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Experimental Electric Retrofitting of an Ice Vehicle with Simulation and Cost Analysis

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Abstract: ***With increasing awareness towards environmental issues, the modern society seems inclined towards use of cleaner fuel in transportation and a drift towards electric vehicles is now being observed world over. Government of India has already made its vision 2030 public in which 100% use of electric vehicles in public transport and increased percentage of electric vehicles in personal passenger vehicles is envisaged. The paper presents a method followed for the conversion process of a traditional ICE vehicle to electric vehicle. The research specifically takes into consideration ARAI guidelines and Indian laws that benefit the process. The paper is presented in three sections. The first section deals with essential electrical components required for the procedure and their selection respectively. The second section contains simulation of selected electric motor along with cost analysis of the complete drive. The third section contains the procedure followed to obtain the final vehicle along with descriptive images for better understanding of placement of the components. The final vehicle obtained is highly cost effective as well as efficient in its performance.***

Keywords**: *BLDC, Conversion, Gearbox, Retrofitting.***

I. INTRODUCTION

With more than 13 million vehicles already in Delhi[1]; manufacturing of new vehicles would only add to the problem. The electric cars utilize large battery packs for storage of energy which increases the already inflated cost of a new car. Hence retrofitting plays an important role and changes the already existing power-train of the vehicle.

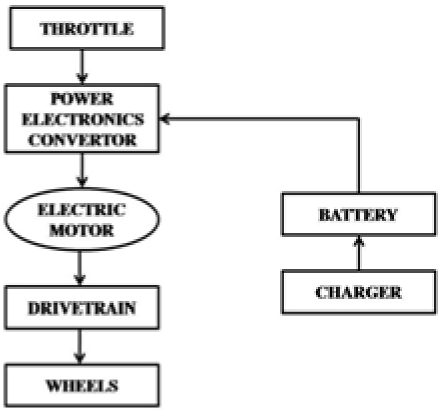

Figure.1. Block diagram of drive train in electric vehicle

The main objective of the project involves parameter calculation for selection of electric vehicle's motor and comparative analysis of selected motor with alternatives available and final cost comparison between ICE vehicles with the retrofitted vehicle. From Yedamale P. [2] paper on bldc drives, the characteristics and performance of bldc motor was understood for analysis along with Howe's paper [3] steps for simulation following comparative analysis using torque-speed curves of different drives in EV. From the many available models the mathematical modelling and simulation was selected due to its flexibility [4]. For understanding the conventional procedure of manufacturing EV,different methods were studied,which offered a more mechanical perspective [5][6].

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II. MOTOR PARAMETERS CALCULATION BASED ON VEHICLE DYNAMICS

Vehicle dynamics basic principles can be used to study the behaviour of the vehicle under given circumstances, primarily focusing on friction offered by road, its inclination and the aerodynamic drag playing on the vehicle.

Table.1. Vehicle Specification

Vehicle data	Values
Vehicle weight	750 kg
Seating capacity	8
No. of gears	4 Forward, 1 Reverse
First gear	3.721
Second gear	2.289
Third gear	1.947
Fourth gear	1.000
Wheel radius	253mm
Passanger weight(assumed)	70kg(each)
Width & height	1410mm, 1640mm

Table.2. Motor Parameter Calculation

Motor data	Values
Weight (vehicle + 8 people)	1310kg
Wheel radius	253mm
Gear ratio (first gear)	3.7
Vehicle speed(desired)	40kmph
Rolling coefficient	0.018
Drag coefficient	0.4
Front area(m^2)	2.3

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Road inclination(degree)	15
Air resistance	69.63N
Rolling resistance	232.084N
Gradient resistance	59.78N
Total resistance	360.5N
Wheel torque required	91.2Nm
Motor torque required	29Nm
Motor rpm required	1553
Motor power	4.71KW

For the purpose of retrofitting, motor parameters[Table.2] should be more than sufficient to replace the engine of the vehicle keeping in view the gear ratios of the gears offered by the vehicle gearbox [7]. For the purpose of experiment, a vehicle with specifications mentioned in Table.1 is used [8].Electric motors have an added advantage of instantly producing torque on requirement. This makes gearbox unnecessary in electric vehicle or a single gear can be used if motors rated torque is less than the required torque by the vehicle.In addition reverse gear is also not required as electric motors can rotate in reverse direction.The experimental vehicles gearbox was fixed to operate on first gear only.

