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Research Article

Modified Mechanical Structure Electric Bike Design Computation and Prototype Model Implementation

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The aim of this paper is to investigate the design computation and prototype model implementation of a Modified Mechanical Structure (MMS) Electric Bike (E-Bike). It is the technology that allows the vehicle to operate with the assistance of electrical energy. All conventional cars will be converted to electric vehicles (EVs) in the future. EVs will be affordable to all types of people, allowing them to fly comfortably and safely. As a result, this paper proposes a design estimate and model implementation of the MMS E-Bike with the smallest number of parts, lowest expense, and lightest weight possible. The most important parts of the designed MMS E-Bike are the battery, MMS, BLDC motor, and electronic commutator with their controller. Because of its adapted mechanical frame nature, the designed E-Bike is low in cost and weight, and it can also go up to 25 kmph. Furthermore, the rider will be able to ride the built MMS E-Bike without any pain to their bodies and should be able to sit comfortably during their journey. In comparison to the Ampere Angel and DMW Electra 20 E-Bikes, the performance of the developed model is tested under various operating conditions, as well as their battery backup.

1. Introduction

With India's growing population, transportation plays an increasingly important role in getting people from one place to another. Traditional-operated vehicles have increased carbon emissions and fuel consumption in the transportation sector on a daily basis. Electric Vehicles (EVs) are a necessary mode of transportation in India to address pollution and the rising demand for nonrenewable energy, and they are equally applicable to all types of citizens [1]. The work in [2] describes the performance of an electric tricycle fitted with solar panels. However, as a result of this report, it was suggested that electric tricycles be modified to include solar panels in order to improve battery autonomy. In addition, simulations of different topologies are addressed, as well as their computation of solar panel power losses and battery autonomy. Also discussed is a workaround for accumulative battery autonomy. The work in [3] shows a prototype model of a smart E-Bike in detail. However, it has a more complex mechanical structure and is a plug-in EV with two/three wheels. The work in [4] introduces the next generation of E-Bikes. A single mild steel bar is bent into various configurations in this article. Mild steel, a mixture of carbon, nickel, chromium, and iron, is used to build the mechanical frame because it has higher tensile and compressive capacities than stainless steel and cast iron. The work in [5] discusses a photovoltaic (PV) device that powers a fish-vending women's tricycle. Women, on the other hand, can easily operate the built model to safely transport fish from the landing center to the market. The work in [6] develops and discusses a battery-operated tricycle for a physically disabled individual. However, this model is better for physically disabled people who need to move from one location to another at a higher rate. The work in [7] discusses E-Bike architecture for the fourth generation. From this article, the deep analysis of the E-Bike was carried out based on their requirements applied for it. The work in [8] shows a well-executed expert method for controlling power factor right buck-boost rectifier-fed BLDC motors. However, the speed control of BLDC motor drives and supply side power factor adjustment has been tested under various operating conditions in this article. The work in [9–13] describes various modern DC-DC converters for EVs, as well as their control methods. In the past, the designs of E-Bike companies were compared in all technical respects, as shown in Table 1. Ampere Angel is India's first E-Bike (cycle) manufacturer [14]. The pedal-assist mode and battery operating mode are the two riding modes. It is simple to switch from one mode to another without difficulty in this vehicle. This E-Bike can be operated by people of all ages, including school children, senior citizens, and people of all ages. The comprehensive analysis of the E-Bike at different countries is addressed [16, 17]. The prototype model of this E-Bike is shown in Figure 1, and the rest of the specifications are listed in Table 1. DMW Electra 20 is a single-rider E-Bike manufactured by DMW EVs in India [15]. As shown in Figure 2, it has special wheels with adjustable front suspension for a smooth ride on bumpy roads. This is also a pedal-assist battery-powered electric bike. It is easy to switch from the pedal assist to battery assist mode, and vice versa. Table 1 lists the rest of the information.

The cost, mechanical structure design, operating position, size, and weight of the current E-Bike were all major issues, according to the literature survey and Table 1. As a result, the aim of this article is to create a prototype model of a Modified Mechanical Structure (MMS) E-Bike with low cost/weight and comfortable transportation. ELECLE 1.0 is the name given to it.

2. Proposed E-Bike Block Diagram and Information

The block diagram of the designed E-Bike is discussed in this section (see Figure 3). It is made up of a battery, a BLDC motor drive, and its controller, as well as a throttle valve. The proposed E-Bike uses a lithium ion battery to power the BLDC motor, which has its shaft coupled to a small chain sprocket. Lithium ion batteries are commonly used in EVs due to their high battery efficiency, low maintenance, and high charge power, as shown in Figure 4 [6]. It is powered by a 48 V, 12 AH lithium ion battery.

