DESIGN AND ANALYSIS OF A MICRO SOLAR ELECTRIC VEHICLE FOR APPLICATION IN PAKISTAN

THESIS SEMINAR

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Contents

Background

Global Transport Sector is the biggest contributor of Greenhouse Gas emissions.

Electric Vehicles provide a cleaner alternative to help solve this problem, being adopted at a rapid pace.

Pakistan still lags behind other countries in EV adoption due to a number of reasons:

1. Electricity shortfall
2. High Prices of EVs.
3. Absence of commercial or residential charging infrastructure.

Literature Review

- The world's first solar powered vehicle was built by William G. Cobb, a General Motors Corp. executive, in 1955. The miniature vehicle called 'Sunmobile', which made use of 12 photoelectric cells made of selenium [1].
- Solar races have a huge role to play in the development of a road worthy solar powered electric vehicle. Two of the most popular solar challenges are the World Solar Challenge held in the Australian continent, over a distance of 3000 kilometers [2], and the American Solar Challenge, which stretches all the way from Omaha, Nebraska to Bend, Oregon [3].
- Commercial solar cars include, Aptera, a car that can produce up to 700 watts of electricity in good solar conditions, thus providing a range of up to 40 miles per day [4]. Lightyear is full-sized luxury sedan with a very aerodynamic design and a range of up to 725 km [5]. Similarly, Sion, is a family sized van, with a range of up to 305 kilometers [6]. Other notable solar cars include Clean Motion, a small, modular delivery van that boasts about 600 watts of solar panels and can supposedly add a range of 130 kilometers per day on a bright sunny day [7]. Squad, a micro car, which gives a range of about 20 km from solar energy and as per the average micro car usage in Europe of 12 km, can be fully sustainable [8].

Motivation

The significant gap that exists in field of solar EV design both in the global context and the context of Pakistan.

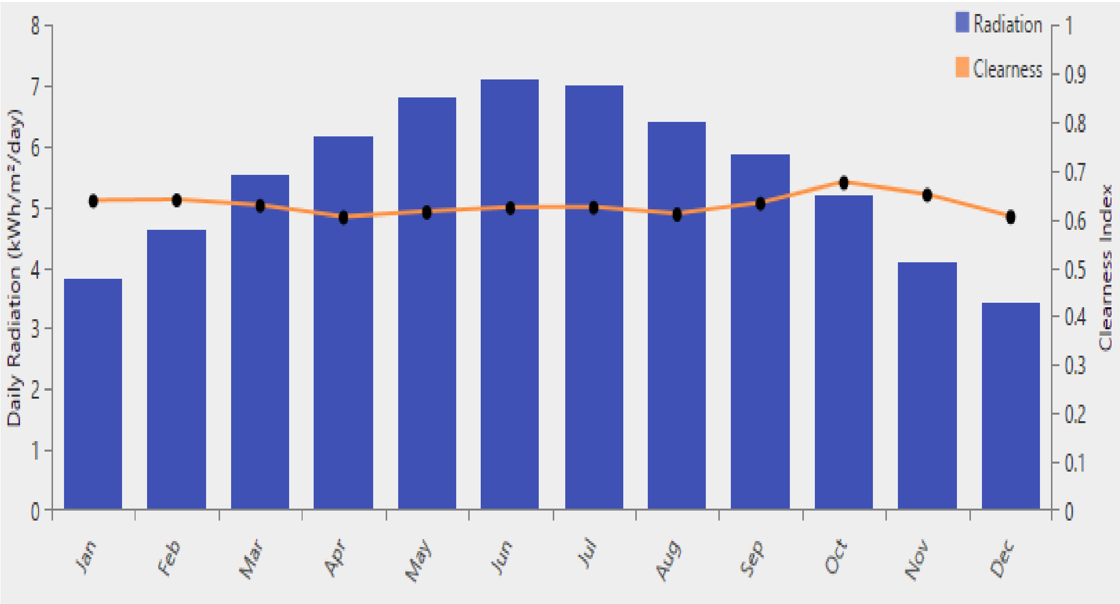
- High prices of EVs.
- Low Average Income.
- Absence of commercial charging infrastructure in Pakistan.
- The inability of residential electrical infrastructure to charge an electric vehicle. At typical electrical service is 5A or 10A at 220V to supply house load, which is not enough to charge an EV at home.

System Design and PV Sizing of a Micro Solar Electric Vehicle

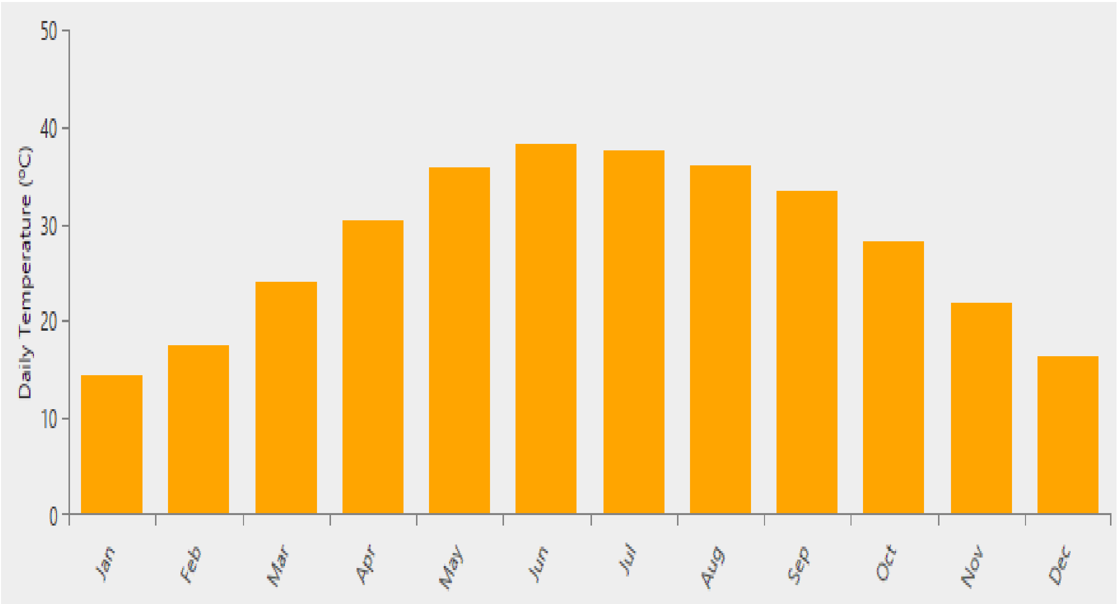
Site Selection

Bahawalpur, a city located in the southern region of Pakistan.

Solar Radiation at the Chosen Location



Source: National Renewable Energy Laboratory



Source: NASA Prediction of Worldwide Energy Resource (POWER) database

Major Components: Load

2021 Chang Li Electric Car

Item	Description
Brand Name	Chang Li
Max. Range	100 km
Dimensions	2450 mm*1350 mm*1750 mm
Wheelbase	1500 mm
No. of seats	3
Motor Size	1200 W
Total Motor Torque	100 Nm
Max Speed	43 km/hr

Major Components: PV Panel & Battery

Name: Kyocera KD 145 SX-UFU

Rated capacity (kW): 0.145

Operating temperature (°C): 45.00

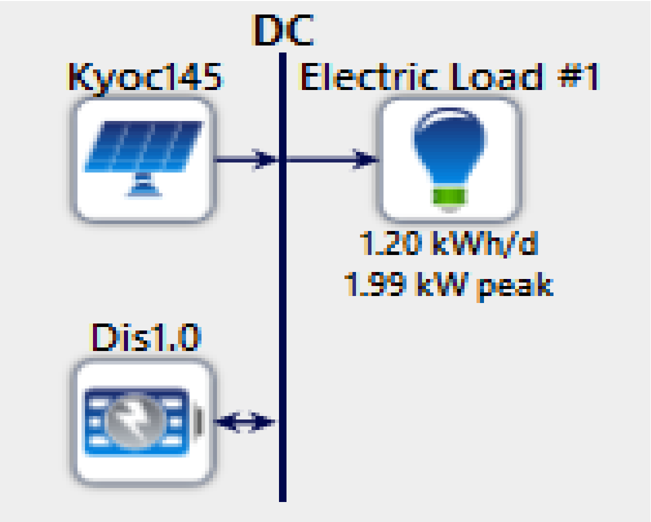
Efficiency (%): 14.4

Capital cost (Rs): 6,960.00 (In Pakistan)

- Name: Discover AES 1.0kWh 24VDC
- Nominal voltage (V): 24
- Nominal capacity (kWh): 0.96
- Nominal capacity (Ah): 40
- Roundtrip efficiency (%): 95
- Capital cost (Rs): 54,376.00

System Design

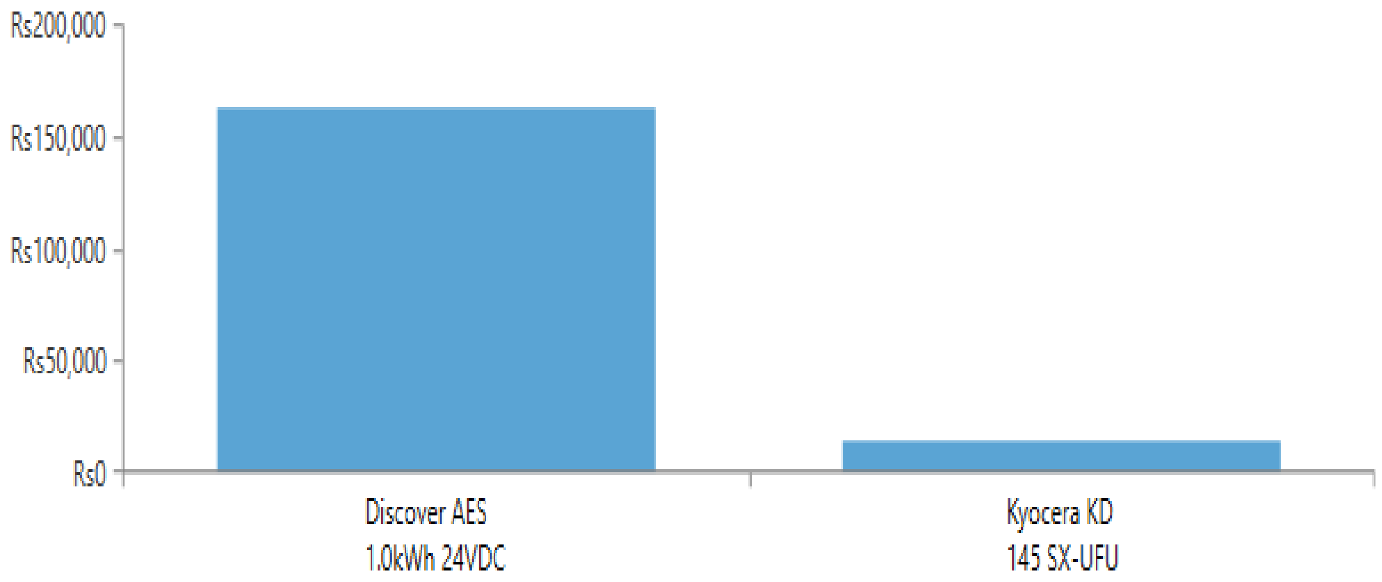
System modelled in HOMER Pro



Item	Quantity
Solar Panels/Kyoc145 (kW)	0.4375
Quantity Required	3
24V, 1kWhr Li-Ion battery, 72V bus	3
Cost/NPC (Rs)	177013.7
Cost/COE (Rs)	54.62492
Cost/Operating cost (Rs/yr)	961.2305
Cost/Initial capital (Rs)	184128
System/Ren Frac (%)	100
Kyoc145/Capital Cost (Rs)	21000
Kyoc145/Production (kWh/yr)	766.9749
Dis1.0/Autonomy (hr)	57.6
Dis1.0/Annual Throughput (kWh/yr)	392.1335
Dis1.0/Nominal Capacity (kWh)	2.88

