CHAPTER 2

DESIGN OF A SOLAR-POWERED AUXILIARY BATTERY FOR ELECTRIC VEHICLES

*Nur Syafiqah Sulaiman[1], Mahyuzie Jenal[2]**

[1-2]Department of Electrical Engineering,
Faculty of Electrical and Electronics Engineering
University Tun Hussein Onn Malaysia,
86400 Parit Raja, Batu Pahat, Johor, Malaysia.
*Corresponding Email: mahyuzie@uthm.edu.my

2.1 INTRODUCTION

After years of the evolution of electric vehicles (EV), it is the most significant changes of world transportation which being off the increasingly growing demand for reducing the greenhouse gas emissions and counter the climate changes. Electric mobility has gained a real movement over the last few decades, as several sense governments, environmental organizations, and consumers have increasingly recognized the environmental and economic benefits of shifting away from traditional internal combustion engine vehicles [1]. Incentives range from tax breaks to ambitious targets as many countries around world enact policies and regulations designed to spur the adoption of EVs and the eventual elimination of gasoline-powered cars [2]. EV manufacturers such as Tesla, BYD and Nissan has invested billions of dollars in research and production to build sophisticated electric cars with better battery technologies and longer available driving distance [3]. Solar EVs can help lessen their dependence on the grid, lowering carbon emissions, and providing additional range in sunny climates by using solar energy to help charge the main battery [4]. Solar Power is one of the renewable energy resources that might show up to be best suitable for EVs is solar power, which could be obtained from the solar panels that be integrated into the vehicle design [5].

Auxiliary batteries electric vehicles (EVs) use auxiliary batteries to integrate with the overall energy management system of the vehicle to optimize and use power efficiently [6]. Auxiliary batteries allow for longer range for the vehicles on the designs that include them, while they could also be used to store energy from renewable sources like fixed units of solar panels and in that way reduce the reliance on them from the grid [7].

Batteries are necessary components of electric vehicles (EVs) to store energy that they need. But one of the biggest hurdles is that, while batteries have advanced enormously, energy density which is the amount of energy that can be stored in a certain weight or size which is still less than for traditional fossil fuel systems. Besides, lithium-ion batteries are quite expensive, which makes EVs more expensive than normal cars [8]. Not to mention that lithium-ion batteries rely on scarce materials such as lithium, cobalt and nickel which not only limited in supply but subject to environmental and ethical dilemmas around the extraction process [9].

These problems underscore the necessity of continuous research into and development of battery technology in order to enhance its efficiency, cost-effectiveness and environmental impact. Solar powered auxiliary systems are one of the potential opportunities to improve the longevity of the EV [10]. It could relieve strain on the main battery to deliver energy for propulsion, ultimately increasing the driving range of the vehicle. In addition, integration with solar energy provides an environmentally friendly solution by diminishing the dependency on grid and lesser carbon footprint of the vehicle [11]. Moreover, the steady enhancement of solar panel effectiveness and energy storage systems paves the way for more significant integration, suggesting that solar-powered extra systems could become a crucial part of the future of EVs [12].

2.2 METHODOLOGY AND SYSTEM OVERVIEW

An EV runs on battery power; however, with the current models available in the market, these batteries have a limited driving range. This structure is made up of components such as a solar panel array, auxiliary battery, energy management system (EMS), and the main EV battery. As a renewable energy source, the solar panel array generates sunlight into electrical energy that is absorbed into the auxiliary battery. An auxiliary battery, which is charged through the energy collected by the solar panels, supplies power to the non-propulsion systems of the EV, such as lighting, climate control, and infotainment, lightening the load on the main EV battery. This not only increases the total driving range, but also enhances the efficiency of the powertrain. The energy management system (EMS) handles the energy flow between the solar panel, the auxiliary battery and the main EV battery. The EMS secures the optimized distribution of energy by charging the auxiliary battery as needed and supplying power to the systems of the vehicle when needed. The main EV battery which powers the vehicle's propulsion system is now tasked to power less after the solar battery is introduced as an auxiliary battery, resulting in increased driving range for the EV, as shown in Figure 2.1.

Figure 2.1: Energy Management System (EMS).