The next form of motor is the Brushless DC (BLDC) motor, which is also known as an electronically commutated motor. It is used to transform electrical energy into mechanical energy in this case (Figure 5). It is driven by DC power, which is converted to AC power by an electronic commutator or inverter and used to drive each step. In an E-Bike, the motor controller unit is used to control the power conversion operation. Hall sensors in the BLDC motor recognise the rotor direction angle [6]. These sensors are installed in the motor's rotor and linked to the motor controller as input. Hall sensors needed DC power, which was provided by a motor controller. Three wires supply stages, two wires supply hall sensors, and the remaining three wires receive input from the hall sensors in a BLDC motor [6, 8]. To control the speed of the BLDC motor, a feedback signal from the hall sensors is needed (48 V, 12 A, 500 W, −2800 rpm). This motor is more suitable for EVs because of their

(i) Better speed versus torque characteristics
(ii) Noiseless operation
(iii) High efficiency
(iv) Long operating life
(v) High dynamic response
(vi) Higher speed ranges [8]

In an E-Bike, the throttle supports motor control and propels the bike forward [8]. It helps you to pedal or simply relax and enjoy the trip. The thumb throttle on E-Bikes is controlled by the thumb. A small lever protrudes from the handlebar towards the bike, which controls the throttle. The throttle model is shown in Figure 6.

The motor controller (see Figure 7) is a mechanism that connects the battery to the BLDC motor. It has a current limit of 0.1 A. The EVs' motor controller is configured to drive the BLDC motor in this case. Table 2 lists the specifications of the designed E-Bike.

3. Design Computation of the Proposed E-Bike

The measures for calculating the mechanical structure weight and electrical system of the proposed E-Bike model are as follows [8].

3.1. Speed Calculation (No Load)

Step 1:

Quantity of teeth on smaller sprocket $t_1 = 14$ (see Figure 8)

Quantity of teeth on larger sprocket $t_2 = 37$

Speed on smaller sprocket:

$N_1 = 2800$ RPM

Taking reduction ratio as 6 [3, 8],

$N_1 = 2800/6 = 460$ RPM

Step 2:

Via the speed ratio formula

$N_1 \ t_1 = N_2 \ t_2$

Speed of the wheel of EV, $N_2 = 460 \times 14/37 = 174$ RPM

Table 1: Comprehensive analysis of existing E-Bike companies.

Model	Ampere Angel [14]	DMW Electra 20 [15]
Battery	36V, 12 AH SLA	36V, 8AH lithium
Wheel size	26 cm	24 cm
Motor	BLDC	BLDC
Cost	Rs. 30,000	Rs. 40,500
Weight	25 kg	27 kg
Location of the battery	Behind to the seat tube	On the down tube
Speed	25 kmph	25 kmph
Limitation	Not applicable for the uphill direction	Not comfortable to sit
Welding points	11	7

Figure 1: Prototype model of the Ampere Angel E-cycle [14].

Figure 2: Prototype model of the DMW Electra 20 E-cycle [15].

Step 3:

Diameter of the wheel of EV = 56 cm = 560 mm

Circumference of the wheel of EV = pi × D

= 3.14 × 560 = 1758 mm.

Step 4:

Speed of EV = speed of the wheel of EV × circumference of the wheel of EV

= 174 × 1758 = 335996 mm/min

= 25 km/hr

3.2. Computation of Essential Power to Drive the E-Bike

Step 1:

Total load acting on the E-Bike is as follows:

Net vehicle weight = 10 kgs

Average human weight = 80 kgs

Average luggage weight = 5 kgs

Battery + motor weight = 5 kgs

Total weight = 100 kgs = 100 × 9.81 = 981 N

Step 2:

To find reaction on each wheel:

The total load which is divided equally on both the wheels of the E-Bike

Force (F_{rw}) = 981/2 = 490.5.5 N

Where reaction the on rear and front wheel are as follows:

$R_{fw} = 0.2 \times 490.5 = 98.1$ N

Step 3:

To obtain the torque on each wheel of the E-Bike:

Total torque = torque on the front wheel of the E-Bike + torque on the rear wheel of the E-Bike

$T = T_{fw} + T_{rw}$

To determine the torque on the front wheel of the E-Bike:

