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Optimizing Electric Vehicle Range through Integrating Rooftop Solar on Vehicle

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ABSTRACT- This paper includes the research work to investigate the optimization of electric vehicle (EV) range by integrating rooftop solar panels onto the vehicle. The primary motivation stems from the increasing power demand for EV charging, requiring substantial grid electricity production. The paper explores the installation of rooftop solar panels to augment the EV range with a single full charge, reducing the dependence on the grid. The simulations are conducted using MATLAB modeling, optimizing solar and grid charging schedules based on solar irradiation data. The outcomes showcase a 1.44 kWh battery integration with an EV equipped with a 1 kW BLDC motor, weighing 800 kg, including payload. The installation of Rooftop Solar Photovoltaic (RTSPV) improved the range of the vehicle with 18.65%, energy consumption is increased with 15.5%, Cost savings in charging the battery is up to 15.5% and travel distance with full charge is increased up to 19.6%. This analysis is made with the reference drive cycle shown in the paper. While the integration of solar panels significantly extends the vehicle range, the research emphasizes the potential for sustainable charging practices to mitigate grid dependence and reduce emissions.

Keywords: Electric vehicles; Solar Panel Integration; Grid Charging, Solar Charging, Range Extension, MATLAB Modeling.

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1. INTRODUCTION

The surge in plug-in electric vehicles (PEVs) has spurred sustainable charging advancements, emphasizing solar integration within DC micro grids. This approach streamlines battery charging while enabling bidirectional energy flow through Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) technologies [1, 2]. Solar plug-in hybrid electric vehicles notably curtail charging expenses, favouring cost-effective Solar Photovoltaic (SPV) charging over conventional grid methods [3]. However, optimizing SPV and grid charging schedules remains pivotal for this model's efficacy [4].

Despite the benefits, seamless integration of on-board solar cells with EV batteries poses challenges [5]. SPV integration not only offers an eco-friendly charging alternative but also eases grid load for EVs [6]. This study concentrates on solar photovoltaic integration into electric vehicle charging setups, highlighting intelligent energy management's importance [7, 8, 9]. The research explores the installation of solar panels atop EVs to harness solar power. Analysing Solar irradiance using NREL's PV watts calculator and NSRDB Viewer for Hyderabad (17.3850° N, 78.4867° E), data reveals irradiance ranging from 4.44 to 6.97 kWh/m2/day [10]. The highest irradiation occurs in March and April, dwindling in August.
This research delves into solar PV systems on EV rooftops, capitalizing on solar irradiation data for effective integration. The discussion underscores SPV's impact on charging dynamics, emphasizing peak irradiation months for efficient harnessing of solar energy.

2. PROPOSED METHODOLOGY

To reduce the pressure on grid to charge the EV, installation of Solar PV panels on EV roof top is proposed and *figure 1* shows the model of RTSPV vehicle which shows the integration of Solar panels on roof top of the vehicle. The methodology depicted in *figure 2*, involves determining the drive cycle, calculating vehicle force, power, and energy, and measuring rooftop area to extend EV range. The rooftop Solar Photovoltaic (RTSPV) system supplements Electric Vehicle battery (EVB) charging during operation, augmenting battery range.

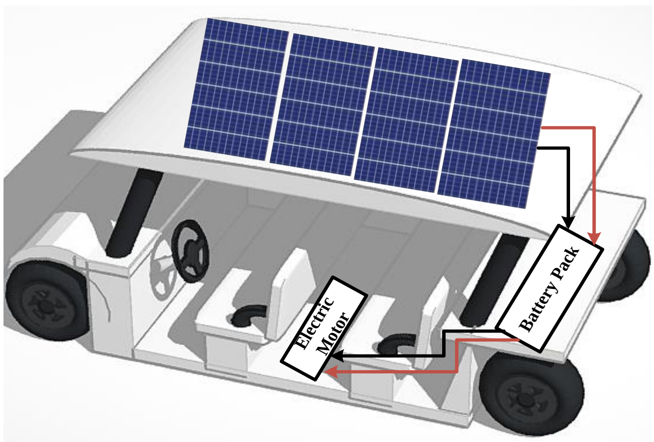

Figure 1: RTSPV vehicle

The charging process for EVB utilizing RTSPV includes an optimized charging timetable. Charging occurs via Grid supply or RTSPV, depending on vehicle status, sunlight availability, and EVB SOC. These parameters dictate the charging mode, detailed in *table 1*. The proposed methodology prioritizes optimizing solar energy for EV charging across diverse driving scenarios, ensuring efficient energy source utilization. Through these strategies, rooftop SPV installations significantly bolster the EV's power needs, enhancing sustainability and energy efficiency. [14, 15]