2.2.1 DESIGN PROCESS OF SOLAR-POWERED AUXILIARY BATTERY SYSTEM

The design process for the solar-powered auxiliary battery system involves several stages, from conceptualization to the selection of components and integration into the electric vehicle (EV). The objective is to create a system that harnesses solar energy efficiently while improving the overall performance and sustainability of the EV. Defining requirements and specifications is the first stage of the design process. Once the system requirements are established, the next step is to select the components that will make up the solar-powered auxiliary battery system. This includes selecting solar panels based on their power output, efficiency, and physical size to fit within the vehicle; choosing a battery based on its capacity to store enough energy for non-propulsion uses, while also being lightweight and compact; designing the EMS to control the flow of energy; and ensuring a power conversion system can deliver usable energy across loads, as illustrated in Figure 2.2.

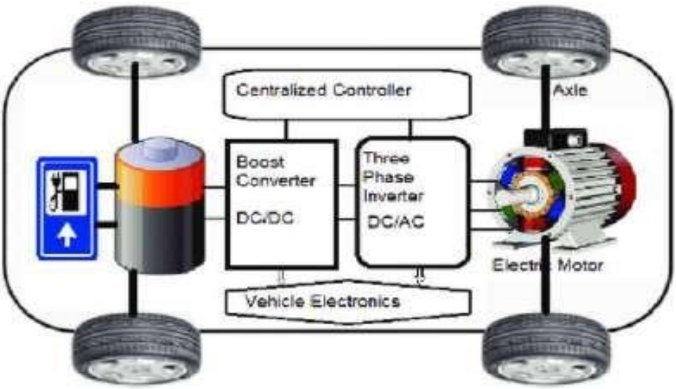

Figure 2.2: Power conversion diagram.

2.2.2 INTEGRATION OF SOLAR POWER WITH THE MAIN EV BATTERY

In EVs, designing the solar-powered auxiliary battery system necessitates the innovation of the solar energy input system through the interface with the existing main EV battery system. It flips stored solar power over to the main battery or directly supplies its own electric energy to beat a vehicle's other components, to lower demand on the primary battery, and ultimately increase overall driving range. This integration uses a controllable bi- directional energy flow system ensuring energy exchange through various techniques. It minimizes load on the main battery by prioritizing solar energy usage when possible, which contributes to overall energy efficiency and sustainability. The operation of this integrated system is shown in Figure 2.3.

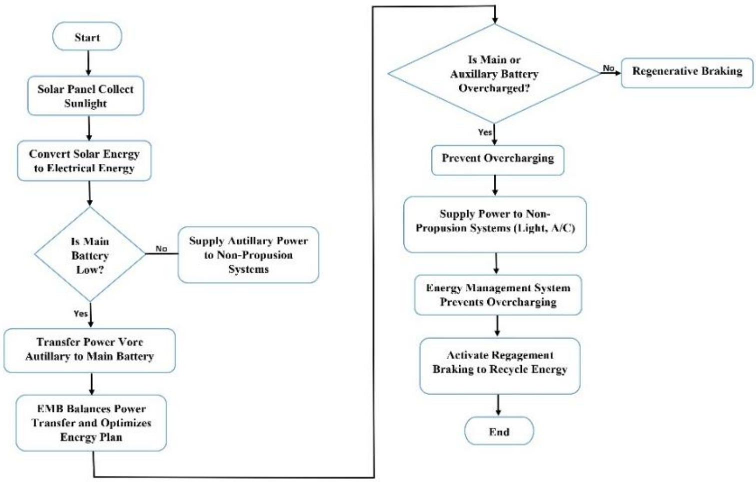

Figure 2.3: Flowchart of integration of solar power with main battery.

2.2.3 SIMULATION OF THE SYSTEM USING MATLAB-SIMULINK

MATLAB-Simulink is used to simulate the designed solar-powered auxiliary battery system to study its performance under different conditions. The simulation model is built up of the interconnected blocks that represent all key components of the system, including the solar panels, charge controller, auxiliary battery, main EV battery and the electric motor. This simulation tests it under different operating conditions such as different solar irradiance, different load demand, and different battery SOC. The outputs from these simulations provide information about the best designs and what improvements can be made. This simulation enables testing of algorithms that manage energy switching between auxiliary battery, sun energy, and main battery. The simulation flow is shown in Figure 2.4.

