# Design of an Electrical Drive-Train for the Retrofit of a Conventional Auto-Rickshaw into an Electric Auto-Rickshaw

Prof. Nagaraj DC[1], Saumya Mishra[2], Sesha Gopal S[3], Swati Naikodi[4], Manaswi Tiple[5]
[1] *Assistant Professor, Dept of Electrical and Electronics Engineering, BMSIT & M, Bangalore, India*
[2,3,4,5] *Dept of Electrical and Electronics Engineering, BMSIT & M, Bangalore, India*

***Abstract*- In this paper, we discuss about the numerous advantages that electric vehicles possess over conventional fuel combustion vehicles that employ fossil fuels to power them. We also propose the design of an electric auto-rickshaw by performing the retrofit of the already existing conventional auto-rickshaw by removing the mechanical drive-train and replacing it with an electric drive-train. The BLDC motor has been chosen due to its high efficiency, low maintenance and robust nature, after an extensive comparison with the other available motor options. The BLDC motor will be controlled by using hall sensors that help in determining the position of the rotor. The BLDC motor is fed using a PWM modulated inverter. This paper also deals with the design and simulation of a DC-DC buck converter that is used to step down the voltage to the necessary level required by the motor to run.**

***Index terms*- BLDC motor, Drive-train, Electric vehicle, Induction motor drive, Pulse width modulation**

## I.INTRODUCTION

According to a survey by the World Health Organization (WHO), 91% of the people in the world stay in a place that has a pollution level far beyond the threshold set by the WHO. Wikipedia, an online encyclopedia also says that approximately 27% of the total air pollution in India is caused due to transportation. Almost 4.2 million people die all around the world, every year due to air pollution related diseases such as asthma. This is a problem of a large magnitude and it needs to be dealt with at once. A recent article from a popular news website shows the comparison between the various places of interest in Delhi from 2018 and from 2020, after the lockdown has been enforced due to the Covid-19 pandemic. The images speak for themselves as they clearly show how clear the sky has become owing to the lack of transportation in Delhi. The air pollution levels in various cities went down by around 50% owing to the lockdown. This is a testimony to how much transportation contributes to the air pollution. 9 out of the 10 most polluted cities in the world are from India. By curbing the use of fossil fuel powered transportation, a majority of the pollution that occurs due to this can be reduced. This is where electric vehicles come into the picture.

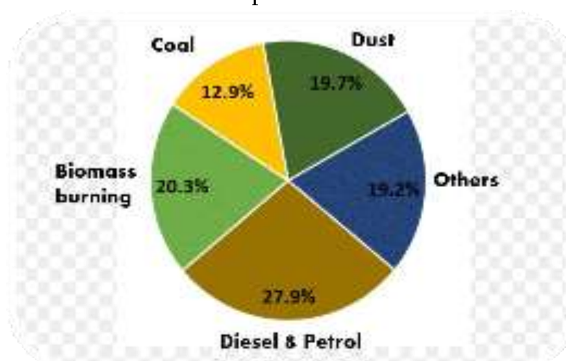


Fig-1: A graph showing the amount of total pollution caused due to different types of fuel being used.

Electric vehicles are vehicles that employ electric motors or traction motors in order to help in the propulsion of the vehicle. The global share of electric vehicles is expected to grow from 2% in 2016 to 22% in 2030. Electric vehicles can be broadly classified into three main types, those being BEV’s or battery electric vehicles which employ a battery as a source in order to not only run the motor but also to run all the other electronics in the vehicle, PHEV’s or plug-in hybrid electric vehicles that can recharge the battery not only through regenerative breaking but also by plugging it in to an external source, and HEV or hybrid electric vehicles which employ both conventional gasoline and electricity in order to power the vehicle.

There are a number of ways in which an electric vehicle can be manufactured. In order to tackle this problem effectively, we need to first find out which mode of transportation will have the most benefit from this. Auto rickshaws make up around 10% of all the urban transportation and is a viable choice to perform the retrofit on, as it not only is a public mode of transport but it also helps a lot of people. The main steps involved in the retrofitting of a vehicle are:

- Dismantling and removing the mechanical drive-train from the vehicle.
- Coupling the motor shaft to one end of the differential.
- Attaching the axles of the wheel to the other end of the differential.
- Making a permanent joint between the motor structure and the body of the vehicle.
- Completing all the internal wirings and connections.

