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Design and Performance Analysis of Solar Hybrid E-Rickshaw

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Abstract
There is increasing demand for sustainable and eco friendly transportation which has led to the increased usage of electric vehicles and the use of renewable energy technologies. Solar hybrid e-rickshaws are a combination of solar photovoltaic (PV) systems and battery-powered electric vehicles, designed to increase efficiency and decrease reliance on grid electricity. This study introduces design and performance analysis of solar hybrid e-rickshaw combined with solar panels, rechargeable batteries, BLDC motors and MPPT charge controllers. The energy consumption, solar energy production, range of the vehicles, charging time, and efficiency of the system are analyzed. The results indicate that the solar assistance proportion of total energy demand is around 25-30%, range of driving extended from about 70 km to 90 km, and driving time reduced. The proposed system is affordable, environment friendly and sustainable transport solution for urban and rural.

Keywords: Solar Energy, E-Rickshaw, Hybrid Electric Vehicle, Solar PV System, Renewable Energy, BLDC Motor, Sustainable Transportation.

1. Introduction

Transport is an important factor for economic development and everyday life. The traditional modes of transport are largely dependent on fossil fuels like petrol and diesel. These fuels have been continuously used, leading to environmental pollution, GHGs and depletion of natural resources. Emissions of CO_2, nitrogen oxides and particulate matter from traditional cars are major sources of global warming and health effects.

For the past few years, EVs have become a cleaner option than standard automobiles. Economical, easy to use and convenient for short distances, e-rickshaws have been a huge hit in India and other developing countries. E-rickshaws are popular as a mode of transport in urban and semi-urban areas, particularly for last-mile connectivity.

Although conventional e-rickshaws have their benefits, they have some drawbacks. They depend solely on grid electricity for charging, resulting in lengthy charging times and high operating costs. Further, battery powered e-rickshaws have a limited driving range, which is approximately 70-100 km per charge. Repeatedly recharging and discharging also decreases battery life.

Addressing these issues is a reason why the integration of renewable energy is an important area of research. Solar energy is amongst the most abundant and environmentally friendly renewable energy sources on Earth. Solar PV can be integrated into e-rickshaws to help charge the battery and to help run the vehicles. This minimises need for outside charging stations and makes the whole system more efficient.
The aim of this research is to design and analyze a solar hybrid e-rickshaw system in which the solar energy is utilized with the battery power as an alternative for sustainable transportation. The system proposed in this work will help to prolong the range of the vehicle, speed up charging time, decrease the electricity consumption, and encourage green mobility.

2. Literature Review

There are a number of researchers working on solar-assisted electric vehicles and hybrid transportation systems. Research has shown that combining solar PV systems with EVs can enhance performance and decrease the operating expenses.
Solar hybrid e-rickshaws (EVs) have been studied, and it has been found that enough auxiliary energy can be generated during the day-time hours by using rooftop solar panels. Numerous studies have documented enhancements in driving range and battery life with solar assist. The system has become even more efficient with the use of advanced technologies such as MPPT charge controllers and regenerative braking systems.
The hybrid energy systems and smart energy management were highlighted in recent developments from 2024 to 2026. Researchers recommended the application of lithium-ion batteries, a system based on artificial intelligence for energy management, and regenerative braking for improving energy efficiency and stress in batteries.
Another significant aspect affecting the performance of the e-rickshaw is the battery technology. A cheaper option but less efficient and less long-lived is to use lead acid batteries. Lithium-ion batteries are more efficient, durable, lightweight, and have improved charge efficiency. Due to their high-efficiency, low maintenance, and torque properties, BLDC motors are popularly used in e-rickshaws. With changing sunlight conditions, MPPT charge controllers can help to maximize the power available from the solar panel.