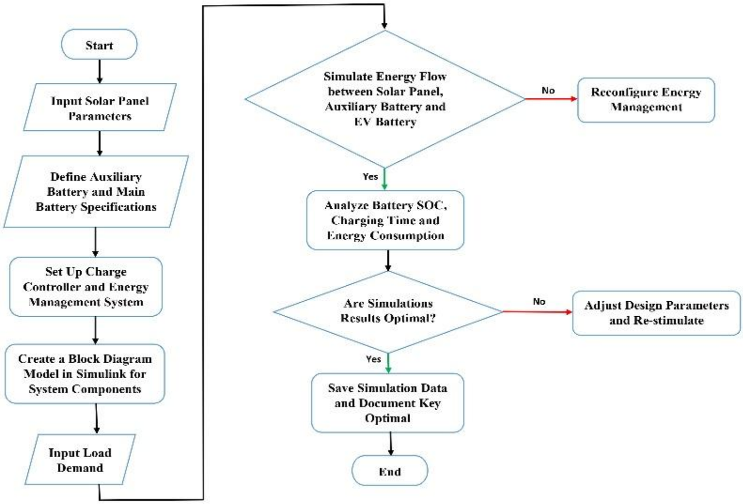

Figure 2.4: Flowchart of the simulation using MATLAB-Simulink.

2.2.4 PROTOTYPE DEVELOPMENT

A remote car (RC) served as the foundational platform to build a prototype which demonstrates solar-powered auxiliary battery systems for electric vehicles through practical implementation. The prototype functioned to demonstrate how solar power charges an auxiliary battery which supplies electrical power to support non-drive functions thus decreasing power draw from the primary source. The system development utilized four main components which consisted of a 5V solar panel, a lithium-ion battery, a charge controller circuit and standard DC loads. The circuit was manually built through hand-soldering on a prototyping board. The charge controller design is illustrated in Figure 2.5 and the full prototype layout is shown in Figure 2.6.

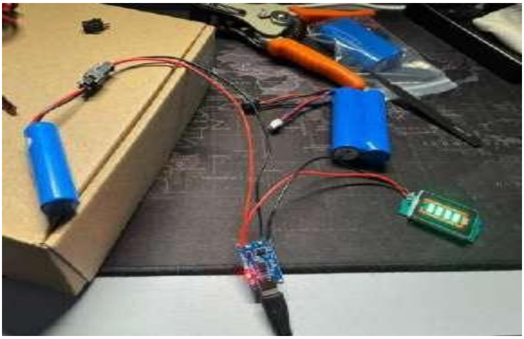

Figure 2.5: TP4056 circuit**.**

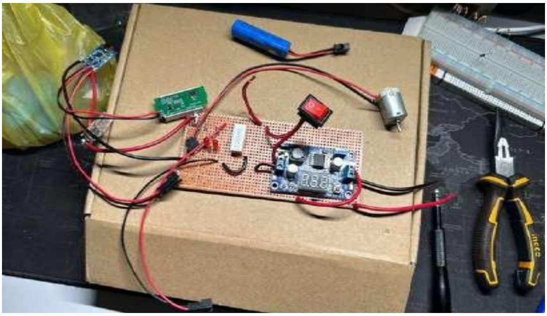

Figure 2.6: Complete load setup.

2.3 RESULT AND ANALYSIS

In order to evaluate the performance of the solar-powered auxiliary battery system under real conditions, testing was conducted at three different times of the day: morning (8:00–9:00 AM), noon (12:00–1:00 PM), and afternoon (4:00–5:00 PM). Each session measured solar panel voltage/current, battery voltage before and after charging, and runtime of auxiliary loads. Tools included multimeters and USB voltmeter-ammeter modules. Weather conditions were also noted. The goal was to analyze charging performance and runtime stability under varying light.

The results from the solar-powered auxiliary battery system for EVs underwent a detailed evaluation through both simulation and prototype implementation in this chapter. The results cover solar panel charging characteristics, energy efficiency, load runtime, and energy transfer behavior. Additionally, this chapter discusses the similarities and differences observed between simulation predictions and real-world prototype performance.

2.3.1 PRELIMINARY RESULT

A preliminary simulation using MATLAB-Simulink served to model the energy flow system before building the physical prototype of a solar-powered auxiliary battery system. The simulation process served two purposes: to test the concept of solar energy battery charging and to evaluate the impact of environmental factors including sunlight intensity and temperature on system performance. The simulation allowed visualization of the solar panel voltage characteristics along with battery charge-discharge behavior and basic energy management component performance including diodes and PWM-controlled switches.