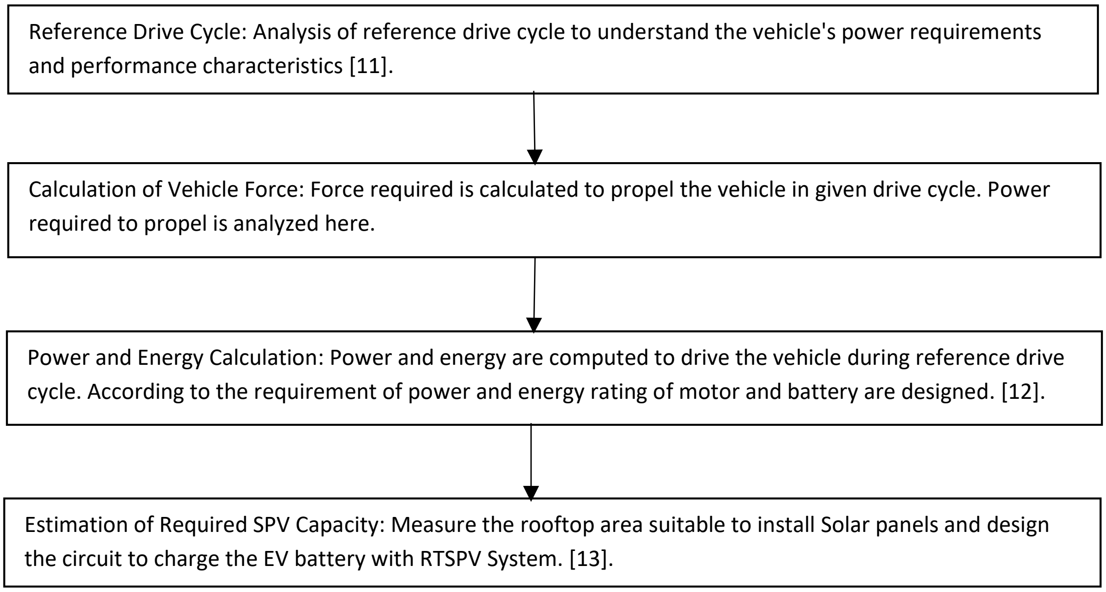

Figure 2: Flow Diagram of in estimating the vehicle power train.

Table 1: charging modes of EVB

Vehicle Status	Sun light	EVB SOC Status	Power Source	Charging Mode
Running	Available	>95%	Solar	No charging initiated
Running	Available	20% to 90%	Solar	RTSPV charging initiated
Running	Not Available	20% to 90%	NA	No charging initiated
Standstill	Available	20% to 90%	Solar	RTSPV charging initiated
Standstill	Not Available	20% to 90%	Grid	Grid charging initiated
Standstill	Not Available	>95%	Grid	No charging initiated

3. BLOCK DIAGRAM AND SIMULATIONS

3.1 Proposed Block Diagram and Flow chart

The proposed block diagram shown in *figure 3* illustrates EV's charging and power distribution system with rooftop Solar Photovoltaic (RTSPV) installation [16]. EV integrates Grid Supply and PV supply, activated via a switch programmed with conditions from the Switch Schedule algorithm (table 1) and shown in the flowchart (*figure 4*) [17]. The power train charges the battery from SPV or Grid supply, providing power to the motor controller for motor activation. The vehicle's charging mode is detailed in the flowchart (*figure 4*) with diverse conditions.