## II. COMPARATIVE STUDY OF VARIOUS TYPES OF MOTORS

Traction motors are motors that help in the propulsion of the vehicle. Traction motors are mostly used in electrically powered rails and in electric vehicles as well as vehicles that employ some sort of electric transmission systems. We have two main types of motors, AC and DC. DC motors are simple to build and are cost effective as well. But they do have a lot of disadvantages. The construction of a DC motor, while easy also seems to be its biggest issue. The presence of slip rings and brushes brings up the possibility of sparks and maintenance issues. The speed torque characteristics of DC motor shows that it cannot be used in a traction motor. If speed increases, torque decreases sharply. The torque of a vehicle determines its accelerative capability. Torque is important for the economy of the vehicle, better handling, and also plays a vital role in the handling of heavier vehicles. Better torque usually means that the vehicle can travel at a given speed with more ease and less revs, thereby making the drive smoother.

Induction motors are usually referred to as AC motors. Apart from the common advantages over DC motors such as rugged construction which in turn means lesser maintenance. This also makes the Induction motor a perfect choice for use in industrial scenarios. Induction motors have excellent torque speed characteristics. The construction of the induction motor is super simple. Squirrel cage motors do not require a slip ring arrangement as well. Compared to a DC motor, it does not have brush arrangement hence maintenance is low. Cost is also low due to lack of brushes. It also has a high efficiency in the order of 85-97%. But low starting torque, increase in rotor losses at higher speeds, reduction of efficiency, and a lower efficiency when compared to permanent magnet motors due to the presence of rotor windings means that IM have their fair share of issues. Another glaring issue is the narrow speed range over which the AC induction motor gives a useful power output. But even with these downsides, induction motors are the perfect choice for electric cars. Tesla, the world’s leading electric car manufacturer uses induction motor drives in their electric cars, namely the Tesla Model S.

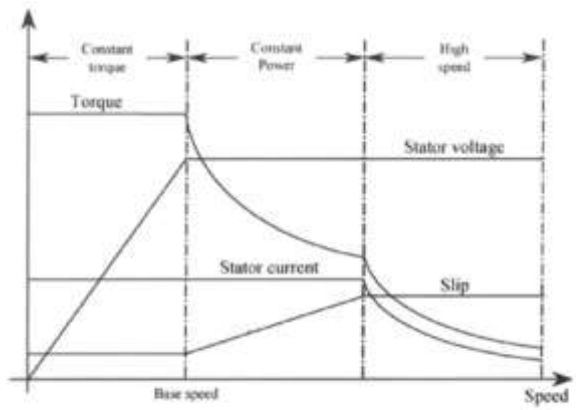


Fig-2: Characteristics of an Induction Motor

Permanent magnet synchronous motors (PMSM) are another type of motor that is being studied extensively. It is a brushless motor, thereby increasing its robustness. This also means that this type of motor requires less maintenance. The biggest advantages of a permanent magnet synchronous motor are the high efficiency, high reliability, high power density and uniform heat dissipation. But similar to induction motors, permanent magnet synchronous motors also have a narrow operative power range, meaning that there is only a narrow speed range where the motor can produce a useful power output. There are also demagnetization issues that occur due to the heat or the armature reaction. Another major disadvantage of the permanent magnet synchronous motor is the cost. These types of motors use rare-earth metals such as Neodymium which is extremely costly, thereby driving up the price of the motor as well.