The virtual system included a DC voltage source which mimicked solar panel output and a lithium-ion battery block alongside a control circuit that employed MOSFETs together with resistors and diodes for its operation, Figure 2.7.

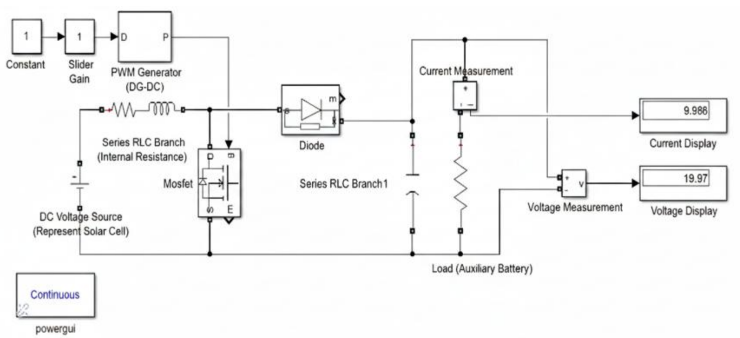

Figure 2.7: Simulation model of auxiliary circuit.

The simulation reproduced different sunlight levels through voltage adjustments of the DC source which represented solar panel output during various times of the day. The system inputs allowed researchers to determine how the auxiliary battery would behave under various charging scenarios including peak power conditions at about 24V and lower performance conditions when voltage dropped between 7V and 10V.

Although simplified, the simulation results confirmed that the solar charging concept was viable. It showed that the auxiliary battery could reliably store energy and supply it to various loads which provided the solar input remained stable. It also emphasized the need for voltage regulation and current protection which led to the decision to include a TP4056 charge controller in the real circuit design. These outcomes are visualized and interpreted in Figure 2.8 and Figure 2.9, which shows the result from the simulation output and waveforms of voltage during operation.

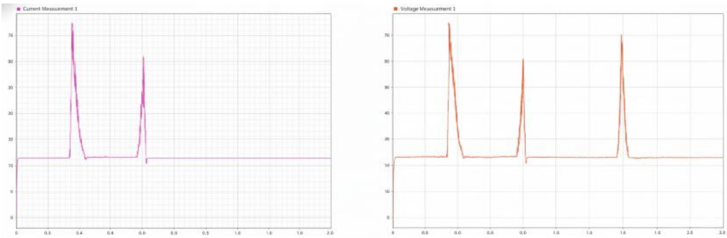

Figure 2.8: Simulation model of auxiliary circuit.

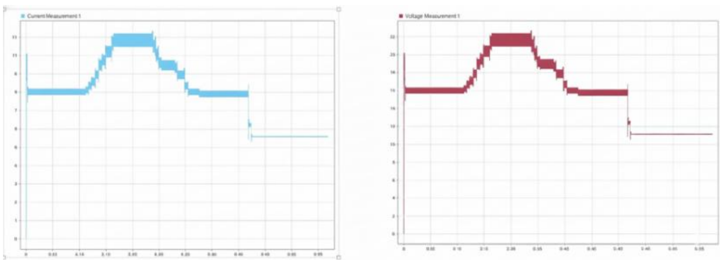

Figure 2.9: Simulation model of auxiliary circuit.

These simulation insights guided the selection of physical components and circuit layout in the prototype phase. Specifically, the simulation helped determine the importance of input voltage thresholds for charging efficiency, the need for unidirectional current flow using diodes and the role of voltage stability for downstream components like a step-up converter. The simulation functioned as a preliminary conceptual instrument yet it proved essential to establish the actual physical structure. The MATLAB-Simulink simulation accurately simulated the energy transfer, solar charging, and auxiliary battery operation under various sunlight patterns and voltage conditions. The outcome enabled comprehension of system behavior, component interactions, and voltage levels that drove the physical design. This supports the system's viability under various operating conditions.

2.3.2 PROTOTYPE DEVELOPMENT USING RC CAR

The theoretical concept found practical application through the development of a working prototype which used an RC car as its base. The RC car operates as a miniature version of electric vehicles by demonstrating the installation of solar-powered auxiliary battery systems through a compact and easily accessible design. The successful creation of this prototype proves that solar power can operate auxiliary electrical systems and deliver extra power to the main vehicle electrical system.

The complete circuit construction took place on a prototyping board which was then securely installed on the RC car chassis. As shown in Figure 2.10, the system wiring and components were cleanly integrated, allowing real-time solar charging and energy flow to the loads.