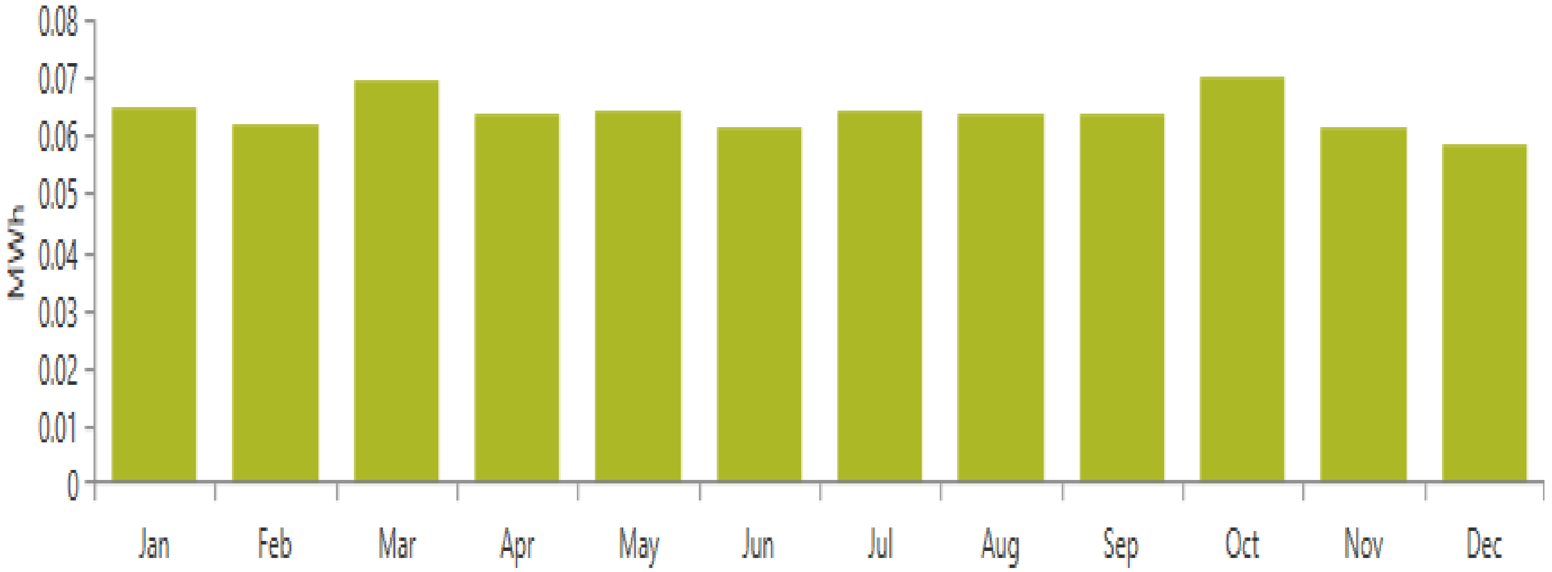
Results

Cost Summary of the System



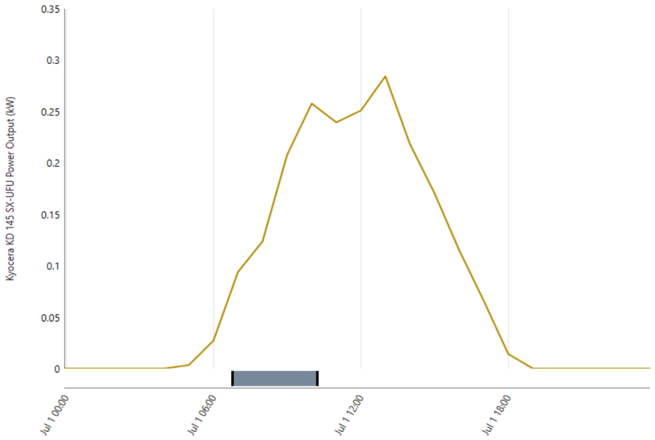
Results

Monthly Electric Production by Solar Panels

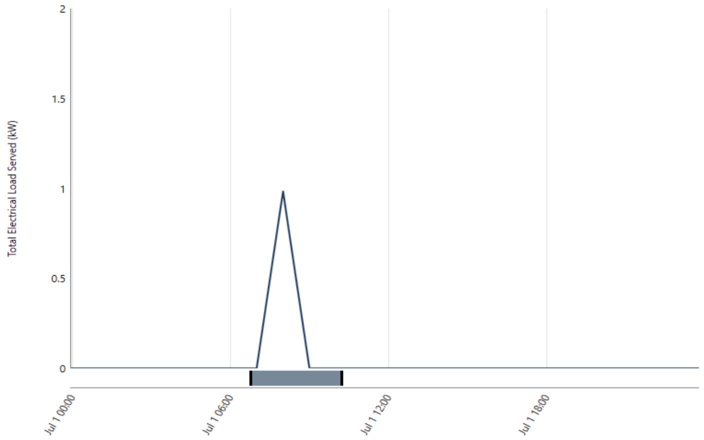


Results

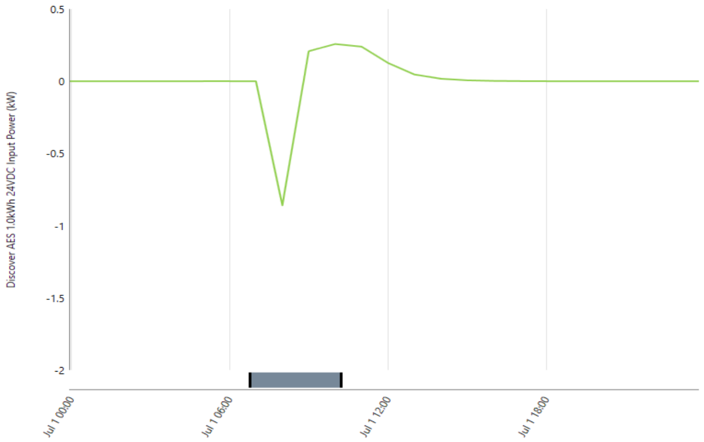
Daily Solar Output by the Solar Panels



Electrical load served by solar panels daily

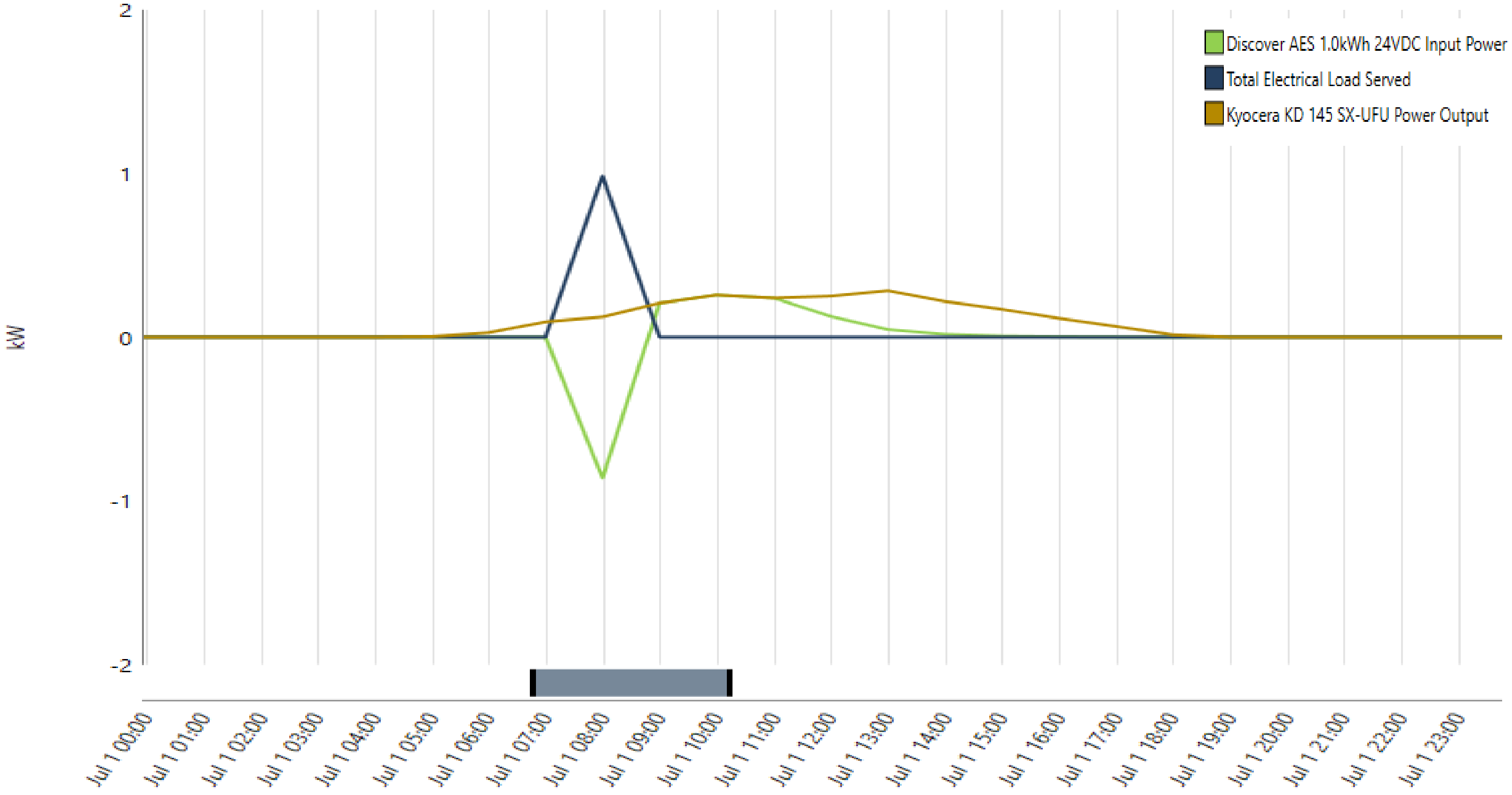


Battery Input Power



Results

Power Sources Comparison



Conclusion

- Presented results shows a successful design and sizing of a micro solar powered electric vehicle.
- The designed solar PV system is capable of serving the electrical load i.e. the DC electric motor of the electric vehicle over a set distance of 30 km.
- In the next chapter, a dynamic model for this solar PV charged electric vehicle is presented.