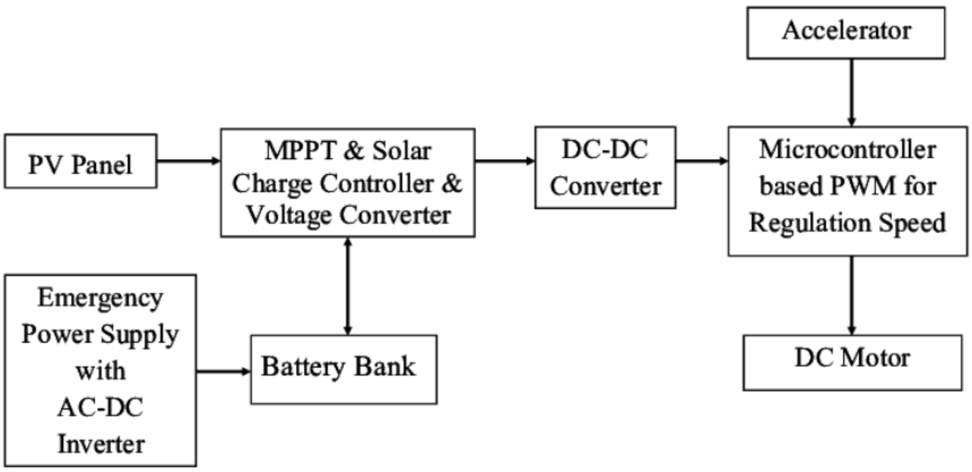

Fig.1 Block diagram of proposed solar powered microcontroller based auto-rickshaw

Research on solar hybrid e-rickshaw has found solar hybrid e-rickshaws are able to:

- Increase efficiency by 15–30%
- Increase range of 10-25%
- Reduce charging frequency
- Lower electricity consumption
- Reduce environmental pollution

There are, however, certain limitations like a small roof surface for installation of solar panels, weather dependence and high installation cost.

3. System Design and Components

The proposed solar hybrid e-rickshaw system consists of the following major components:

1. Solar PV Panel
2. Battery System
3. BLDC Motor
4. MPPT Charge Controller
5. Motor Controller
6. Chassis and Mechanical Structure

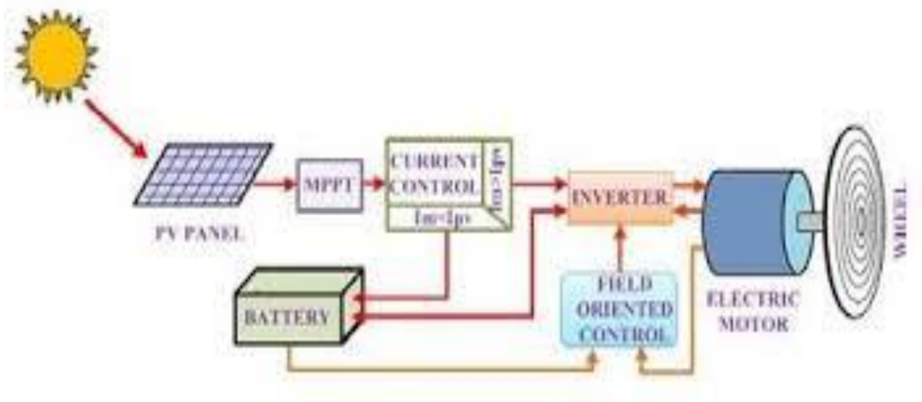

Fig.2 Block diagram of a solar electric vehicle.

3.1 Solar PV Panel

Solar photovoltaic panels convert sunlight into electrical energy. These panels are mounted on the roof of the e-rickshaw to capture maximum sunlight during daytime.

Typical specifications:

- Power: 300–500 W
- Voltage: 24V/48V
- Efficiency: 15–20%

The solar panels reduce battery load and provide renewable energy support.

3.2 Battery System

The battery stores electrical energy generated from solar panels and supplies power to the motor during operation.

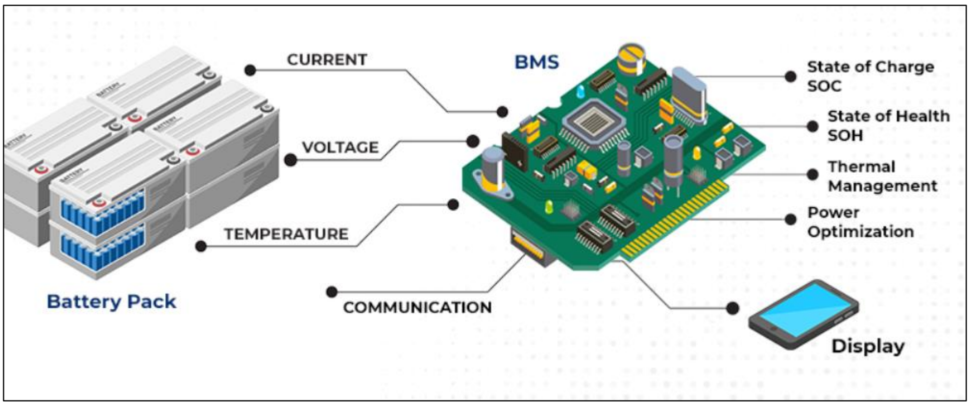

Fig.3 Battery system for electric vehicles

Two major battery types are:

- Lead-acid battery
- Lithium-ion battery

Typical battery specifications:

- Voltage: 48V
- Capacity: 80–120 Ah

Lithium-ion batteries provide better efficiency and longer service life compared to lead-acid batteries.

