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Solar Powered E-Rickshaw with Minimum Losses

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Abstract - The current solar-assisted E-rickshaws typically utilize a single solar panel for battery charging. This research paper suggests an enhancement to the existing solutions by incorporating two solar panels connected in parallel strings, with each string containing a series capacitor. One solar panel is mounted on top of the E-rickshaw, while the other is positioned on the backside. This arrangement enables the collection of a greater amount of solar energy, ultimately leading to a significant increase in the E-rickshaw's daily range compared to the single-panel approach. Rather than employing a conventional central converter-based solar battery charger, this paper employs a partial power processing scheme based on a buck converter. This scheme ensures precise Maximum Power Point Tracking (MPPT) for both solar panels, enabling the efficient harvesting of the maximum available solar energy. By utilizing a dedicated dc-dc converter-based parallel power processing scheme, the ratings of components (especially current) are reduced, lessening the power processing burden on the converters. Moreover, this scheme can also be applied to supply solar power from two different PV panels mounted at different angles on a rooftop to a DC-micro grid. The functionality and control procedures of this scheme have been verified through simulation-based work conducted on the PSIM platform.

Key Words: E-vehicle, Renewable energy, BLDC motor, Boost Converter

1. INTRODUCTION

The growing awareness of global warming and climate change, coupled with the diminishing availability of non-renewable fossil fuels, has compelled humanity to focus its research and development efforts on renewable energy harvesting to a greater extent. Thanks to ongoing research in solar photovoltaic (PV) and power electronic converters, the efficiency of solar power harvesting systems has significantly improved. Furthermore, advancements in technology and supportive government policies have contributed to a substantial decrease in the cost of solar power. As a result, solar power is being applied in innovative ways, such as in the realm of solar-assisted electric vehicles, opening up new possibilities for its utilization [1][2][3].

Considering the issues of pollution and increased traffic, the most effective approach to revitalizing the rickshaw is to develop a more efficient design powered by a clean energy source. An electric drive train presents a viable solution as it produces no pollutants at the tailpipe. Compared to the current alternative-fuel-powered rickshaws, using a renewable energy source would be an even better solution. One way to achieve this is by implementing an energy system that can harness multiple renewable energy sources, such as an electric system. In addition to energy storage systems like batteries, the electricity can be sourced from renewable options like solar, wind, hydro, or other available sources. It is possible to integrate certain renewable sources, like solar cells, directly onto the vehicle itself, or alternatively, the batteries can be charged separately by renewable sources through off-site recharging stations. Alternatively, a combination of both options can be explored for an optimal solution. The approach introduced in this research paper employs two solar panels connected in parallel to collect solar energy for charging the E-rickshaw's battery. By utilizing both the top and backside areas of the vehicle, a greater amount of available solar energy can be harvested. The power ratings of the solar panels intended for the top and backside will differ, and this aspect will be discussed later in the paper. E-rickshaws commonly employ a 48V, 100 Ampere-hour lead-acid battery, roughly equivalent to 4.8-5 kWh [5][6][8]. To maximize the power harvested from the solar panels, a partial power processing scheme based on a buck converter is proposed in this paper, supported by simulation work to demonstrate its effectiveness. The use of parallel-connected solar panels enables precise Maximum Power Point Tracking (MPPT) by employing dedicated dc-dc converters for each solar panel. Moreover, this approach is anticipated to be advantageous and more efficient compared to most central converter-based solar chargers described in existing literature [2][3][4].

2. CONVENTIONAL AUTO RICKSHAW SYSTEM

Auto rickshaws, which are well-suited for the Indian environment due to their small and narrow size, enable easy maneuvering on congested roads. These vehicles have a top speed of 55 km/h or 34 mi/h and typically carry one to four passengers along with their belongings. However, despite the favorable design features, auto rickshaws contribute significantly to the pollution problem in major Indian cities. This issue arises from inadequate vehicle maintenance practices and the utilization of inefficient engines with minimal pollution control mechanisms [1][2][3][4][7].

The drive train, as depicted in Figure 1, typically consists of an air-cooled two-stroke or four-stroke gasoline engine coupled with a transmission system (a four-speed gearbox). While newer vehicles may be powered by diesel, LPG, or CNG. The engine models commonly have capacities ranging from 145 to 175 cm^3 and maximum power output ranging from 6.3 to 8.5 hp. An 8- or 9-liter fuel tank usually provides fuel for the vehicle's operation over a period of two to three days. The electrical system incorporates a conventional 12-volt lead-acid battery for lighting, engine control, and ignition purposes. The weight of the vehicle varies from 277 to 470 kg for larger models.

