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Design of Motor and Power Electronic Converters for Electric Vehicle Conversion

Dr.S.Allirani,
Senior member IEEE
Associate Professor,
Dept. Of Electrical and Electronics,
Sri Ramakrishna Engineering College,
Coimbatore, India
allirani.saminathan@srec.ac.in

Madhumithaa.V,
Student member IEEE,
Dept. of Electrical and Electronics,
Sri Ramakrishna Engineering College, Coimbatore, India.
madhumithaavl@gmail.com

Gowtham.K,
Dept. of Mechanical,
Sri Ramakrishna Engineering College, Coimbatore, India

Abstract

In recent times, the transportation system has made a major leap from internal combustion engine vehicles to electric vehicles, where conventional IC transmission system has been replaced by pure electric or hybrid electric transmission systems. In order to support this change in the industry and as a means of promoting sustainable energy in the automotive sector, we have proposed an electric transmission system that runs with the help of an induction motor and power electronic converters. At present the vehicles use brushless DC motors which are comparatively expensive for a converted electric vehicle and moreover they have power capacity restrictions and cannot be used for high power demanding vehicles. The proposed design of an electric induction motor is cost effective, has simpler construction, is easily available in the market and finally it will overcome the power capacity restrictions of a BLDC motor. They are coupled and operated with high efficiency DC-DC power converters for better performance and reduced power loss. Furthermore, induction motors lack commutators which reduces the electronic commutator cost of a brushless DC motor. Power converters are key structures that are used to control motor characteristics and one such suitable converter will be discussed in this paper.

Keywords- *Brushless DC motors, Electronic commutators, Transmission system, Induction motors Internal Combustion engine, DC-DC converters.*

I. INTRODUCTION

The present growth of the automotive sector has been rapid and has made a commendable increase in the production of electric vehicles. Soon there will be a great switching from usage of fossil fuels to electric energy for transportation. It is evident that the changing sector requires a lot of new industry to produce motors as well as other components required for an electric vehicle and establishing new industries will require at least a minimal period of time. Also switching entirely to electric vehicles will lead to abandon the existing IC engine vehicles. So, in order to create a significant contribution to this change we have suggested to convert an existing IC engine vehicle to an electric vehicle by replacing only the transmission system, which is the engine gearbox and sprocket in a two-wheeler. The IC engine is replaced by an electric induction motor, a DC-DC converter, inverter and a motor drive. The abundant availability of induction motor for various power ratings in the market as well as its

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simple construction makes it the most suitable type of motor for usage in a retrofitted vehicle. Many other advantages for selection of an induction motor are discussed below. The usage of power electronic converters is an equally important aspect that has to be considered while manufacturing an electric vehicle. A suitable design of a DC-DC power converter compatible for the selected vehicle existing in the market and its motor design are also addressed further in this paper.

II. LITERATURE SURVEY

At present there are various types of electric vehicles in the market all over the world. The Indian market has been evolving day by day with new electric vehicles being produced increasing at an exponential rate especially in the past few years. Developed countries like the USA and other European countries have introduced advanced electric vehicles with high range and efficiency. The existing EV market uses various types of motor in its transmission system. They can be BLDC that are mostly use for low range and low power electric two wheelers but these motors have limited power capacity and hence research has been conducted to develop motors that can be more efficient for large vehicles. Few of the two wheelers available in the market has been studied for the experiment is listed below:

1. **Okinawa praise**: This is a two-wheeler and it employs BLDC motor in transmission. The power rating of vehicle is 1000 watts. The range of this vehicle is 55km to 75km per charge. Its top speed is 75kmph.[2]. Its battery capacity is 72V 45A. It costs approximately 60,000 rupees.
2. **Palatino princess**: It is a two-wheeled vehicle. It also uses BLDC motor in its transmission system. The power rating of the vehicle is 250 watts. The range of the vehicle is around 60 kms per charge. Its top speed is 25km per hour. The battery capacity is 40V 20Ah. It costs around 40,000 rupees.
3. **Techno Electra Neo**: this is a two-wheeler and it employs BLDC motor in transmission. The power rating of this vehicle is 250 watts. The range is between 60km to 65km per charge. Its battery capacity is 12V 20A. It costs around 40,000 rupees.
4. **Ampere Zeal**: This is a two-wheeler manufactured in India and it uses BLDC motor in its transmission system. The power rating of this vehicle is 1.2 kilowatts and its battery capacity is 60V 30A. It has range of 75km per hour and the top speed it can reach is 55 kmph. It costs around 65,000 rupees.
5. **Komaki X**: It is a two-wheel vehicle. It also uses BLDC motor in its transmission system. The power rating of the vehicle is 1.18 kilowatts. Its battery capacity is 60V 30A. It has a range of 70kms per charge but it has a very low speed compared to its competitors. Is costs around 30,000 rupees.

