Cm36-3650 BLDC Motor Control System Analysis and Stabilization

A brushless DC (BLDC) motor control system integrated with a solar photovoltaic (PV) and battery energy storage system in a Simulink environment is the subject of this work thesis. Early simulations showed extreme instability, with divergent torque and speed signals, especi ally when trying to control speeds that were higher than what the motor could physically achi eve. By carefully adjusting the parameters, especially the observer poles and PID controller gains, stable operation was achieved with a 2 Nm load at a practical reference speed of 250 RPM. The battery's energy and charge characteristics, including its nominal voltage, capacity, and charge/discharge current limits, as well as the solar panel's power generation capabilities, were crucial for system power delivery.

Data shows that the solar panel with a capacity of 300 W can power the engine for approximately 14.6 hours at 250 RPM and 2 Nm after fully charging the 943.5 Wh battery, which takes around 4.4 hours. This report further explains motor physical system limitations, control loop adjustment, and the difference between load torque (Nm) vs mass (kg) applies here. It also offers a detailed comparison while operating with a greater torque load of 13 Nm..

Short explanation

For the industry having dependable and efficient control systems for BLDC motors is crucial, especially in hybrid energy setups that mix solar panels with battery storage. The aim of this study was to analyze and stabilize a Simulink model of the system, which initially faced significant challenges with control stability and adherence to the physical constraints of the motor.

The system was modeled using Matlab /Simulink, integrating a BLDC motor, a gearbox, a solar PV array, a boost converter, a battery bank, and a Battery Management System (BMS). The motor control utilized a sensorless observer for speed and position estimation, coupled with cascaded PID controllers for speed and current regulation. System parameters were defined and managed via a MATLAB script, allowing for systematic modification and analysis.

Initial parameters, including motor characteristics (e.g., rated voltage, no-load speed, electrical constants), gearbox ratio, and control gains (Proportional-Integral-Derivative (PID) gains for speed and current loops, and observer poles), were iteratively refined. The primary diagnostic tools were Simulink scopes, visualizing reference speed, estimated rotor speed, and measured torque.

3. Results

Initial Instability at High Speed Targets

Early simulations, particularly when attempting to achieve a 3000 RPM output speed with a 2:1 gearbox (requiring 6000 RPM from the motor), consistently resulted in severe instability. The "Reference and estimated rotor speed" plots showed the estimated speed diverging to extremely high values (e.g., 45×103 RPM), while "Measured torques" exhibited large, uncontrolled oscillations [1, 2, 3]. This behavior was primarily attributed to:

- Physical Motor Limitation: The motor parameters initially defined (e.g., a 24V motor with a 3000 RPM no-load speed) were physically incapable of reaching the commanded 6000 RPM required by the gearbox for the 3000 RPM output target.
- Unstable Observer Poles: The observer's pole configuration, specifically the presence of a positive pole in Lobs (e.g., [-35000 2000]), caused its internal state estimation to diverge, leading to inaccurate feedback for the controllers.
- Aggressive PID Gains: The initial speed control PID gains (SpeedCtrl_P = 10, SpeedCtrl_I = 20, SpeedCtrl_D = 0.5) were excessively high, contributing to oscillatory and unstable responses.

Stable Operation at Speed (250 RPM Output, 2 Nm Load)

Following a series of parameter adjustments, stable operation was successfully achieved at a reduced, physically achievable output speed target. With the BLDC_MOTOR_RPM_TARGET set to 250 RPM (meaning the motor aims for 500 RPM, well within its 250 RPM no-load capability) and a Tload of 2 Nm, the system demonstrated stable tracking [4].

The key parameter changes that led to this stabilization included:

- Motor Parameters: The bldcMotor parameters were adjusted to reflect a motor with a 250 RPM no-load speed at 24V, including recalculated kV_RPM_per_V and backEMFConstant_V_per_rad_s, and adjusted terminalResistance_Ohm, terminalInductance_H, and poles to be more typical for such a low-speed motor.
- Observer Stability: The observer poles (bldcControl.observerPoles and Lobs) were corrected to be entirely negative (e.g., [-1000 -500]), ensuring the observer's stability and accurate state estimation.
- Conservative PID Gains: The speed control PID gains (bldcControl.speedKp = 0.1, bldcControl.speedKi = 0.02, bldcControl.speedKd = 0.0005) and current loop gains (bldcControl.currentKp = 0.6, bldcControl.currentKi = 30) were significantly reduced to more conservative values, preventing oscillations and saturation.

The plot in [4] clearly illustrates the estimated rotor speed (blue line) smoothly and accurately tracking the 250 RPM reference (yellow line). The measured torque also exhibited a stable response after an initial transient, indicating effective load management.

Solar PV System Characteristics

The solar photovoltaic (PV) system serves as the primary renewable energy source for the hybrid system. It is configured with a single 300 W panel. Key electrical characteristics of this panel include an open-circuit voltage (Voc) of 39 V and a short-circuit current (Isc) of

9.80 A. At its maximum power point (MPP), the panel delivers 32.5 V and 9.23 A. The panel's efficiency is specified at 20.30%.

The solar panel's power output is highly dependent on environmental factors such as irradiance (set at 1000 W/m^2 for standard test conditions) and temperature. The system incorporates Maximum Power Point Tracking (MPPT) to ensure the PV array operates at its optimal power output, feeding energy into the common DC bus via a boost converter. The solar panel's contribution directly influences the charging capability of the battery and the direct power supply to the motor.

Battery Energy and Charge Characteristics

The battery pack, central to the hybrid energy system, provides energy storage and load balancing capabilities. It is comprised of Li-ion cells, with each cell having a nominal voltage of 3.7 V. The entire pack has a nominal voltage of 74 V, indicating a series configuration of 20 cells. The battery pack boasts a total capacity of 12.75 Ah (12750 mAh), equating to a total energy storage of 943.5 Wh.

This energy capacity dictates the total energy available to the motor and other loads over time. The battery's ability to supply or absorb power instantaneously is governed by its maximum charge and discharge current limits. These were set at 12.75 A (1C rate) for charging and 25.5 A (2C rate) for discharging. These limits are crucial as they govern the instantaneous power that can be drawn from or supplied to the battery, directly impacting the motor's performance under varying load conditions and ensuring the battery operates within safe parameters. A Battery Management System (BMS) actively manages these charge and discharge processes.

3.5. Battery Charging and Discharge Duration

To assess the energy autonomy of the system, calculations were performed to estimate the battery charging time and the motor's operational duration.

Battery Charging Time: Assuming optimal sunlight conditions and an overall efficiency of 90% for the solar PV system delivering power to the battery, and considering an 80% charging efficiency for the Li-ion battery:

- Effective Solar Charging Power: 300 W×0.90=270 WError! Filename not specified.
- Energy required to fully charge battery (considering efficiency): 943.5 Wh/0.80=1179.375 Wh
- Time to Charge Battery: 1179.375 Wh/270 W≈4.4 hours
- Motor Power Consumption and Run Time: At the stable operating point of 250 RPM output and a 2 Nm load, the motor's power consumption was calculated:
- Output Mechanical Power: Poutput_mechanical=Tload×ωoutput =2 Nm×(250 RPM×602π rad/s/RPM)≈52.36 WError! Filename not specified.

- Motor Electrical Input Power (accounting for gearbox and motor efficiencies of 0.95 and 0.85 respectively): $P_{motor\_electrical\_input} = 52.36\ W/(0.95 \times 0.85) \approx 64.8\ W$
- Motor Run Time (from a fully charged battery): Battery Energy Capacity (Wh)/Motor Electrical Input Power (W)
- Motor Run Time: $943.5\ Wh/64.8\ W \approx 14.6$ hours
- These calculations indicate that under ideal conditions, the 300 W solar panel can fully charge the 943.5 Wh battery in approximately 4.4 hours, and this charged battery can then power the BLDC motor at 250 RPM and 2 Nm load for about 14.6 hours.