Dynamic Modeling Of Micro Solar Electric Vehicle In Matlab/Simulink

Dynamic Model: Block Diagram

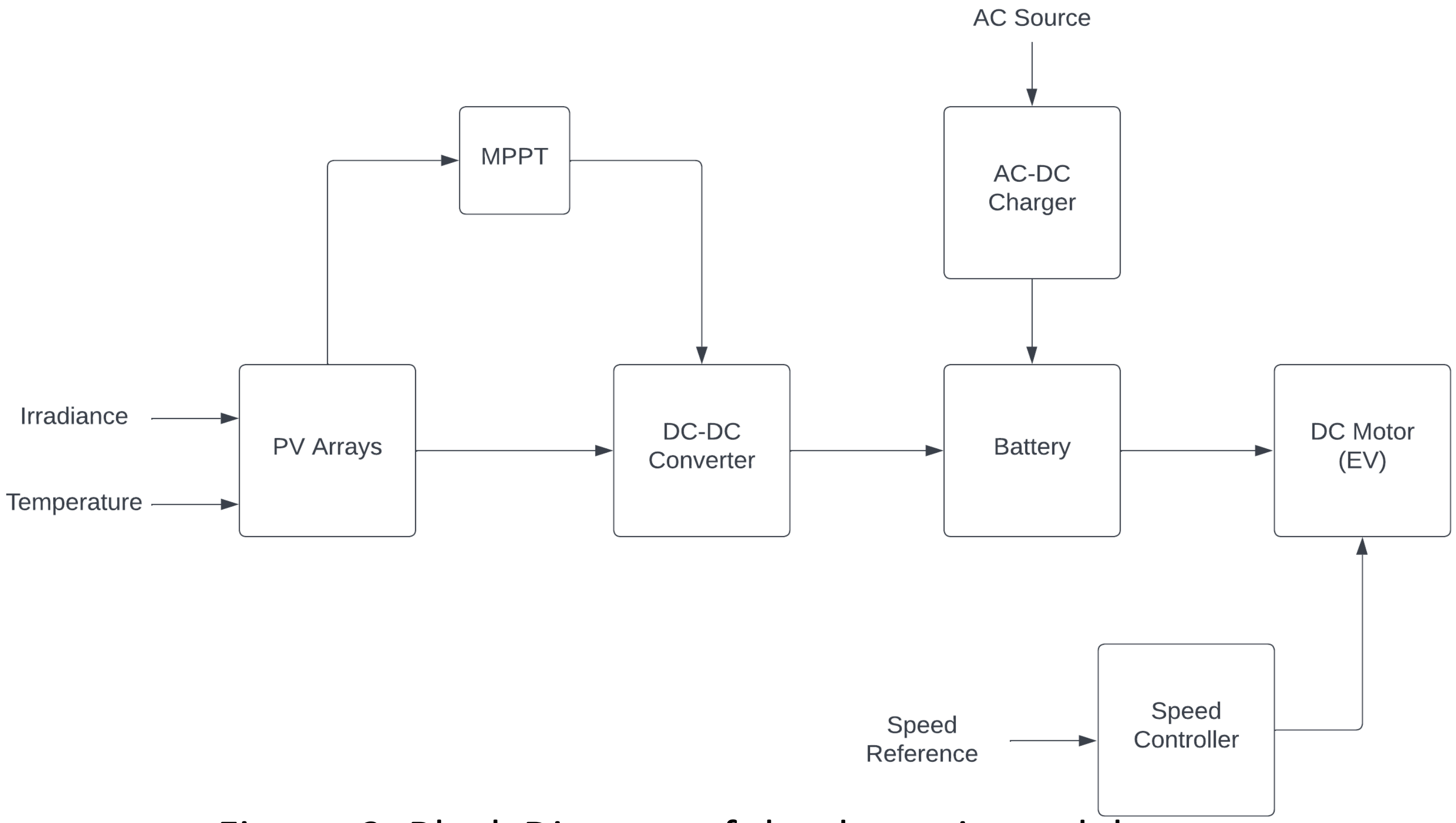


Figure 2: Block Diagram of the dynamic model

Dynamic Model Blocks: PV Array

- Based on the results from HOMER Pro [1] the model consisted of three 24V, 150W solar PV (Advance Solar Hydro Wind Power API – 150) modules connected in series, making the bus voltage to be 72V.

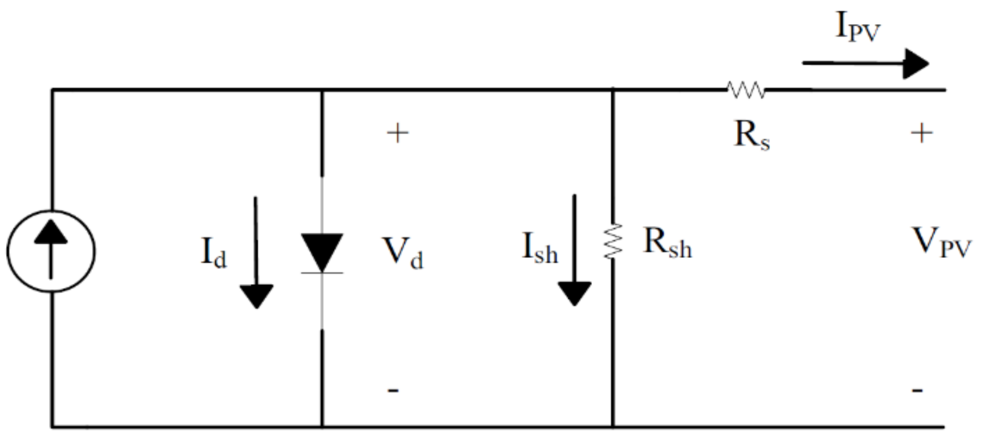


Figure 3: Equivalent circuit of a PV module

Dynamic Model Blocks: Maximum Power Point Tracking (MPPT) Controller

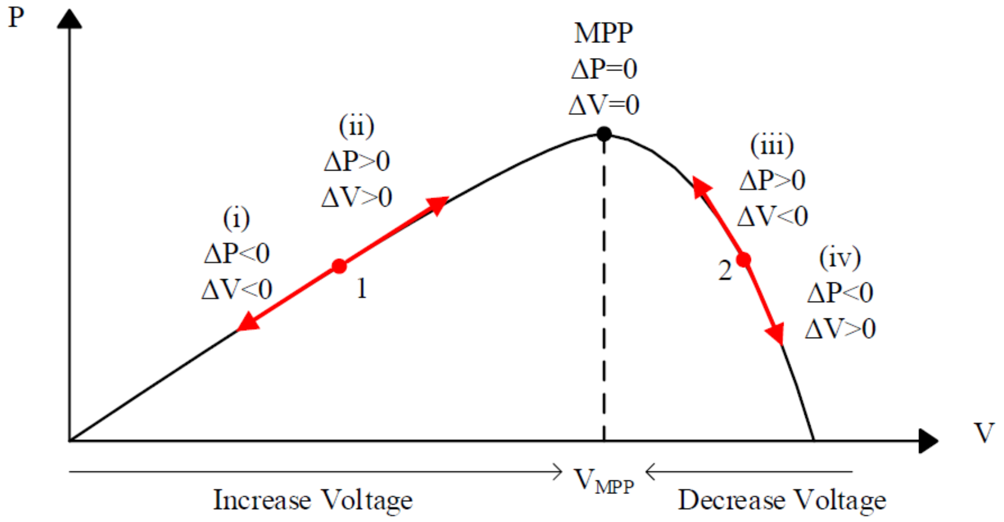


Figure 4: Working Principle of MPPT (P&O Method)

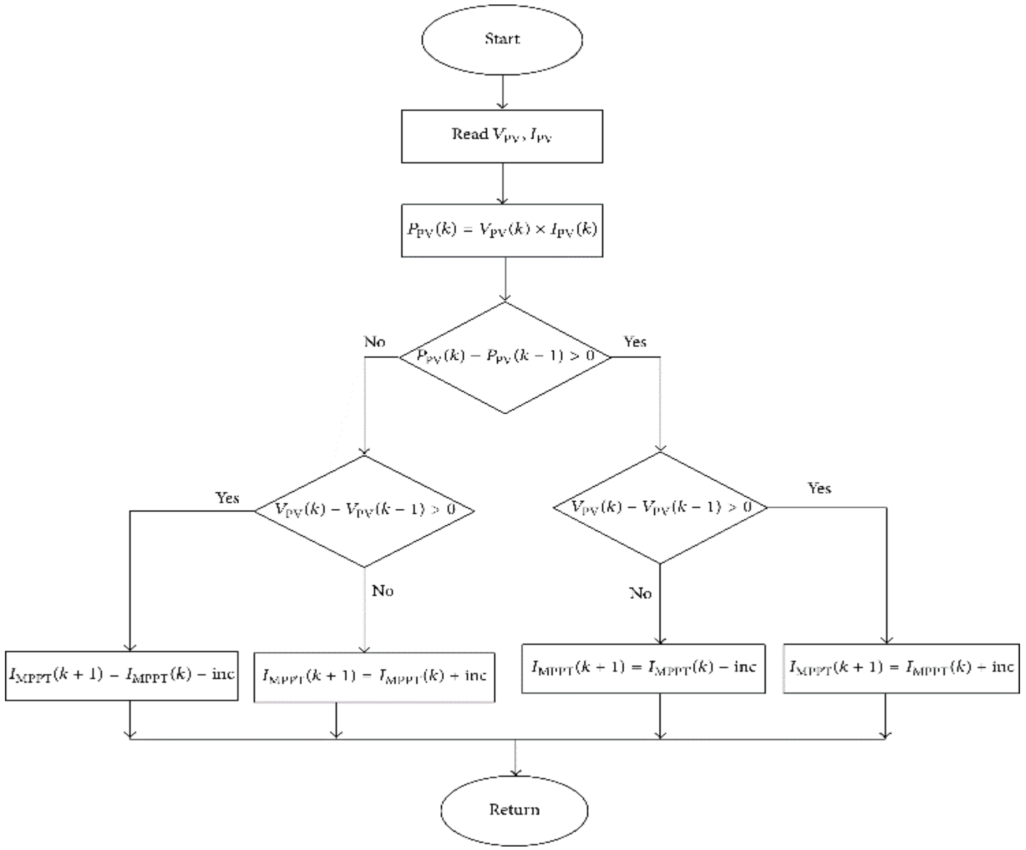


Figure 5: P&O Algorithm Flowchart

Dynamic Model Blocks: DC-DC Converter

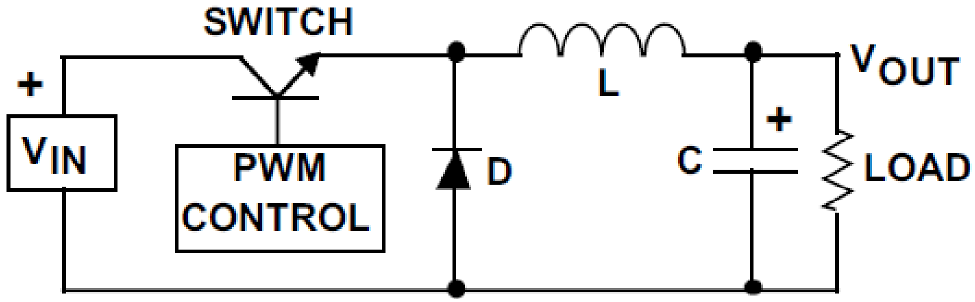


Figure 6: DC-DC Converter (Buck Converter)

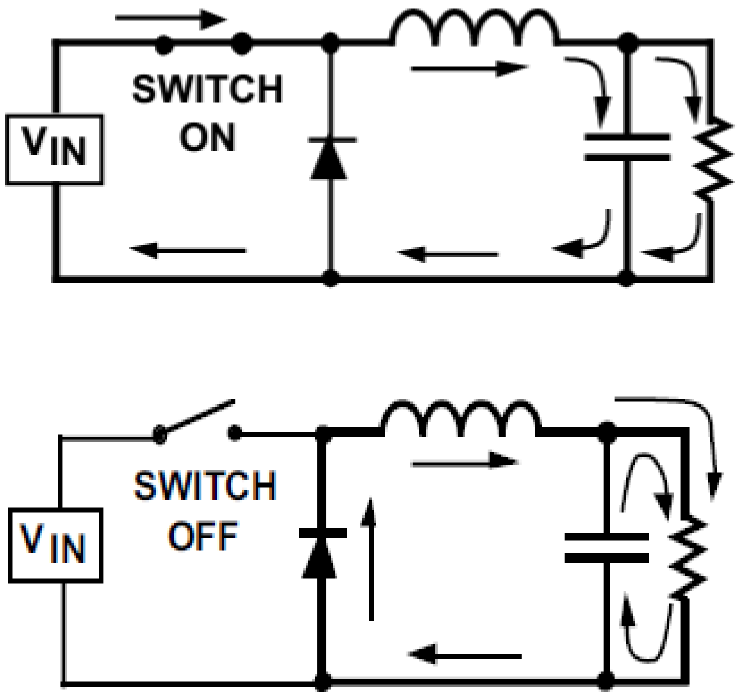


Figure 7: Buck Converter Operation (ON & OFF Modes)

