Conversion of internal combustion engine car to semi-autonomous electric car

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Abstract. Climate change, Green House Gases (GHG) and global warming are well-known terms in the world today. Global research efforts are focused towards increasing efficiency and reducing GHG emissions from various emitters to deal with climate change. Since the transportation sector accounts for a large share of global GHG emissions it is justifiable that curbing global warming should transpire in this sector. Worldwide there are large number of research taking place in the electrification of transportation sector and autonomous vehicles. In the footsteps of this global trend towards electrification, autonomous driving and automation of the transportation sector, a research to convert an existing internal combustion engine car to an electric car and implementation of few features found in SAE level 1 autonomous vehicles are explored through this project. These features include controlling vehicles remotely, collision detection, parking assistance, etc.

1. Introduction
Worldwide, motor vehicles emit well over 900 million metric tons of carbon dioxide (CO2) each year, accounting for more than 15 percent of global fossil-fuel derived CO2 emissions. In the industrialized world alone, 20-25 percent of GHG emissions come from the transportation sector. The transport related GHG emissions is growing at a rapid pace, due to the continued increase in transportation and related activity. Since early 1970s, the global fleets of vehicles have been mounting at a rate of 16 million vehicles per year [1]. A similar growth in fuel consumption accompanies this expansion. If this kind of linear growth continues, by the year 2025 there will be well over one billion vehicles on the world’s roads. In a response to the significant growth in transportation related GHG emissions, governments and policymakers worldwide are considering steps to reverse this trend. However, regulating and reducing emissions from this sector poses a significant challenge, due to the particular makeup of the transportation sector. Unlike stationary fuel combustion, transportation-related emissions come from dispersed sources and only a few point-source emitters, such as oil/natural gas wells, refineries, or compressor stations, contribute to emissions from the transportation sector. The
majority comes from the millions of vehicles traveling in the world’s roads. As a result, successful GHG mitigation policies are being formulated around the world to target all of these small, nonpoint source emitters, either through regulatory means or through various incentive programs. Most of the recent innovations to control emissions from the transportation sector is based on the use of electric vehicles that can optimize the drive characteristics [2][3], assist the driver in maintaining speed, detect collisions, find alternate routes to pre-set destination, etc. all on its own [4]. These are hence called autonomous vehicles, the intelligent emission free transportation solution for the future.

2. Design

2.1. Conversion of I.C. Engine Powered Car
In the design, I.C. engine and its allied systems such as intake and exhaust system were replaced with a driver motor, battery pack, charger and motor controller.

![Figure 1. Layout of electric car](image)

2.1.1. Calculations. The dimensions and weight of the car is as shown in table 1.

| Dimension               | Name                  | Value     | Unit   |
|-------------------------|-----------------------|-----------|--------|
| Overall Length          | length\_car           | 3335      | mm     |
| Overall width           | width\_car            | 1440      | mm     |
| Overall height          | height\_car           | 1405      | mm     |
| Wheelbase               | Wheelbase             | 2175      | mm     |
| Curb Weight             | curbweight\_car       | 650       | N      |
| Gross Car weight        | grossweight\_car      | 1100      | N      |
| Weight of Battery Pack  | weight\_battery       | (26.6 × 5)|        |
| (5 Lead acid batteries) |                       | 133       | N      |
| Weight of motor         | weight\_motor         | 9         | N      |
| Weight of I.C.E +       | weight\_I.C.E         | 250       | N      |
| Exhaust                 |                       |           |        |
| New weight of the car   | weight\_car           | 650+250+133+9|   |
|                         |                       | 542       | N      |
The drag force is calculated as shown in table 2.

### Table 2. Calculation of drag force.

| Coefficient of Drag | Coefficient of Drag | Value | Unit |
|---------------------|---------------------|-------|------|
| $C_d[13][14]$       | $C_d[13][14]$       | 0.35  | -    |
| Density of air $\rho_{\text{air}}$ | Density of air $\rho_{\text{air}}$ | 1.18  | kg/m$^3$ |
| Cross sectional area $A_c$ | Cross sectional area $A_c$ | 1.61856 | m$^2$ |
| Drag force $F_d(\text{at } V_{\text{car}}=40\text{kmph})$ | Drag force $F_d(\text{at } V_{\text{car}}=40\text{kmph})$ | 41.263 | N |

The rolling resistance force and internal resistance force was calculated as:

### Table 3. Calculation of Rolling Resistance Force and Gradient Force.

| Coefficient of rolling resistance $\mu_{rr}$ | Coefficient of rolling resistance $\mu_{rr}$ | Value | Unit |
|---------------------------------------------|---------------------------------------------|-------|------|
| Rolling Resistance Force $F_{rr}$ | Rolling Resistance Force $F_{rr}$ | $\mu_{rr}\times \text{weight}_{\text{car}}$ | N |
| Gradient Force $F_{gr}$ | Gradient Force $F_{gr}$ | $\text{Sin } \theta \times \text{weight}_{\text{car}}$ | N |