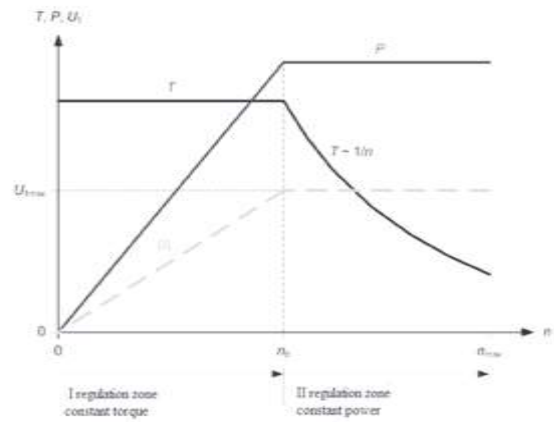


Fig-3: Torque-speed characteristics of a PMSM

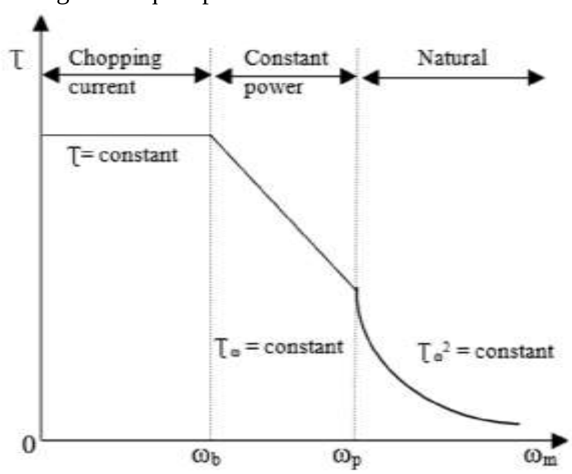


Fig-4: Characteristics of a SRM.

The switched reluctance motor is another type of motor that runs by the reluctance torque. The unique aspect of this motor is the power delivery. Unlike brushed DC motors, the power is delivered to the stator instead of the rotor. This greatly simplifies the mechanical design of the motor as the power is not being delivered to a moving part, but this also adds to the complexity of the electrical design. This means that a switching mechanism needs to be added to the motor, thereby giving the motor its name. Switched reluctance motors are actually being considered as a viable option for Hybrid Electric Vehicles (HEV) due to the ease of construction, excellent speed torque characteristics and a fairly simple control process. But this motor also has a lot of significant disadvantages such as high noise and high torque ripple.

Brushless DC motors (BLDC) are the most suited for our application. They possess excellent speed torque characteristics, a wide speed range compared to induction motors, higher power densities and low maintenance due to the lack of brushes. This also means that BLDC motors do not suffer from sparking issues that conventional brushed DC motors suffer from. The BLDC technically is a type of synchronous motor owing to the fact that the magnetic field produced by the rotor and stator rotate at the same synchronous frequency. The pair poles are energized in a sequential manner such that rotation is started and maintained. Apart from the already mentioned characteristics of a BLDC motor, it is lighter, easier to control, and less prone to failures that occur in brushed motors. By employing BLDC motors in electric vehicles, an important thing that needs to be addressed is the battery. The battery acts as a source for the BLDC motor and thereby, it must be highly efficient. The use of rechargeable batteries can help increase the efficiency of the entire system. The usage of rechargeable batteries also lets us use regenerative braking in order to replenish the charge of the battery.

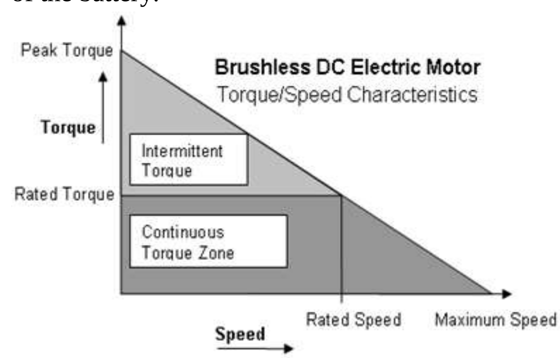


Fig-5: Torque-speed characteristics of a BLDC motor

## III. DRIVE CIRCUIT FOR THE VEHICLE

We have now reached a conclusion through inspection that the BLDC motor is a viable choice that can serve our purpose. We also require a circuit to drive the motor in order to deliver the necessary power to the motor. We will be using hall sensors in order to detect the position of the rotor and to effectively perform motor control. We also use a pulse width modulated induction motor drive. For our application, we need to perform two main tasks:

- Calculation of the force required and the torque produced in order to help us in motor selection.
- Design of the DC-DC buck converter in order to step down the voltage to the required levels.