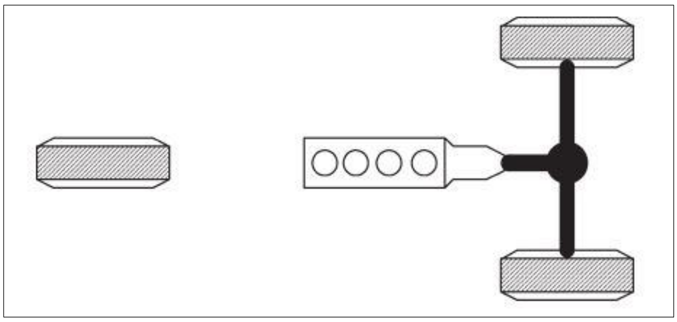

Fig -1: Drive train of a conventional auto rickshaw three-wheeler

In recent decades, India has undertaken various measures to promote alternative energy sources. Within the transportation sector, considerable attention and effort have been directed towards technologies utilizing Compressed Natural Gas (CNG) and Liquefied Petroleum Gas (LPG). The Ministry of Non-Conventional Energy Sources (MNES) attributes this focus partly to India's aim of reducing dependence on energy imports. However, a significant driving force behind this initiative has been the public. Following a public-interest litigation filed in the Supreme Court in 1985, highlighting the government's failure to safeguard Delhi's environment, attention was drawn to the pollution caused by vehicle emissions, estimated to account for 70% of the total pollution. This led to the implementation of various policies and initiatives, culminating in the complete replacement of Delhi's bus fleet with CNG buses in 2001. Presently, several major Indian cities mandate that only zero-emission vehicles operate within their boundaries, with some even banning petrol-powered rickshaws[7][8][9][10].

However, there are three main drawbacks to adopting CNG and LPG technologies for rickshaws. Firstly, in the case of two-stroke configurations, oil is still added to the chamber, contributing to pollution. Secondly, the introduction of these technologies does not alleviate India's dependence on foreign oil, which remains a significant concern for the country. Lastly, CNG and LPG are nonrenewable energy sources, posing a limitation in terms of sustainability[1][2][3].

Auto rickshaws, also known as tuk-tuks or three-wheelers, are a common mode of transportation in many countries, particularly in Asia. These vehicles typically consist of a three-wheeled structure with seating for passengers and an enclosed cabin for the driver. Let's delve into the detailed working of an auto rickshaw:

i. Engine: Auto rickshaws are powered by an internal combustion engine. The type of engine can vary depending on the specific model and region. Commonly used engines include gasoline/petrol, diesel, or compressed natural gas (CNG) engines
ii. Transmission: Auto rickshaws employ a manual transmission system, usually with four or five forward gears and a reverse gear. The driver operates the gear shifter to select the appropriate gear ratio for the vehicle's speed and load conditions
iii. Clutch: Like in most manual transmission vehicles, an auto rickshaw is equipped with a clutch system. The clutch allows the driver to engage or disengage power transmission between the engine and the transmission. By pressing the clutch pedal, the driver can change gears smoothly without damaging the engine or the transmission
iv. Acceleration and Braking: Auto rickshaws use a combination of accelerator pedals and hand-operated brakes for acceleration and deceleration. The driver controls the speed by manipulating the accelerator pedal, while braking is achieved by applying pressure to the handbrake or foot brake, depending on the specific design
v. Suspension: To provide a relatively comfortable ride, auto rickshaws typically feature a suspension system. This system includes shock absorbers and springs, which help absorb bumps and vibrations from the road, minimizing the impact felt by passengers
vi. Steering: Auto rickshaws employ a handlebar-like steering system, similar to that of a motorcycle. The driver uses the handlebar to steer the vehicle, allowing for maneuverability in tight spaces
vii. Electrical System: Auto rickshaws have an electrical system that powers various components, such as headlights, taillights, indicators, horn, and other electrical accessories. It typically includes a battery and an alternator to generate and store electrical energy
viii. Safety Features: Auto rickshaws often come equipped with safety features such as seat belts, rearview mirrors, and sometimes even protective grills or enclosures to ensure passenger safety.

