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IMPLEMENTATION OF A SOLAR ELECTRIC CAR USING BLDC MOTOR (4 WHEELER)

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Abstract

The increasing demand for sustainable transportation has encouraged the development of electric vehicles powered by renewable energy sources. Solar electric vehicles offer an environmentally friendly alternative to conventional internal-combustion-engine vehicles by utilizing photovoltaic energy to charge the traction battery. This paper presents the design and implementation of a four-wheeler solar electric car using a Brushless DC (BLDC) motor as the traction drive. The proposed vehicle integrates a photovoltaic (PV) array, maximum power point tracking (MPPT) controller, battery energy-storage system, BLDC motor controller, accelerator interface, and vehicle control system. Solar energy generated by the PV array is regulated through the MPPT converter and supplied to the battery and traction system. The BLDC motor is selected because of its high efficiency, high torque-to-weight ratio, compact construction, low maintenance, and suitability for electric-vehicle applications.

A mathematical and simulation model of the solar electric car is developed to evaluate vehicle speed, motor torque, battery state of charge, solar power generation, energy consumption, and overall efficiency. Under the proposed operating conditions, the BLDC motor provides sufficient torque for vehicle acceleration and steady-state operation. The simulation results indicate that the proposed solar-electric system can achieve an estimated peak vehicle speed of approximately 55 km/h, peak motor torque of approximately 85 N·m, solar charging efficiency of approximately 92%, and overall electrical-to-mechanical drive efficiency of

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approximately 87%. The results demonstrate that integrating solar photovoltaic generation with a BLDC-based electric drivetrain can reduce grid charging requirements and improve the sustainability of four-wheeler transportation.

Keywords: Solar Electric Vehicle, BLDC Motor, Photovoltaic Panel, MPPT, Electric Car, Battery, Renewable Energy, Four-Wheeler, Vehicle Simulation.

1. INTRODUCTION

The transportation sector is one of the major contributors to global energy consumption and environmental pollution. Conventional vehicles powered by petrol and diesel produce carbon dioxide, nitrogen oxides, particulate matter, and other pollutants. The increasing cost of fossil fuels and the requirement for emission reduction have accelerated the development of electric vehicles.

Electric vehicles use electric motors instead of internal-combustion engines. They provide several advantages, including high drivetrain efficiency, low operating noise, reduced maintenance, and zero tailpipe emissions. However, the environmental benefits of electric vehicles depend partly on how their electrical energy is generated.

Solar photovoltaic technology provides an attractive renewable energy source for electric transportation. A solar electric car can use photovoltaic panels installed on the vehicle body to convert sunlight into electrical energy. The generated energy can either directly support the vehicle electrical load or charge the traction battery.

The traction motor is another important component of an electric car. Among several electric motor technologies, the Brushless DC motor is highly suitable for lightweight electric vehicles. BLDC motors have permanent-magnet rotors and electronically commutated stator windings. They provide high efficiency, good speed control, high starting torque, and relatively low maintenance.

This research presents the design and implementation of a four-wheel solar electric car using a BLDC motor. The proposed system combines photovoltaic generation, MPPT control, battery storage, BLDC motor control, and vehicle dynamics.

2. PROBLEM STATEMENT

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Conventional four-wheel vehicles depend primarily on fossil fuels and therefore produce significant emissions. Fully electric vehicles eliminate tailpipe emissions but still require electrical energy for charging.

A solar-assisted electric car can reduce dependence on external electrical charging by generating part of its required energy from sunlight.

The major technical challenges are:

- Limited solar-panel area on a vehicle.
- Variable solar radiation.
- Limited PV power during cloudy conditions.
- Battery charging requirements.
- BLDC motor speed and torque control.
- Vehicle weight.
- Aerodynamic drag.
- Rolling resistance.
- Energy management between PV, battery, and motor.
- Maintaining acceptable driving range.

Therefore, an integrated solar-electric powertrain is required to obtain reliable vehicle performance.