3.3 BLDC Motor

A Brushless DC (BLDC) motor is used for propulsion. BLDC motors offer:

- High efficiency
- Better speed control
- Low maintenance
- High torque capability

Fig.4 BLDC Motor

Motor specifications:

- Power: 800–1500 W
- Efficiency: 85–90%

3.4 MPPT Charge Controller

Maximum Power Point Tracking (MPPT) charge controller is a device that extracts the maximum power from solar panels and controls charging voltage. It also helps to prevent overcharging of the battery and to enhance the efficiency of the charging process.

Fig.5 MPPT charge controller

3.5 Working Principle

The working of solar hybrid e-rickshaws is as follows:

1. The light of the sun is absorbed by solar panels.
2. Energy of the sun is transformed into electrical energy.
3. The MPPT controller controls the voltage and current.
4. Electrical energy is stored in the battery.
5. The power to the BLDC motor is controlled by the motor controller.
6. The wheels are connected to the motor and the motor moves the vehicle.

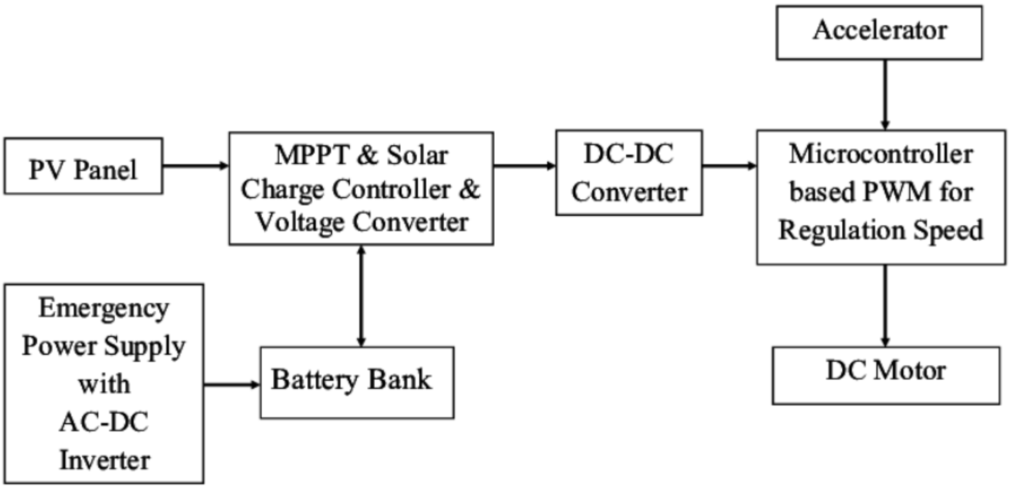

Fig.6 Solar power microcontroller based on auto rickshaw

There are three modes of operation for the system:

- Solar mode
- Battery mode
- Hybrid mode

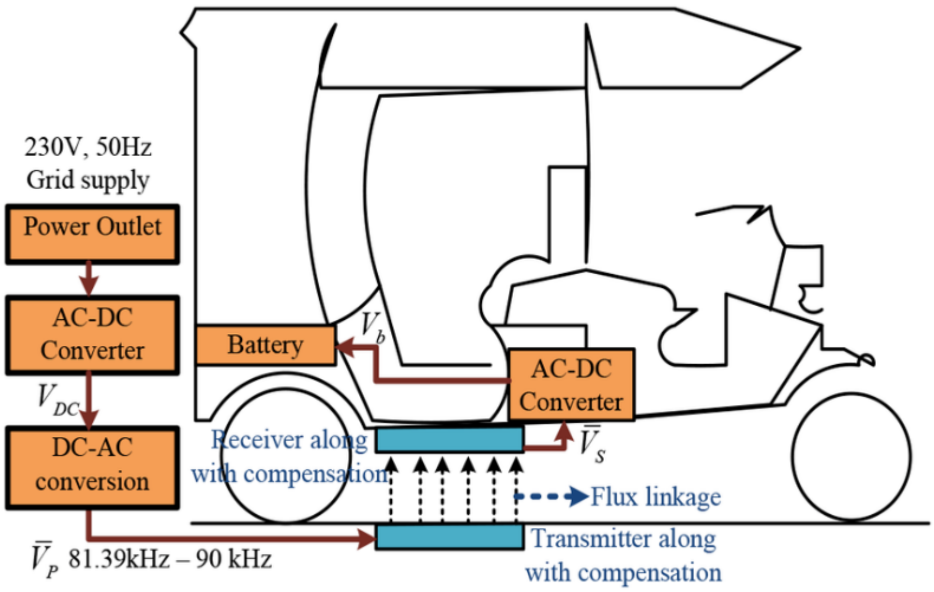

Fig.7 Pictorial view of WPT charging of e-rickshaw

4. Mathematical Analysis and Performance Evaluation

4.1 Traction Power Requirement

The traction power needed for the vehicle is determined as follows:

P=V×I

Where:

- (V = 48V)
- (I = 20A)

Therefore,

(P = 48 ×20 = 960W)

Around 1kW traction power is needed for vehicles to operate.