*A. Design calculations for motor selection:*

We have performed the design calculations for the parameters given below:

Gross weight of the auto rickshaw = 600 Kg

Kerb weight of the vehicle = 290 Kg

Maximum velocity = 40 Km/h

Wheel (rim) diameter: 10 inch = 25.4 cm = 0.254 m.

Circumference of the wheel = $\pi d$ = 79.76 cm = 0.7976 m

Wheel speed = 752 rpm

Assume, transmission efficiency = 0.85

Transmission ratio (Differential rating) = 10:1

Gradient = 9°

We need to first calculate the total force that is required in order to propel the auto-rickshaw of the above parameters forward, followed by the total power output of the motor in order to sustain that motion.

*B. Calculation and theory:*

The force required for driving a vehicle forward is:

$$F_{total} = F_r + F_g + F_a$$

Where,

$F_r$ = Force required to overcome rolling resistance.

$F_g$ = Gradient resistance.

$F_a$ = Air resistance.

$F_{total}$ = Total tractive force that the output of the motor must overcome in order to move the vehicle.

Rolling resistance:

$$F_r = C_{rr} \times M \times g$$

Where, $C_{rr}$ is the coefficient of rolling resistance. It is a value that will be experimentally determined for different materials and can vary by the load on the wheels, material of the wheels and that of the surface.

$$F_r = 0.02 \times 600 \times 9.81 = 117.72N$$

Air resistance:

$F_a$ = (drag-coefficient) × (area of the front surface) × (velocity)$^2$ in Km/h

Here, drag-coefficient ≈ 0.0032 for small vehicles.

Area of the front surface = $(height) \times (width)$

$$= 1.7 \times 1.2 = 2.04\ m^2$$

$$F_a = 0.0032 \times 2.04 \times 40^2 = 10.44N$$

Gradient resistance:

$$F_g = \pm(weight) \times \sin\theta$$

For bodies that have wheels, the rolling resistance has to be considered in place of the weight, therefore the above equation now becomes:

$$F_g = \pm(rolling\ resistance) \times \sin\theta$$

$$= 117.72 \times \sin(9°) = 18.42\ N$$

Therefore, $Total\ force = F_r + F_a + F_g$

$$= 117.72 + 10.44 + 18.42 = 146.58N$$

Motor torque:

$$\tau_m = \frac{\tau_\omega}{(gear\ ratio) \times (transmission\ \eta)} = 2.24Nm$$

Motor power:

$$Motor\ power = \frac{2\pi NT}{60}$$

Here, N is the RPM of the motor.

$$N = N_{wheel} \times gear\ ratio = 7520\ RPM$$

Therefore, $motor\ power = \frac{2\pi \times 7520 \times 2.24}{60} = 1.76KW$

Thus, the power that needs to be given by the motor is around 1.76 KW, which means we will require a motor with a rated power greater than 1.76 KW.

## IV. DESIGN OF DC-DC BUCK CONVERTER

As discussed above, we will be using a DC-DC converter in order to step down the voltage so that the efficiency can be as high as possible. In our case, we need a buck converter. The requirements for our particular use case are as follows:

- Battery voltage: 48V DC
- System voltage: 12V DC
- Head lamps = 35 KW (1 no.) = $\frac{35}{12} = 3A$
- Side indicator lamps = 10KW (2 no.) = $2\left(\frac{10}{12}\right) = 1.7A$
- Stop lamp = 10 W (2 no.) = $2\left(\frac{10}{12}\right) = 1.7A$
- Horn = 12V DC = 1A

This means that we will not only need to step down the voltage to 12V but also maintain a current of around 7.5A in order to satisfy the other electrical components.