Comparison for Higher Torque Loads (e.g., 13 Nm)

While stable operation was achieved at 2 Nm, extending this stability to significantly higher torque loads, such as 13 Nm, presents a new set of challenges, particularly for the current motor (250 RPM no-load). The motor's capability to deliver torque is directly related to its current handling capacity and torque constant (Kt).

For the assumed 250 RPM motor, its calculated stall torque at the output of the 2:1 gearbox is approximately 34.8 Nm. This indicates that the motor is physically capable of generating 13 Nm of torque. However, delivering 13 Nm of torque will require a much higher current from the motor and, consequently, from the inverter and power supply (battery/PV system) compared to 2 Nm.

The primary challenges and considerations when increasing the load torque to 13 Nm would be:

- Current Demand and Saturation: To produce 13 Nm of torque, the motor will draw significantly more current. The motor's continuous and peak current limits (bldcMotor.maxCurrentA), as well as the inverter's and power supply's current delivery capabilities, must be sufficient. If the current demand exceeds these limits, the motor will not be able to produce the required torque, leading to speed deviations, increased error, and potential instability as the control loops saturate.
- Thermal Management: Higher continuous currents, necessitated by a 13 Nm load, will generate substantially more heat within the motor windings and the power electronic components of the inverter. Sustained operation at this higher load might lead to overheating and damage if the thermal design (e.g., heatsinks, cooling fans) is inadequate.
- Power System Capacity: The solar PV and battery system must be robust enough to supply the increased power demand associated with 13 Nm of torque at 250 RPM output. This involves ensuring the battery can discharge at the required C-rate (25.5 A max) and the converters (boost, BMS) can handle the higher power flow without exceeding their design limits. The battery's energy capacity (943.5 Wh) determines how long it can sustain this high power output. Similarly, the 300 W solar panel's output must contribute significantly, or the battery will rapidly deplete.

- Control Loop Response and Tuning: While the current and speed control loops were tuned for stability at 2 Nm, they might require further fine-tuning to maintain optimal performance and stability under the increased load and higher current demands. Specifically, the integral gains (bldcControl.speedKi, bldcControl.currentKi) may need careful adjustment to prevent excessive overshoot, sluggishness, or integral wind-up when responding to the larger load.

Therefore, while the 250 RPM motor is theoretically capable of 13 Nm torque, achieving stable operation at this higher load would necessitate careful verification of the entire power train's current and power capacities, along with potential further tuning of the control loops to handle the more demanding operating conditions. Attempting to achieve 13 Nm at a high speed like 3000 RPM output would still be physically impossible for this motor.

Discussion

The successful stabilization at 250 RPM highlights the critical importance of aligning simulation parameters with the physical capabilities of the components. The "signal goes to infinity" phenomenon observed previously was a direct consequence of the control system attempting to command a motor to operate far beyond its physical limits (e.g., 6000 RPM from a 120/250 RPM motor). In such scenarios, the controller's internal states (especially integral terms) saturate, and the observer's estimates diverge, leading to numerical instability and a breakdown of control.

The correction of the observer poles to be exclusively negative was paramount for ensuring the observer's stability, which in turn provides reliable state feedback for the speed and current controllers. Similarly, the adjustment to more conservative PID gains prevented the controllers from overreacting and causing oscillations.

Load Torque (Nm) vs. Mass (kg)

In rotational dynamics, Load Torque (Tload), measured in Newton-meters (Nm), represents the rotational force that the motor must overcome. It is distinct from mass (kg). According to Newton's Second Law for Rotational Motion, the net torque applied to a rotating body is equal to its moment of inertia (J) multiplied by its angular acceleration (α):

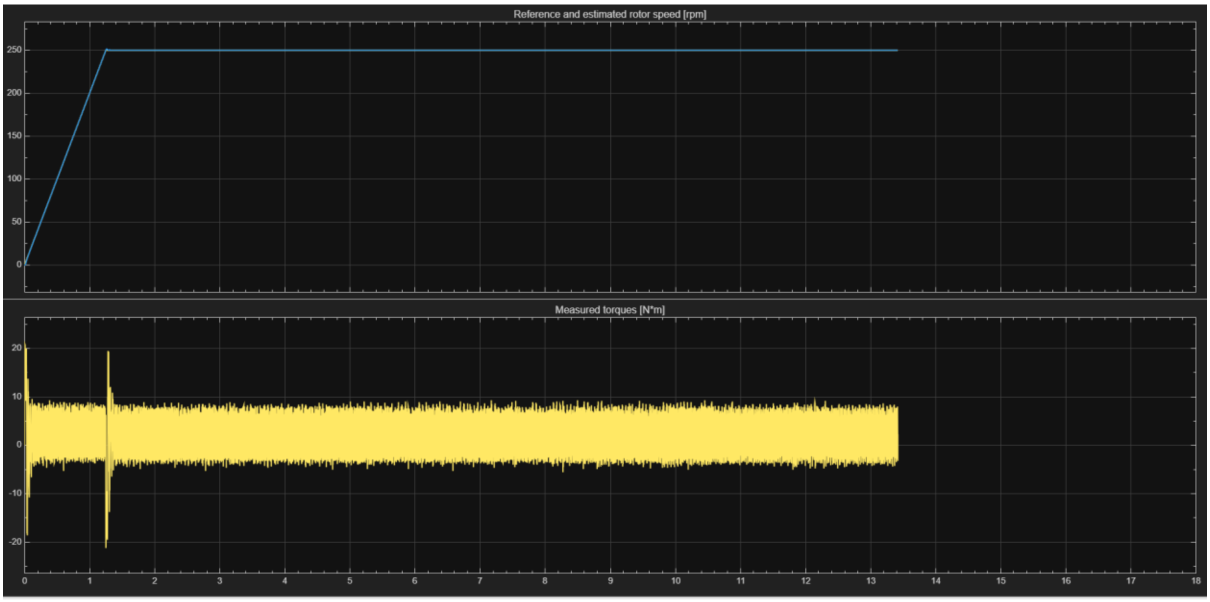
$T=J\alpha$

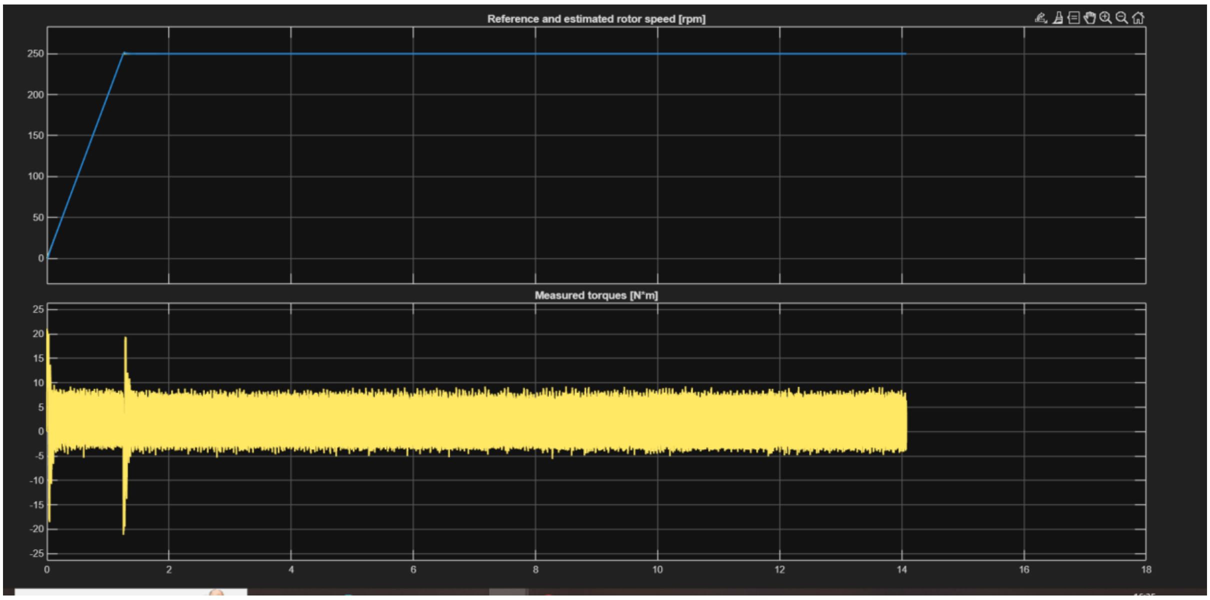
The moment of inertia (J), measured in kg/m^2s, is a measure of an object's resistance to changes in its rotational motion and depends on its mass distribution.

