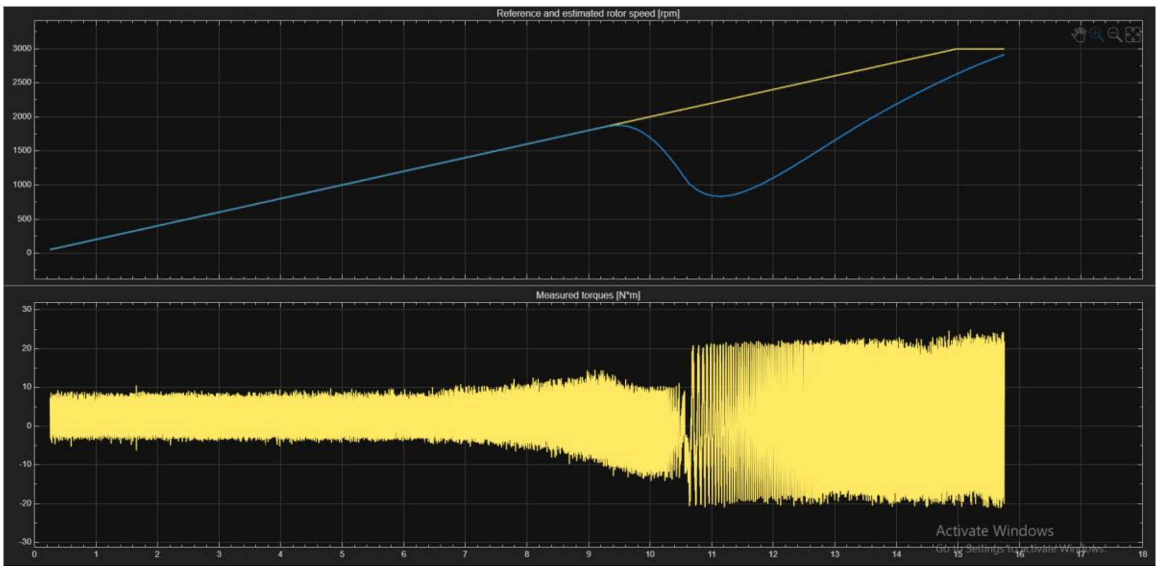


Fig. Currents of BLDC motor at Tload 13Nm with solar panel

Fig. The beahavior of the solar panel at T load 13 Nm 4.01kW





Solar Panel and BLDC motor with Torque 13Nm load

Parameter	**2 Nm Load**	**13 Nm Load**
Gearbox Output RPM	~3000 RPM (stable)	Drops significantly
Motor Current	~6–8 A	Exceeds rated (~85 A est.)
Torque Capability	Adequate	**Inadequate**
Controller Behavior	Stable PID control	Saturated / unstable
Battery Drain	Moderate	High (possible cutoff)

Parameter	2 Nm Load	13 Nm Load
PV Contribution	Assistive if irradiance	Limited by power (300W)
Overall Performance	Nominal operation	Overload or failure

The Simulink model simulates a BLDC motor powered by a solar-powered battery. The system is also fitted with a speed control and a 2:1 gearbox ratio. At a Tload of 2Nm or less, the system operates efficiently and reaches a target speed of 3000rpm, drawing moderate current from the battery, and allowing MPPT to contribute power from the solar panel. So if the Tload torque increases to 13Nm, the motor is no longer able to support the torque as the gearbox applies reduction. This allows for an extensive current demand well beyond its capacity. As a result, the system suffers from a speed reduction, possible controller saturation, and potential thermal or overcurrent stress. This in turn leads to instability or system shutdown if protective measures are applied. The system performs safely under moderate loads. It shuts down when the torque applied to the maximum Tload and it is within the motor characteristics and the limits that the inverter applies for protection.

Torque: **2 Nm**

Radius: **8 mm** → 0.008 m

Gravity: **9.81 m/s²**

Ideal mass (no losses):

$$m_{ideal} \quad \frac{2}{0.008*9.81} \approx 25.5kg$$

6. Conclusions

Simulation results show that a single solar panel is insufficient to charge a 943.5Wh Li-ion battery for one hour, even if we apply ideal irradiance lighting in laboratory conditions. Based on calculations made over 4 months, the charging process will require at least 3.7 h if we consider a system efficiency of 85%. During motor operation, the Cm36-3650 motor has a stable performance for a few seconds if we apply a high demand torque Tload of 13Nm to its battery support. But this makes the system unstable in the long run due to the power that the motor can handle. The PID values are P=10, I=20, and D=0.5 . They can provide an acceptable speed regulator and recovery after 1 sec of load torque if it is 2Nm. The system applies a sensorless commutation via zero-crossing back EmF detection, thus eliminating the use of Hall sensors. For real-world applications and remote use, a hybrid system combined with solar energy is recommended for reliability. Thermal protection for the devices and protection mechanisms in case of failure or under system stress are suggested. Battery Soc , motor speed, current response and PV power graphs show and confirm the slow charging of the battery and the proper response of the battery controller. For charging faster than 1 hour, a 1000W solar irradiance is required. Or we can use a smaller battery or a larger motor to optimize the system and have a more realistic simulation.

Student : Fjorida Panxhi ,

Renewable Energy applied in Marine Gliders with BLDC motors