Dynamic Model Blocks: Li-Ion Battery

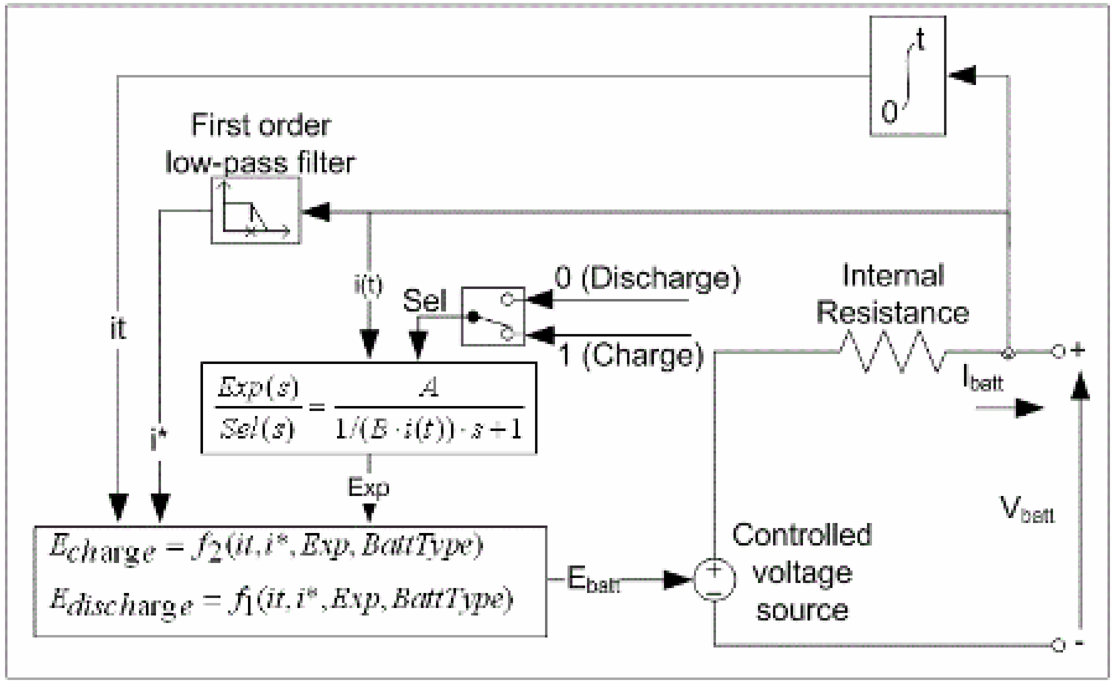


Figure 8: Equivalent circuit of a rechargeable battery model

Dynamic Model Blocks: AC-DC Charger

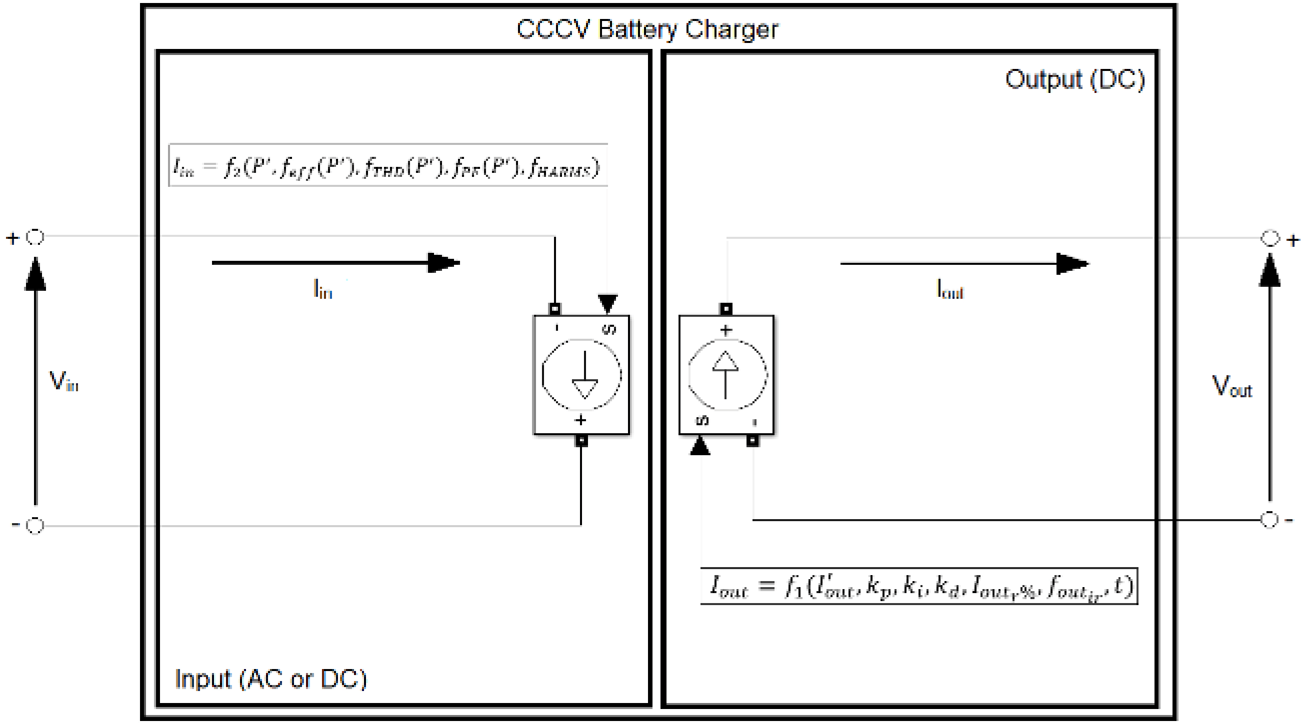


Figure 9: AC-DC Charging Block

Dynamic Model Blocks: DC Machine & Speed Control

DC Machine

- Since our micro solar electric vehicle would be running a DC motor, in order to develop the model of such a motor, we have used the DC machine block in Simulink. The DC machine block allows us to implement both a wound-field or permanent DC machine. However, in our case, we are using a wound-field DC machine in series configuration.