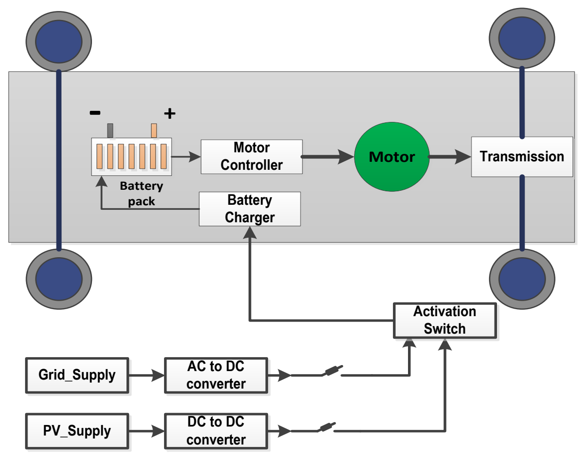

Figure 3: Proposed block diagram

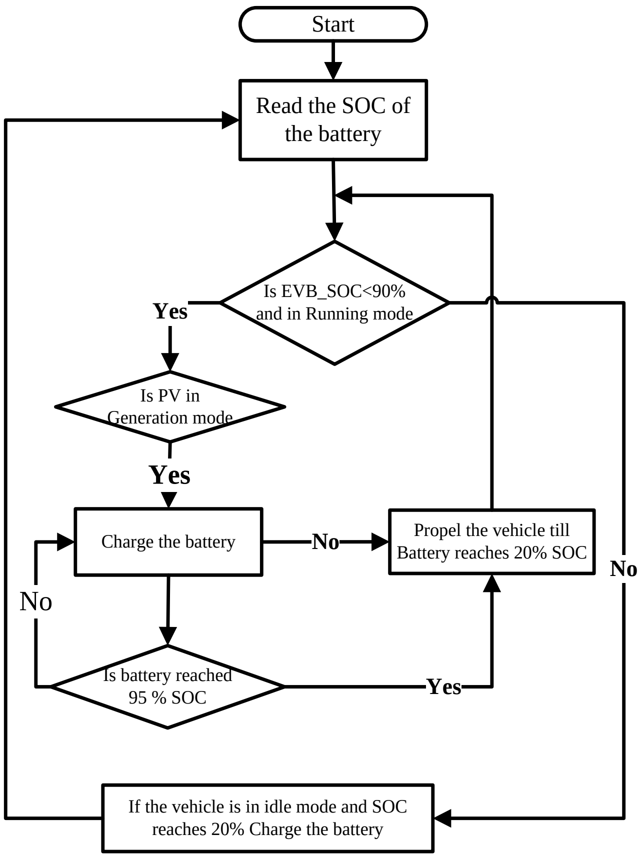

Figure 4: Flowchart to show the conditions of charging EVB

3.2 Reference inputs and their ratings:

A 315W-rated solar panel is analyzed based on the vehicle rooftop dimensions. *Figure 5* displays (Current Vs Voltage) I-V and (Power vs Voltage) P-V curves of the PV system. The IV and PV curves *(figure 5* depict the SPV modules' performance characteristics, offering insights into efficiency under varying voltage and current. Understanding these curves aids in gauging power generation potential and integrating SPV effectively into EV charging [18, 19].

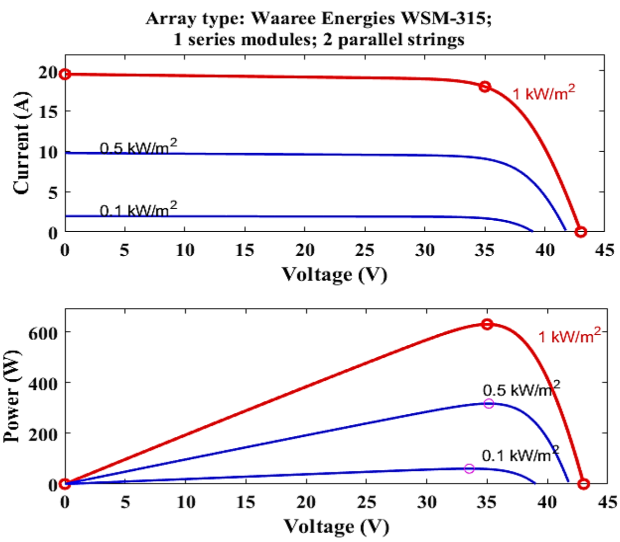

Figure 5: Simulation results of IV and PV curves of Solar panel

Simulink simulation, utilizing these curves, facilitates in-depth analysis of solar panel performance impacting EV charging. This data-driven model enhances energy efficiency and sustainability [20, 21]. Utilizing MATLAB's capabilities, this analysis targets insights into EV energy efficiency, operational behavior, and charging patterns. Vehicle technical parameters in MATLAB Simulink are detailed in table 2. The study's outcomes guide enhancements in vehicle design and energy management, fostering intelligent and sustainable EV solutions [22, 23, and 24].