Figure 2.10: Fully assembled RC car prototype.

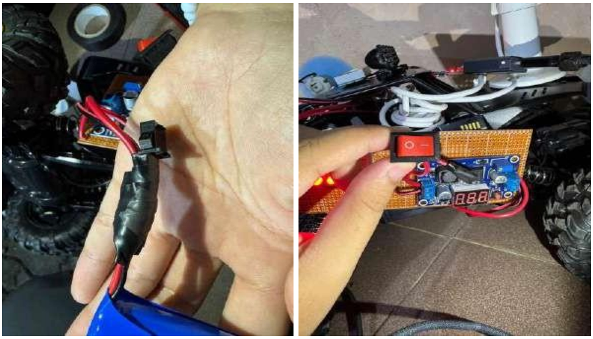

Figure 2.11: Wiring tap assist and switch.

2.3.3 EXPERIMENTAL TEST AND RESULTS

The prototype RC car underwent testing to measure its solar-powered auxiliary battery system functionality and performance under different lighting conditions which included direct sunlight along with cloudy weather and indoor LED lighting. The tests measured solar panel output voltage together with battery voltage before and after charging as well as charging current and runtime of connected loads. The testing process included the Assist Mode evaluation which determined how well the system could enhance main motor power by drawing from the auxiliary battery. The values presented in the charging and discharging tests were derived by averaging multiple observations recorded over a three-day period. For consistency and accuracy, measurements were taken in 30- minute intervals under similar environmental conditions across each day. This approach helped reduce the influence of temporary fluctuations in sunlight and temperature.

2.3.3.1 CHARGING PERFORMANCE

The solar panel was connected to the TP4056 charge controller and 14500 lithium-ion battery. Charging behavior was measured over a 30-minute interval in each condition and taken as average findings. The battery voltage rise was used as an indicator of charging efficiency. As shown in Figure 12, the graph plots the battery voltage rise with time, indicating effective charging under sunlight.

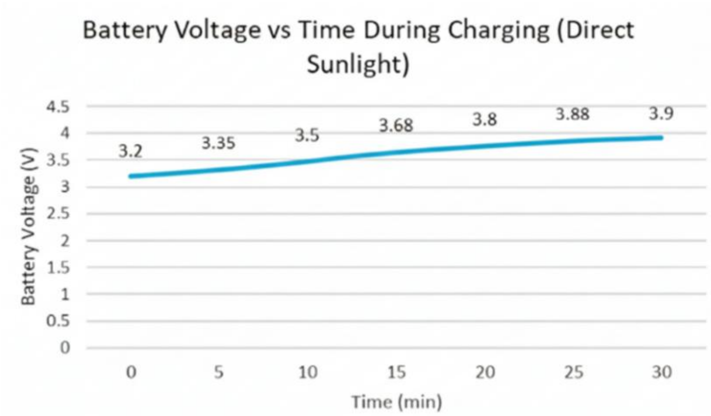

Figure 2.12: Graph of battery voltage vs Time During Charging.

The plot shows a continuous descending trend of the battery voltage with elapsed time when discharging under load (e.g., an LED or a fan). The voltage decreases gradually in the early stage, showing a comparatively stable discharge behavior. With progression of time, voltage drop rates slightly increase, especially after some point of time, which reflects the battery is approaching lower state of charge. This is typical battery discharge behavior, where the voltage remains fairly flat at the start and then degrades more quickly as the battery empties.

Table 2.1 summarizes voltage/current levels and charging durations under different light conditions.

Table 2.1: Charging performance under different lighting conditions.

Condition	Solar Panel	Charging	Batt. Volt.	Batt. Volt.	Duration
	Voltage (V)	**Current (mA)**	**Start (V)**	**End (V)**	**(min)**
Direct Sunlight	5.1	1200	4.10	4.10	30
Cloudy Weather	4.6	720	3.20	3.90	30
Indoor LED Light	4.2	120	3.20	3.25	30

These results indicate that the system charges efficiently under direct sunlight. Performance is noticeably reduced in cloudy and indoor environments, reflecting the limitations of low-light solar collection.

As shown in Figure 2.13, this is the actual multimeter reading captured during the charging test, validating the data collection. Figure shows the charging state on the multimeter as this is how the result is collected.

Figure 2.13: Multimeter of charging reading.