It's important to note that the exact workings of an auto rickshaw can vary depending on the specific model, region, and regulatory requirements. However, the aforementioned components and systems provide a general overview of how auto rickshaws operate.

3. SOLAR POWERED E-RICKSHAW

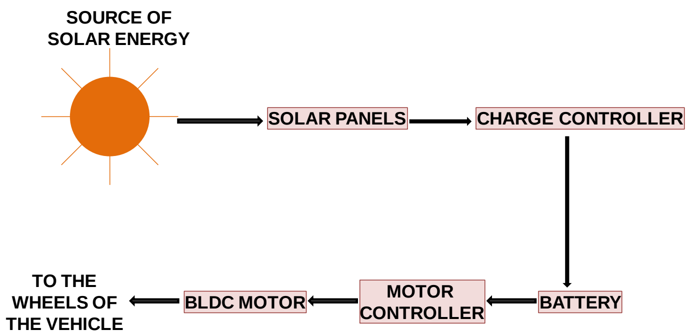

Fig -2: Block diagram of Electric auto rickshaw

Solar-powered e-rickshaws, also known as solar-assisted e-rickshaws, utilize solar energy as a renewable power source to propel the vehicle. Here is a general overview of how solar-powered e-rickshaws work:

i. Solar Panels: Solar panels are mounted on the roof or other suitable locations of the e-rickshaw. These panels consist of photovoltaic cells that convert sunlight into electrical energy. The number and capacity of solar panels can vary depending on the specific design and requirements
ii. Charge Controller: A charge controller is typically installed in the system to regulate and control the flow of electrical energy from the solar panels to the battery. It ensures that

the battery is charged efficiently and prevents overcharging or damage to the battery

iii. Battery: Solar-powered e-rickshaws use a battery to store the electrical energy generated by the solar panels. This battery acts as an energy storage system and provides power to the electric motor that drives the vehicle. Commonly used batteries include lead-acid batteries or lithium-ion batteries, depending on the design and requirements

iv. Electric Motor: Solar-powered e-rickshaws are equipped with an electric motor that is responsible for propelling the vehicle. The motor receives power from the battery and converts electrical energy into mechanical energy, which drives the wheels of the e-rickshaw

v. Control System: A control system manages the operation of the solar-powered e-rickshaw. It includes components such as switches, sensors, and a controller that regulate the flow of power between the solar panels, battery, and motor. The control system ensures the efficient use of solar energy and manages the charging and discharging of the battery

During daylight hours, the solar panels capture sunlight and convert it into electrical energy. This energy is used to charge the battery through the charge controller. The charged battery then supplies power to the electric motor, enabling the e-rickshaw to move. The solar panels continue to generate electricity as long as there is sunlight, allowing the e-rickshaw to use solar energy for propulsion.

It's important to note that the specifics of the working of solar-powered e-rickshaws can vary based on the design, configuration, and components used in different models. Additionally, the e-rickshaw may also have a provision for charging the battery through conventional charging methods, such as plugging into an electrical outlet, to ensure sufficient power availability during periods of limited sunlight.

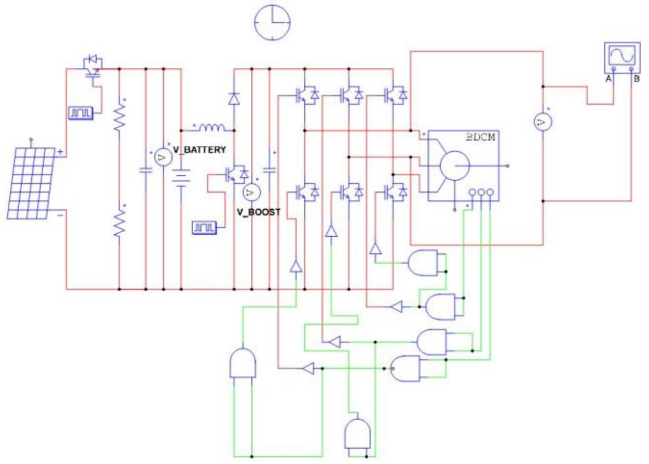

Fig -3: Simulation diagram of Electric auto rickshaw system

The Fig. 3 shows the simulation diagram of the Electric auto rickshaw system. The solar panel receives the solar power from the sun. The solar power is not constant always variable. The solar panel charges a battery. The batter receives varying power from solar panel this varying power is stabilized by using charge controller. A charge controller, also known as a solar regulator, is an essential component in a solar power system. Its main function is to regulate the charging process of batteries from solar panels and prevent overcharging or excessive discharge. Here's a general overview of how a charge controller works: Solar Panel Input: The charge controller is connected between the solar panels and the battery bank. It receives the direct current (DC) output from the solar panels.