3.3 Vehicle Parameters used for Simulation in MATLAB

The proposed Switch Schedule algorithm is simulated in MATLAB using vehicle parameters shown in *table 2*. Reference drive cycle is considered to implement the vehicle parameters along with the irradiance curves which are designed to test the said steps in *figure 2*. The Drive cycle demonstrates algorithm access points, and Irradiance reflects sun irradiance at 17.3850° N, 78.4867° E throughout the year. MATLAB simulation, aligned with *table 1* conditions and flowchart in figure 4, is implemented using subsystems in MATLAB 2023b version and simulation model is shown in *figure 6*.

Table 2 Vehicle parameters taken as inputs of MATLAB

Vehicle Parameters		**Motor ratings**	
Mass of the vehicle	500Kg	Motor:	BLDC
Payload	300 Kg	Power Rating:	1000 W
Gross vehicle weight	800 kg	Speed:	1200 rpm
Vehicle Length x Width x Height	1939mm x 1116mm x 40mm	Torque:	5Nm
Vehicle Performance:		Battery: $LiFePO_4$	
Range of the vehicle	60 Km	Voltage	48 V
Vehicle Top Speed:	25Kmph	Capacity	30 Ah
Gravitational Force	9.81 m/s^2	Coefficient of Density Cd	0.44
Rolling Resistance Coefficient µ	0.013	Air Density Coefficient ρ	1.2 kg/m^3

The Drive cycle illustrates vehicle velocity in kmph, facilitating the calculation of Force needed to propel the vehicle using *equation 1*, a dynamic vehicle equation based on data in *table 2*. The MATLAB Vehicle model incorporates *equations 1 to 4*, enabling motor activation per the Drive cycle's activation signal.

$$F_{trac} = F_{aero} + F_{rr} + F_g + F_{acc} \quad (1)$$

$$Power = F_{trac} * Velocity \quad (2)$$

$$Energy = \int_0^T mv(g\mu + a) + \frac{1}{2}\rho C_d A_f V^3) * t \quad (3)$$

$$Torque = F_{trac} * r_{wheel} \quad (4)$$

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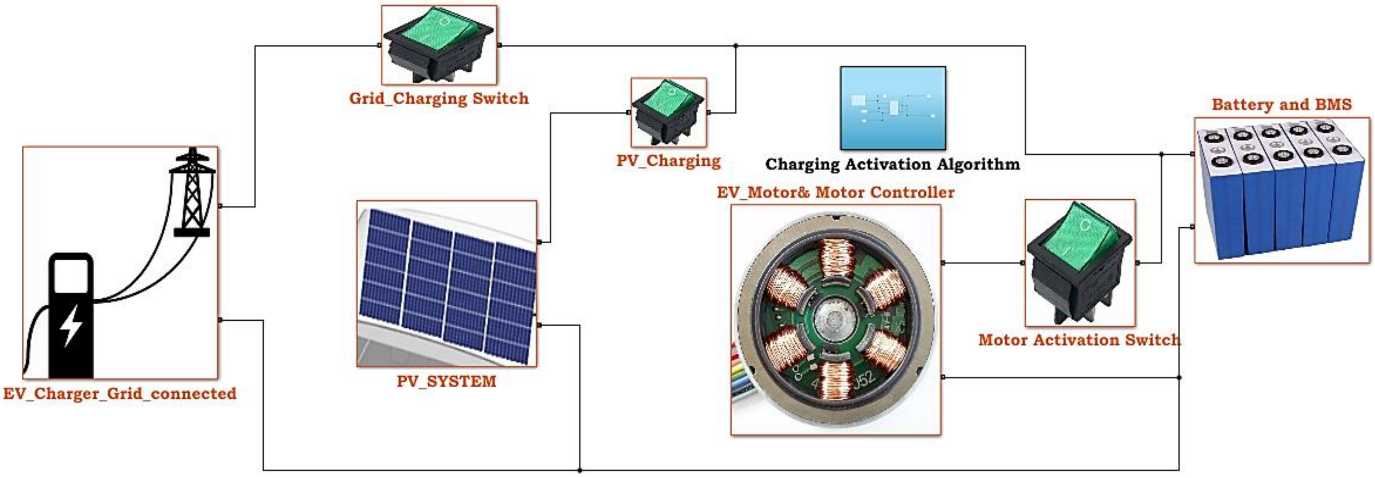