Acceleration in Level Condition

| Time $T_{40}$ | Time $T_{40}$ | Value | Unit |
|----------------|----------------|-------|------|
| 0 – 40 kmph time | 0 – 40 kmph time | 12 | s |
| Acceleration $\text{Acc}$ | Acceleration $\text{Acc}$ | $(m/s)/t_{40}$ | m/s$^2$ |
| Acceleration Force $F_I$ | Acceleration Force $F_I$ | 51.157 | N |

Acceleration in gradient condition

| Time $t_{20}$ | Time $t_{20}$ | Value | Unit |
|----------------|----------------|-------|------|
| 0 – 20 kmph time | 0 – 20 kmph time | 10 | s |
| Acceleration $\text{Acc}$ | Acceleration $\text{Acc}$ | $(m/s)/t_{20}$ | m/(s$^2$) |
| Acceleration Force $F_{II}$ | Acceleration Force $F_{II}$ | $\text{acc} \times \text{weight}_{\text{car}}\div 9.81$ | N |

The maximum starting force and force to maintain constant speed is calculated in table 4.
Table 4. Calculation of starting force and force to maintain constant speed.

| Total Force at Starting on level ground | \( F_{\text{I,Start}} = F_I + F_{rr} \) |
|----------------------------------------|----------------------------------------|
|                                        | 60.37 N                                 |

| Total Force at Starting on inclined road | \( F_{\text{II}} + F_{gr} + F_{rr} \) |
|------------------------------------------|----------------------------------------|
|                                        | 134.025 N                              |

| Total Force at Top Speed                | \( F_{rr} + F_d(40 \text{ kmph}) \)   |
|-----------------------------------------|----------------------------------------|
|                                        | 50.477 N                               |

Total Tractive Effort (TTE) [4][5][6]

\[ TTE = F_{gr} + F_{rr} + F_{ma} = 134.025 \text{ N} \]

TTE for level road starting

\[ TTE = F_{rr} + F_{ma} = 60.37 \text{ N} \]

Total torque required \( \tau \):

\[ \tau = TTE \times \text{wheell} \times R_f = 134.025 \times 0.37 \times 1.1 = 54.29 \text{Nm} \]

Motor Torque required \( \tau \div GR = 15.2 \text{Nm} \)

2.1.2. Driver Motor. The above calculations help to arrive at a conclusion that the motor required for the conversion must have a torque of 15.2 Nm. The motor chosen for conversion is a BLDC motor with a peak torque of 16 Nm and a running torque around 6 Nm at 3500 rpm. This motor also features regenerative breaking for energy recovery [8][9][10].

2.2. Semi-Autonomous Electric Car

A microcontroller is used for implementing the semi-autonomous features. The microcontroller is connected to the motor controller and a mobile device (smartphone) is used to communicate with the microcontroller. Bluetooth module is used to transmit the signal from the smartphone to the microcontroller. The forward and reverse movement of the car can be remotely controlled using the smartphone. This enables parking assistance and parking into tight spots using the smartphone. PWM signals are transmitted to the motor controller by the microcontroller, essentially eliminating the need for a throttle. The ultrasonic sensors for collision detection are connected to the microcontroller which processes the input signals.

The steering column coupled to a DC motor, which is controlled by the microcontroller [11] using relay switching, steers the vehicle.

3. Fabrication

3.1. Conversion to electric car
The parts such as: the engine, the intake system, the exhaust system, starter, radiator, coolant tank and fuel lines and filter are removed and weighed on Weigh Bridge.

The motor was mounted in the space replacing the I.C. engine and was coupled directly to the gearbox shaft, using an adapter plate and a coupling made using EN8 carbon steel. The controller was connected to the BLDC motor. Battery packs were installed at the back of the car. A star coupling was used to couple the motor to the transmission box. Contactors were used as a safety measure in the electrical circuit. The battery packs supplies 60 V to the controller, the controller controls the amount of current that passes to the motor. The batteries were interconnected using brass connectors. The controller regulates the power transmitted to the motor allowing the motor to rotate. The motor coupled to the gear box transmits power to the trans-axle and thus power is transmitted to the wheels of the car.

3.2. Semi-autonomous capabilities

Ultrasonic sensors are placed at ideal locations in the front and back of the car. These are connected to the microcontroller which processes the input signals. The microcontroller is placed inside the vehicle. It is powered by the on-board 12V batteries and is connected to the motor controller. A Bluetooth communication module helps to receive and transmit signals to a mobile device. This enables remote control of the vehicle using the mobile device.

The steering control of the vehicle is achieved using a DC motor, controlled using the microcontroller, which is also connected and controlled using the mobile device.