$T_1 = R_{fw}\ x\ \mathrm{D}/2 = 98.1 \times (56 \times 10^{-2})/2$

= 30 Nm

Total torque on wheel = $T_1 + T_2 = 60$ Nm

Step 4:

To compute the power on the BLDC motor of the E-Bike:

= $2 \times \mathrm{pi}\ x\ \mathrm{N}_2 \times \mathrm{T}_1/60$

= 2 × 3.14 × 174 × 30/60 = 500 W

Battery capacity calculation: 500 W EV is run for 1 hour, watt-hours = 500 × 1 = 500 watt-hours, and the efficiency of the battery is 85%. Watt-hours = 500/0.85 = 588 watt-hours. Ampere hour (at 48 V) = 588/48 = 12 AH.

4. MMS of the E-Bike

The proposed E-MMS Bike's frame concept was created using the AutoCAD 2017 software. The top tube, head tube fork, down tube, seat tube, seat stay, and chain stay made up the basic E-Bike structure [4, 8]. This new tube, which will provide support, will connect the head tube fork and seat tube. The Kevlar cable was also added for additional support of the proposed E-Bike. The Kevlar cable is a superdurable material that does not conduct electricity. This cable provides perfect dimension stability and protects the E-Bike from oscillations.

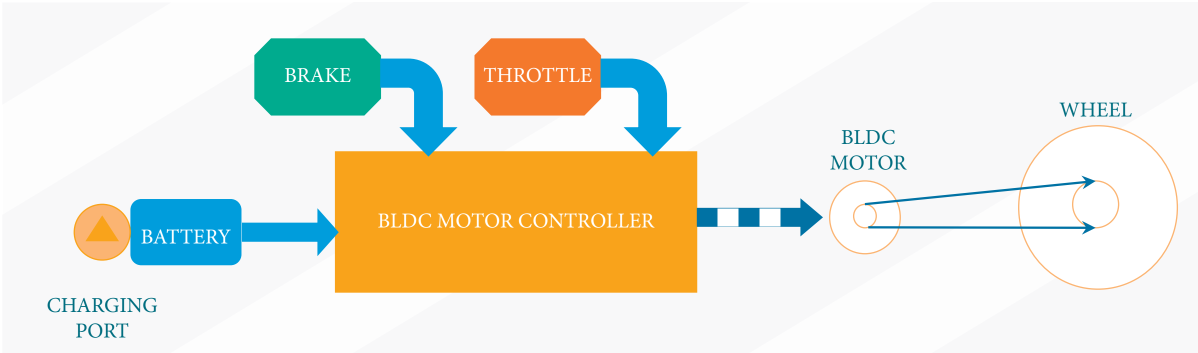

Figure 3: Block diagram of the proposed prototype model of ELECLE 1.0.

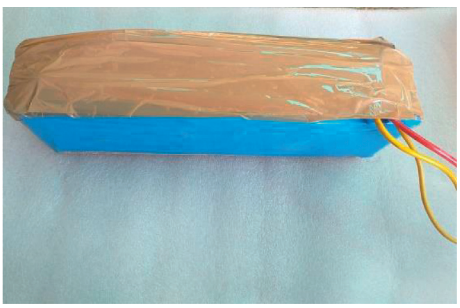

Figure 4: Model of the lithium ion battery.

Figure 5: Model of the BLDC motor drive.

In the proposed E-Bike, the Kevlar cable replaces the top tube, down tube, seat stay, and chain stay. As a result of these changes, the weight/cost of the E-Bike was reduced, as was its MMS. Figure 9 depicts the planned E-Bike as well as its MMS dimensions.

5. Prototype Model of the MMS E-Bike and Result Analysis

Mild steel was used to create the E-Bike frame. The frame was created using AutoCAD software and precise mechanical calculations. Welding points for this frame were 4 to 6 points. The rider would not be scared while riding because of the basic frame design. Since the rider's center of gravity is closer to the seat tube, he or she can handle the bike with less effort. The bike's weight was reduced to less than ten kilograms. Mild steel materials are simple to work with when it comes to welding and cutting. These materials are

Figure 6: Model of the throttle.

Figure 7: Typical model of the motor controller.

capable of high loading while remaining low in cost. The electric bike is made of mild steel, which gives it enough power. Figures 9 and 10 represent the final prototype model of the planned E-Bike, as well as its dimensions.