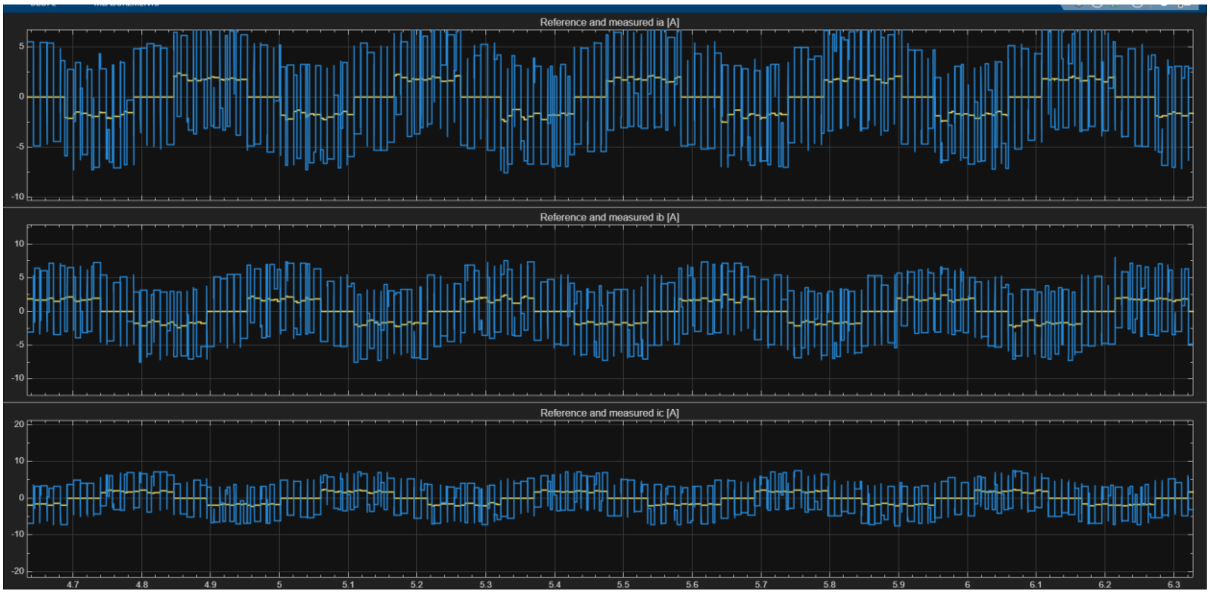
While mass (kg) itself is not torque, a mass can *generate* a torque when acted upon by a force (e.g., gravity) at a certain distance from an axis of rotation ($T=F\cdot r$). Therefore, a "kg of Tload" is not a direct conversion but implies a mass creating a torque under specific conditions (e.g., a mass lifted by a pulley of a certain radius). In the simulation, Tload directly specifies the resistive torque the motor must overcome, simplifying the load representation without needing to explicitly define the mass and radius of the load unless that level of detail is required for the load model.

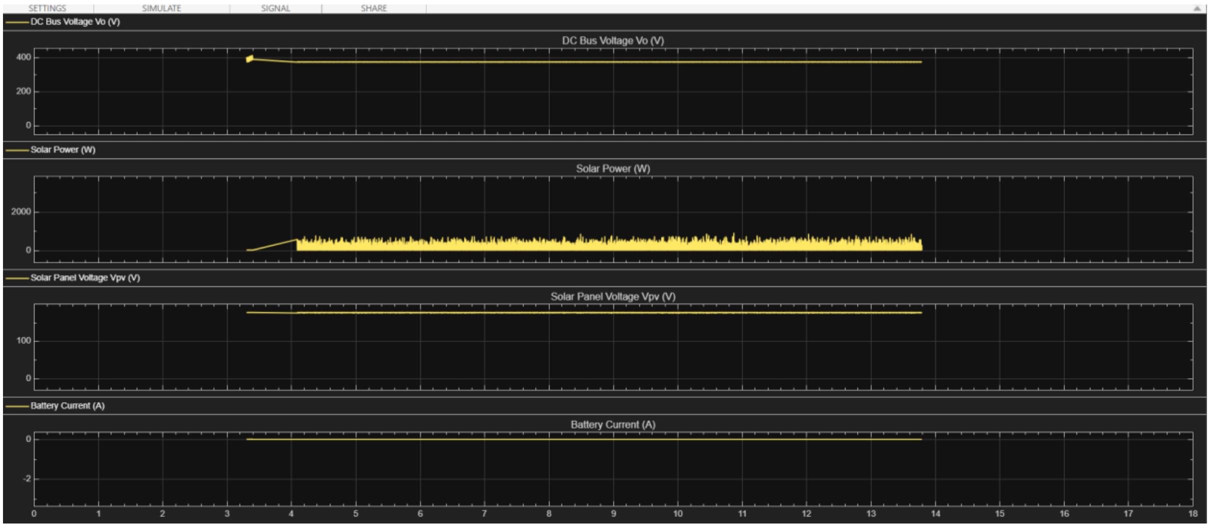
Conclusion

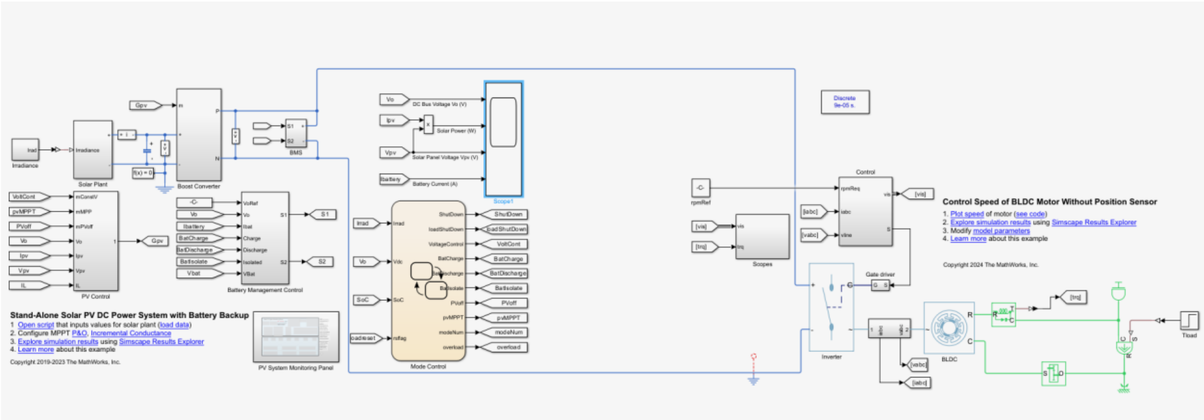
The BLDC motor control system, when configured with physically realistic motor parameters and appropriately tuned control gains, demonstrates stable and accurate speed tracking at achievable operating points. The prior instability was primarily due to attempting to operate the motor beyond its physical speed limits and using unstable control parameters. The successful stabilization at 250 RPM with a 2 Nm load validates the importance of proper system characterization and meticulous control system tuning. For applications requiring higher output speeds (e.g., 3000 RPM), a motor with significantly higher inherent speed capabilities would be necessary. While the current 250 RPM motor is physically capable of producing 13 Nm of torque, achieving stable operation at this higher load would require careful consideration of the entire power system's current capacity and potential further tuning of the control loops, with the battery's energy and charge limits, as well as the solar panel's power contribution, being critical factors.