Figure 6: Simulation model of proposed system

4. RESULTS

4.1 Conditions to Charge of the battery

Figure 7 depicts simulation results for different scenarios mentioned in the algorithm where the *figure 7c* shows vehicle running status, *figure 7a* represents irradiance, EVB charge enabling switch curve is shown in *figure 7b, d*. Switch activation aligns with vehicle running conditions, with motor status and battery SOC are shown in *figure 8* and *figure 9*. It shows that motor operation is following the path of vehicle running status and battery SOC is reducing in faster rate while battery alone is functioning and while EV getting charged with PV, battery SOC degradation rate is also reduced. Details are tabulated in *table 3*.

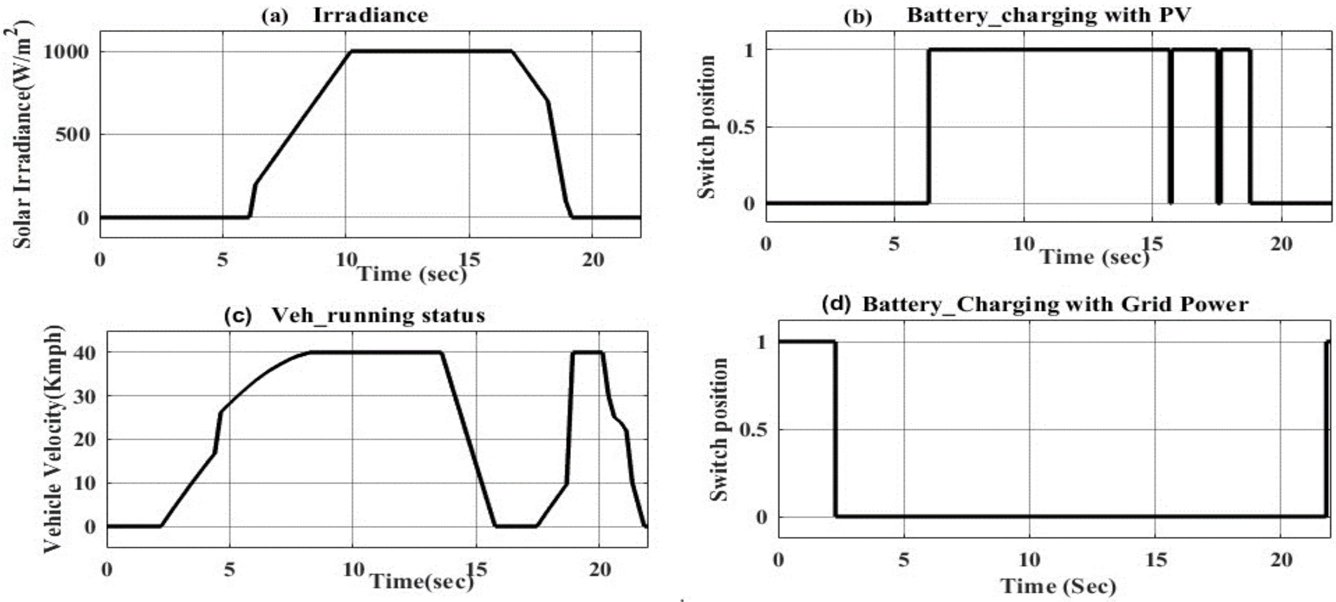

Figure 7: Simulation results of Switch Schedule algorithm

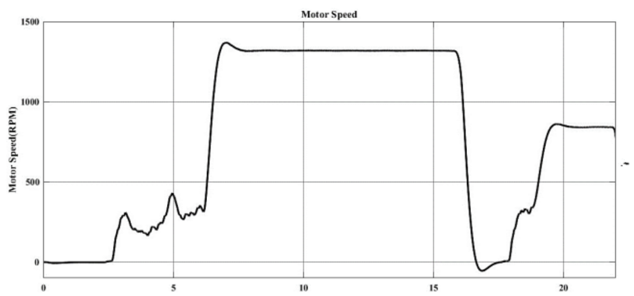

Figure 8: Motor Speed while vehicle is running

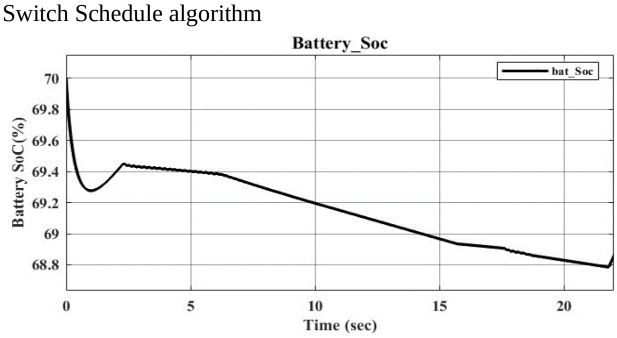

Figure 9: Battery SOC

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4.2 Battery and its results

As per literature, the simulated battery is a lithium-ion type with a 48V, 30Ah rating, displaying voltage and State of Charge (SOC) in *figure 9*. During vehicle travel, the battery exhibits slow discharge due to simultaneous Solar PV charging. Upon rest, it resumes charging via Grid supply. *Table 3* outlines the response of a 48V, 30Ah battery-powered EV with and without integrated 315W RTSPV, running at an average speed of 21.7 kmph. The comparative analysis of the vehicle's performance parameters with and without the Rooftop Solar Photovoltaic (RTSPV) system reveals noteworthy insights. The analysis includes vehicle range and charging costs, assuming ₹8 as the per unit electricity charges.

Table 3: Vehicle output parameters with and without integration of rooftop solar panel

Parameters	Vehicle without RTSPV	Vehicle with RTSPV
Range of the Vehicle in km	56.6	67.1
Energy consumed in kWh	1.44	1.707
Time taken to travel with one full charge in hours	2.5	2.99
Per unit Electricity charges	8	8
Cost consumption for one km (Rupees)	0.20	0.17

5. DISCUSSION

An 800 kg Golf cart, fitted with a 315W rooftop solar panel, exhibits a 90% system efficiency, powering a 1kW BLDC motor. Variations in solar irradiance affect the 48V, 30Ah Lithium-ion batteries charging, impacting the vehicle's energy consumption. Results show enhanced range and distance coverage with solar integration, reducing consumption costs.

