Design And Prototype Production Of An Electric Motorcycle

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Abstract : **Electric Vehicles are expected to reduce the emissions caused by the road transport. However the electric vehicles present in the market currently have some major disadvantages. The conventional vehicles are better in terms of speed and provide required torque for different road conditions. In this paper, design and conversion of a normal motorcycle to an Electric Motorcycle (EM) is described. A 97.2cc Internal Combustion Engine motorcycle is selected and converted to EM. A brushless DC (BLDC) motor of 1.5 kW power is used. The performance of this motor is enhanced by coupling it to the 4-speed gearbox of the motorcycle. The power source used is lead-acid battery pack. Finally the testing of the Electric Motorcycle is done and required graphs are plotted to analyze the variation of theoretical and actual values. The coupling of motor with the gearbox enabled to achieve greater torque and vehicle speed. From the graphs plotted it was found that the coupling ratio of 0.5 between the motor and the gearbox helped to increase the speed of the bike while using the motor of same rpm. The theoretical speed calculated was 60 kmph and the actual speed of 55 kmph was achieved.**

IndexTerms **- Electric vehicle; Electric motorcycle; Battery-electric vehicles**

I. INTRODUCTION

Internal-combustion-engine (ICE) vehicles entail various problems, first and foremost pollution. Hence, the need to find an appropriate substitute has notably increased in recent years. Hybrid electric vehicles (HEVs) and electric vehicles (EVs) are suitable substitutes for their ICE counterparts, since they are capable of operating with a much lower impact on the environment. However, EVs have failed to gain popularity because of an inherent problem, as the energy-storage capacity of electric batteries is much lower than that of fossil fuels. In other words, when the source of energy changes from ICE to electricity, for longer running time on a single charge of the battery, it is required to minimize the losses of the vehicle. Most EVs on the market are equipped with one single-speed gearbox that exhibits a trade-off between efficiency and dynamic performance. It is anticipated that applying a multi-speed transmission in EVs can not only reduce the size of the motor, but also provide an appropriate balance between efficiency and dynamic performance. Research demonstrates that an electric motor equipped with a multi-speed transmission can provide the desired power in more than one way, and hence, reduce the energy consumption of the vehicle through gear-shifting [1].

The number of gears needed by any given vehicle is related to the power to weight ratio and the power band of the motivating device, humans have a very low power to weight ratio (150 lbs/horsepower approx) and a very narrow power band (60 to 150 rpm at the crankset) so require many gears to maximize the utilization of a limited resource. It is true that electric motors make peak torque at zero rpm, however an electric motor makes zero power at zero rpm that means the efficiency of the motor at zero rpm is also zero no matter how much torque it is generating. If the motor spends a lot of time near zero rpm trying to accelerate the vehicle through a low numerical final drive then the motor is going to operate out of its efficient range and use a lot of amp hours available from the batteries just to heat up. A selectable higher numerical final drive that is a gearbox can help keep the amp draw down to a reasonable level at low speeds[2]

In this paper a retrofitting kit is developed for a geared motorcycle. Retrofitting means addition of new technology. And matched the parameters of engine with those of the motor (Brake Horse Power, RPM ratings, Torque) and Analyze the engine .The electric bikes available in the market have a lot of disadvantages. The cost of buying a new bike is also high. Currently the vehicles which do not certify according to emission standards because of their long usage are to be thrown into scrap. The speed of current available electric bikes is less and are not suitable for all kinds of roads. The maintenance of these bikes is also high and is not easily possible. Instead a retrofitting kit can be installed in the existing bike to overcome these disadvantages of current electric vehicles.