Maximum Power Point Tracking (MPPT): If the charge controller has MPPT capabilities (common in advanced models), it employs MPPT algorithms to maximize the power transfer from the solar panels to the battery bank. MPPT ensures that the charge controller extracts the maximum available power from the solar panels, adjusting the voltage and current for optimal performance.

Battery Charging: The charge controller monitors the state of charge (SOC) of the battery bank. It measures parameters such as battery voltage, current, and temperature to determine the appropriate charging stage. The charging process typically consists of three stages: bulk, absorption, and float.

a. Bulk Charging: During the bulk charging stage, the charge controller delivers the maximum current output from the solar panels to rapidly recharge the battery bank. The voltage is maintained at a constant level, usually around 14.4-14.8 volts for a 12-volt system.

b. Absorption Charging: Once the battery voltage reaches a predetermined threshold, the charge controller switches to the absorption charging stage. The voltage is maintained at a slightly lower level, typically around 13.6-14.4 volts, to avoid overcharging. During this stage, the charge controller gradually reduces the charging current as the battery approaches full capacity.

c. Float Charging: When the battery is fully charged, the charge controller enters the float charging stage. The voltage is lowered to a maintenance level, typically around 13.2-13.8 volts, to keep the battery at full capacity without causing excessive gassing or water loss.

Battery Protection: Charge controllers also incorporate various protection mechanisms to safeguard the battery bank and the solar system:

a. Overcharge Protection: The charge controller prevents overcharging by regulating the voltage and current supplied to the battery bank. It maintains the battery voltage within safe limits and automatically adjusts the charging rate.

b. Low Voltage Disconnect (LVD): To prevent excessive discharge, the charge controller monitors the battery voltage. If the voltage drops below a specified threshold, it disconnects the load from the battery to avoid damage caused by deep discharge.

c. Temperature Compensation: Some charge controllers feature temperature sensors to adjust the charging voltage based on battery temperature. This compensates for temperature variations that affect battery performance and longevity.

Display and Monitoring: Charge controllers may include a built-in display or interface for monitoring system performance, battery status, charging stages, and other relevant information. This allows users to observe and manage their solar power system effectively

As shown in the figure 4, the charge controller stabilizes the voltage at approximate 48V

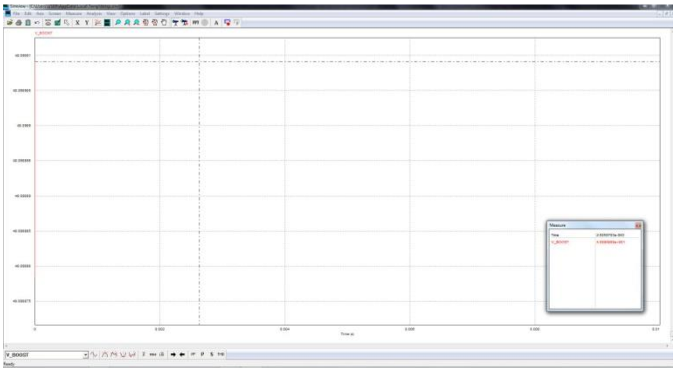

Fig -4: Simulation result 1: Output of the charge controller of Electric auto rickshaw system