Further using formulas[Appendix 1] associated with aerodynamic drag, rolling resistance and gradient resistance, and assuming other related coefficients and speed desired [Table.2] for the retrofitted vehicle, torque and power required from the motor is calculated.

The bldc motor selected, based on calculation and motor availability, has specification as 72V,118 A max continuous current, 160 A peak current and 3000 rpm rated speed.

A. Conversion Procedureand Component Selection

In conversion of ICE vehicle to electric vehicle a key component as identified during the problem statement phase was to keep a low cost while not tampering with the mechanical integrity of the vehicle's body thereby component selection and retrofitting played a critical role. The vehicle chassis selected for the conversion process was Maruti Omni owing to its light weight chassis, flexible operation considering Indian roads and lower cost.

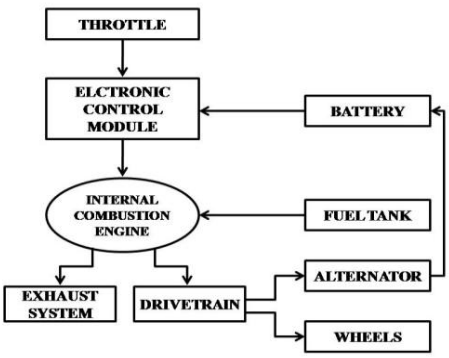

Figure.2. Block diagram of drive train in ICE vehicle

The vehicle's engine, cooling system, radiators, fuel tank and clutch assembly were removed. The electric vehicle components required for assembling a new drive train consisting of electric motor, motor controllers along with electronic throttle, battery management system and battery were identified for the selection procedure.

1)Electric Motor Selection

In considering a suitable electric motor, four major requirements namely high initial torque, high speed, variable load handling capacity and net weight of the motor were considered. With regards to variety of motors, three motor were shortlisted for high torque requirement namely dc series motor, induction motor and bldc motor. The dc series motor has capability of producing high initial torque but at the same time the speed falls drastically at higher torque conditions. The induction motor has capability of self-start but at the same time has low starting torque along withrequirement of advanced control system for dynamic stability. The brushless dc motor (bldc) is a synchronous motor which has rotors with permanent magnets allowing for a high initial torque and lighter weight. Both the induction and bldc may be used but owing to faster response to changing load conditions and lighter weight of the latter, the bldc motor is selected.

2)Battery Pack Selection

In considering a suitable battery pack three major requirements namely power output, weight and cost were considered for selection. The options available were lithium polymer battery pack and lead acid battery pack. The lead acid battery has heavier weight, high maintenance cost and low initial cost. The lithium polymer based battery pack has capability of fast charging, lighter weight, low maintenance cost and high initial cost. Therefore a lithium polymer based battery pack offers more advantage in comparison hence LiPo battery is selected.

B. Bldc motor simulation results

After necessary power requirement have been calculated for the bldc motor, the mathematical equations governing the bldc are used for formulation of simulink model fig.3 and the results for the same are shown in fig.4, fig.5 and fig.6.The basic modelling of bldc drive is further extension from the mathematical models [9][10].The fig.3 is the final system used for simulation of the bldc motor.

The bldc motor under rated load torque of 30Nm with three different frequencies 50Hz, 35Hz and 20Hz from the frequency range of 0 to 100 percent are chosen for the purpose of simulation. The varying frequency represents the throttle input to the motor controller thereby controlling the speed [9].Fig.4 shows the speed profile for these selected frequencies, asthe frequency decreases for the motor at rated