Speed Control

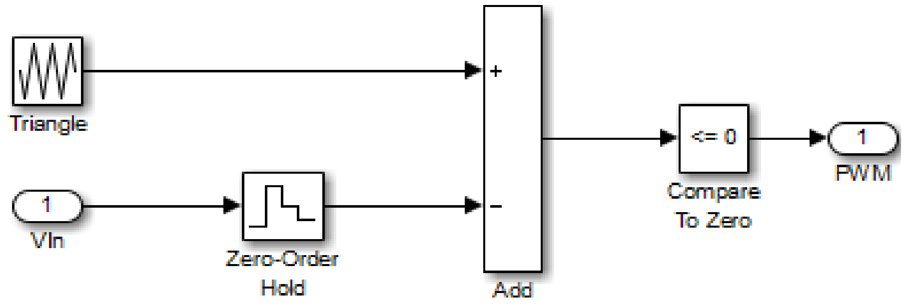


Figure 10: Speed Control Circuit

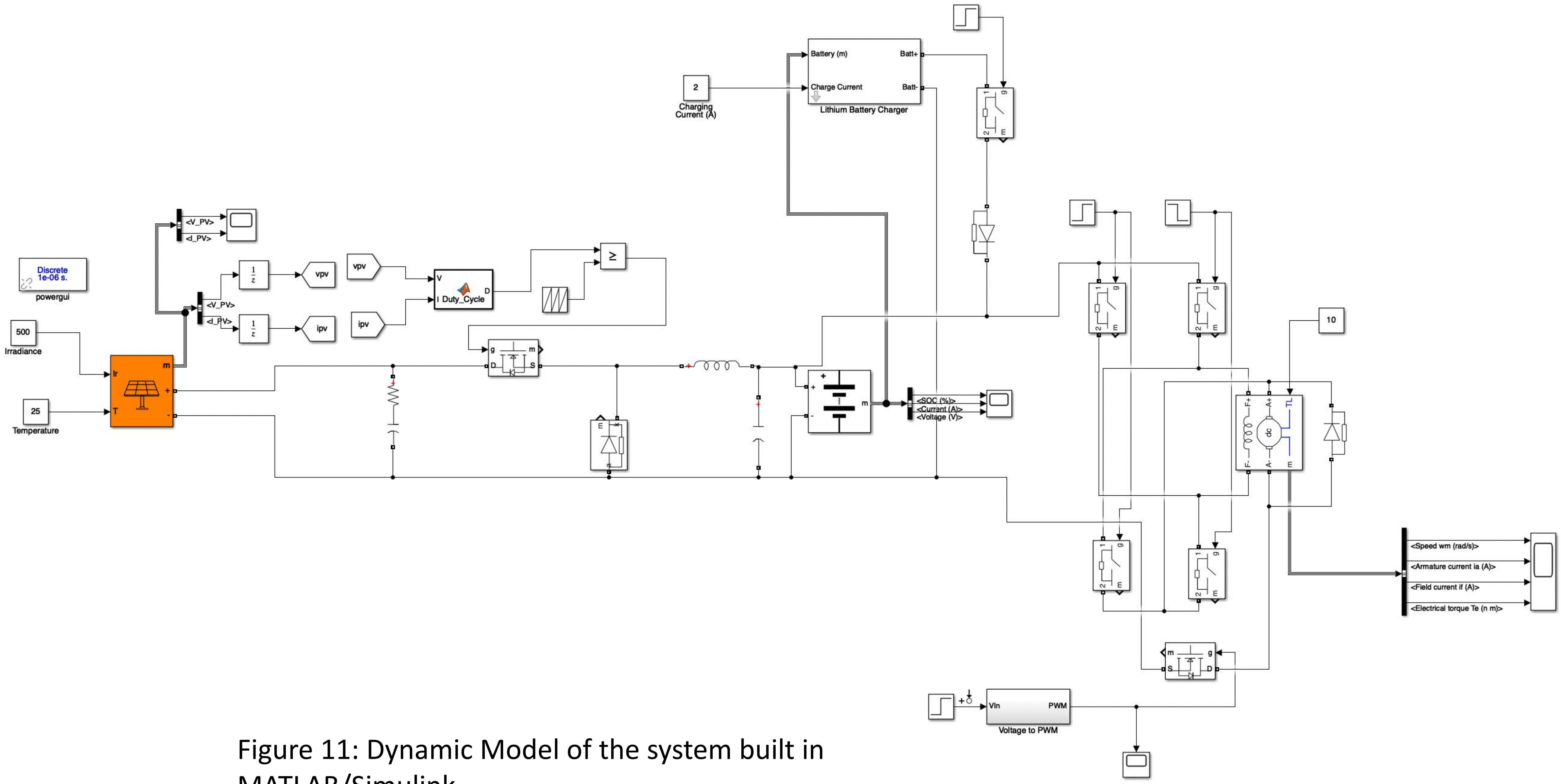


Figure 11: Dynamic Model of the system built in MATLAB/Simulink

Results: PV Operation

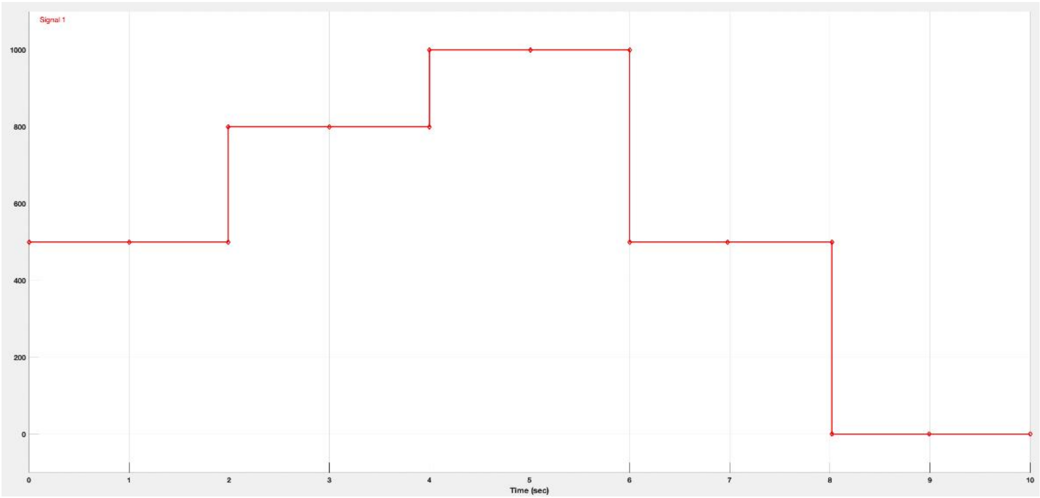


Figure 12: Variable Irradiance Values to measure PV Response

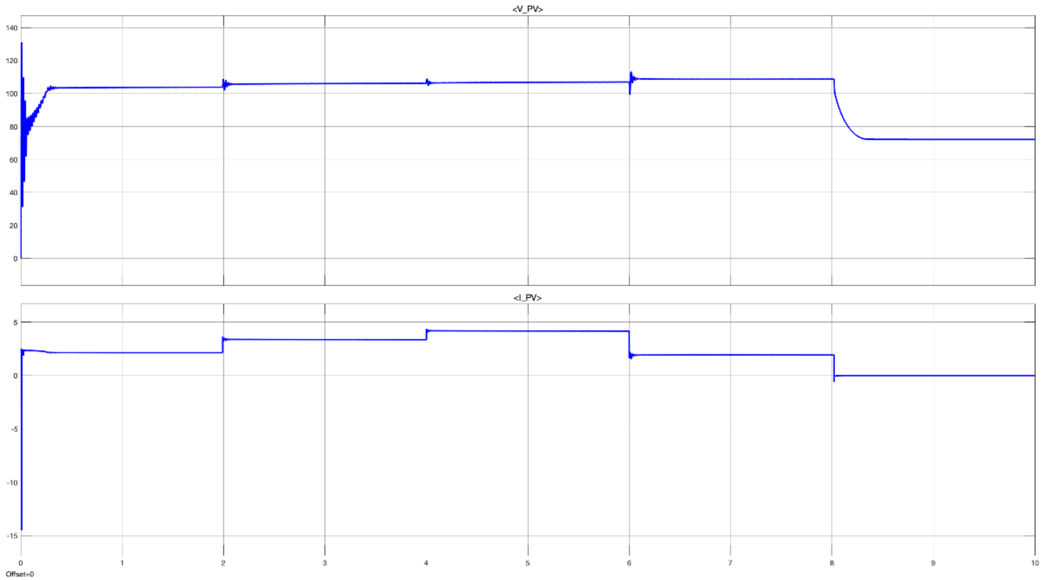


Figure 13: PV Voltage and Current variance as per changing Irradiance

Results: Battery Operation

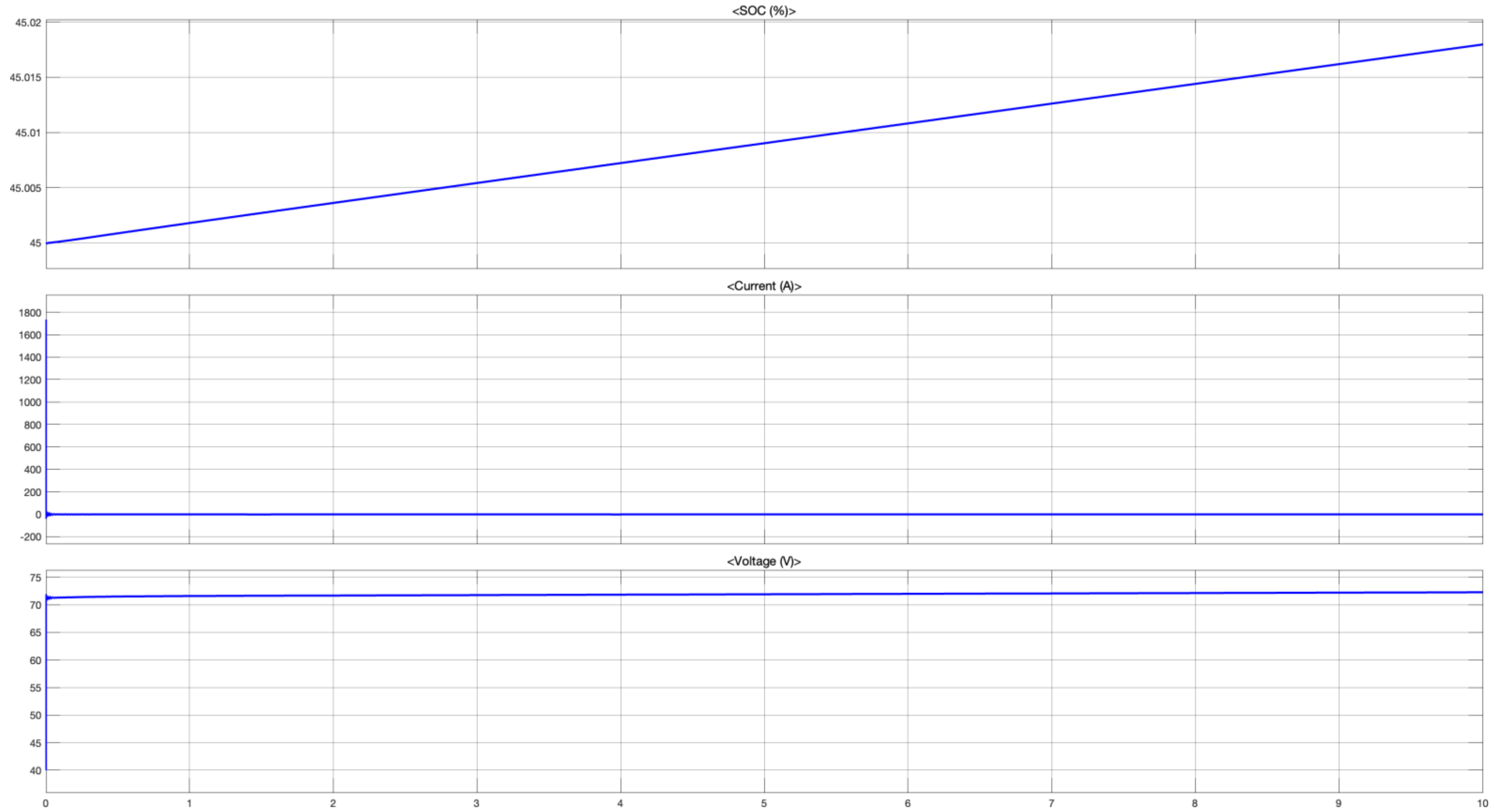


Figure 14: Battery Charging Mode (From PV Panels)

Results: Battery Operation

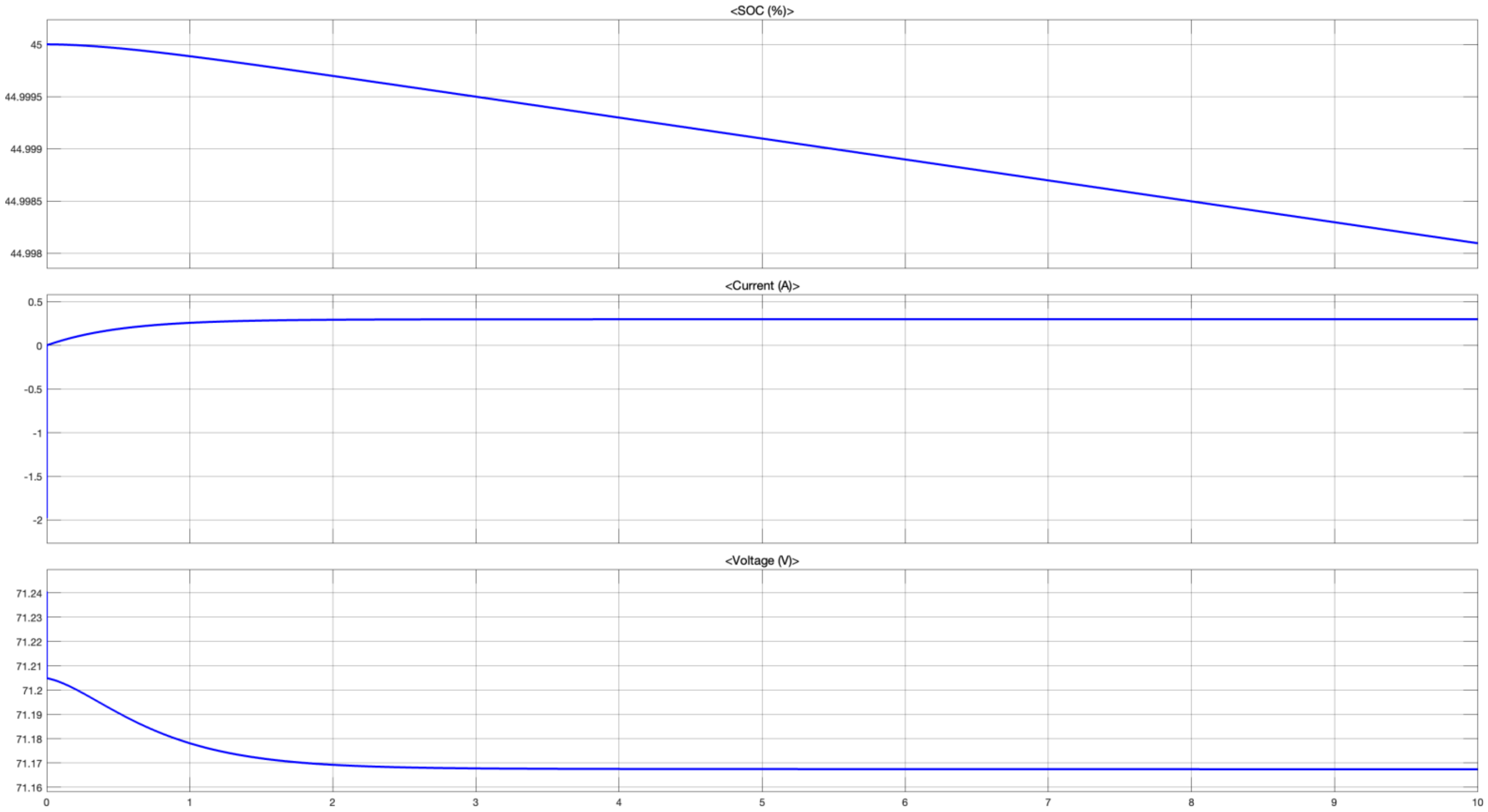


Figure 15: Battery discharging Mode (During vehicle operation)