Types of motors used in the electric vehicles manufactured at present are listed below:[1]

Brushed DC motor: This motor has a powerful starting torque making it an ideal choice for electric vehicles as they usually require the motor to start with a load. But they have a major issue of sparking, that can cause initiation of fire and can be dangerous. Hence these motors are not preferred by many manufacturing brands.

Induction Motor: These motors run on alternating current and do not require a commutator, therefore eliminating the problem of sparking. These motors when coupled with an ideal capacitor can give excellent starting and running torque. They are not commonly used for two wheeled electric vehicles, but some automotive companies such as Tesla Motors use this type of electric motor to produce a pure electric vehicle.

Brushless DC motor: This motor is both brushless and it runs on DC. It is used widely in electric vehicle manufacturing and it has a higher efficiency than DC motors. They are expensive and also encounter with the problem of torque ripple. Their control circuitry is very specific and hard to design and implement.

Permanent Magnet Synchronous Motor: These are the latest modern technology enhanced motors used in electric vehicles. They overcome most of the setbacks of conventional motors but they are very expensive for a retrofitted vehicle. Higher end cars employ such motors in their transmission systems.

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III. THE EXISTING VEHICLE CONSTRAINTS

Since a converted electric vehicle consists of the mechanical components and chassis of the IC engine vehicle which is modified, there will be few technical constraints with regard to the space availability. It will also have some pre-determined values of torque values that are required to be supported by the motor being modelled. The IC engine vehicle chosen as an example for torque and other specification consideration is Hero splendor.

Fig.1 Frame of the vehicle without engine and gearbox

The available space dimensions to fit in motor and other components are

- Lateral length = within 30cm
- Height = between 17-19cm

The motor designed should will occupy only 25 percent or less, so as to accommodate the battery and controller circuits. A possible simulation model depicting the placement arrangement of the motor and battery pack within the available frame space in the given vehicle is shown below.

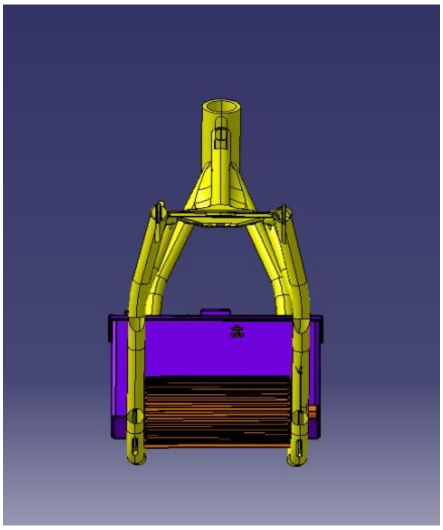

Fig.2 CATIA model of motor and battery pack arrangement in the vehicle frame

For an IC engine the torque values are managed according the gear ratios in the gearbox. Wherein there is no need to employ a gearbox for an electric vehicle because the motor's speed and torque governance is done by varying the voltage and current inputs to the motor by the means of converters and a closed-loop feedback control by a controller.

Therefore, the maximum torque required at the wheel is calculated. It is derived from the existing maximum torque which the IC engine was able to give. The output torque of the converted vehicle will be almost equal to the calculated torque.

The torque values produced by the IC engine of the vehicle with the corresponding gear ratios and gears are listed below in the table

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TABLE I

Gear	Gear ratio	Torque (Nm)
1	2.059	16.57 at 2915rpm
2	1.706	13.73 at 3517rpm
3	1.238	9.96 at 4846rpm
4	0.9583	7.71 at 6261rpm

That the maximum torque required to propel the vehicle at all possible conditions is satisfied by the IC engine with existing gearbox and sprocket with its corresponding gear and sprocket ratio.
Maximum torque at wheels:
The maximum torque produced by the engine 8.06 Nm at 6000 RPM and the maximum multiplier of torque is at first gear with gear ratio of 2.057 as given in the table
Maximum output torque at output shaft T_{shaft} (Nm) Engine torque x gear ratio
T_{shaft} = 8.05 x 2.059= 16.57 Nm at 6000 RPM
Torque at the shaft will be equal to the torque at the driving sprocket.
Torque at driven sprocket (T_{DN}) =Driving sprocket torque (T_{shaft}) x Sprocket ratio
T_{DN} = 16.57 x 3.07
where 3.07 is the existing sprocket ratio of the vehicle.
Torque driven sprocket (T_{DN}) =50.86 Nm
Torque required at wheel (T_{wheel}) = T_{DN} x wheel radius(r), r = 24 inches for this vehicle
T_{wheel} = 50.86Nm x 0.305m
Required maximum torque at wheel (T_{wheel})= 15.512Nm
The sprocket ratios can be modified as such the designed motor is able to give the maximum torque at the wheel