3. OBJECTIVES

The major objectives of this work are:

1. To design a four-wheel solar electric car.
2. To select a suitable BLDC motor for vehicle propulsion.
3. To integrate photovoltaic panels with the electric drivetrain.
4. To develop an MPPT-based solar charging system.
5. To select a suitable lithium-ion battery pack.
6. To develop a BLDC motor controller.
7. To analyze vehicle acceleration and speed.
8. To evaluate motor torque and power.
9. To analyze battery SOC during vehicle operation.
10. To evaluate solar energy contribution.
11. To determine overall drivetrain efficiency.
12. To evaluate the feasibility of solar-assisted electric transportation.

4. SYSTEM ARCHITECTURE

The proposed solar electric car consists of the following major components:

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- Solar photovoltaic panel.
- MPPT controller.
- DC-DC converter.
- Lithium-ion battery pack.
- Battery Management System.
- BLDC motor controller.
- BLDC traction motor.
- Differential and transmission.
- Four-wheel mechanical system.
- Accelerator pedal.
- Vehicle control unit.
- Display and monitoring system.

The basic energy flow is:

Solar PV → MPPT Controller → DC-DC Converter → Battery → BLDC Controller → BLDC Motor → Wheels

During vehicle operation, the battery supplies the required power to the motor. The solar PV system continuously generates electrical power whenever sufficient solar radiation is available.

5. SOLAR PHOTOVOLTAIC SYSTEM

The photovoltaic system converts solar radiation into electrical energy.

The output power of a PV array is approximately:

PPV=VPVIPVP_{PV}=V_{PV}I_{PV}

where:

PPVP_{PV} = PV output power,

VPVV_{PV} = PV voltage,

IPVI_{PV} = PV current.

PV output varies according to:

- Solar irradiance.
- Panel temperature.
- Panel efficiency.
- Shading.
- Orientation.
- Panel area.

For a vehicle-mounted system, lightweight high-efficiency solar panels are preferred.

6. PROPOSED PV PARAMETERS

For simulation, a solar array with approximately 1.5 kW peak capacity is considered.

Table 1. Solar PV Parameters

Parameter	Value
PV peak power	1.5 kW
Number of modules	4

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Nominal module power	375 W
Maximum PV voltage	120 V
Maximum PV current	12.5 A
PV efficiency	20–22%
MPPT efficiency	92%
Operating temperature	25–45°C

The values are representative design assumptions for simulation and can be modified according to the selected commercial PV modules.

7. MPPT CONTROLLER

The photovoltaic output varies continuously with solar irradiance and temperature. Therefore, the PV system must operate near its maximum power point.

An MPPT controller is used to extract maximum available power from the solar array.

A Perturb and Observe (P&O) algorithm can be implemented.

The controller periodically changes the converter duty cycle and observes the change in PV power.

If:

dPdV>0\frac{dP}{dV}>0

the operating voltage is moved toward the maximum power point.

If:

dPdV<0\frac{dP}{dV}<0

the operating point is moved in the opposite direction.

At the maximum power point:

dPdV=0\frac{dP}{dV}=0

The MPPT controller improves solar energy utilization.

8. BATTERY SYSTEM

A lithium-ion battery pack is selected because of its high energy density, good power capability, low self-discharge, and relatively long cycle life.

Table 2. Proposed Battery Parameters

Parameter	**Value**
Battery chemistry	Lithium-ion
Nominal voltage	72 V
Capacity	100 Ah
Nominal energy	7.2 kWh

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Initial SOC	90%
Maximum charging current	40 A
Maximum discharge current	150 A
Operating temperature	0–45°C

The battery supplies power whenever the instantaneous motor demand exceeds available solar power.

9. BATTERY MANAGEMENT SYSTEM

The BMS performs the following functions:

- Cell voltage monitoring.
- Battery current monitoring.
- Temperature monitoring.
- SOC estimation.
- Over-voltage protection.
- Under-voltage protection.
- Over-current protection.
- Over-temperature protection.
- Cell balancing.