Results: Battery Operation

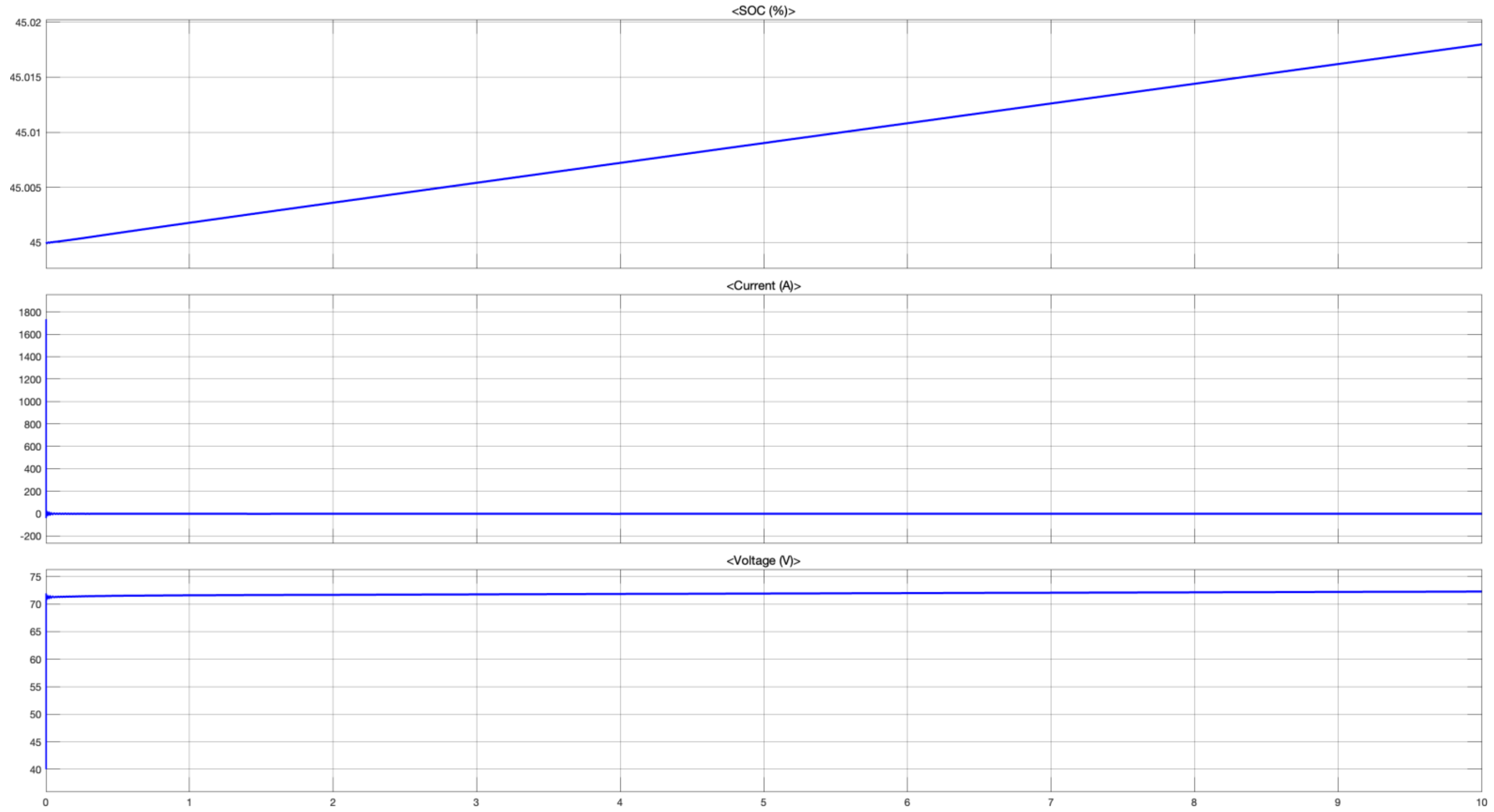


Figure 16: Battery Charging Mode (From AC Source)