NOMENCLATURE

P	Motor power	η_m	Motor transmission efficiency
F_D	Drag force	C_R	Coefficient of rolling resistance

C_D	Drag coefficient of air	SR	Speed Ratio
m	Mass of vehicle	T_{1KMPH}	Tyre at 1KMPH
g	Acceleration due to gravity	S_1	Speed on 1st gear (km/hr)
A	Frontal surface area	S_2	Speed on 2nd gear (km/hr)
ρ_a	Density of air	S_3	Speed on 3rd gear (km/hr)
V	Speed of motorcycle (km/hr)	S_4	Speed on 4th gear (km/hr)
PR	Primary Reduction	CR	Coupling ratio
GR	Gear Ratio	T_e	Effective torque
FR	Final Reduction	T_W	Torque at wheel
G_1	Gear ratio for 1st gear	TE	Tractive Effort
G_2	Gear ratio for 2nd gear	r	Tire radius
G_3	Gear ratio for 3rd gear	a	Acceleration of motorcycle
G_4	Gear ratio for 4th gear		

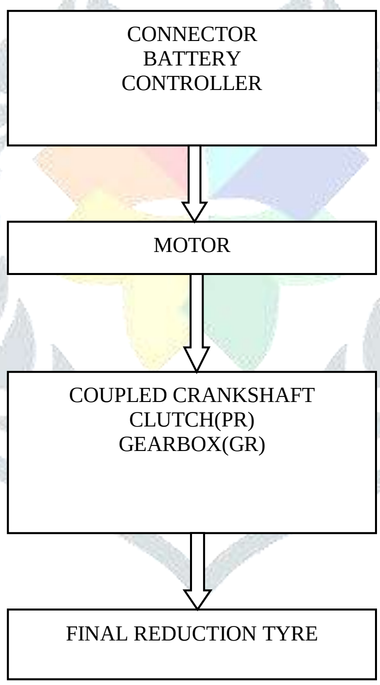

Fig 1: Block Diagram of electric motorcycle powertrain

II. MOTOR SELECTION

The motor power should be able to supply the required load. The required power considering the air drag power and rolling resistance power on a flat road can be calculated by the following formula:

$$P = F_D \frac{V}{\eta_m} \quad [W] \quad (1)$$

$$F_D = C_R mg + \frac{1}{2}\rho_a C_D A V^2 \quad [N] \quad (2)$$

Where F_D is the drag force, η_m is motor transmission efficiency, C_R is the rolling resistance, m is the mass of vehicle, g is acceleration due to gravity, ρ_a is the air density, C_D is the drag coefficient, A is the frontal area, V is the velocity of motorcycle. The data of Table 1 is used calculate the required power of the motor.

Table 1: Data for calculation of motor power

Gravitational acceleration	g=9.81 m/s^2
Rolling resistance coefficient	C_R=0.009
Air drag coefficient	C_D=0.5
Mass of vehicle	m=150 kg
Air density	ρ_a =1.225 kg/m^3
Frontal area	A=0.8 m^2
Velocity of motorcycle	V=60 km/hr
Mechanical efficiency	$\eta_m = 0.95$

To run the motorcycle at 60 km/hr the power of the motor calculated is 1426.299 W. Thus a BLDC motor of power 1500 W is used in this prototype. The speed of this motor is 3000 rpm. The peak voltage is 50 V and peak current is 46 A. The peak power is 2500 W. The motor characteristic are shown in Fig 2 .