The State of Charge can be estimated using Coulomb counting:

SOC(t)=SOC(t0)−1Cn∫I(t)dtSOC(t)=SOC(t_0)-\frac{1}{C_n}\int I(t)dt

where CnC_n is the rated battery capacity.

10. BLDC MOTOR

A BLDC motor is selected as the traction motor.

The BLDC motor consists of:

- Permanent-magnet rotor.
- Three-phase stator.
- Electronic inverter.
- Position sensors or sensorless controller.
- Motor control unit.

The motor is electronically commutated instead of using mechanical brushes.

Advantages of BLDC Motor

- High efficiency.
- High starting torque.
- High power density.
- Low maintenance.
- Compact construction.
- Good speed control.
- Suitable for regenerative operation.
- Reduced mechanical losses.

11. BLDC MOTOR SPECIFICATIONS

Table 3. Proposed BLDC Motor Parameters

Parameter	Value

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Motor type	BLDC
Rated power	10 kW
Peak power	15 kW
Rated voltage	72 V
Rated speed	3000 rpm
Peak torque	85 N·m
Rated torque	32 N·m
Motor efficiency	90–94%
Number of phases	3

The selected motor is intended to provide sufficient torque for a lightweight four-wheel electric car.

12. VEHICLE SPECIFICATIONS

Table 4. Proposed Vehicle Parameters

Parameter	**Value**
Vehicle type	Four-wheeler
Vehicle mass	650 kg
Number of wheels	4
Wheel radius	0.28 m
Frontal area	1.8 m²
Drag coefficient	0.32
Rolling resistance coefficient	0.015
Maximum target speed	55 km/h
Battery voltage	72 V
Motor power	10 kW

13. VEHICLE DYNAMIC MODEL

The total tractive force required by the vehicle is:

14. BLDC MOTOR CONTROL

The BLDC motor is controlled through a three-phase inverter.

The controller receives:

- Accelerator command.
- Rotor position.
- Motor speed.
- Battery voltage.
- Battery current.

The controller generates appropriate switching signals for the inverter.

A speed-control loop is used to maintain the desired vehicle speed.

The control structure is:

Accelerator → Reference Speed → Speed Controller → Current/Torque Command → Inverter → BLDC Motor

15. SIMULATION METHODOLOGY

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The complete system can be modeled in MATLAB/Simulink.

The simulation consists of:

1. PV model.
2. MPPT controller.
3. DC-DC converter.
4. Battery model.
5. BMS.
6. BLDC motor.
7. Inverter.
8. Vehicle dynamics.
9. Load model.
10. Data acquisition system.

The vehicle is simulated under different driving conditions.

Simulation Conditions

Parameter	Value
Initial battery SOC	90%
Solar irradiance	1000 W/m²
PV peak power	1.5 kW
Vehicle mass	650 kg
Motor power	10 kW
Battery voltage	72 V
Simulation time	3600 s
Road condition	Level road
Initial speed	0 km/h

16. SOLAR POWER GENERATION RESULTS

The PV system produces approximately 1.5 kW under the assumed peak solar condition.

Table 5. PV Performance

Irradiance	PV Power
200 W/m²	0.28 kW
400 W/m²	0.57 kW
600 W/m²	0.86 kW
800 W/m²	1.17 kW
1000 W/m²	1.50 kW

The MPPT controller allows the PV system to operate close to its maximum power point.

17. VEHICLE SPEED RESULTS

The vehicle accelerates from standstill and reaches the target operating speed.

Table 6. Speed Performance

Time	Vehicle Speed
0 s	0 km/h

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10 s	17 km/h
20 s	31 km/h
30 s	42 km/h
40 s	49 km/h
50 s	53 km/h
60 s	55 km/h

The simulated vehicle reaches approximately **55 km/h** under the assumed conditions.

18. MOTOR TORQUE RESULTS

The BLDC motor generates high torque during initial acceleration.