2.3.4 LOAD PERFORMANCE TEST

The auxiliary battery powered several EV systems: an LED strip (0.4 W), a mini fan (0.7 W), and a 10 Ω resistor simulating higher power draw. Each load was tested independently, measuring runtime from full charge until the voltage dropped below ~2.50 V. Figure 2.14 shows the discharging pattern, with voltage rising smoothly during direct sunlight charging. The rise is rapid at first, indicating efficient energy absorption, and gradually slows as the battery nears full capacity for typical behavior in charging curves.

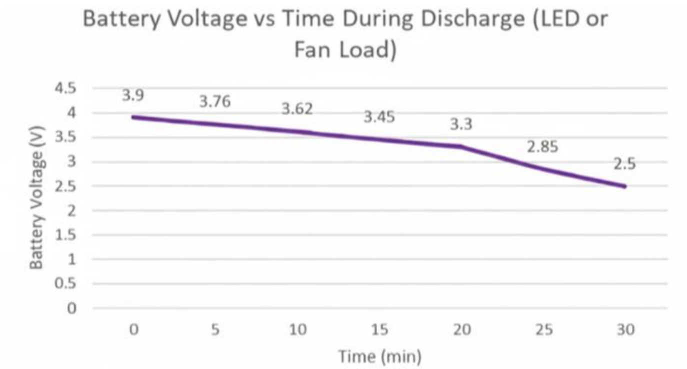

Figure 2.14: Graph Battery Voltage vs Time During Discharge.

Table 2.2 contains the recorded performance data for each load. This shows that the auxiliary battery is capable of powering small loads for reasonable durations, especially under optimal charging conditions.

Table 2.2: Load runtime from fully charged auxiliary battery.

Load Type	Power (W)	Initial Battery Voltage (V)	Run-time (min)	Final Battery Voltage (V)
LED Strip	1.0	3.90	45	2.65
Mini Fan	0.7	3.90	30	2.75
10Ω Resistor	~2.4	3.90	30	2.60

2.3.4.1 EXPERIMENTAL TEST AND RESULTS

To evaluate the effect of the auxiliary battery in Assist Mode, the step-up converter was activated to provide a 7.4V output connected to the RC car's main motor power line. The switch allowed manual control of assist activation. Voltage and runtime were observed before and after activation. Table 2.3 presents the recorded values and effect of assist mode activation.

Table 2.3: Effect of Assist Mode Activation.

Test Phase	Main Battery Voltage (V)	Auxiliary Assist Voltage (V)	Motor Behavior
Before Assist Mode	7.1	-	Moderate speed, slight delay
After Assist Mode	7.1	7.4 (from the step-up)	Noticeable torque increase, smoother

2.3.5 ENERGY EFFICIENCY COMPARISON

To evaluate the overall effectiveness of the solar-powered auxiliary battery system, a basic energy efficiency analysis was conducted by comparing the estimated energy input from the solar panel to the energy stored and later consumed by the auxiliary battery. The prototype solar panel generated 5.1 volts at 420 milliamps across 30 minutes of full sunlight which resulted in a total input energy of 1070 milliwatt-hours. The 14500 lithium-ion battery (800mAh, 3.7V nominal) experienced voltage increase from 3.6V to 3.9V during this time which represents an estimated energy storage of 890mWh. The solar-to-battery energy conversion efficiency reached 83.2% during the testing which slightly exceeded the 77.8% efficiency observed in the MATLAB simulation. As shown in Table 2.4 the prototype slightly outperformed the simulation results in terms of solar energy conversion.

Table 2.4: Energy efficiency comparison between simulation and prototype.

Condition	System	Solar Energy Input (mWh)	Battery Energy Stored (mWh)	Efficiency (%)
Direct Sunlight	Simulation	1260	980	77.8
Direct Sunlight	Prototype	1070	890	83.2

The slight increase in efficiency observed in the prototype may be attributed to measurement assumptions and energy losses not modeled in the simulation. The relatively close alignment between simulation and prototype results suggests that the simulation model provided a reasonable baseline for guiding hardware design.

2.4 DISCUSSION OF KEY FINDINGS

Both the MATLAB-Simulink simulation and physical prototype showed solar energy collection works efficiently with compact lithium-ion battery storage for auxiliary load power requirements and propulsion system assistance. The prototype tests confirmed that the TP4056 charge controller managed charging safely, and the 14500-battery achieved full charge under direct sunlight within approximately 30 minutes. The system's energy flow and management proved effective because its behavior matched the simulation patterns. The system showed operational success yet displayed practical issues during its operation. When exposed to cloudy or indoor lighting conditions the system's performance dropped significantly. The 800mAh battery capacity restricts usage time, making the system suitable primarily for light auxiliary loads in its current form. Simulation outputs, prototype development, and performance tests confirmed all the objectives of the project. These results affirm the overall success and relevance of the project.