The vehicle equipped with the RTSPV system demonstrates a commendable improvement in range, showcasing an 18.65% increase from 56.6 km to 67.1 km. While the energy consumption rises marginally by 18.75%, from 1.44 kWh to 1.707 kWh, the extended range suggests enhanced efficiency. Despite the increase in energy consumption, the cost consumption per kilometre experiences a notable reduction of 15.5%, dropping from 0.2035 Rupees/km to 0.1717 Rupees/km. This reduction signifies potential cost savings over the vehicle's lifespan. The time taken to travel with a full charge sees a 19.6% increase with the RTSPV system, from 2.5 hours to 2.99 hours.

However, it's crucial to note that both scenarios incur the same electrical charges of 8 Rupees for a unit charge. These findings underscore the trade-offs and advantages associated with the integration of RTSPV systems in electric vehicles. The observed increase in energy consumption and charging time is counterbalanced by the substantial improvement in range and the economic benefit of reduced cost consumption per kilometre, reinforcing the potential viability and sustainability of solar-powered electric vehicles.

6. CONCLUSIONS

The integration of RTSPV with the EV notably enhances the vehicle's range by 18.65%. This integration diminishes reliance on grid power for EV operation within specific time and distance limits. However, the additional cost incurred for installing solar panels on the EV rooftop stands as a significant limitation to widespread adoption. Despite a slight increase in energy consumption and charging time, the vehicle exhibits an impressive 18.65% boost in range, reaching 67.1 km. Moreover, the 15.5% reduction in cost consumption per kilometre, from 0.20 Rupees/km to 0.17 Rupees/km, highlights potential cost savings. These findings emphasize the favourable trade-offs and economic advantages associated with RTSPV integration, supporting the viability and sustainability of solar-powered electric vehicles.

Future implications involve integrating diverse renewable sources and devising efficient battery charging schedules to prevent degradation and optimize energy utilization, essential for sustainable development.

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Conflicts of Interest: Declare conflicts of interest or state “The authors declare no conflict of interest.”
Human and Animal Related Study: If the work does not involve the use of human/animal subjects.

Appendix:
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Figure A4: Figure 4: Flowchart to show the conditions of charging EVB.
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