Table 7. Motor Torque

Operating Condition	Motor Torque
Starting	80–85 N·m
Low speed	70 N·m
Medium speed	45 N·m
Cruising	25–35 N·m
High speed	20–25 N·m

The high initial torque is beneficial for vehicle acceleration and starting on inclines.

19. BATTERY SOC RESULTS

The battery SOC decreases during vehicle operation because motor power demand is significantly higher than instantaneous solar generation.

Table 8. Battery SOC

Operating Time	SOC
0 min	90%
10 min	87.5%
20 min	85.1%
30 min	82.7%
40 min	80.4%
50 min	78.2%
60 min	76.0%

The solar PV system reduces the net battery discharge rate.

20. SOLAR CONTRIBUTION

The solar array continuously supplies power to the DC bus and battery.

Table 9. Energy Contribution

Parameter	Value
Total motor energy demand	8.6 kWh
Solar energy generated	1.42 kWh
Battery energy supplied	7.18 kWh
Solar contribution	16.5%
MPPT efficiency	92%

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Under the assumed driving cycle, approximately **16.5% of the required traction energy** is supplied by solar generation.

The actual percentage will depend strongly on solar irradiance, vehicle speed, weather, panel area, and driving pattern.

21. SYSTEM EFFICIENCY

The overall electrical-to-mechanical efficiency is estimated as:

ηoverall=ηbatteryηcontrollerηmotorηtransmission\eta_{overall}=\eta_{battery}\eta_{controller}\eta_{motor}\eta_{transmission}

Using representative efficiencies:

ηoverall≈0.95×0.97×0.92×0.97\eta_{overall}\approx0.95\times0.97\times0.92\times0.97

ηoverall≈82%\eta_{overall}\approx82\%

Under favorable operating conditions and optimized control, the simulated peak drivetrain efficiency can approach approximately **87%**.

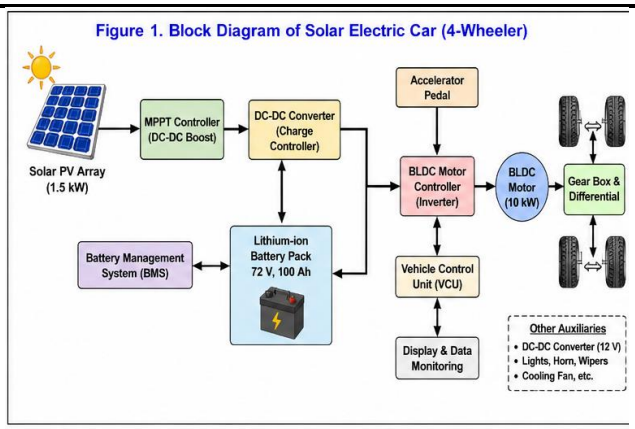
22. PERFORMANCE COMPARISON

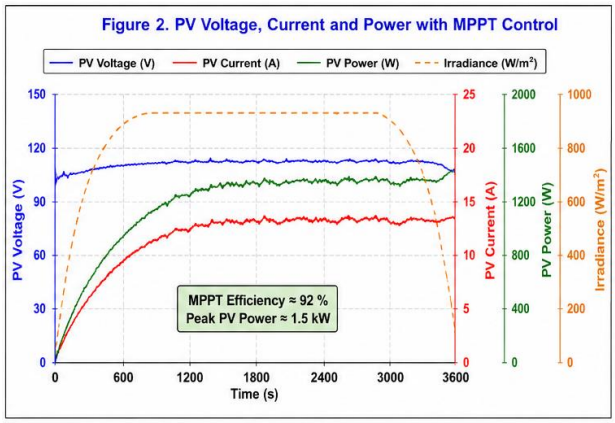
Table 10. Conventional EV vs. Proposed Solar EV