2.5 CONCLUSION

The project successfully designed and tested a solar-powered auxiliary battery system for an RC car, demonstrating its potential application in electric vehicles. Simulations confirmed the concept's viability for energy harvesting and battery charging, while the prototype reliably charged a 14500 lithium-ion battery, powered small auxiliary loads, and supplied boosted voltage via Assist Mode. Despite limitations in battery capacity and lack of MPPT, real-world performance closely matched simulations, showing that solar-assisted auxiliary systems can be practical and scalable with further development.

BIBLIOGRAPHY

[1] De Abreu, V., D'agosto, M., Angelo, A., Marujo, L., & Carneiro, P. (2023). Action Plan Focused on Electric Mobility (APOEM): A Tool for Assessment of the Potential Environmental Benefits of Urban Mobility. Sustainability. https://doi.org/10.3390/su151310218.

[2] Carey, J. (2023). The other benefit of electric vehicles. Proceedings of the National Academy of Sciences of the United States of America, 120. https://doi.org/10.1073/pnas.2220923120.

[3] Cheng, Y. (2023). Tesla and BYD Comparison Analysis. Advances in Economics, Management and Political Sciences. https://doi.org/10.54254/2754-1169/38/20231917.

[4] Tavakoli, A., Saha, S., Arif, M., Haque, E., Mendis, N., & Oo, A. (2020). Impacts of grid integration of solar PV and electric vehicle on grid stability, power quality and energy economics: a review. IET Energy Systems Integration. https://doi.org/10.1049/iet-esi.2019.0047.

[5] Muhammad Umair, I., Nabil M. Hidayat, I., Ahmad, A., Hakimi, N., Ali, N., Mawardi, M., & Abdullah, E. (2024). A renewable approach to electric vehicle charging through solar energy storage. PLOS ONE, 19. https://doi.org/10.1371/journal.pone.0297376.

[6] Sidharthan, V., Kashyap, Y., & Kosmopoulos, P. (2023). Adaptive-Energy-Sharing-Based Energy Management Strategy of Hybrid Sources in Electric Vehicles. Energies. https://doi.org/10.3390/en16031214.

[7] Rahman, A., Aung, K., Ihsan, S., Shah, R., Qubeissi, M., & Aljarrah, M. (2023). Solar Energy Dependent Supercapacitor System with ANFIS Controller for Auxiliary Load of Electric Vehicles. Energies. https://doi.org/10.3390/en16062690.

[8] J, B., Pandeya, M., & Vishnoi, R. (2024). Emerging Battery Technologies for High-Power Electric Vehicles. 2024 International Conference on Optimization Computing and Wireless Communication (ICOCWC), 1-6.,https://doi.org/10.1109/ICOCWC60930.2024.1047063

[9] Kallitsis, E., Korre, A., Kelsall, G., Kupfersberger, M., & Nie, Z. (2020). Environmental life cycle assessment of the production in China of lithium-ion batteries with nickel-cobalt-manganese cathodes utilising novel electrode chemistries. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2020.120067.

[10] Biju, A., Madhuria, O., Sam, M., Hari, A., & Sebastian, A. (2023). Effective Solar-Powered EV-Charging System with Enhanced Voltage Regulation. 2023 9th International Conference on Smart Computing and Communications (ICSCC), 718-723. https://doi.org/10.1109/ICSCC59169.2023.10335081.

[11] Pandey, N., Yadav, R., Maitra, S., Sharma, P., & Pachauri, R. (2024). Eco-Friendly EV Charging: Utilizing Grid-Linked Solar Photovoltaic Systems. 2024 IEEE Third International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES), 280-285. https://doi.org/10.1109/ICPEICES62430.2024.10719359

[12] Cabrane, Z., Batool, D., Kim, J., & Yoo, K. (2020). Design and simulation studies of battery-supercapacitor hybrid energy storage system for improved performances of traction system of solar vehicle. Journal of energy storage, 32, 101943. https://doi.org/10.1016/j.est.2020.101943.