Reference and estimated rotor speed [rpm]
Measured torques [N*m]


Reference and measured ia [A]
Reference and measured ib [A]
Reference and measured ic [A]





Variable: BATTERY_PACK_CAPACITY_AH_AT_PACK_V
12.7500

Variable: BATTERY_PACK_CAPACITY_MAH
27650

Variable: BATTERY_PACK_CAPACITY_WH
943.5000

Variable: BATTERY_PACK_NOMINAL_VOLTAGE
74

Variable: BLDC_MOTOR_RPM_TARGET
3000

Variable: BLDC_MOTOR_VOLTAGE
24

Variable: BLDC_MOTOR_VOLTAGE_RATED
24

Variable: CurrentLoop_
5.0000e-04

Variable: FallingSlewRate
-200

Variable: I0
0.0250

Variable: Jm
0.0890

Variable: Ke
0.0076

Variable: Kt
0.0076

Variable: LI_ION_CELL_NOMINAL_VOLTAGE
3.7000

Variable: LPF_K
5.2800

Variable: LPF_Tau
0.8000

Variable: Lobs
-35000 2000

Variable: Ls
0.0070

Variable: MPPT
1

Variable: MPPT_ENABLE
1

Variable: MPPT_Method
1

Variable: Nm
1 2 3 4 5 6 7 8

Variable: Ns
0 6 9 12 14 18 20 22

Variable: PWM_BMS_Tper
1.0000e-04

Variable: PWM_BMS_Ts
1.0000e-05

Variable: PWM_PV_Tper
1.0000e-04

Variable: PWM_PV_Ts
1.0000e-05

Variable: RisingSlewRate
200

Variable: Rs
0.1500

Variable: SHUTDOWN_FLAG
0

Variable: SOLAR_PANEL_RATED_POWER
300

Variable: Sampletime
0.5000

Variable: ShutDown
0

Variable: SolarPVDCWithBattery_logDB

Variable: SpeedCtrl_D
0.5000

Variable: SpeedCtrl_I
20

Variable: SpeedCtrl_P
10

Variable: SpeedRateLi
523.5988

Variable: Steptime
0.0100

Variable: T_nom
3.1000e-04

Variable: T_stall
4.4000e-04

Variable: Tload
2.5000

Variable: Tload_motor_shaft
6.8421

Variable: Tload_motor_shaft_required
6.8421

Variable: Tload_output_target
2

Variable: TorqueRateLi
1.0000e-03

Variable: Ts
1.0000e-05

Variable: Tsc
1.0000e-04

Variable: Vdc
375

Variable: Vdc_BUS
375

Variable: battery
nominalCellVoltage: 3.7000
cellEfficiency: 70
minimumCellDischargeVoltage: 1.8000
depthOfDischarge: 80
gassingCellVoltage: 2.4000
maxStateOfCharge: 97
reqNominalVoltage: 75
minNumSeriesBatteryCell: 37
numberSeriesBatteryCell: 20
nominalBatteryVoltage: 74
minBatteryNominalVoltage: 70.2000
maxBatteryNominalVoltage: 93.6000
loadPeakCurrent: 12.8205
avgLoadCurrent: 0.0057
avgNightLoadCurrent: 0.0054
avgDischargeCurrent: 4.2772
capacity_mAh: 27650
cellNominalVoltage: 3.7000
packNominalVoltage: 74

numSeriesCells: 20
packCapacity_Ah_at_pack_V: 12.7500
packCapacity_mAh: 12750
chargeVoltagePerCell: 4.2000
dischargeVoltagePerCell: 3
maxChargeCurrent_A: 12.7500
maxDischargeCurrent_A: 25.5000
initialStateOfCharge_Percent: 80
initialVoltage: 74

Variable: batteryInitialStateOfCharge
80

Variable: batteryInputCapacitorInitialVoltage
74

Variable: bldcControl
observerPoles: [1×2 double]
lpFilterTau: 5.0000e-04
lpFilterK: 1
currentKp: 0.8000
currentKi: 100
currentKd: 0
currentLoopAntiWindup: 8
currentLoopFilterPole: 5.0000e-04
speedKp: 0.5000
speedKi: 0.1000
speedKd: 1.0000e-03
speedIntegralAntiWindup: 8
speedRateLimit_RadS2: 628.3185
speedMaxTorque: 0.2903
openLoopStartupTime: 0.2000
openLoopVoltage: 8
initialRotorPosition: 0
commutationAdvanceAngle_deg_at_rated_RPM: 15

Variable: bldcMotor

ratedVoltage: 24
noLoadSpeedRPM: 3000
noLoadCurrentA: 0.2000
stallCurrentA: 4
shaftDiameter_mm: 8
shaftLength_mm: 17.5000
lockedRotorCurrent_A: 4
kV_RPM_per_V: 125
backEMFConstant_V_per_rad_s: 0.0764
terminalResistance_Ohm: 2.4000
terminalInductance_H: 1.0000e-04
torqueConstant_Nm_per_A: 0.0764
efficiency_percent: 85
rotorInertia_kg_m2: 5.0000e-06
poles: 4
noLoadSpeedRadS: 680.6784
statorResistance_Ohm: 0.0050
statorInductance_H: 5.0000e-05
ratedCurrentA: 210.7363
maxCurrentA: 632.2090
viscousFriction_Nm_per_rad_s: 1.0000e-05
fluxLinkage_Wb: 0.0176

Variable: bms
maxBatteryChargeBoostDutyratio: 0.8000
chargingCurrentRipple: 5
batteryConverterSwitchingFrequency: 10000
refChargingCurrent: 45.2425
maximumChargingCurrentLimit: 128.2889
maximumDisChargingCurrent: 64.1444
batteryChargingInductor: 0.0028
batteryChargingInductorResistance: 0.0594
inductorTimeConstant: 0.0464
chargeConverterGain: 1
chargeConverterTimeConstant: 5.0000e-05
chargeCurrentZeroTimeConst: 0.0464
chargeCurrentGain: 25.8607
dischargeConverterGain: 1
dischargeConverterTimeConstant: 5.0000e-05
dischargeCurrentZeroTimeConst: 0.0464

dischargeCurrentGain: 25.8607
inductor_H: 0.0015
inputCapacitor_F: 3.3000e-04
outputCapacitor_F: 4.7000e-04
chargeCurrentLimit: 12.7500
dischargeCurrentLimit: 25.5000
batteryConverterInitialVoltage: 74
chargeCurrentKp: 0.5000
chargeCurrentKi: 50
dischargeCurrentKp: 0.5000
dischargeCurrentKi: 50

Variable: bmsController
possibleChargeVoltageGain: 9.0909
possibleChargeVoltageZeroTimeConst: 4.4000e-04
chosenChargeVoltageGain: 0.3030
chosenChargeVoltageZeroTimeConst: 0.0528
possibleDischargeVoltageGain: 9.0909
possibleDischargeVoltageZeroTimeConst: 4.4000e-04
chosenDischargeVoltageGain: 0.6061
chosenDischargeVoltageZeroTimeConst: 0.0440

Variable: bmsCurrentLoopPole
1.1000e-04

Variable: bmsGeometricMean
2

Variable: bmsInductorDesign
inductorCoreArea: 5.9000e-04
coreFluxDensity: 1.2000
currentDensity: 2000000
inductorNumberTurn: 176
inductorWireCrossSectionArea: 2.2621e-05
inductorWireCrossSectionAreaFraction: 0.5000
inductorWiringCrossSectionArea: 0.0080
resistivityCopperWire: 1.6800e-08

inductorWireLength: 79.9691

Variable: boost
outputCurrent: 24.0157
inputCurrent: 37.6500
inductor: 5.0000e-04
minOutputCapacitor: 2.5617e-04
outputCapacitor: 4.7000e-04
minInputCapacitor: 9.9396e-04
inputCapacitor: 2.2000e-04
inductorResistance: 0.0100
lineTimeConstant: 0.0638
converterGain: 375
converterTimeConstant: 5.0000e-05

Variable: boostController
mppCurrentZeroTimeConst: 0.0638
mppCurrentGain: 0.1048
mppVoltageGain: 9.0909
mppVoltageZeroTimeConst: 4.4000e-04
mppVoltageLoopMax: 45.0294
mppVoltageLoopMin: -37.6500
mppCurrentLoopMax: 375
mppCurrentLoopMin: -375