Results: DC Machine Operation

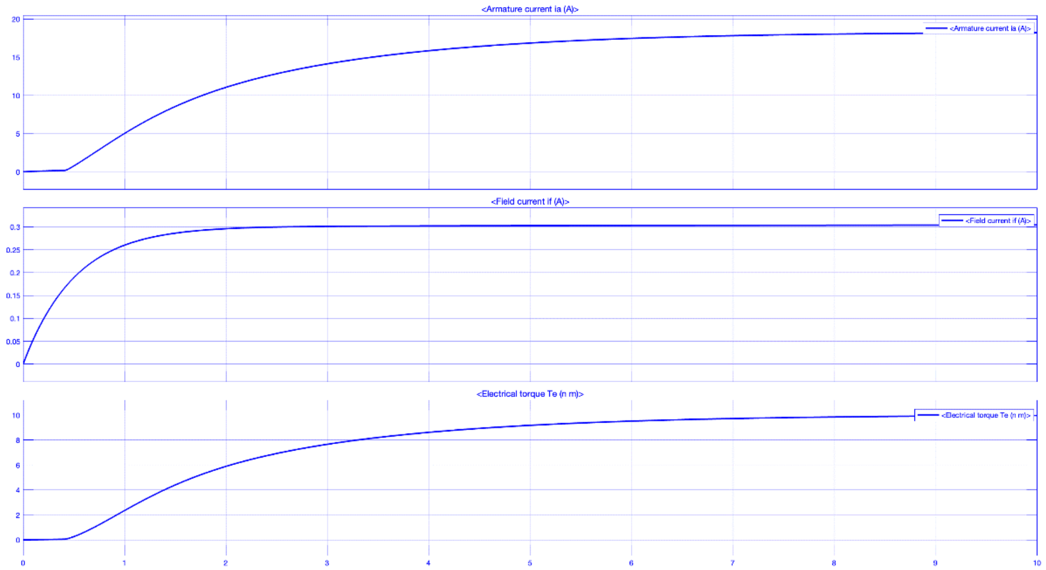


Figure 17: DC Machine Normal Operation

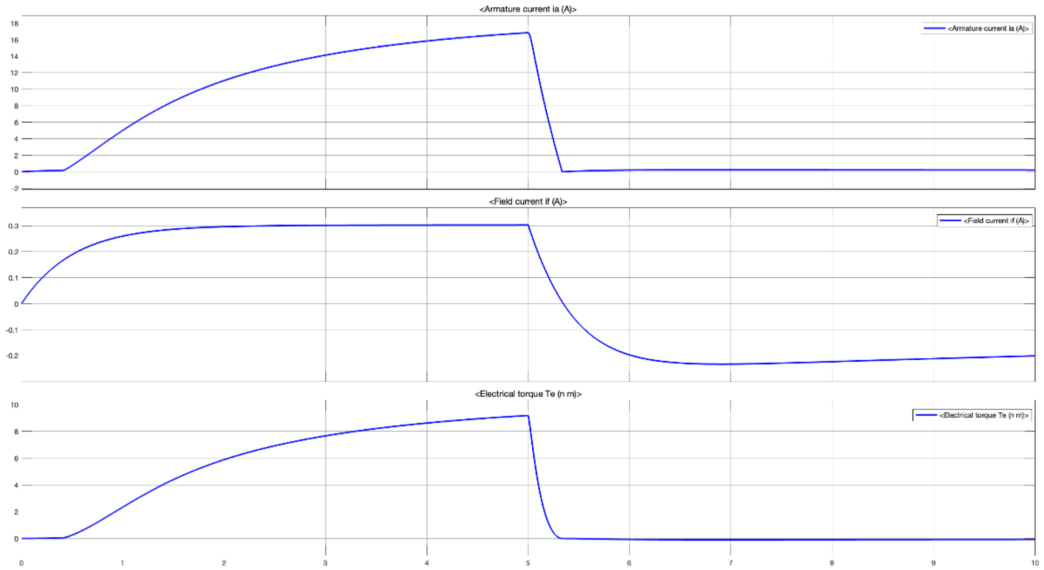


Figure 18: DC Machine Forward & Reverse Operation

Results: DC Machine Variable Load Operation

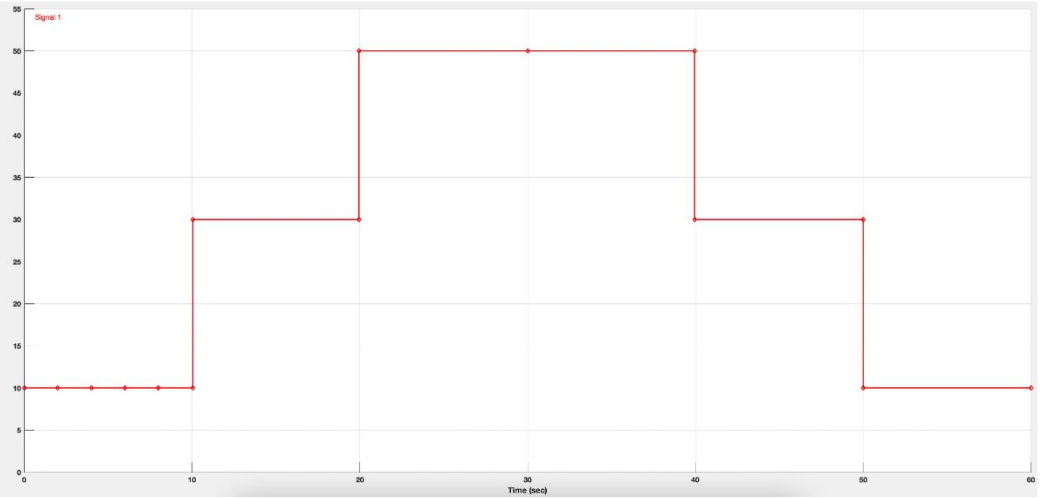


Figure 19: Variable Load Profile for DC Machine

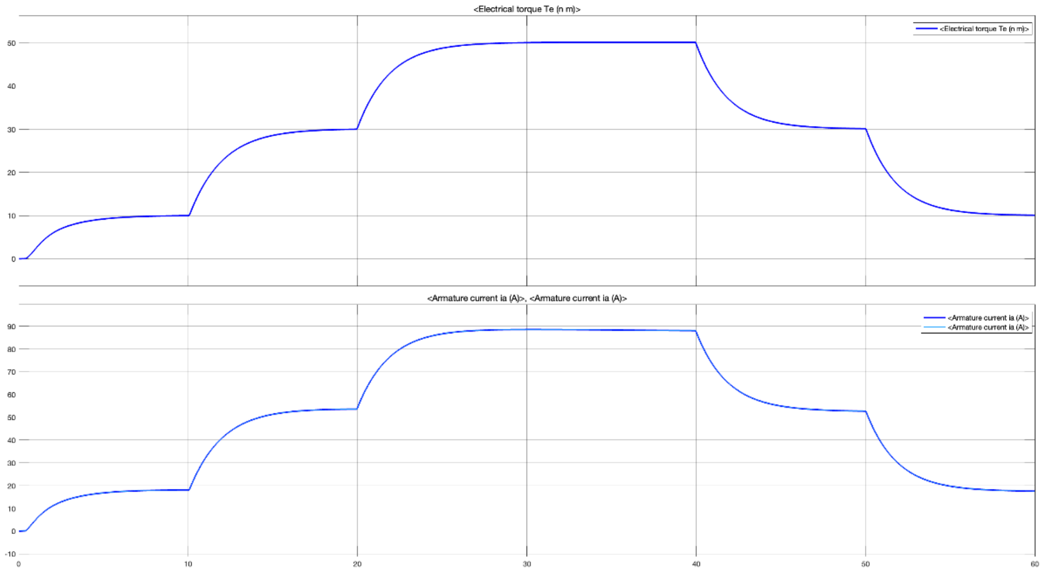


Figure 20: DC Machine Dynamics under Variable Load

Results: DC Machine Variable Speed Operation

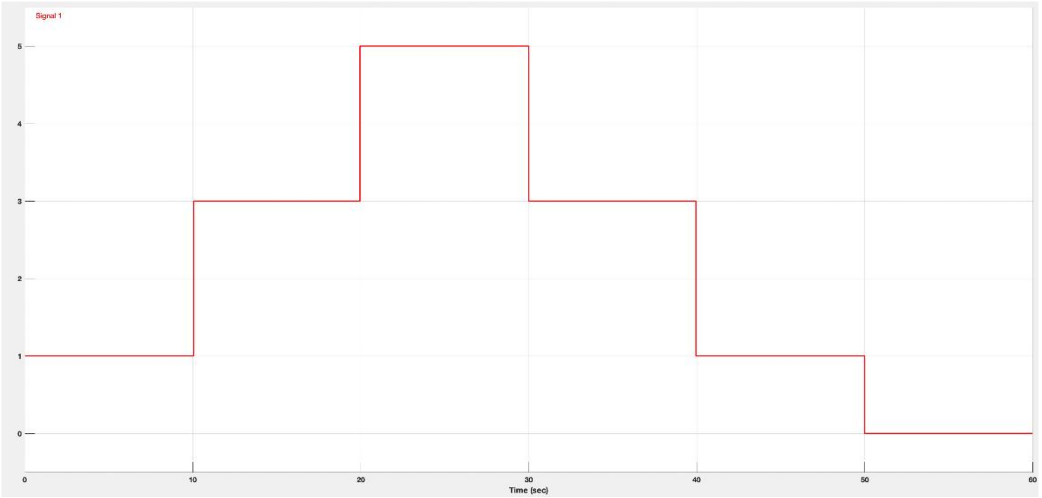


Figure 21: Variable Speed Reference for DC Machine

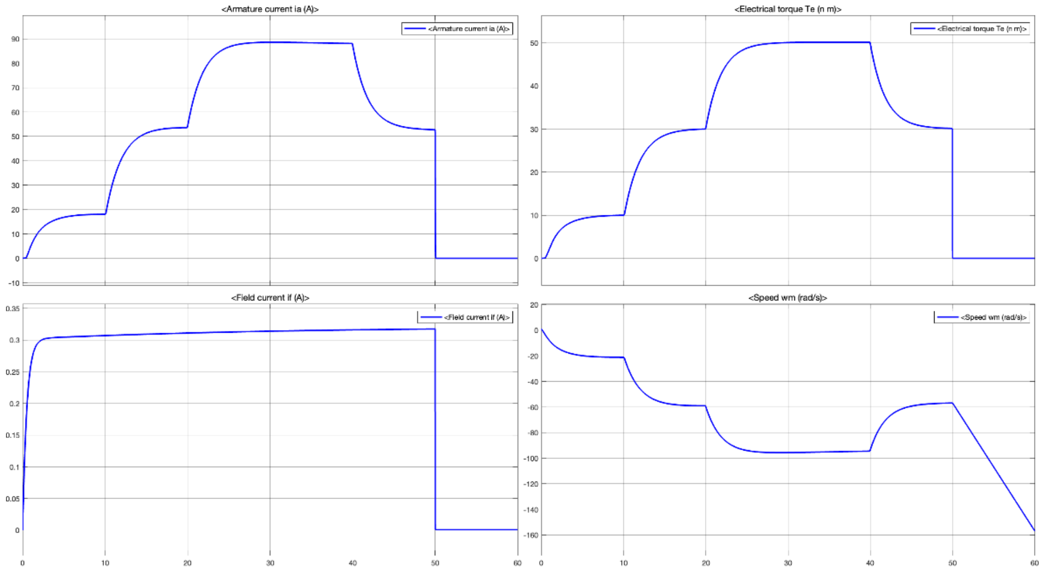


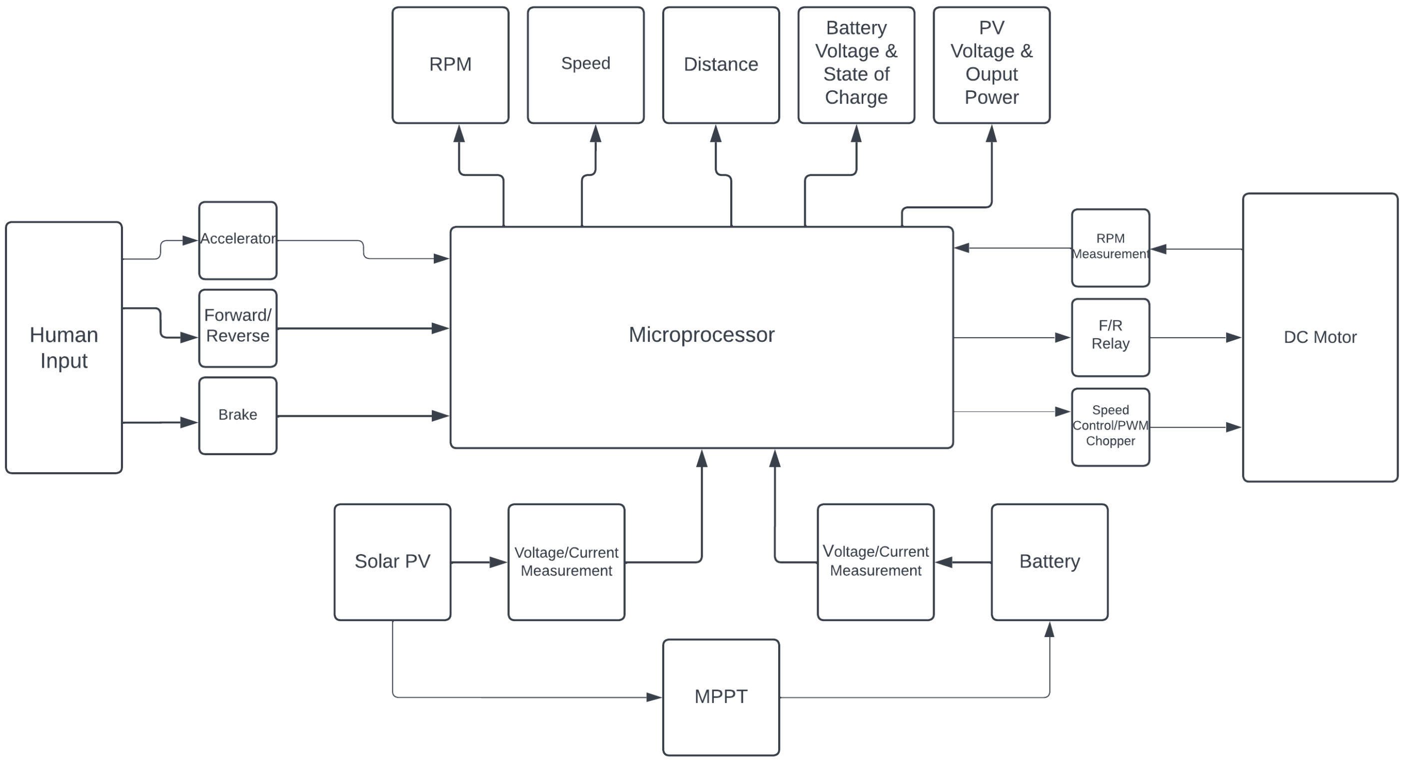
Figure 22: DC Machine Dynamics under Variable Speed Reference

Conclusion

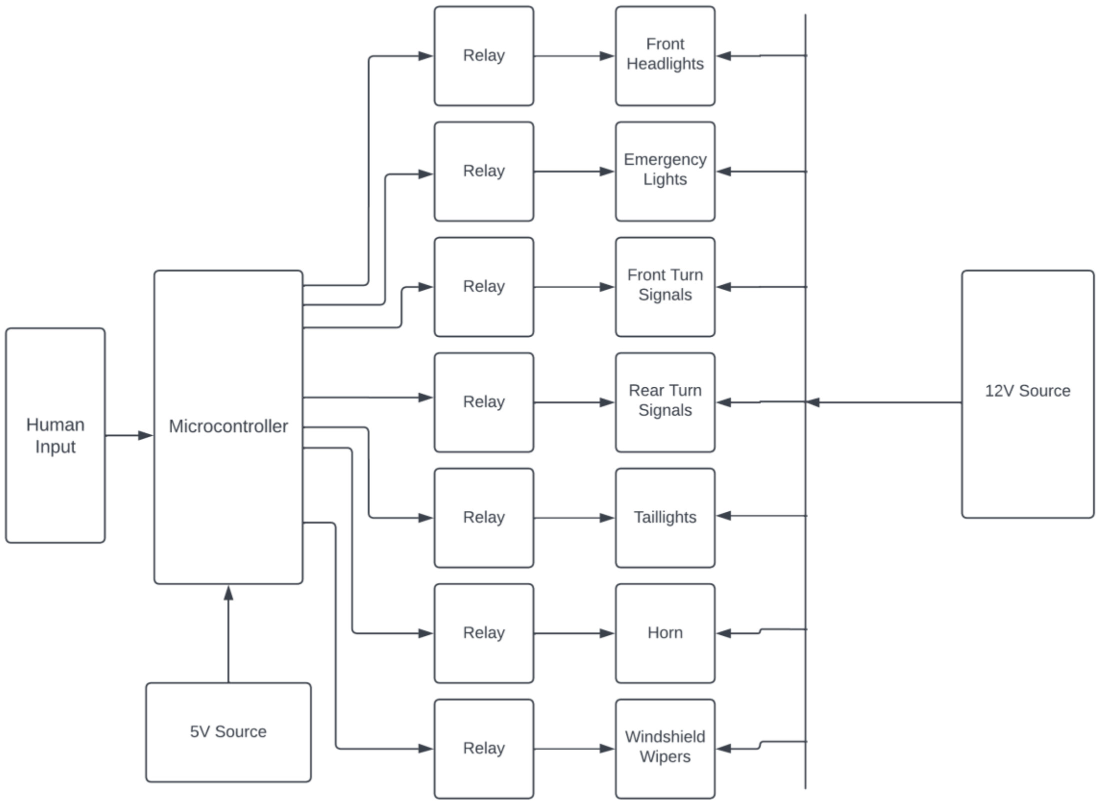
- The said micro solar electric vehicle was designed in HOMER Pro, and a system sizing was done. According to this system sizing, the micro solar electric vehicle would require 3, 24V, 150W PV modules (Advance Solar Hydro Wind Power API – 150) to add a range of approximately 30 KMs to the pre-existing battery range of the electric vehicle.
- The electric vehicle can also be charged from a 220V AC outlet with the help of the onboard AC-DC charging block, which allows the electric vehicle to charge at extremely low currents, easily supported by the current residential electricity infrastructure in Pakistan.
- In addition, a dynamic model of the micro solar electric vehicle was developed to be studied in much more details. The dynamic model focused on three different aspects of the systems i.e. power generation by PV modules, battery charging from PV modules as well as an external AC source, and finally DC-motor operations in forward and reverse mode. Other notable features of the model include a maximum point power tracker and a PWM chopper based speed control circuit.
- The dynamic model of the system not only helped us fully understand the working of the system in different modes, conditions and situations, but also helped us understand how the system will react to any variations in the environmental factors such as irradiance and temperature etc.

Design of Instrumentation and Control System for a Micro-Solar EV

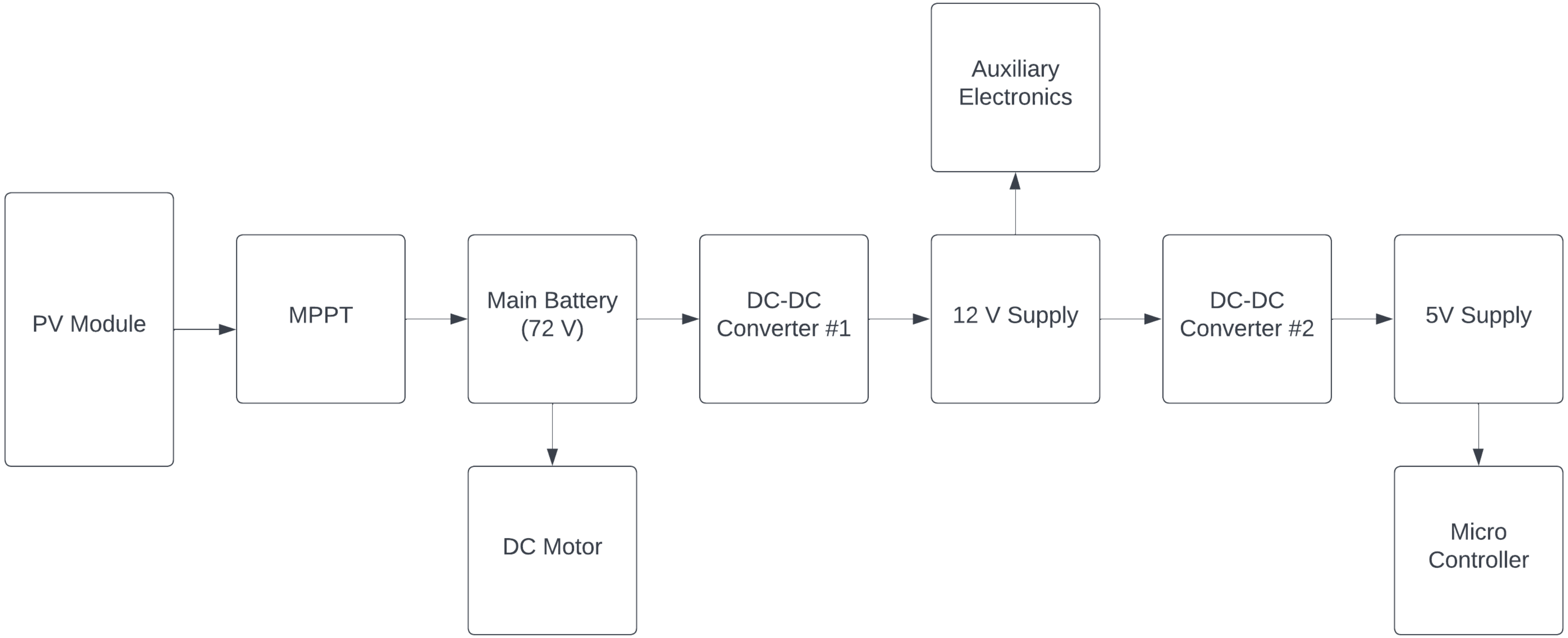
Control and Monitoring Circuit: Block Diagram