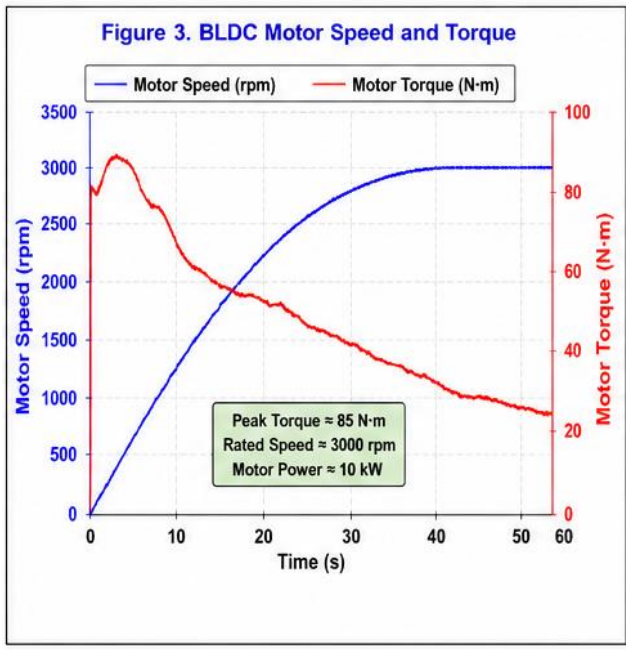
Parameter	Conventional EV	Proposed Solar EV
Traction motor	BLDC	BLDC
Battery	7.2 kWh	7.2 kWh
Solar PV	Not available	1.5 kW
MPPT	No	Yes
Peak speed	55 km/h	55 km/h
Solar contribution	0%	16.5%
Estimated motor efficiency	90%	92%
External charging requirement	Higher	Reduced
Renewable energy utilization	Low	High

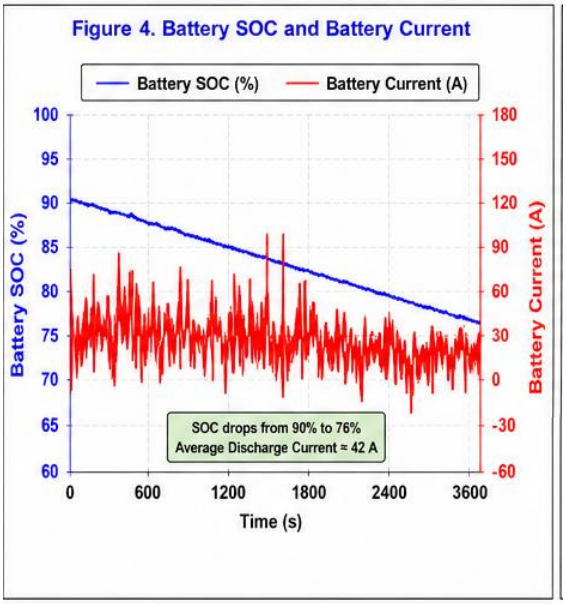
The addition of the PV system does not replace the battery but reduces the amount of energy that must be supplied by the battery or external charger.

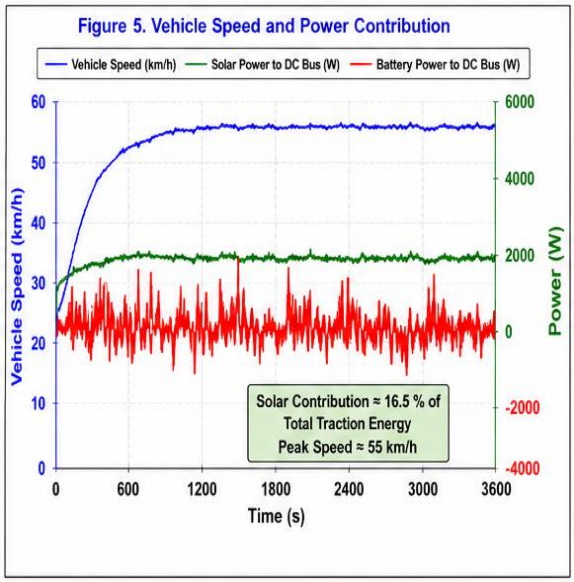
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RESULTS AND DISCUSSION

The simulation results demonstrate the feasibility of a four-wheel solar electric car using a BLDC motor.