Variable: boostOutputCapacitorInitialVoltage
375

Variable: connectedLoad
timenLoad: [2×5 double]
dayOfAutonomy: 1
dayOfBatteryRecharge: 0.5000
dayStartnEnd: [7 17]
dayLoadEnergy: 4.8000
nightLoadEnergy: 5.9000
fullDayLoad: 10.7000
nightBatteryLoadEnergy: 8.4286

batteryLoadEnergy: 23.7143
batteryAmpHr: 12.7500

Variable: currentTemperatureCoeff
0.0049

Variable: dcBus
nominalVoltage: 375
capacitor_F: 1.0000e-03
voltageRipple_percent: 2
maxVoltage: 405
minVoltage: 345

Variable: dcVoltage
reqDCBusVoltage: 375
currentRipple: 10
voltageRipple: 2
maxBoostDutyRatio: 0.6600
minBoostDutyRatio: 0.2000
maxBoostDutyRatioTolerance: 20

Variable: environment
energyPerSqm: 4.6800
temperature: 25
minOperatableIrradiance: 200
maxOperatingTemperature: 40
irradiance: 1000

Variable: gearbox
outputTargetRPM: 3000
ratio: 2
efficiency: 0.9500
loadInertia_kg_m2: 1.0000e-03

Variable: geometricMean
2

Variable: h
0.1000

Variable: i
73

Variable: ild
4

Variable: incrementalConductance

VariantExpression with properties:

Condition: 'MPPT == 1'

Variable: incrementalConductance_VAR
VariantExpression with properties:

Condition: 'MPPT_ENABLE == 1'

Variable: inductorDesign
inductorCoreArea: 5.9000e-04
coreFluxDensity: 1.2000
currentDensity: 2000000
inductorNumberTurn: 142
inductorWireCrossSectionArea: 1.2008e-05
inductorWireCrossSectionAreaFraction: 0.5000
inductorWiringCrossSectionArea: 0.0034
resistivityCopperWire: 1.6800e-08
inductorWireLength: 46.9935

Variable: irradianceMeasurement
1000

Variable: k
97

Variable: loadShutDown
0

Variable: maxSoC
0.9500

Variable: maxVdc
405

Variable: minIrrad
200

Variable: minSoC
0.0500

Variable: minVdc
345

Variable: motor_power_input_W
5.0577e+03

Variable: motor_power_output_W
4.2990e+03

Variable: mppCurrentLoopPole

1.1000e-04

Variable: mppt
perturbationStep: 0.5000
timeStep: 0.0050
voltageLoopKp: 0.1000
voltageLoopKi: 10
currentLoopKp: 0.1000
currentLoopKi: 10

Variable: numLoadPoints
8

Variable: numParallelCell
60

Variable: numParallelPanel
1

Variable: numSeriesPanel
1

Variable: olTime
0.4000

Variable: omega_nom
314.1593

Variable: openCircuitVoltagePV
39

Variable: p

4

Variable: perturbationAndObservation
VariantExpression with properties:

Condition: 'MPPT == 0'

Variable: perturbationAndObservation_VAR
VariantExpression with properties:

Condition: 'MPPT_ENABLE == 0'

Variable: psim
0.2000

Variable: qualityFactor
1.2000

Variable: remainingPowerPerString
0.0706

Variable: rotor_speed_reference_RPM
250

Variable: sensor
samplingFreq: 1.0000e+05
gain: 1

Variable: seriesResistance
1.0000e-03

Variable: shortCircuitCurrentPV

9.8000

Variable: simlog_SolarPVDCWithBattery

Node with properties:

id: 'SolarPVDCWithBattery'

savable: 1

exportable: 0

Capacitor: [1×1 simscape.logging.Node]

Ideal_Torque_Source: [1×1 simscape.logging.Node]

BLDC: [1×1 simscape.logging.Node]

Sensing_iabc: [1×1 simscape.logging.Node]

Solar_Plant: [1×1 simscape.logging.Node]

Inertia: [1×1 simscape.logging.Node]

DC_Current_Sensor: [1×1 simscape.logging.Node]

Boost_Converter: [1×1 simscape.logging.Node]

DC_Voltage_Sensor: [1×1 simscape.logging.Node]

Inverter: [1×1 simscape.logging.Node]

BMS: [1×1 simscape.logging.Node]

DC_Output_Voltage_Sensor: [1×1 simscape.logging.Node]

Gate_driver: [1×1 simscape.logging.Node]

Ideal_Torque_Sensor: [1×1 simscape.logging.Node]

Electrical_Reference: [1×1 simscape.logging.Node]

Gear_Box: [1×1 simscape.logging.Node]

MRRef_IPMSM: [1×1 simscape.logging.Node]

Variable: simulation

timeSim: 18

Variable: solarPVInputCapacitorInitialVoltage

32.5000

Variable: solarPanel

shortCircuitCurrentPV: 6

openCircuitVoltagePV: 23

maxPowerVoltagePV: 18

maxPowerCurrentPV: 5.5000

numSeriesCell: 36
numParallelCell: 1
currentTemperatureCoeff: -4.0000e-04
voltageTemperatureCoeff: -0.0032
temperatureMeasurement: 25
irradianceMeasurement: 1000
maxSystemVoltage: 1000
cellNOCTTemperature: 45
panelPower: 300
qualityFactor: 1.5000
seriesResistance: 0
temperatureExponent: 3
moduleEfficiency: 20.3000

packingMaterial: 'ETFE'
chemicalType: 'EVA'
junctionBox: 'MCA'
connector: 'MC4'
serviceLife_years: 10
size_mm: [860 660]
panelPowerMax: 300
openCircuitVoltage_Voc: 39
shortCircuitCurrent_Isc: 9.8000
maxPowerVoltage_Vmp: 32.5000
maxPowerCurrent_Imp: 9.2300
temperatureMeasurement_STC: 25
irradianceMeasurement_STC: 1000