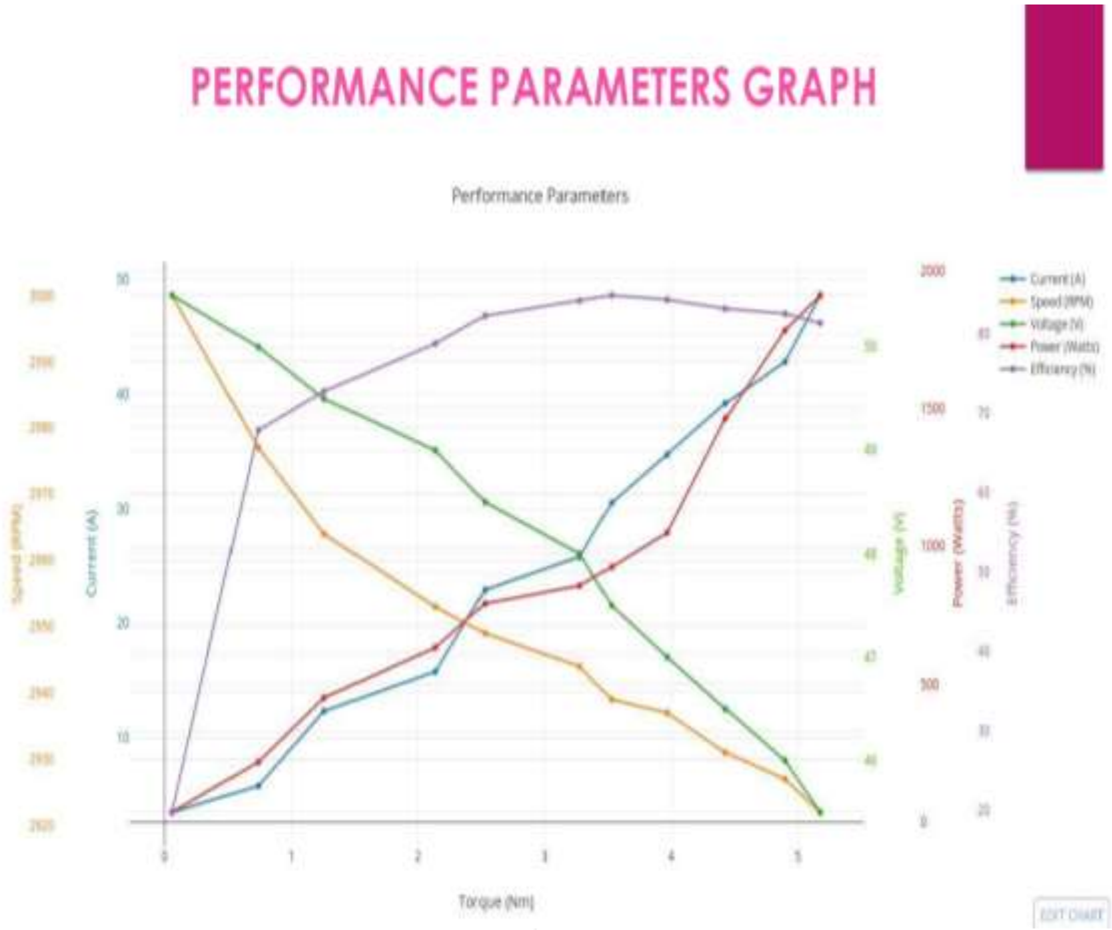

Fig 2: Characteristics of BLDC motor[3]

III. DETERMINATION OF COUPLING RATIO

The motor is coupled to the gearbox by a chain sprocket assembly. The shaft of the motor is mounted with a sprocket which is connected by a chain to the sprocket mounted on the crankshaft. Since the engine(piston and crankshaft) and the gearbox form a single unit a modification is made in which the piston and the connecting rod is cut and only the crankshaft is assembled in the gearbox.

Fig 3: Piston-Crank Assembly

Fig 4: Crankshaft (piston eliminated)

Fig 5: Crankshaft Assembled inside Gearbox

The motion provided by the motor reaches the rear wheel by passing through 3 reductions namely Primary reduction (PR), Gear reduction (SR) and the Final reduction (FR).

1)PR-Primary Reduction: It is the drive ratio of the engine to the transmission
2)GR-Gear Reduction: It is the ratio of no. of teeth on input gear to that of the output gear
3)FR-Final Reduction: Final drive refers to the drive ratio for the transmission to the rear wheel motorcycles usually use a belt or a chain

The formula for calculating PR, GR and FR is as follows:

$$\text{Primary Reduction}=\frac{\text{No of teeth on clutch}}{\text{No of teeth on crankshaft gear}}$$

$$\text{Gear Reduction}=\frac{\text{No of teeth on output gear}}{\text{No of teeth on input gear}}$$

$$\text{Final Reduction}=\frac{\text{No of teeth on rear sprocket}}{\text{No of teeth on front sprocket}}$$

Since a 4 speed gearbox is used there will be 4 gear reductions G_1, G_2, G_3, G_4. The data given in Table 2 is used to calculate the values of PR, GR and FR and the Table 3 shows the corresponding values.