IV. MOTOR DESIGN

The motor designed is a three-phase asynchronous induction motor with power rating of 745 watts.
The motor parameter calculations are as follows:
Output equation is [6]
$P_o= C_0 D^2 Ln$ where C_0 is $\pi^2 B_{av}\, ac \times 10^{-3}$
B_{av} = Specific magnetic loading
ac = Specific electric loading
where B_{av} and ac have reference values [4]
n = Speed in RPS
D and L are the main dimensions of the motor
Stator turns per phase is [5]
$T_s = \frac{E_s}{4.44\ \varphi K_w}$
where E_s is the input voltage
φ is the flux per pole
f is the supply frequency of the AC voltage
Number of stator slots is given by
$S_s = \frac{\pi D}{Y_{ss}}$
D is the stator diameter
Y_{ss} is the stator slot pitch
Conductor per slot is given as
$Z_{ss} = \frac{6\mathrm{Ts}}{S_s}$
$T_s = T_r$ where T_r is the number of turns in rotor per phase.
Stator resistance is given by the equation

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$r_s = \frac{\rho T_s L_{ms}}{a_s}$ [5]
where L_{ms} is the length of mean turn of stator
a_s= area of stator conductor
ρ is the resistivity of the material used for the winding.
Rotor resistance can be written as
$r_r = \frac{\rho T_s L_{mr}}{a_r}$
here the value a_r is the area of rotor conductor
L_{mr} is the length of mean turn of stator.
The motor parameters were calculated and input as given below:

TABLE II

S. No	Parameters	Values
1	Efficiency (%)	73.2386
2	Power Factor	0.0857116
3	Rated Slip	0.594443
4	Input Power (kW)	1.01724
5	Output Power (kW)	0.745009
6	Total Loss (W)	272.227
7	Mechanical Shaft Torque (Nm)	5.1875
Stator details		
8	Number of Stator Slots	58
9	Outer Diameter of Stator (mm)	130
10	Inner Diameter of Stator (mm)	85
11	Length of Stator Core (mm)	75
12	Coil Pitch	9
13	Copper Loss of Stator Winding (W)	173.698
14	Stator Phase Current (A)	2.45188
Rotor details		
15	Number of Rotor Slots	18
16	Air Gap (mm)	0.1
17	Skew Width(mm)	0.5
18	Length of Rotor (mm)	75

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19	Copper Loss of Rotor Winding (W)	71.6623
20	Rotor Phase Current (A)	1.42696
21	Resistivity of Rotor Bar at 75 Centigrade (ohm.mm^2/m)	0.0263158
22	Resistivity of Rotor Ring at 75 Centigrade (ohm.mm^2/m)	0.02631
23	Rotor Leakage Reactance X2 (ohm)	7.72963
Winding arrangement		
The 3-phase, 2-layer winding can be arranged in 9 slots as below: AAAZZZBBB		
24	Angle per slot (elec. degrees)	20
25	Phase-A axis (electrical degrees)	110
26	First slot centre (electrical degrees)	0
Breakdown operation		
27	Break-Down Slip	0.7
28	Break-Down Torque (Nm)	16.3311
29	Break-Down Torque Ratio	3.14816
30	Break-Down Phase Current (A)	7.63642

V. SIMULATION RESULTS OF MOTOR

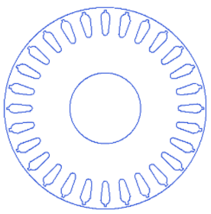

Fig.3 Rotor design

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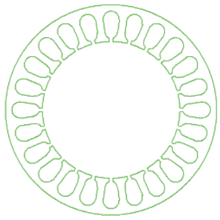