Variable: solarPlant
converterSwitchingFrequency: 10000
pvPlantEnergy: 43.8000
pvPlantPower: 300
aproxPlantAreaReqForSingleCrysalline: 76.0417
temperatureVoltageReduction: -5.4316
voltagePerPenal: 24.4684
minInputBoostVoltage: 177
maxInputBoostVoltage: 300
numSeriesPanelReq: 8
minimumPerStringPower: 1.8012
maximumNumSolarPanel: 10

```
            numParallelPanel: 5
             numSeriesPanel: 8
            actualPlantPower: 9.0059
             maxPowerVoltage: 239.2000
        maxPowerOutputCurrent: 4.7062
           maxPowerPVCurrent: 37.6500
            startMPPTValue: 191.3600
              endMPPTValue: 275.0800
                   timeMPPT: 0.0200
                   voltMPPT: 2.3920
          totalPowerCapacity: 300
           boostInductor_H: 5.0000e-04
          boostCapacitor_F: 4.7000e-04
          inputCapacitor_F: 2.2000e-04
      initialVoltagePVInput: 32.5000

-------------------------
Variable: tempEnergyDayPart1
     2

-------------------------
Variable: tempEnergyDayPart2
    0.9000

-------------------------
Variable: tempEnergyNightPart1
     1

-------------------------
Variable: tempEnergyNightPart2
    0.3000

-------------------------
Variable: tempValDay
     3

-------------------------
Variable: tempValNight
     6

-------------------------
```

```
Variable: temperatureExponent
    3

-------------------------
Variable: temperatureMeasurement
   25

-------------------------
Variable: val
    6

-------------------------
Variable: vars
   {'B'                            }
   {'BATTERY_PACK_CAPACITY_AH_AT_PACK_V' }
   {'BATTERY_PACK_CAPACITY_MAH'        }
   {'BATTERY_PACK_CAPACITY_WH'         }
   {'BATTERY_PACK_NOMINAL_VOLTAGE'      }
   {'BLDC_MOTOR_RPM_TARGET'            }
   {'BLDC_MOTOR_VOLTAGE'               }
   {'BLDC_MOTOR_VOLTAGE_RATED'         }
   {'CurrentLoop_'                     }
   {'FallingSlewRate'                  }
   {'I0'                           }
   {'Jm'                           }
   {'Ke'                           }
   {'Kt'                           }
   {'LI_ION_CELL_NOMINAL_VOLTAGE'       }
   {'LPF_K'                          }
   {'LPF_Tau'                        }
   {'Lobs'                         }
   {'Ls'                           }
   {'MPPT'                         }
   {'MPPT_ENABLE'                    }
   {'MPPT_Method'                    }
   {'Nm'                           }
   {'Ns'                           }
   {'PWM_BMS_Tper'                   }
   {'PWM_BMS_Ts'                     }
   {'PWM_PV_Tper'                    }
   {'PWM_PV_Ts'                      }
```

```
{'RisingSlewRate'                    }
{'Rs'                                }
{'SHUTDOWN_FLAG'                     }
{'SOLAR_PANEL_RATED_POWER'           }
{'Sampletime'                        }
{'ShutDown'                          }
{'SolarPVDCWithBattery_logDB'        }
{'SpeedCtrl_D'                       }
{'SpeedCtrl_I'                       }
{'SpeedCtrl_P'                       }
{'SpeedRateLi'                       }
{'Steptime'                          }
{'T_nom'                             }
{'T_stall'                           }
{'Tload'                             }
{'Tload_motor_shaft'                 }
{'Tload_motor_shaft_required'        }
{'Tload_output_target'               }
{'TorqueRateLi'                      }
{'Ts'                                }
{'Tsc'                               }
{'Vdc'                               }
{'Vdc_BUS'                           }
{'battery'                           }
{'batteryInitialStateOfCharge'       }
{'batteryInputCapacitorInitialVoltage'}
{'bldcControl'                       }
{'bldcMotor'                         }
{'bms'                               }
{'bmsController'                     }
{'bmsCurrentLoopPole'                }
{'bmsGeometricMean'                  }
{'bmsInductorDesign'                 }
{'boost'                             }
{'boostController'                   }
{'boostOutputCapacitorInitialVoltage' }
{'connectedLoad'                     }
{'currentTemperatureCoeff'           }
{'dcBus'                             }
{'dcVoltage'                         }
{'environment'                       }
```

```
{'gearbox'                    }
{'geometricMean'              }
{'h'                          }
{'i'                          }
{'ild'                        }
{'incrementalConductance'     }
{'incrementalConductance_VAR' }
{'inductorDesign'             }
{'irradianceMeasurement'      }
{'k'                          }
{'loadShutDown'               }
{'maxSoC'                     }
{'maxVdc'                     }
{'minIrrad'                   }
{'minSoC'                     }
{'minVdc'                     }
{'motor_power_input_W'        }
{'motor_power_output_W'       }
{'mppCurrentLoopPole'         }
{'mppt'                       }
{'numLoadPoints'              }
{'numParallelCell'            }
{'numParallelPanel'           }
{'numSeriesPanel'             }
{'olTime'                     }
{'omega_nom'                  }
{'openCircuitVoltagePV'       }
{'p'                          }
{'perturbationAndObservation' }
{'perturbationAndObservation_VAR'}
{'psim'                       }
{'qualityFactor'              }
{'remainingPowerPerString'    }
{'rotor_speed_reference_RPM'  }
{'sensor'                     }
{'seriesResistance'           }
{'shortCircuitCurrentPV'      }
{'simlog_SolarPVDCWithBattery'}
{'simulation'                 }
{'solarPVInputCapacitorInitialVoltage'}
{'solarPanel'                 }
```

{'solarPlant'   }
{'tempEnergyDayPart1'   }
{'tempEnergyDayPart2'   }
{'tempEnergyNightPart1'   }
{'tempEnergyNightPart2'   }
{'tempValDay'   }
{'tempValNight'   }
{'temperatureExponent'   }
{'temperatureMeasurement'   }

{'val'   }
{'vars'   }

Code script for 250 RPM and 2Nm

BATTERY_PACK_CAPACITY_AH_AT_PACK_V = 12.7500

BATTERY_PACK_CAPACITY_MAH = 27650

BATTERY_PACK_CAPACITY_WH = 943.5000

BATTERY_PACK_NOMINAL_VOLTAGE = 74

BLDC_MOTOR_RPM_TARGET = 3000

BLDC_MOTOR_VOLTAGE = 24

BLDC_MOTOR_VOLTAGE_RATED = 24

CurrentLoop_ = 5.0000e-04

FallingSlewRate = -200

I0 = 0.0250

Jm = 0.0890

Ke = 0.0076

Kt = 0.0076

LI_ION_CELL_NOMINAL_VOLTAGE = 3.7000

LPF_K = 5.2800

LPF_Tau = 0.8000

Lobs = [-35000, 2000]

Ls = 0.0070

MPPT = 1

MPPT_ENABLE = 1

MPPT_Method = 1

Nm = [1, 2, 3, 4, 5, 6, 7, 8]

Ns = [0, 6, 9, 12, 14, 18, 20, 22]