Table 2: Data for calculating the reductions

No of teeth on clutch	67
No of teeth on crank gear	18
No of teeth on 1st Gear	Input=11 teeth Output=35 teeth
No of teeth on 2nd Gear	Input=17 teeth Output=29 teeth
No of teeth on 3rd Gear	Input=21 teeth Output=26 teeth
No of teeth on 4th Gear	Input=24 teeth Output=23 teeth
No of teeth on rear sprocket	47
No of teeth on front sprocket	14

Table 3: Calculated values of reductions

Primary Reduction	PR=3.722
1st Gear Reduction	G_1 =3.182
2nd Gear Reduction	G_2 =1.706
3rd Gear Reduction	G_3 =1.238
4th Gear Reduction	G_4 =0.958
Final Reduction	FR=3.357

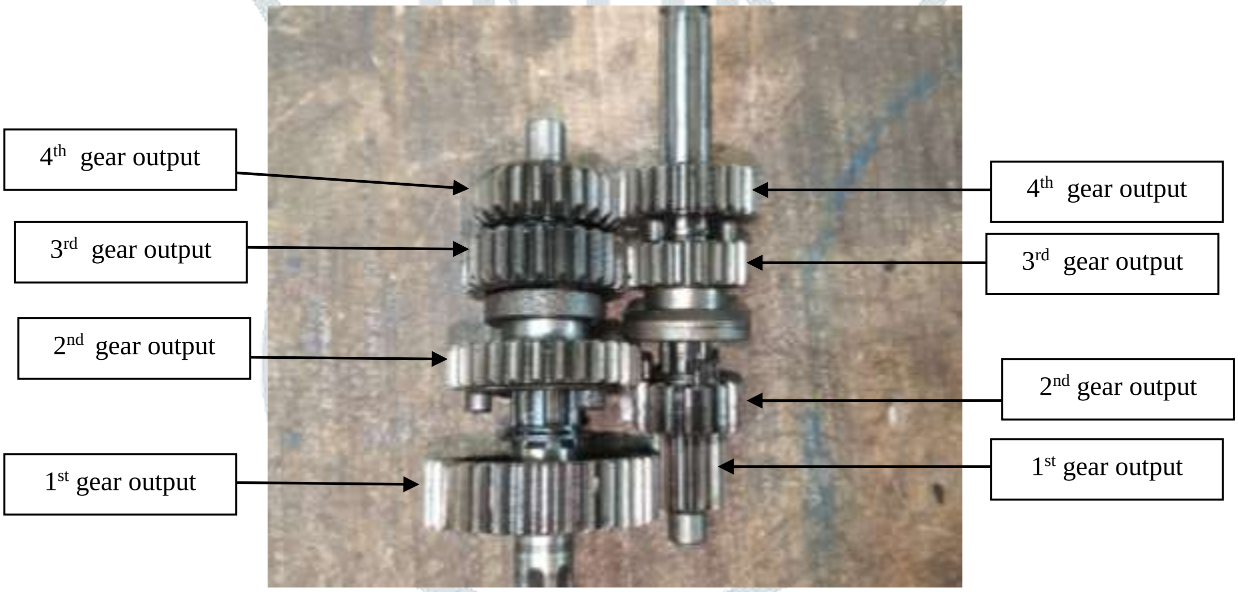

Fig 6: Arrangement of gears

3.1) Speed Calculations:

The speed obtained on each gear is calculated analytically. Speed Ratio (SR) is calculated first. The significance of SR is that the mechanical damage on the clutch can be found. Also at what speed bike will be at red line (10000 RPM) and true speed of vehicle can be found. It is given by the formula:

$$Speed\ Ratio\ (SR) = T_{1KMPH} \times PR \times GR \times FR \quad (3)$$

$$SR = \frac{Motor\ Speed}{Vehicle\ Speed} \quad (4)$$

T_{1KMPH}-Tyre at 1KMPH

$$T_{1KMPH} = \frac{10^3}{60 \times Tyre\ Circumferene(m)} \quad (5)$$

Tyre Circumference=1970 mm

=1.97 m

$\therefore T_{1KMPH} = \frac{10^3}{60 \times 1.97}$

$T_{1KMPH} = 8.565$

Now the vehicle speed is calculated from equation (4). Since there are 4 gears S1, S2, S3 and S4 will be the four speeds on each of the 4 gears respectively. In the first case the coupling ratio between the motor and the gearbox is taken as 1:1. The motor speed is 3000 rpm. Table 4 shows the speed on each gear.