Auxiliary Circuit: Block Diagram



Main Power Stage: Block Diagram

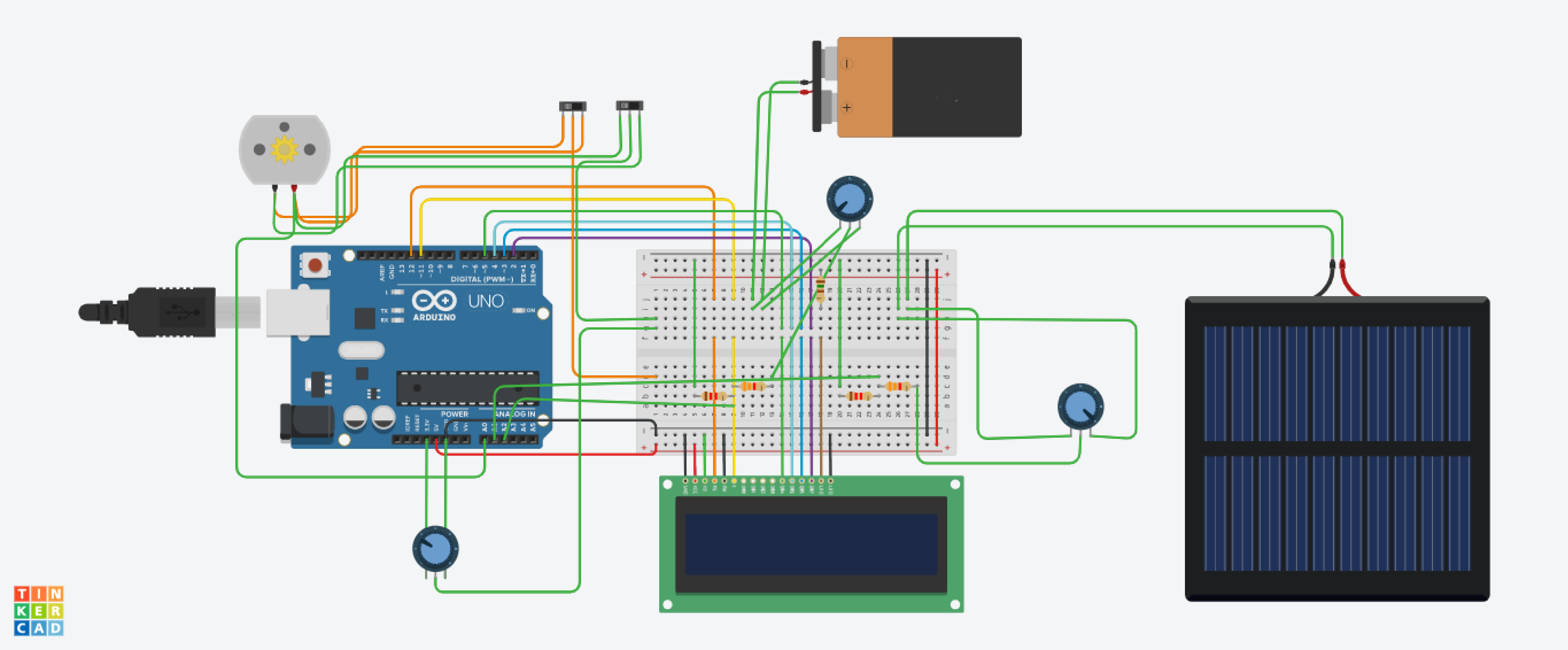


Major Components of the Instrumentation and Control System

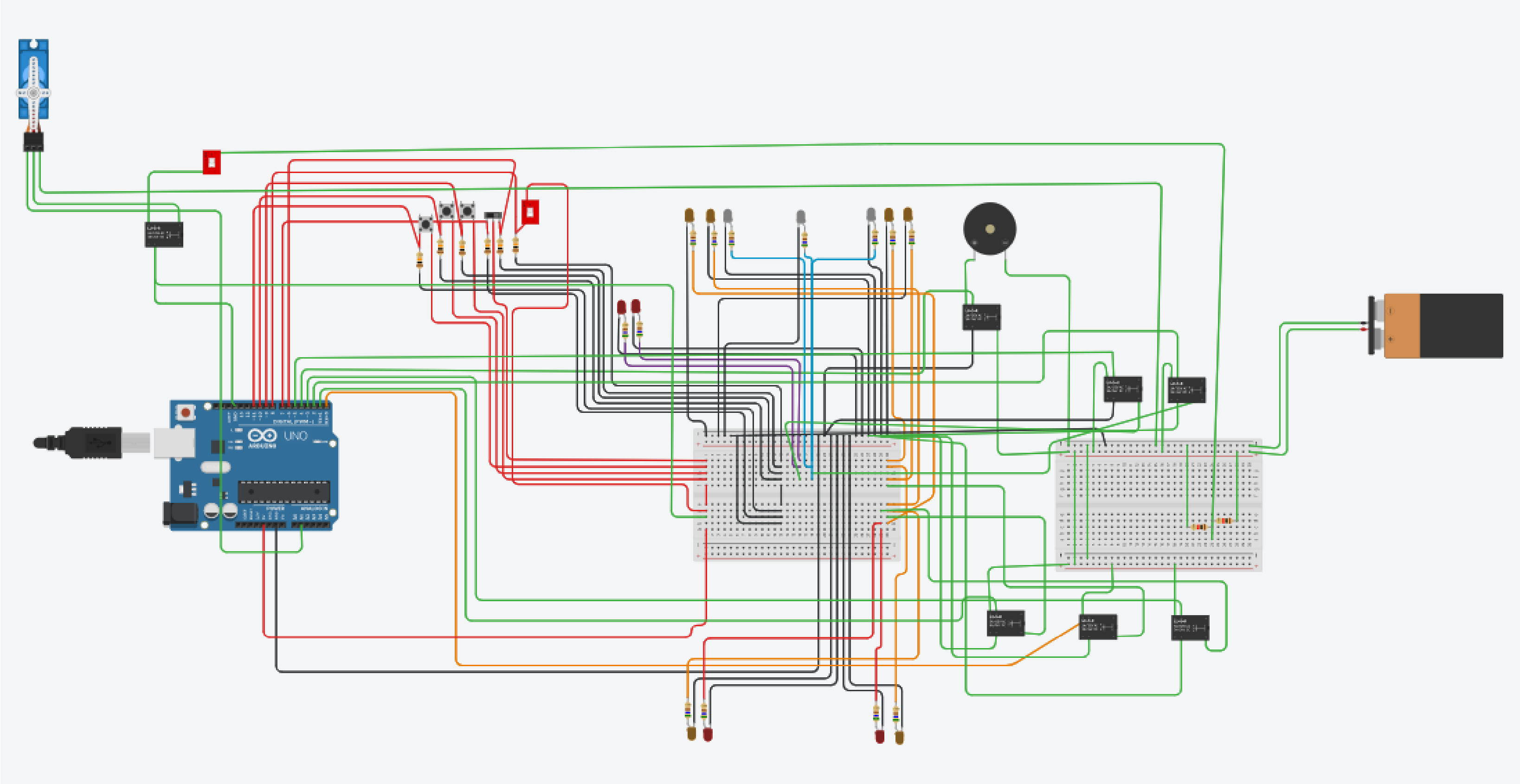
A. DC-DC Converters
B. LCD Display
C. Forward/Reverse Control
D. Speed Control
E. RPM Meter
F. Speedometer
G. Odometer
H. Battery Voltage & SOC
I. PV Voltage and Output Power
J. Headlights
K. Turn Signals
L. Hazard Lights
M. Taillights
N. Horn
O. Windshield Wipers

User Interface

Control and Monitoring Unit: Tinkercad Model



Auxiliary Circuit: Tinkercad Model



Conclusion

This marks the successful design of an instrumentation and control system of a micro solar EV

The design was divided into two parts:

1. First part comprising of the monitoring and control unit of the micro-solar EV
2. Second part being the auxiliary circuit of the micro solar EV

Tinkercad being a comprehensive design tool, helps design models that can be converted into functioning hardware systems with very little to no modifications. This includes the components to be used and the code needed to run the systems.

Contributions

- Identification of the challenges to EV adoption in the global context as well as the context of developing countries like Pakistan.
- Gap analysis of both academic and industrial research on the use of on-board solar PV modules to power electric vehicles.
- System design and PV sizing of a micro-solar electric vehicle based on the 3 passenger Chang Li electric vehicle for application in Pakistan.
- Dynamic modeling of a micro solar electric vehicle, including PV to battery charging, AC source to battery charging, maximum power point tracking, and the operation of DC motor under variable loads and speeds.
- Design of a ready to build, instrumentation and control system for a micro solar using Tinkercad with all the monitoring, control and auxiliary electronics along with detailed wiring schematics.

Future Research

- Investigate the feasibility of a micro solar electric vehicle in different areas, especially in areas, which do not get enough sun year round. This could have implications on the PV design and system sizing of the car.
- When building a dynamic model, there is a large number of factors that can be considered, to make the dynamic model as accurate as possible. These factors could involve acceleration and braking characteristics, body design of the vehicle, passenger weight, passenger driving behavior, suspension characteristics, drag produced by tires etc.
- The design approach is versatile and can be applied to a number of different applications for example the design of golf-carts, auto-rickshaws, agricultural equipment, commercial fleets etc.

References

1. H. com Editors, “William Cobb demonstrates first solar-powered car,” HISTORY. https://www.history.com/this-day-in-history/william-cobb-demonstrates-first-solar-powered-car (accessed Sep. 30, 2021).
2. “About | Bridgestone World Solar Challenge,” Feb. 09, 2021. https://worldsolarchallenge.org/about (accessed Sep. 30, 2021).
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8. “Solar City Car for Daily Urban Mobility,” Squad Mobility. https://www.squadmobility.com (accessed Oct. 03, 2021).

List of Publications

1. A. Husnain, M. T. Iqbal, “System Design and PV Sizing of a Micro Solar Electric Vehicle for Pakistan.” Presented at the 9th IEEE Conference on Technologies for Sustainability (SusTech 2022), Sunny Riverside, California

2. A. Husnain, M. T. Iqbal, “Dynamic Modeling of a Micro Solar Electric Vehicle for Pakistan using Simulink.” Presented at the IEMTRONICS 2022 (International IOT, Electronics and Mechatronics Conference), Toronto, Canada.

3. A. Husnain, M. T. Iqbal, “Design and Simulation of a Solar Parking System to meet all Energy needs of 10 Electric Cars.” Presented at The 30th Annual Newfoundland Electrical and Computer Engineering Conference (NECEC 2021), St. John’s, NL.

Thank you for Listening.
Any Questions?