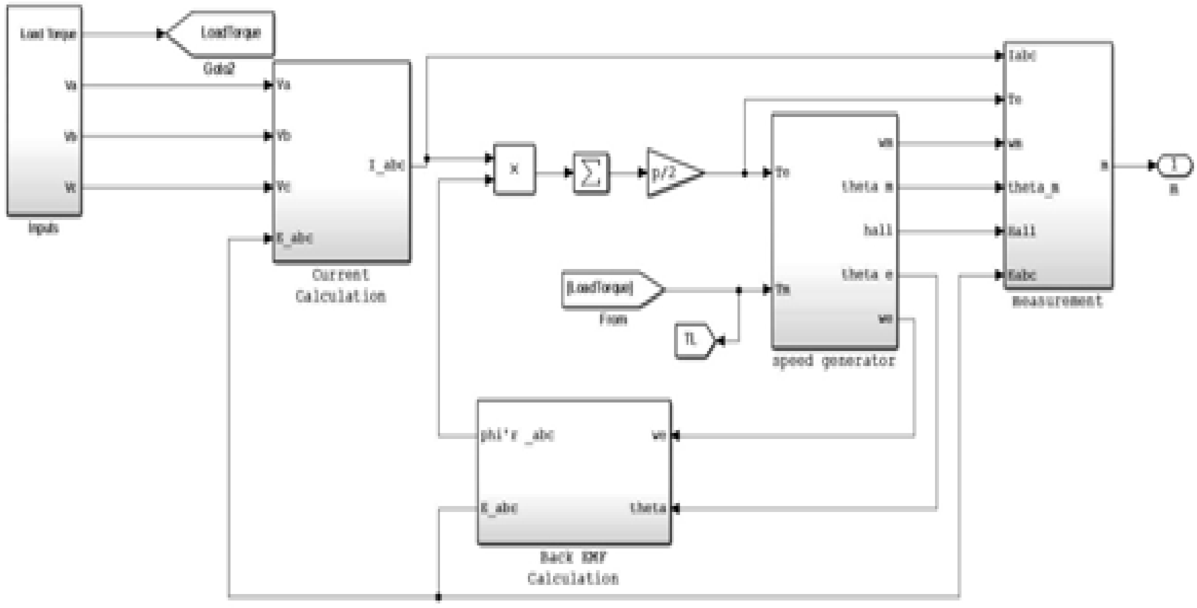

Figure.3. Block diagram of BLDC Simulink model

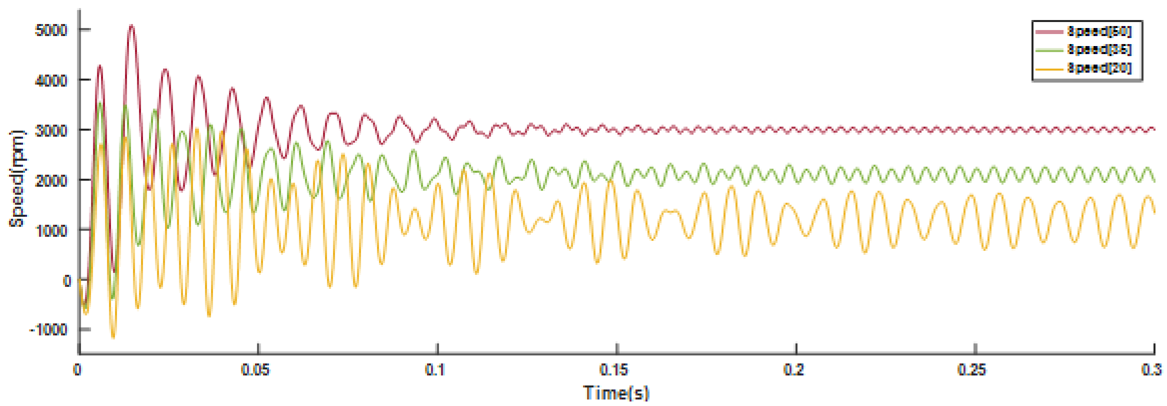

Figure.4. Speed profile of the BLDC motor at frequencies of 50, 35 and 20 Hz resp. at 30Nm torque.