Table 4: Speed on each gear (without coupling ratio)

Speed on 1st gear	S_1=8.919 kmph
Speed on 2nd gear	S_2=16.64 kmph
Speed on 3rd gear	S_3=22.92 kmph
Speed on 4th gear	S_4=29.62 kmph

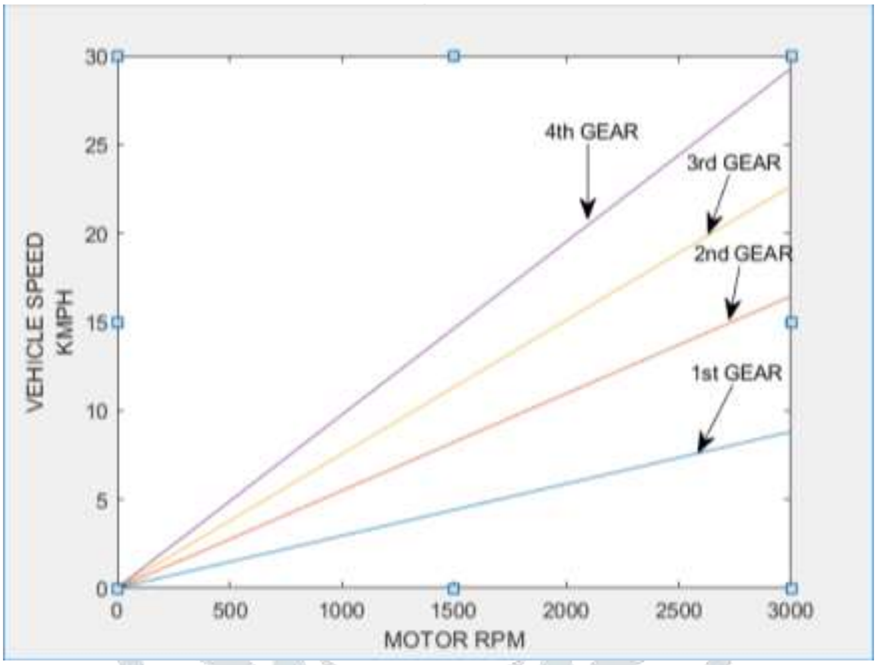

Fig 7: Graph of Vehicle speed V/S Motor RPM (without coupling ratio)

The speed on the 4th gear obtained is 29.62 km/hr. The requirement of 60 km/hr is not fulfilled by the rpm of motor. Thus coupling ratio between the motor and the gearbox is calculated for speed of 60 km/hr.

For 60Kmph Speed on 4th gear

$60 = \frac{3000}{8.565 \times 3.7222 \times 3.357 \times X}$

$X = 0.4672$

$X = CR \times 4^{th}$ gear ratio:
$0.4672 = CR \times 0.958$
$CR = 0.4877$

$CR \approx 0.5$

A coupling ratio of 0.5 is selected. Thus a sprocket of 24 teeth is mounted on motor shaft coupled to a 12 teeth sprocket mounted on crankshaft. Table 5 shows speed on each gear with the coupling ratio of 0.5 between the motor and the gearbox.