Fig.4 Stator design

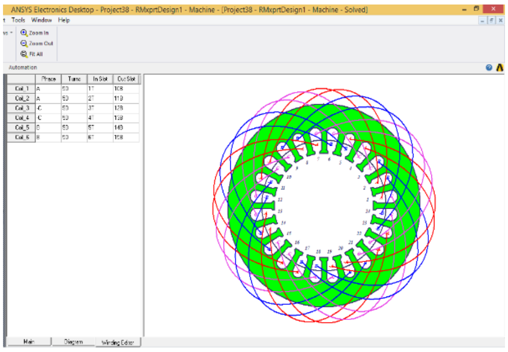

Fig.5 Coil windings for three phase

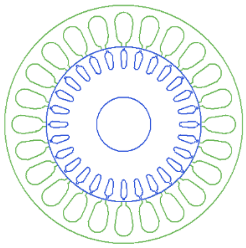

Fig.6 Design of 1HP three phase induction motor

The output characteristics of the designed motor can be understood from the obtained graphs from simulation below:

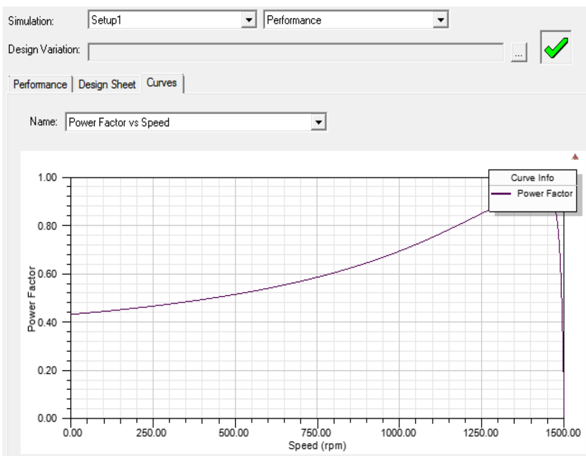

Fig.7 Power factor vs speed characteristics

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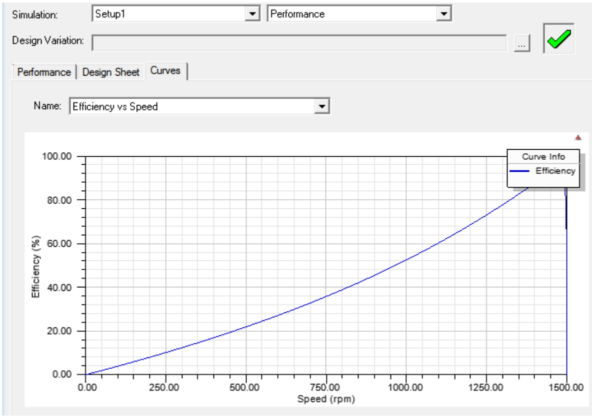

Fig.8 Efficiency vs speed characteristics

The output graphs denote that the motor's efficiency and power factor can reach a maximum up to 95% and unity power factor under ideal simulating conditions. However, in real time the efficiency and power factors are proportional to the losses, on the terrain chosen for driving the vehicle and on factors such as temperature. The average values of efficiency and power factor after considering all other factors for losses are given in the Table 2.

VI. CONVERTER DESIGN

A DC-DC converter is used to step-up or step-down DC voltage in a DC circuit. They are commonly referred as choppers and are classified according to their operation. A DC-DC converter used to step up voltage is step-up chopper or otherwise type B chopper [7]. In a step-up chopper the output voltage V_o is greater than input voltage and its conversion ratio is given as

$M = \frac{1}{1-D}$[8]

where D is the duty cycle of the step-up chopper.

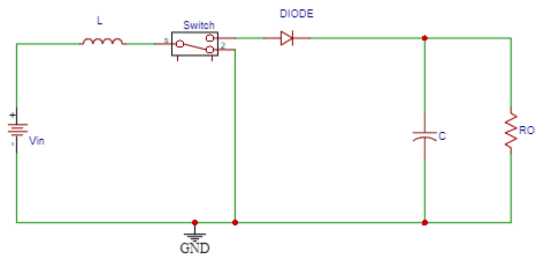

Fig 9 Schematic of a boost converter

The schematic represents a boost converter designed for the application of integrating in an electric vehicle. The voltage, current and power ratings are chosen according to the maximum demand from the load, in this case the maximum ratings of the designed induction motor is taken as a reference. The DC-DC converter schematic shown will operate in two switching modes where switched mode 1 when the switch is in position 1 and mode 2 when switch is in position 2. The switch is realized using a power MOSFET.

The design parameters are calculated as follows:

Total time period per cycle $T=\frac{1}{f}$

f is frequency in Hz

Output voltage $V_o = \frac{1}{T_s}\int_0^{T_s} V_s(t)dt$

where V_s is the input voltage and T_s is the switching period.

Inductor voltage $V_L = L\frac{I_{L1}-I_{L2}}{T_{on}}$ [9]

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Average inductor current I $=\frac{V_s}{(1-D)^2 R}$

T_{on}=T_s, I_L is the current through the inductor and L is the inductance.