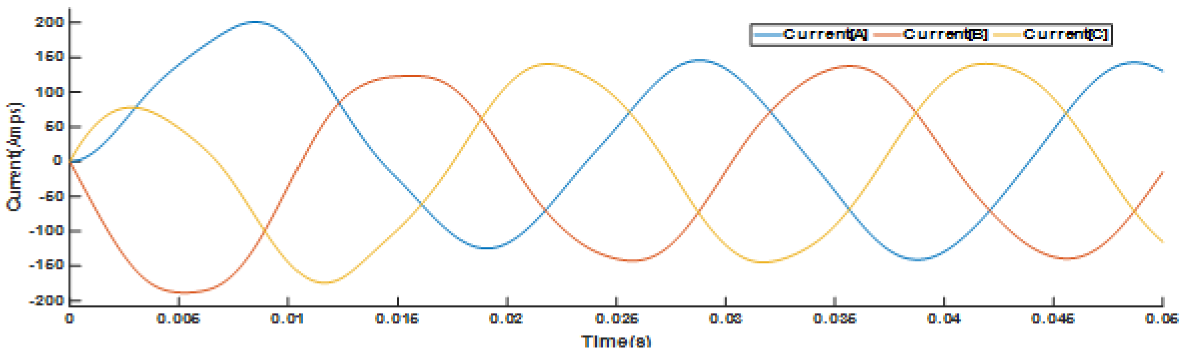

Figure.5. Current profile of the BLDC motor at frequency of 50Hz at 30Nm torque.

load torque,the speed of the motor achieves 3000, 2060 and 1181 rpm, which are visible to be decreasing with respect to the frequencies. Hence a higher controllability for the motor's speed range is achieved. The current profile fig.5 depicts a maximum current of 144A for the ratedload torque with frequency 50 Hz. The maximum current limitis taken in consideration for the selection of wire gauge for the main tractive system and safety component. In Fig.6 back emf profiles corresponding to the chosen frequencies is shown. As the frequency decreases distortion in the back emf increases for rated load torque and a voltage of 72 V.

The back emf profiles reflect higher stability of torque at higher frequencies than at lower frequencies [11].

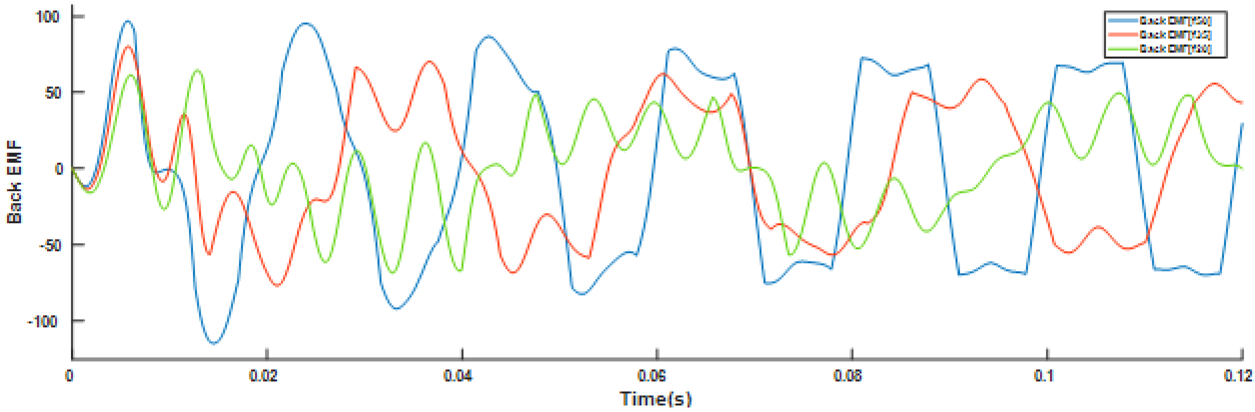

Figure.6. Back EMF profile of the BLDC motor at frequencies of 50, 35 and 20 Hz resp. at 30Nm torque. torque.

C. Operational cost comparision of electrical retrofitted vehicle with ice vehicle

The electric vehicle's cost is compared with ICE vehicle to verify the designed EV is cost effective and prove the overall process allows for manufacturing of a cost efficient product [12].