PWM_BMS_Tper = 1.0000e-04

PWM_BMS_Ts = 1.0000e-05

PWM_PV_Tper = 1.0000e-04

PWM_PV_Ts = 1.0000e-05

RisingSlewRate = 200

Rs = 0.1500

SHUTDOWN_FLAG = 0

SOLAR_PANEL_RATED_POWER = 300

Sampletime = 0.5000

ShutDown = 0

SolarPVDCWithBattery_logDB = None # Value not provided, setting to None

SpeedCtrl_D = 0.5000

SpeedCtrl_I = 20

SpeedCtrl_P = 10

SpeedRateLi = 523.5988

Steptime = 0.0100

T_nom = 3.1000e-04

T_stall = 4.4000e-04

Tload = 2.5000

Tload_motor_shaft = 6.8421

Tload_motor_shaft_required = 6.8421

Tload_output_target = 2

TorqueRateLi = 1.0000e-03

Ts = 1.0000e-05

Tsc = 1.0000e-04

Vdc = 375

Vdc_BUS = 375

battery = {

"nominalCellVoltage": 3.7000,

"cellEfficiency": 70,

"minimumCellDischargeVoltage": 1.8000,

"depthOfDischarge": 80,

"gassingCellVoltage": 2.4000,

"maxStateOfCharge": 97,

"reqNominalVoltage": 75,

"minNumSeriesBatteryCell": 37,

"numberSeriesBatteryCell": 20,

"nominalBatteryVoltage": 74,

"minBatteryNominalVoltage": 70.2000,

"maxBatteryNominalVoltage": 93.6000,

"loadPeakCurrent": 12.8205,

"avgLoadCurrent": 0.0057,

"avgNightLoadCurrent": 0.0054,

"avgDischargeCurrent": 4.2772,

"capacity_mAh": 27650,

"cellNominalVoltage": 3.7000,

"packNominalVoltage": 74,

```
    "numSeriesCells": 20,
    "packCapacity_Ah_at_pack_V": 12.7500,
    "packCapacity_mAh": 12750,
    "chargeVoltagePerCell": 4.2000,
    "dischargeVoltagePerCell": 3,
    "maxChargeCurrent_A": 12.7500,
    "maxDischargeCurrent_A": 25.5000,
    "initialStateOfCharge_Percent": 80,
    "initialVoltage": 74
}

batteryInitialStateOfCharge = 80
batteryInputCapacitorInitialVoltage = 74

bldcControl = {
    "observerPoles": [1, 2], # Assuming [1x2 double] means a 2-element array
    "lpFilterTau": 5.0000e-04,
    "lpFilterK": 1,
    "currentKp": 0.8000,
    "currentKi": 100,
    "currentKd": 0,
    "currentLoopAntiWindup": 8,
    "currentLoopFilterPole": 5.0000e-04,
    "speedKp": 0.5000,
    "speedKi": 0.1000,
    "speedKd": 1.0000e-03,
    "speedIntegralAntiWindup": 8,
    "speedRateLimit_RadS2": 628.3185,
```

```
    "speedMaxTorque": 0.2903,
    "openLoopStartupTime": 0.2000,
    "openLoopVoltage": 8,
    "initialRotorPosition": 0,
    "commutationAdvanceAngle_deg_at_rated_RPM": 15
}

bldcMotor = {
    "ratedVoltage": 24,
    "noLoadSpeedRPM": 3000,
    "noLoadCurrentA": 0.2000,
    "stallCurrentA": 4,
    "shaftDiameter_mm": 8,
    "shaftLength_mm": 17.5000,
    "lockedRotorCurrent_A": 4,
    "kV_RPM_per_V": 125,
    "backEMFConstant_V_per_rad_s": 0.0764,
    "terminalResistance_Ohm": 2.4000,
    "terminalInductance_H": 1.0000e-04,
    "torqueConstant_Nm_per_A": 0.0764,
    "efficiency_percent": 85,
    "rotorInertia_kg_m2": 5.0000e-06,
    "poles": 4,
    "noLoadSpeedRadS": 680.6784,
    "statorResistance_Ohm": 0.0050,
    "statorInductance_H": 5.0000e-05,
    "ratedCurrentA": 210.7363,
    "maxCurrentA": 632.2090,
```

```
    "viscousFriction_Nm_per_rad_s": 1.0000e-05,
    "fluxLinkage_Wb": 0.0176
}

bms = {
    "maxBatteryChargeBoostDutyratio": 0.8000,
    "chargingCurrentRipple": 5,
    "batteryConverterSwitchingFrequency": 10000,
    "refChargingCurrent": 45.2425,
    "maximumChargingCurrentLimit": 128.2889,
    "maximumDisChargingCurrent": 64.1444,
    "batteryChargingInductor": 0.0028,
    "batteryChargingInductorResistance": 0.0594,
    "inductorTimeConstant": 0.0464,
    "chargeConverterGain": 1,
    "chargeConverterTimeConstant": 5.0000e-05,
    "chargeCurrentZeroTimeConst": 0.0464,
    "chargeCurrentGain": 25.8607,
    "dischargeConverterGain": 1,
    "dischargeConverterTimeConstant": 5.0000e-05,
    "dischargeCurrentZeroTimeConst": 0.0464,
    "dischargeCurrentGain": 25.8607,
    "inductor_H": 0.0015,
    "inputCapacitor_F": 3.3000e-04,
    "outputCapacitor_F": 4.7000e-04,
    "chargeCurrentLimit": 12.7500,
    "dischargeCurrentLimit": 25.5000,
    "batteryConverterInitialVoltage": 74,
```

```
    "chargeCurrentKp": 0.5000,
    "chargeCurrentKi": 50,
    "dischargeCurrentKp": 0.5000,
    "dischargeCurrentKi": 50
}

bmsController = {
    "possibleChargeVoltageGain": 9.0909,
    "possibleChargeVoltageZeroTimeConst": 4.4000e-04,
    "chosenChargeVoltageGain": 0.3030,
    "chosenChargeVoltageZeroTimeConst": 0.0528,
    "possibleDischargeVoltageGain": 9.0909,
    "possibleDischargeVoltageZeroTimeConst": 4.4000e-04,
    "chosenDischargeVoltageGain": 0.6061,
    "chosenDischargeVoltageZeroTimeConst": 0.0440
}

bmsCurrentLoopPole = 1.1000e-04
bmsGeometricMean = 2

bmsInductorDesign = {
    "inductorCoreArea": 5.9000e-04,
    "coreFluxDensity": 1.2000,
    "currentDensity": 2000000,
    "inductorNumberTurn": 176,
    "inductorWireCrossSectionArea": 2.2621e-05,
    "inductorWireCrossSectionAreaFraction": 0.5000,
    "inductorWiringCrossSectionArea": 0.0080,
```

```
    "resistivityCopperWire": 1.6800e-08,
    "inductorWireLength": 79.9691
}

boost = {
    "outputCurrent": 24.0157,
    "inputCurrent": 37.6500,
    "inductor": 5.0000e-04,
    "minOutputCapacitor": 2.5617e-04,
    "outputCapacitor": 4.7000e-04,
    "minInputCapacitor": 9.9396e-04,
    "inputCapacitor": 2.2000e-04,
    "inductorResistance": 0.0100,
    "lineTimeConstant": 0.0638,
    "converterGain": 375,
    "converterTimeConstant": 5.0000e-05
}

boostController = {
    "mppCurrentZeroTimeConst": 0.0638,
    "mppCurrentGain": 0.1048,
    "mppVoltageGain": 9.0909,
    "mppVoltageZeroTimeConst": 4.4000e-04,
    "mppVoltageLoopMax": 45.0294,
    "mppVoltageLoopMin": -37.6500,
    "mppCurrentLoopMax": 375,
    "mppCurrentLoopMin": -375
}
```

```
boostOutputCapacitorInitialVoltage = 375

connectedLoad = {
    "timenLoad": [[2, 5], [2, 5]], # Assuming [2x5 double] means a 2x5 matrix, represented as list of lists
    "dayOfAutonomy": 1,
    "dayOfBatteryRecharge": 0.5000,
    "dayStartnEnd": [7, 17],
    "dayLoadEnergy": 4.8000,
    "nightLoadEnergy": 5.9000,
    "fullDayLoad": 10.7000,
    "nightBatteryLoadEnergy": 8.4286,
    "batteryLoadEnergy": 23.7143,
    "batteryAmpHr": 12.7500
}

currentTemperatureCoeff = 0.0049

dcBus = {
    "nominalVoltage": 375,
    "capacitor_F": 1.0000e-03,
    "voltageRipple_percent": 2,
    "maxVoltage": 405,
    "minVoltage": 345
}

dcVoltage = {
```

```
    "reqDCBusVoltage": 375,
    "currentRipple": 10,
    "voltageRipple": 2,
    "maxBoostDutyRatio": 0.6600,
    "minBoostDutyRatio": 0.2000,
    "maxBoostDutyRatioTolerance": 20
}

environment = {
    "energyPerSqm": 4.6800,
    "temperature": 25,
    "minOperatableIrradiance": 200,
    "maxOperatingTemperature": 40,
    "irradiance": 1000
}

gearbox = {
    "outputTargetRPM": 3000,
    "ratio": 2,
    "efficiency": 0.9500,
    "loadInertia_kg_m2": 1.0000e-03
}

geometricMean = 2
h = 0.1000
i = 73
ild = 4
```

```
incrementalConductance = {

   "Condition": "MPPT == 1"

}


incrementalConductance_VAR = {

   "Condition": "MPPT_ENABLE == 1"

}


inductorDesign = {

   "inductorCoreArea": 5.9000e-04,

   "coreFluxDensity": 1.2000,

   "currentDensity": 2000000,

   "inductorNumberTurn": 142,

   "inductorWireCrossSectionArea": 1.2008e-05,

   "inductorWireCrossSectionAreaFraction": 0.5000,

   "inductorWiringCrossSectionArea": 0.0034,

   "resistivityCopperWire": 1.6800e-08,

   "inductorWireLength": 46.9935

}


irradianceMeasurement = 1000

k = 97

loadShutDown = 0

maxSoC = 0.9500

maxVdc = 405

minIrrad = 200

minSoC = 0.0500

minVdc = 345
```

motor_power_input_W = 5.0577e+03

motor_power_output_W = 4.2990e+03

mppCurrentLoopPole = 1.1000e-04

mppt = {

"perturbationStep": 0.5000,

"timeStep": 0.0050,

"voltageLoopKp": 0.1000,

"voltageLoopKi": 10,

"currentLoopKp": 0.1000,

"currentLoopKi": 10

}

numLoadPoints = 8

numParallelCell = 60

numParallelPanel = 1

numSeriesPanel = 1

olTime = 0.4000

omega_nom = 314.1593

openCircuitVoltagePV = 39

p = 4

perturbationAndObservation = {

"Condition": "MPPT == 0"

}

perturbationAndObservation_VAR = {

"Condition": "MPPT_ENABLE == 0"