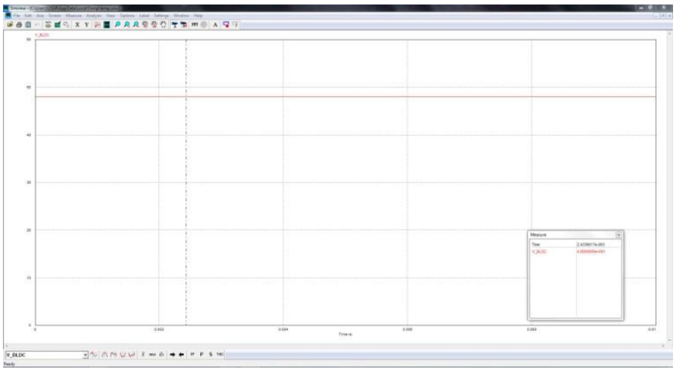

Fig -5: Simulation result 2: Output of the boost converter

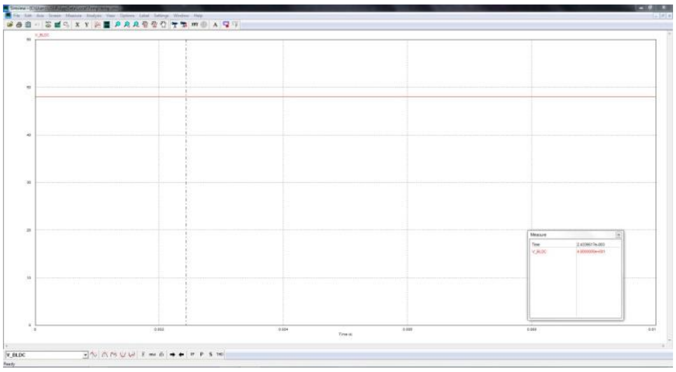

Fig -6: Simulation result 3: Input to the BLDC motor

Designing a boost converter involves selecting appropriate components and determining their values based on the desired input and output voltages, current requirements, and efficiency considerations. Here's a simplified design process for a 20V to 48V boost converter:

i. Determine Specifications:
- Input Voltage (Vin): 20V
- Output Voltage (Vout): 48V
- Output Current (Iout): Desired maximum output current

ii. Calculate Duty Cycle:
The duty cycle (D) represents the ratio of the switch's on-time to the total switching period. It can be calculated using the following formula:

$D = V_{out} / V_{in}$

In this case, D = 48V / 20V = 2.4

iii. Choose Switching Frequency:
Select a suitable switching frequency for your application. Common values range from tens of kilohertz to several megahertz. A higher frequency allows for smaller components but may lead to increased switching losses.

iv. Inductor Selection:
- Determine the maximum ripple current (ΔI) that the inductor can tolerate. This affects the inductor's size and power dissipation.
- Calculate the inductance (L) using the following formula:

$L = ((V_{in} - V_{out}) * D) / (\Delta I * f) = 2mH$

where f is the chosen switching frequency.

v. Capacitor Selection:
- Choose an output capacitor (C) with sufficient capacitance to handle the output current and maintain low output voltage ripple.
- The minimum capacitance can be estimated using the following formula:

$C = (I_{out} * D) / (\Delta V * f) = 44\mu F$

where ΔV is the acceptable output voltage ripple.

vi. Diode Selection:
- Select a diode with appropriate voltage and current ratings. The diode should have low forward voltage drop and fast switching characteristics.
- Consider Schottky diodes for their low forward voltage drop.

vii. Control and Protection Circuitry:
- Determine if you need a dedicated boost controller IC or if you will design a control circuit using discrete components.
- Consider incorporating protection features like over current protection, overvoltage protection, and thermal protection.

viii. Efficiency Considerations:
- Optimize component selection and minimize power losses to improve efficiency.
- Consider using high-efficiency components and techniques such as synchronous rectification (using a synchronous rectifier MOSFET instead of a diode).

3. CONCLUSIONS

The rickshaw plays a crucial role in the automotive industry of India. We have examined this role as well as the utilization of alternative technologies, particularly renewable energy technologies, in this sector. Extensive research supports the integration of renewable energy technologies in rickshaws. Consequently, simulations have been conducted to assess the infrastructure support and the rickshaw itself. The simulations and testing have demonstrated that an all-electric rickshaw with solar assistance can achieve a practical operating range on a single charge. As a case study, one rickshaw design considered here has a potential range of approximately 90 km. By implementing suitable control systems and maximizing solar energy input, it becomes feasible to achieve the average daily range of the vehicle, thereby validating the concept of a plug-in electric rickshaw with solar assistance. Moving forward, efforts should be directed towards enhancing the efficiency of the electrical system and all mechanical components. Future experimental verification should focus on the performance of the solar panels installed on the prototype, particularly assessing the impact of rapidly changing atmospheric conditions (such as driving through tree-lined streets) on the overall vehicle efficiency. Additionally, forthcoming research will encompass a comprehensive analysis of solar technologies, including their dimensions and configurations. For instance, exploring the advantages of incorporating a partial sun-tracking system and MPPT system, along with the associated tradeoffs, will be investigated. Furthermore, it is necessary to conduct further investigations into the efficiency of the motor and controller to optimize the overall vehicle efficiency..

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