Table 5: Speed on each gear (with coupling ratio)

Speed on 1st gear	S_1=17.8 kmph
Speed on 2nd gear	S_2=33.3 kmph
Speed on 3rd gear	S_3=45.9 kmph
Speed on 4th gear	S_4=59.3 kmph

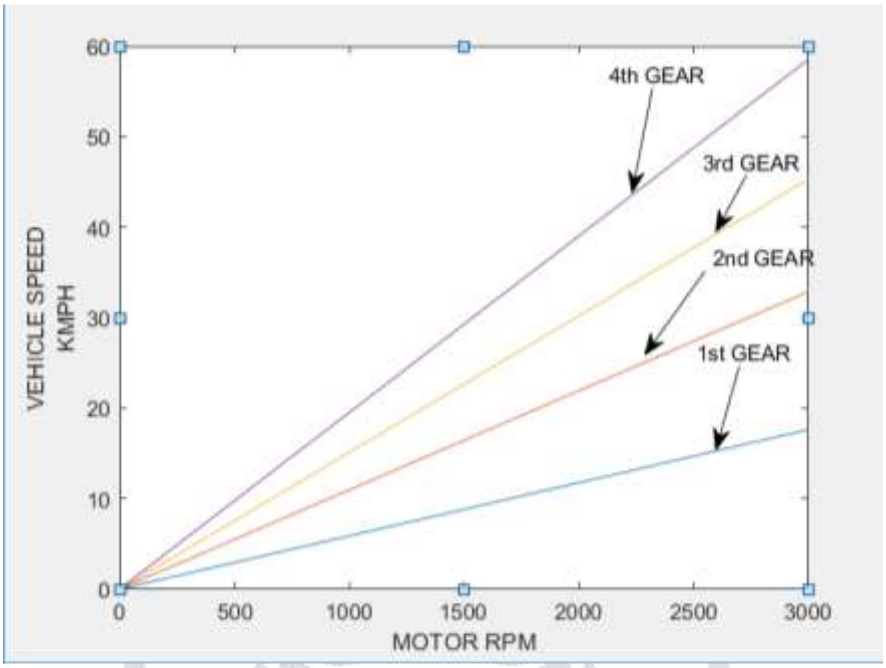

Fig 8: Graph of Vehicle speed V/S Motor RPM (with coupling ratio)

Fig 9: Assembly of gearbox and motor

IV. ELECTRIC SYSTEM LAYOUT

The complete system layout with various components is shown in Fig 10. The main power is supplied by a lead-acid battery pack. The positive of battery pack is connected to the MCB (Miniature Circuit Breaker) which acts as a safety device. This further is connected to the ignition switch and the controller through the connector board. The three phase wires of BLDC motor are connected to the controller via the connector board. The hall effect sensor acts as a feedback to the controller from the motor which ensures its correct working. The accelerator handle sends the torque command to the BLDC controller which further sends signals to the BLDC motor. The voltage converter is connected to the various other systems like headlight, signal light, etc. It supplies correct amount of voltage to these systems.