4. Performance Evaluation

The tests as shown in table 4.1 were conducted to evaluate the performance of the converted car.

| Sl. No. | Tests                                      | Reference Standard         |
|--------|--------------------------------------------|----------------------------|
| 1      | Grade Ability test                         | AIS:003-1999               |
| 2      | Brake test                                 | IS:11852-2001              |
| 3      | Measurement of maximum power and 30 minute power | AIS041 Rev 1-2003         |
| 4      | Speed Limiting Device (SLD) or Function (SLF) | AIS-018:2001               |
| 5      | Range Test                                 | AIS:040 Rev 1              |

5. Results

5.1. Range Calculation

5.1.1. Approximate range calculation – Theoretical calculation. The converted car has an estimated range of 75km (pessimistic value), as calculated by theoretical approximations. The theoretical calculation was done by accounting for peak power rating.

\[
\text{Approximate range} = \frac{\text{Battery pack capacity}}{\text{Peak power rating of the controller}} \times \text{Top speed}
\]

\[
\text{Approximate range} = \frac{5.28\, \text{kWh}}{2.4\, \text{kW}} \times 40\, \text{km/h} = 88\, \text{km}
\]
5.1.2. **Approximate range calculation – Experimental method.** The average current consumption value per day was noted by measuring current value for every 500 meters, similarly the voltage value from the battery pack at every 500 meters was noted when the car was running using ammeter and voltmeter arrangement. The power consumed per day was computed.

The battery pack capacity divided by the average power consumption which gives the number of hours the car can run a day with specified power consumption. It is assumed that the power source is having an efficiency of 85% and the average speed attained was 40kmph. The car was driven 3 km daily for 10 days on level road. The figure 5.1 shows the plot of average voltage, average current consumption and power consumption for 10 days.

![Figure 2. Average power consumption for 10 days.](image)

The average power consumption was found to be 1.46kW during the experiment conducted over 10 days.

\[
\text{Hours} = \frac{\text{Battery Pack Capacity in kWh}}{\text{Average power consumption}}
\]

\[
\text{Hours} = \frac{5.28 \text{ kWh}}{1.46 \text{ kW}} = 3.616 \text{ hours}
\]

\[
\text{Range} = \text{Speed} \times \text{Time} = 144 \text{km}
\]

Assuming 75 % efficiency the system then range is found to be 108km approximate. The deviation from theoretical value occurs because the theoretical value was calculated by always assuming peak power consumption but, the car does not consume peak power throughout the drive.

5.2. **Cost benefit comparison**

The conversion has resulted in a functioning electric Maruti 800. This car has a top speed of 70 km/hr and a range of 80km. The peak torque of 53Nm is obtained at the starting. The total cost for the conversion was under Rs.80,000.

1. Consider the vehicle in its original state, with a mileage of 16km/l running for 40km a day. In 30 days it would run 1200km, at current cost of petrol Rs.70/L, it would incur a running cost of Rs.5250/month.
2. For the converted car of battery pack 5.28kWh, roughly 7 units of electricity would be required for a full charge. The range for a 5.28kWh battery pack is well above 80km and would require around 15 full charges a month. This translates to a monthly running cost lesser than Rs.800, at a tariff rate of 7.5 (0-500 units and above).
3. The savings from conversion is Rs.4450 per month or Rs.53,400 per year. The cost of conversion would be recovered in two years’ time.

5.3. Semi-autonomous feature
The feature, remote steering and speed control, enables the driver to control the vehicle from outside the vehicle. In the current situation, parking in tight spots is overlooked since the driver cannot get out of the vehicles after parking. With the remote steering feature, the driver can navigate and park from outside the vehicle. The rotational speed of the steering motor can be controlled by a potentiometer this feature was installed enable users to set the rotational speed of the steering wheel according to their wish.

The plot figure 5.2 shows how much the steering actually turns when the command for the same is executed in the android application, for turning. The steering turns by 6 degree when turning from the centre, but towards either ends the load on the motor is higher and hence the angle turned per pulse reduces to 5 degree.

The vehicle can now be driven using the digital interface or using an android platform-based application and need not be driven in the traditional manner. This enables amputees and those without legs to drive the car.

Figure 3. Plot of angle turned by the wheels per pulse to the turning angle of the car.

6. Conclusion
The conversion of I.C. Engine powered car to an electric car was done after thorough calculations, allowing tremendous reduction in the cost of components; as opposed to purchasing and importing a conversion kit from abroad. The converted car now requires only 20 percent of the original running cost, when charging the batteries from the electricity grid [12]. When charging from a renewable source of energy such as a solar charging station, the car can be run free of cost, as done at our
campus. This way the initial investment made can soon be recovered. The use of semi-autonomous features in the car makes it more user-friendly.

7. References

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