4.2 Daily Energy Consumption The daily energy consumption is equal to:

E = P ×t

Where:

- (P = 1000W)
- (t = 5 hours)

Thus,

(E = 1000 ×5 = 5000Wh = 5kWh/day)

An electric car uses almost 5 kW a day.

4.3 Battery Energy Storage

The capacity of a battery is determined by:

The battery's EMF, E {battery} is equal to V multiplied by Ah.

For:

- (V = 48V)
- (Ah = 100Ah)

($E_{battery}$= 48 ×100 = 4800Wh
= 4.8kWh)

The battery efficiency is assumed to be 90%:

Usable energy:

$E_{usable} = 4.8 \times 0.9$

$= 4.32kWh$

4.4 Solar Energy Generation

The amount of solar energy that can be produced each day is calculated with the help of the following:

$E = A \times r \times H \times PR$

Where:

- (Area, $A = 2m^2$)
- (Efficiency of solar panel, $r = 0.18 = 18\%$)
- (Annual average solar radiation, $H = 5kWh/m^2/day$)
- (Performance ratio, $PR = 0.75$)

Therefore,

$E = A \times r \times H \times PR$

$E = 2 \times 0.18 \times 5 \times 0.75 = 1.35kWh/day$)

The solar panel can produce around 1.35 kWh of energy per day.

4.5 Solar Contribution Ratio

The percentage of contribution from the sun is:

$=1.35 \div 5 \times 100$

$= \frac{1.35}{5} \times 100$

$=27\%$

Thus solar energy accounts for almost 25–30% of the total energy consumption.

4.6 Vehicle Range Estimation Assuming:

The range is 16 km/1kWh energy.

Without solar support:

$Range = 4.32 \times 16 = 69km$

With solar support:

$Range = 5.67 \times 16 = 90.7km$

So, the driving range is enhanced from 70 km to 90 km with solar assistance.

4.7 Charging Time Reduction

Without solar support:

Charging time:

$=4.8 \div 1$

$= \frac{4.8}{1}$

$= 4.8$ hours

With solar assistance:

Required charging energy:

$=4.8 - 1.35$

$= 3.45kWh$

Charging time reduces to almost 3.5 hours.

4.8 System Efficiency

The overall efficiency is the ratio of the useful output to the total input given by:

$$\eta = \eta_p \times \eta_b \times \eta_m$$

Where:

- Solar panel efficiency, η_p= 18%
- Battery efficiency, η_b = 90%
- Motor efficiency, η_m = 88%

Thus,

$$[\eta = 0.18 \times 0.90 \times 0.88 = 0.142]$$

The overall efficiency is around 14.2%.

5. Advantages and Limitations

Advantages

- Eco-friendly transportation
- Reduced electricity consumption
- Increased driving range
- Lower operational cost–lower carbon footprint
- Improved battery life
- Renewable energy utilization

Limitations

The initial installation cost is too high.

The area of the roof space is limited for solar panels.

- Weather dependency
- Reduce solar energy generation when clouds are present.

6. Conclusion

The solar hybrid e-rickshaw is a new and eco-friendly mode of transportation in today's society. The combination of solar PV technology for the e-rickshaws and battery technology helps decrease reliance on grid power, and enhances vehicle performance. The research shows that solar aid can achieve considerable enhancements in vehicle range, shorten charging duration and lower operational costs. From the performance analysis, it is revealed that the proposed system can give a contribution of around 27% towards solar energy and increase the range from 70 km to about 90 km. It also helps to minimise battery stress and optimize energy usage.

This proposed model is especially applicable in a nation like India, which has availability of solar radiation all year round. Solar hybrid e-rickshaws have great potential to mitigate environmental pollution and to encourage sustainable urban and rural transport.

The future could see more enhancements such as AI-driven energy management systems, more efficient solar panels, regenerative braking systems, and advanced lithium-ion batteries for further performance and reliability.

Overall, solar hybrid e-rickshaws provide a practical, economical, and eco-friendly solution for green transportation and renewable energy utilization.

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