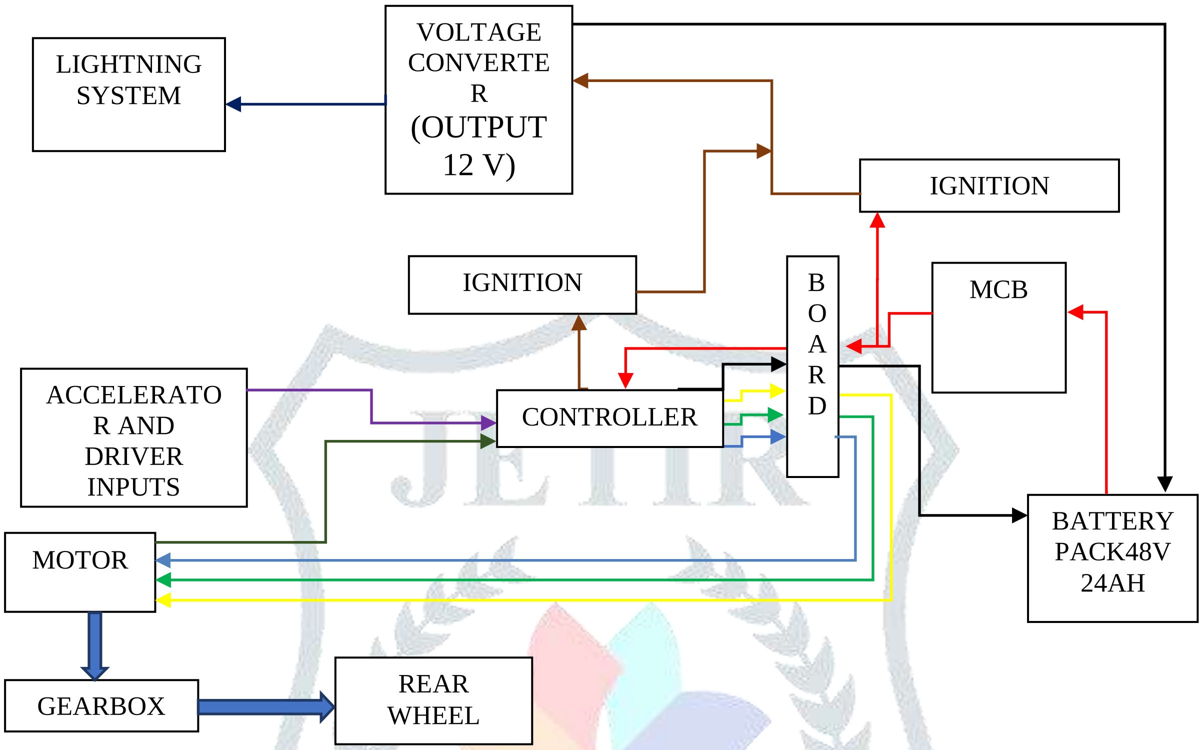

Fig 10: Complete system layout block diagram

BATTERY +ve :

BATTERY -ve :

MOTOR PHASE WIRE:

CONTROLLER FEEDBACK (HALL EFFECT SENSOR):

DRIVER INPUTS:

POWER FLOW DIRECTION:

V. ANALYSIS

Table 6 shows the overall gear ratios on each gear.

Table 6: Overall gear ratios on each gear

Overall gear ratio 1st gear	G_1=0.5×3.722×3.182×3.357= 19.88
Overall gear ratio 2nd gear	G_2=0.5×3.722×1.706×3.357= 10.66

Overall gear ratio 3rd gear	G_3=0.5×3.722×1.238×3.357= 7.73
Overall gear ratio 4th gear	G_4=0.5×3.722×0.958×3.357= 5.98

5.1) Tire torque calculations:

The torque at the wheel is different than the effective torque. The effective torque T_e is calculated by the equation (6) and the torque at wheel T_W by equation (7).

$$T_e = \frac{P \times 60}{2\pi N} \quad (6)$$

$$T_w = T_e \times \eta_t \times G \quad (7)$$

$$\eta_t = 100\%$$

Table 7 : Torque at wheel on each gear

Torque at wheel 1st gear	113.9 Nm
Torque at wheel 2nd gear	61.07 Nm
Torque at wheel 3rd gear	44.31 Nm
Torque at wheel 4th gear	34.3 Nm