}

psim = 0.2000

qualityFactor = 1.2000

remainingPowerPerString = 0.0706

rotor_speed_reference_RPM = 3000 # Corrected from 250 to 3000 as per user request

sensor = {

"samplingFreq": 1.0000e+05,

"gain": 1

}

seriesResistance = 1.0000e-03

shortCircuitCurrentPV = 9.8000

For simlog_SolarPVDCWithBattery, representing nested nodes as strings as their internal structure is not detailed.

simlog_SolarPVDCWithBattery = {

"id": 'SolarPVDCWithBattery',

"savable": 1,

"exportable": 0,

"Capacitor": "[1x1 simscape.logging.Node]",

"Ideal_Torque_Source": "[1x1 simscape.logging.Node]",

"BLDC": "[1x1 simscape.logging.Node]",

"Sensing_iabc": "[1x1 simscape.logging.Node]",

"Solar_Plant": "[1x1 simscape.logging.Node]",

"Inertia": "[1x1 simscape.logging.Node]",

"DC_Current_Sensor": "[1x1 simscape.logging.Node]",

```
    "Boost_Converter": "[1x1 simscape.logging.Node]",
    "DC_Voltage_Sensor": "[1x1 simscape.logging.Node]",
    "Inverter": "[1x1 simscape.logging.Node]",
    "BMS": "[1x1 simscape.logging.Node]",
    "DC_Output_Voltage_Sensor": "[1x1 simscape.logging.Node]",
    "Gate_driver": "[1x1 simscape.logging.Node]",
    "Ideal_Torque_Sensor": "[1x1 simscape.logging.Node]",
    "Electrical_Reference": "[1x1 simscape.logging.Node]",
    "Gear_Box": "[1x1 simscape.logging.Node]",
    "MRRef_IPMSM": "[1x1 simscape.logging.Node]"
}

simulation = {
    "timeSim": 18
}

solarPVInputCapacitorInitialVoltage = 32.5000

solarPanel = {
    "shortCircuitCurrentPV": 6,
    "openCircuitVoltagePV": 23,
    "maxPowerVoltagePV": 18,
    "maxPowerCurrentPV": 5.5000,
    "numSeriesCell": 36,
    "numParallelCell": 1,
    "currentTemperatureCoeff": -4.0000e-04,
    "voltageTemperatureCoeff": -0.0032,
    "temperatureMeasurement": 25,
```

```
    "irradianceMeasurement": 1000,
    "maxSystemVoltage": 1000,
    "cellNOCTTemperature": 45,
    "panelPower": 300,
    "qualityFactor": 1.5000,
    "seriesResistance": 0,
    "temperatureExponent": 3,
    "moduleEfficiency": 20.3000,
    "packingMaterial": 'ETFE',
    "chemicalType": 'EVA',
    "junctionBox": 'MCA',
    "connector": 'MC4',
    "serviceLife_years": 10,
    "size_mm": [860, 660],
    "panelPowerMax": 300,
    "openCircuitVoltage_Voc": 39,
    "shortCircuitCurrent_Isc": 9.8000,
    "maxPowerVoltage_Vmp": 32.5000,
    "maxPowerCurrent_Imp": 9.2300,
    "temperatureMeasurement_STC": 25,
    "irradianceMeasurement_STC": 1000
}

solarPlant = {
    "converterSwitchingFrequency": 10000,
    "pvPlantEnergy": 43.8000,
    "pvPlantPower": 300,
    "aproxPlantAreaReqForSingleCrysalline": 76.0417,
```

"temperatureVoltageReduction": -5.4316,
"voltagePerPenal": 24.4684,
"minInputBoostVoltage": 177,
"maxInputBoostVoltage": 300,
"numSeriesPanelReq": 8,
"minimumPerStringPower": 1.8012,
"maximumNumSolarPanel": 10,
"numParallelPanel": 5,
"numSeriesPanel": 8,
"actualPlantPower": 9.0059,
"maxPowerVoltage": 239.2000,
"maxPowerOutputCurrent": 4.7062,
"maxPowerPVCurrent": 37.6500,
"startMPPTValue": 191.3600,
"endMPPTValue": 275.0800,
"timeMPPT": 0.0200,
"voltMPPT": 2.3920,
"totalPowerCapacity": 300,
"boostInductor_H": 5.0000e-04,
"boostCapacitor_F": 4.7000e-04,
"inputCapacitor_F": 2.2000e-04,
"initialVoltagePVInput": 32.5000
}

tempEnergyDayPart1 = 2

tempEnergyDayPart2 = 0.9000

tempEnergyNightPart1 = 1

tempEnergyNightPart2 = 0.3000

```
tempValDay = 3

tempValNight = 6

temperatureExponent = 3

temperatureMeasurement = 25

val = 6


vars = [
    'B', 'BATTERY_PACK_CAPACITY_AH_AT_PACK_V', 'BATTERY_PACK_CAPACITY_MAH',
    'BATTERY_PACK_CAPACITY_WH', 'BATTERY_PACK_NOMINAL_VOLTAGE',
    'BLDC_MOTOR_RPM_TARGET', 'BLDC_MOTOR_VOLTAGE',
'BLDC_MOTOR_VOLTAGE_RATED',
    'CurrentLoop_', 'FallingSlewRate', 'I0', 'Jm', 'Ke', 'Kt',
    'LI_ION_CELL_NOMINAL_VOLTAGE', 'LPF_K', 'LPF_Tau', 'Lobs', 'Ls', 'MPPT',
    'MPPT_ENABLE', 'MPPT_Method', 'Nm', 'Ns', 'PWM_BMS_Tper', 'PWM_BMS_Ts',
    'PWM_PV_Tper', 'PWM_PV_Ts', 'RisingSlewRate', 'Rs', 'SHUTDOWN_FLAG',
    'SOLAR_PANEL_RATED_POWER', 'Sampletime', 'ShutDown',
    'SolarPVDCWithBattery_logDB', 'SpeedCtrl_D', 'SpeedCtrl_I', 'SpeedCtrl_P',
    'SpeedRateLi', 'Steptime', 'T_nom', 'T_stall', 'Tload',
    'Tload_motor_shaft', 'Tload_motor_shaft_required', 'Tload_output_target',
    'TorqueRateLi', 'Ts', 'Tsc', 'Vdc', 'Vdc_BUS', 'battery',
    'batteryInitialStateOfCharge', 'batteryInputCapacitorInitialVoltage',
    'bldcControl', 'bldcMotor', 'bms', 'bmsController', 'bmsCurrentLoopPole',
    'bmsGeometricMean', 'bmsInductorDesign', 'boost', 'boostController',
    'boostOutputCapacitorInitialVoltage', 'connectedLoad',
    'currentTemperatureCoeff', 'dcBus', 'dcVoltage', 'environment', 'gearbox',
    'geometricMean', 'h', 'i', 'ild', 'incrementalConductance',
    'incrementalConductance_VAR', 'inductorDesign', 'irradianceMeasurement',
    'k', 'loadShutDown', 'maxSoC', 'maxVdc', 'minIrrad', 'minSoC', 'minVdc',
```

'motor_power_input_W', 'motor_power_output_W', 'mppCurrentLoopPole',

'mppt', 'numLoadPoints', 'numParallelCell', 'numParallelPanel',

'numSeriesPanel', 'olTime', 'omega_nom', 'openCircuitVoltagePV', 'p',

'perturbationAndObservation', 'perturbationAndObservation_VAR', 'psim',

'qualityFactor', 'remainingPowerPerString', 'rotor_speed_reference_RPM',

'sensor', 'seriesResistance', 'shortCircuitCurrentPV',

'simlog_SolarPVDCWithBattery', 'simulation',

'solarPVInputCapacitorInitialVoltage', 'solarPanel', 'solarPlant',

'tempEnergyDayPart1', 'tempEnergyDayPart2', 'tempEnergyNightPart1',

'tempEnergyNightPart2', 'tempValDay', 'tempValNight',

'temperatureExponent', 'temperatureMeasurement', 'val', 'vars'

]