*A. Design of the DC-DC buck converter:*

$$\Delta V_c = 2.5\%\ of\ V_0 = 0.025 \times 12 = 0.3V$$

$$\Delta I_{load} = 5\%\ of\ I_0 = 0.05 \times 7.5 = 0.38A$$
$$\Delta I_e = 10\%\ of\ I_0 = 0.1 \times 0.75A$$
$$Duty\ cycle\ (d) = \frac{V_0}{V_{dc}} = \frac{12}{48} = 0.25 = 25\%$$
$$L_e = \frac{V_0(V_{dc} - V_0)}{\Delta I_e f V_{dc}} = \frac{12(48-12)}{0.75 \times 20 \times 10^3 \times 48} = 600\mu H$$
$$C_e = \frac{\Delta I_e}{\Delta V_c \times 8f} = \frac{0.75}{0.3 \times 8 \times 20 \times 10^3} = 15.63\mu F$$
$$R = \frac{V_0}{I_0} = \frac{12}{7.5} = 1.6\Omega$$
$$L = \frac{\Delta V_c d}{\Delta I_{load} \times f} = \frac{0.3 \times 0.25}{0.38 \times 20 \times 10^3} = 9{,}86\mu H$$

In order to test the design, we need to simulate the DC-DC buck converter using our calculated values. The simulation has been done using Simulink. The block diagram and the simulation results are shown below:

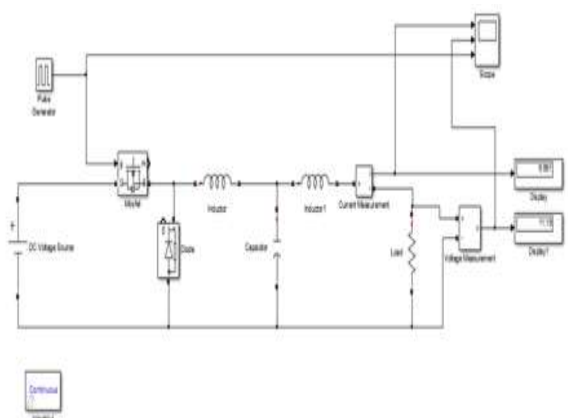

Fig-6: Simulink block diagram of the DC-DC buck converter

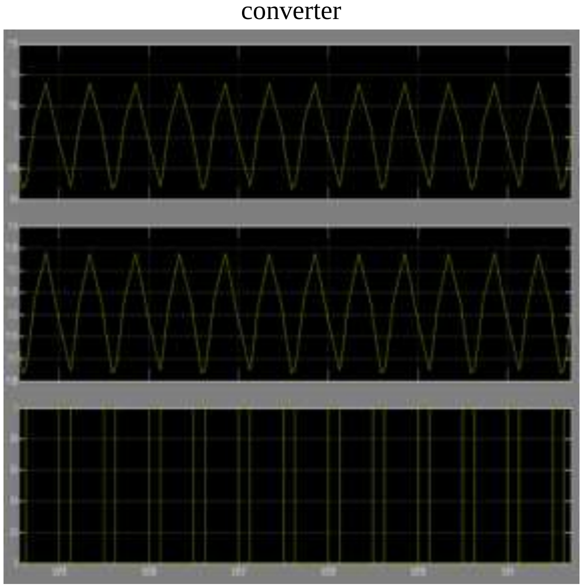

Fig-7: Simulation output waveforms

## V. OBSERVATIONS

It is seen that the output waveforms and the values of the output seem to be satisfactory. The observations we can make out of the waveforms are:

- There are small variations in output voltage and current
- For continuous current conduction, the value of Inductance should be more than critical inductance
- Load side inductor further reduces harmonics in the waveforms.
- We also need to consider the acceleration factor. Mostly, the acceleration of a vehicle is around 2-5 meters per second square. So, we also consider an average acceleration as 3.5 m/s2.

## VI. CONCLUSION

The study of the various motors for the usage in an electric vehicle have been studied. It is found out that the BLDC motor is perfect for this application. We also realize the need for the motor drive circuit. The study of various parameters such as the total force required in order to propel the vehicle forward and the total torque produced has been performed and the calculations have been performed for the given input parameters. Based on these parameters, we have selected what might be the suitable components that can be employed in order to fabricate the required electric drive-train that can successfully be retrofit into a conventional auto-rickshaw. We have also studied more about how the supply for the motor can be given, where we zeroed down on using a 48V battery and then stepping down the voltage to the required 12V using a DC-DC converter, more specifically a DC-DC buck converter. We have successfully designed a DC-DC buck converter for the required voltage. We have also performed the necessary calculations and simulations and the DC-DC buck converter works as desired.

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