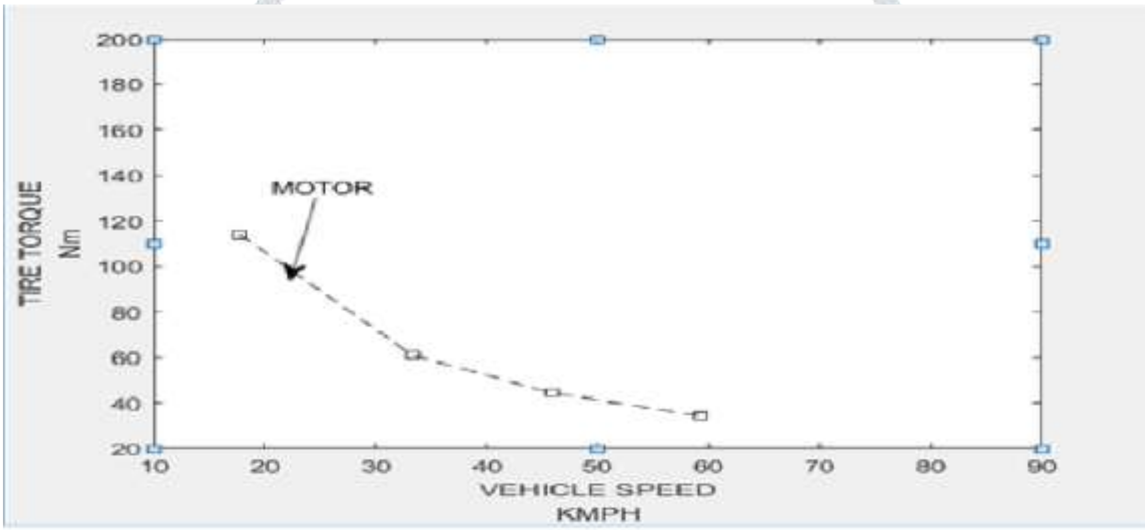

Fig 11: Tire torque V/S Vehicle speed

5.2) Acceleration on each gear

The acceleration can be calculated by determining the tractive effort (TE). The tractive effort is given by the equation:

$$\text{Tractive Effort (TE)} = \frac{T_w}{r} \quad (8)$$

$$\text{Acceleration (a)} = \frac{TE}{m} \quad (9)$$

Table 8: Tractive effort on each gear

Tractive Effort (1st gear)	363.317 N
Tractive Effort (2nd gear)	194.800 N
Tractive Effort (3rd gear)	141.339 N
Tractive Effort (4th gear)	109.409 N

Table 9: Acceleration on each gear

Acceleration (1st gear)	2.422 m/s^2
Acceleration (2nd gear)	1.299 m/s^2
Acceleration (3rd gear)	0.942 m/s^2
Acceleration (4th gear)	0.729 m/s^2

5.3) RPM of tire at each gear

RPM readings of rear tire at each gear shift at 3000 Motor RPM:

1st gear $N_1 = \frac{3000}{19.88} = 151$ RPM
2nd gear $N_2 = \frac{3000}{10.66} = 281$ RPM
3rd gear $N_3 = \frac{3000}{7.73} = 388$ RPM
4th gear $N_4 = \frac{3000}{5.98} = 502$ RPM

The actual values of rpm of rear tire measured by tachometer at each gear shift at 3000 Motor RPM:

1st gear $N_1=130$ RPM
2nd gear $N_2=248$ RPM
3rd gear $N_3=348$ RPM
4th gear $N_4=467$ RPM

By considering the actual and calculated values the efficiencies of each gear is calculated as follows:

1st gear $\eta_1 = \frac{130}{151} = 86\%$
2nd gear $\eta_2 = \frac{248}{281} = 88\%$
3rd gear $\eta_3 = \frac{348}{388} = 90\%$
4th gear $\eta_4 = \frac{467}{502} = 93\%$

The actual values of derived vehicle speed at each gear is calculated by equation (10):

Actual value of derived vehicle speed = Vehicle speed x Efficiency of gear (10)

Table 10: Actual derived vehicle speed

1st gear	S_1=15.3 kmph
2nd gear	S_2=29.3 kmph
3rd gear	S_3=41.31 kmph
4th gear	S_4=55.15 kmph

Table 11: Actual values of vehicle speeds on each gear as measured on speedometer

1st gear	S_1=14 kmph
2nd gear	S_2=28 kmph
3rd gear	S_3=40 kmph
4th gear	S_4=55 kmph

From Table 10 and 11 it seen that the calculated and actual values are almost same.

Fig 12: The manufactured electric motorcycle

VI. CONCLUSION

In this paper the manufacturing and performance analysis of an electric motorcycle is explained. The motor used here is a shaft BLDC motor which is coupled to a 4-speed gearbox. The coupling of the gearbox to the motor enables to achieve the required torque and speed while running the motor in its efficiency range. The graph of vehicle speed V/S Motor rpm with and without coupling ratio shows clearly that the coupling ratio of 0.5 enabled to achieve a speed of 60 km/hr with the same 3000 rpm of the motor. Also the torque obtained at the wheel is more which could not have been achieved by installing only the motor. The theoretical speed calculated is 60 km/hr and the actual speed obtained after testing the bike is 55km/hr. These results are obtained by using an existing gearbox of the conventional motorbike. If a gearbox is particularly designed for the motor and an optimized motor is used higher values of speed and torque can be obtained and the efficiency of the overall system can be improved.

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