5.1. Proposed E-Bike Dimensions (Figures 9 and 10)

Distance from the ground to seat = 100 cm

Distance from the ground to motor = 20 cm

Seat tube distance = 45 cm

Distance from the head tube to seat tube = 75 cm

Front wheel diameter = 56 cm

Rear wheel diameter = 56 cm

No. of teeth on the motor sprocket = 14

No. of teeth on the rear wheel sprocket = 37

Table 3 shows the efficiency of the designed E-Bike. In comparison to the Ampere Angel and the DMW Electra 20, the built E-Bike has superior performance in terms of cost, speed, welding points, weight, and operating position (see Table 1).

Table 2: Specifications of the proposed E-Bike.

S. no.	Components	Specifications	Quantity
1	Brushless DC motor	Voltage- 48 V; current- 12 A; power- 500 W; and speed- 2800 RPM	1
2	Mechanical structure (welding)	Mild steel	-
3	Battery	Voltage- 48 V and current- 12 A	1
4	Wheel with disc	28 inches	2

Figure 8: Chain sprocket with teeth.

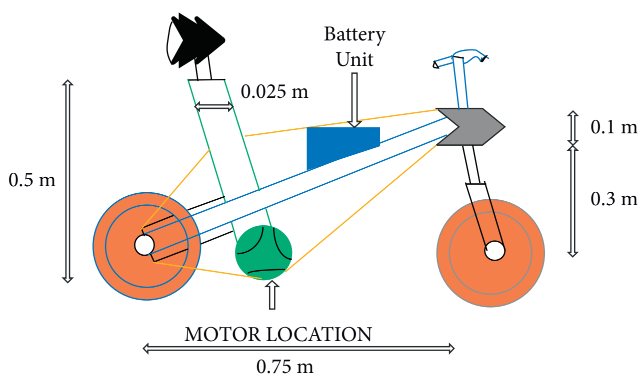

Figure 9: MMS E-Bike design using AutoCAD software.

Figure 10: Prototype model of the proposed E-Bike.

Table 3: Result analysis of the designed E-Bike (ELECLE 1.0).

Model	ELECLE 1.0 (proposed model)
Battery and backup	48 V, 12 AH Li-ion and 1.2 hour
Wheel size	30 cm
Motor	BLDC
Cost	Rs. 20,000
Weight	20 kg
Location of the battery	Between top and down tubes
Speed	25 kmph
Limitation	Vibration and comfort to travel
Welding points	4

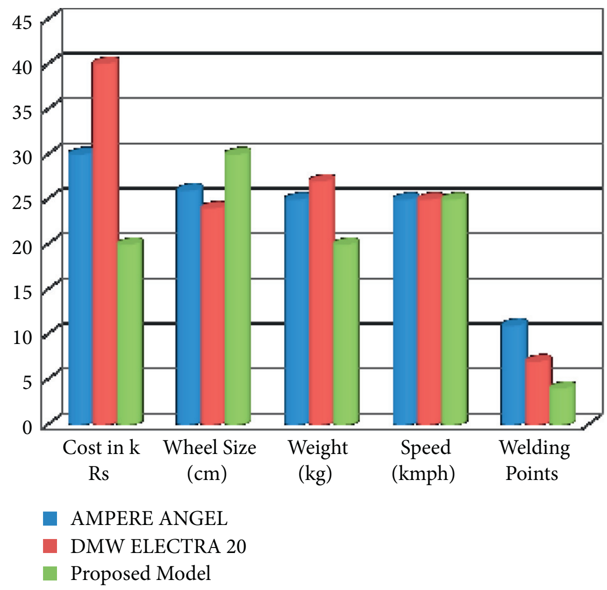

Figure 11: Comprehensive graphical analysis of the proposed E-Bike and existing E-Bike model.

Figure 11 shows the graphical analysis of the proposed E-Bike and existing E-Bike models. From this chart, it is evident that the designed model has low cost, less number of joints, and less model weight over the existing model.

6. Conclusions

This article successfully illustrated the concept computation and prototype model implementation of the MMS E-Bike. The computation of the electrical and mechanical systems was specifically discussed. The E-Bike is constructed based on its calculations by assembling and connecting the battery, MMS, BLDC motor, and electronic commutator to their controller mechanically and electrically. The key advantages of the designed E-Bike are its low cost and light weight, which are due to the MMS and materials used in its construction. It could also reach speeds of up to 25 kmph, particularly in hilly areas. Riders should be able to ride the E-Bike without experiencing any pain in their bodies and should be able to sit comfortably when transporting. The built model has been put through its paces with companies including Ampere Angel and DMW Electra 20 E-Bikes. Depending on the weight of the E-Bike, it can be increased to a high power level.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare no conflicts of interest.

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