Capacitor current i_c= $I_L - \frac{V_o}{R}$

R is the load resistance

Output voltage ripple Δv $=\frac{V_o}{2RC} DT_s$

where c is the capacitance and D is the duty cycle of the converter.

The output of the designed circuit is evaluated using Simulink and output graphs are obtained.

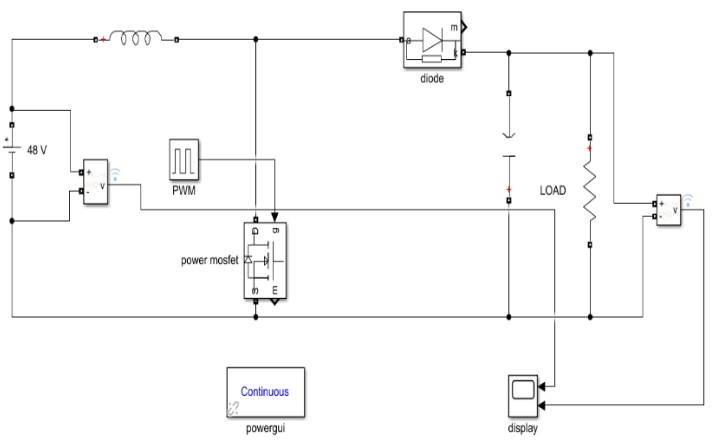

Fig.10 MATLAB simulation of boost converter

VII. RESULTS AND CONCLUSIONS

The graphs obtained from simulation of the boost converter for output voltage and current are as follows:

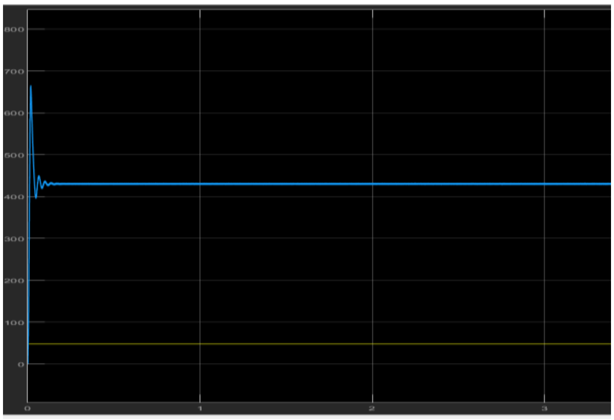

Fig.11 Output and input voltage waveforms of the converter

- Output voltage
- Input voltage

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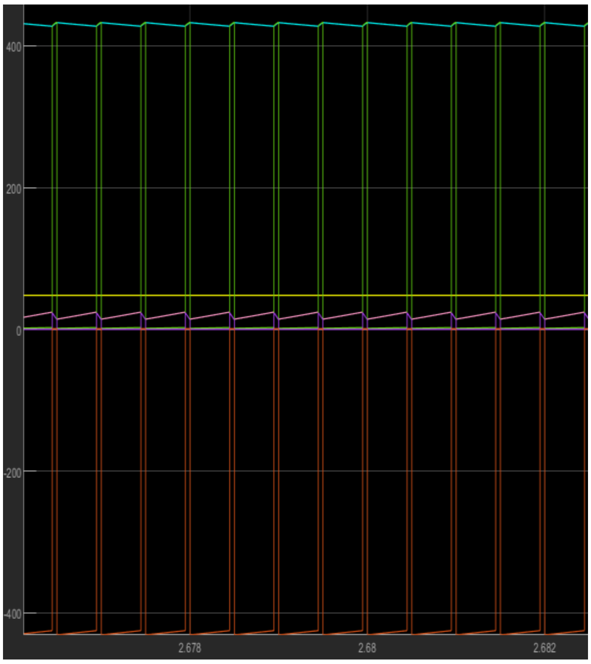

Fig.12 Current and voltage output waveforms

- Diode voltage
- Output voltage
- Diode current
- MOSFET voltage
- Input voltage

The output voltage is obtained as desired for the given application. The voltage ripple of this circuit is less than 1%. The output voltage ripples can be further reduced by using various mitigation techniques and one such technique is addition of auxiliary capacitor [10] in parallel to the existing capacitor to reduce output voltage ripples of the converter. The reduction in voltage ripple will substantially contribute to increase in the efficiency of the converter as well as the overall system performance. Thus, from the simulations we find that the motor and converter designed give the estimated power to drive the vehicle taken for consideration for the design constraints.

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