Table.3. Initial Parameters for cost calculation

Parameters	Petrol	CNG	Electrical
Energy in 1L of fuel	11Kwh	14.6Kwh	-
Efficiency of fuel	0.2	0.42	0.8
Avg distance per litre of car on fuel	17(km/L)	20(km/kg)	-
Cost of 1L or 1kwh fuel	74	45.2	8
Average Distance travelled(Assumed)	18000 km/Yr	18000 km/Yr	18000 km/Yr

Maintenance cost yearly for petrol and CNG is assumed to be Rs 15000 and Rs 20000 respectively. For EV the installation cost with maintenance is taken as Rs 250000.

Table.4. Final cost calculation

	Petrol	CNG	Electrical
Energy required per km	0.129 (kwh/km)	0.306 kwh/km	0.129(kwh/ km)
Running cost	4.35 Rs/km	2.51 Rs/km	0.95 Rs/km
Total expenses in 5 yrs	Rs 4,66,500	Rs 3,25,900	Rs. 3,35,500

The cost calculations are carried out using initial parameters from Table.3 [12] and cost calculation formula [Appendix 2]. From the above calculation we have conclude that EV is a highly cost effective option in comparison to its ICE counterpart.

III. EXPERIMENTAL SETUP FOR RETROFITTING PROCESS

Once the initial stage is completed the retrofitting process started. The following are the steps followed in the retrofitting stage:

1.Initially the fueltank is removed along with exhaust system, the engine, gearbox and then radiator.

Figure.7. Coupled motor with gearbox

2. To couple the motor an adaptor plate is mounted between the motor and the transmission. After attaching the custom adapter plate we mount the motor using custom mounting brackets.

Figure.8. Mounting of motor coupled with gearbox

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3. The placement of the motor controller is done such that the wire harnesses can be as short as possible.

Figure.9. Final placement of motor controller

4. Final assembly of the retrofitted drive along with lithium polymer battery pack.

Figure.10. Final assembly of drive train

IV. RESULT AND DISCUSSION

A carefully generalised method was formed for conversion of any ICE vehicle into an electric vehicle. The motor of higher specification with respect to rpm (motor: 3000 rpm) was used due to market availability and hence the speed of the vehicle was found higher than desired speed. For cost effectiveness the existing gear box was modified for use. Every single step of the method was carefully evaluated and simulated to ensure high efficiency and cost effectiveness. The maximum speed achieved in initial test run was 46kmph on a stretch of 3km which heated up the tractive system wires. Therefore the wires with gauge corresponding to 1.25 times the maximum current were used as replacement to avoid the heating issue.The final vehicle's weight is within 10% which is less than limit defined by ARAI for a retrofitted vehicle[13]. The LiPo battery allows for extremely low maintenance cost and reducing the net charge time by great margin with respect to traditional lead acid battery.

V. CONCLUSION

Due to fast depletion of fossil fuel sources and increasing pollution levels, the need of the hour is to find and develop an affordable solution which can help tackle the problem. The method devised in this project is one of the many methods that may be employed to current scenarios specifically pertaining to India. The method deploys steps and evaluates selection of optimum equipment ensuring cost as well as energy efficiency with a lower carbon footprint.

APPENDIX 1

The following calculations are represented via Table(a) where the following notations are used:
F_r=rolling resistance, m= mass of body, a_g= acceleration due to gravity, c= rolling resistance coefficient F_D=drag force, A=body area, ρ = density of fluid, v= flow velocity, F_P=pulling force,h=elevation,l=length

Force	**Formula**
Rolling resistance	$F_r = c\,W$
Drag force	$F_D=0.5*(c_D \rho v^2 A)$ here $A=2.3m^2$
Gradient resistance for inclined movement	$F_p = W * \frac{h}{l} = m\, a_g \sin\alpha$ Let a°=15°
Net resistance	$F_r+F_D+F_p$ + Transmission losses

APPENDIX 2

Parameters	**Cost Calculation formulae**
Energy required per kilometer	(energy of 1 litrefuel)X(efficiency)/(Mileage(kmpl))
Running cost	(cost of 1 litre fuel)/(Mileage(kmpl))
Total expenses in 5 years	(running cost)x(distance travelled in 5 years) + (maintenance cost of 5 years)

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