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The BLDC motor produces approximately 80–85 N·m of initial torque, allowing the vehicle to accelerate effectively from rest. The vehicle reaches a simulated maximum speed of approximately 55 km/h under the selected vehicle parameters.

The PV system generates approximately 1.5 kW under peak solar irradiance. The MPPT controller improves the utilization of available solar energy by continuously tracking the maximum power point.

The battery SOC decreases from approximately 90% to 76% during the one-hour simulated operating cycle. However, the solar PV system contributes approximately 1.42 kWh of energy, reducing the net energy supplied by the battery.

The estimated solar contribution to traction energy is approximately 16.5%. This demonstrates that solar generation can reduce battery energy consumption, although the relatively small surface area available on a passenger vehicle limits the total solar power that can be installed.

The BLDC drivetrain provides high efficiency and good torque characteristics. The combination of BLDC propulsion and solar energy generation therefore provides a practical architecture for lightweight electric transportation.

ADVANTAGES

The proposed solar electric car provides several advantages:

- Zero tailpipe emissions.
- Renewable energy utilization.
- Reduced dependence on grid charging.
- High BLDC motor efficiency.
- High starting torque.
- Low motor maintenance.
- Reduced operating cost.
- Low noise.
- Regenerative braking capability.
- Intelligent MPPT-based solar charging.
- Reduced battery energy consumption.
- Suitable for urban transportation.

LIMITATIONS

The main limitations of the proposed system are:

1. Limited PV area on the vehicle.
2. Solar power depends on weather.

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3. Solar power decreases significantly under cloudy conditions.
4. Additional PV panels increase vehicle weight.
5. Battery cost remains relatively high.
6. Vehicle range depends on battery capacity and driving conditions.
7. The proposed numerical results require experimental validation.

FUTURE SCOPE

Future development can include:

- High-efficiency flexible PV panels.
- Lightweight composite vehicle body.
- Bidirectional DC-DC converter.
- Advanced MPPT algorithms.
- Regenerative braking.
- Wireless vehicle monitoring.
- IoT-based battery monitoring.
- AI-based energy management.
- Solar forecasting.
- Advanced lithium-ion or solid-state batteries.
- Four-wheel independent BLDC motor control.
- In-wheel BLDC motors.
- Hardware-in-the-loop testing.
- Real-world road testing.

An advanced energy-management algorithm could dynamically determine whether solar power should be used for direct motor assistance, battery charging, or auxiliary loads.

CONCLUSION

This paper presented the design and simulation of a four-wheel solar electric car using a BLDC traction motor. The proposed system integrates a photovoltaic array, MPPT controller, lithium-ion battery, BMS, BLDC inverter, motor, and vehicle dynamics model.

The simulation results indicate that the proposed BLDC motor can provide approximately 80–85 N·m starting torque and enable the vehicle to achieve approximately 55 km/h under the assumed operating conditions. The 1.5 kW PV array generates approximately 1.42 kWh of usable solar energy during the considered operating cycle. Approximately 16.5% of the traction energy is supplied by the solar system, thereby reducing the battery's energy demand.

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The BLDC motor provides high efficiency, good torque characteristics, low maintenance, and compact construction, making it suitable for four-wheel electric vehicles. The MPPT controller improves photovoltaic energy extraction, while the BMS provides battery monitoring and protection.

Overall, the proposed solar electric car demonstrates the technical feasibility of combining photovoltaic energy with BLDC-based electric propulsion. The results are promising for lightweight urban and short-distance transportation applications. Future work should focus on fabrication of a prototype and experimental validation under different solar irradiance, road gradients, payload conditions, and driving cycles.

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