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Modelling of a Power Train for Plug-in Electric Vehicles

Vikas Gupta*
vikas@cpdm.iisc.ernet.in

Abstract

In this paper author modelled a novel propulsion system for plug in electric vehicles starting from Lithium ion battery to drive train, it also include a controller and a Brush Dc Motor. While modelling this propulsion system the author used a High Boost Converter which gives quite a high boost to input voltage thus with the help of a High Boost converter the author tried to reduces number of batteries in an electric vehicle since a High Boost converter amplifies a small input voltage to quite a high output voltage, thus this system reduces the number of batteries in an electric vehicle. Reducing number of batteries will decrease the overall weight of the electric vehicle and will also provide more space for passengers in the vehicle. Less weight vehicles gives more miles per charge as compared to heavy vehicles. This propulsion system is also low cost and simple in design as it uses a Brush Dc Motor since brush dc motor and its controller are low cost and the controller design for Brush Dc Motor is also easy

*Center for Product Design and Manufacturing, Indian Institute of Science, Bangalore, India

and simple. This propulsion system uses high quality power semiconductors which has minimum losses and are thermally protected and the number of circuit elements used is also very less which gives this propulsion system additional advantage from road shocks. IC 555 Timer is used in this propulsion system, IC 555 Timer ICs are the most widely used and stable ICs and they are easily available, so there is no road block like non-availability of electronic components in designing this propulsion system. This propulsion system can use all 5 types of brush dc motors. The main focus is to model a power train of an electric vehicle in traffic congestion scenario where more than 50 vehicles are present and the driver has to maintain a fix distance with the cars which are in its immediate front and back and to vary speed and acceleration of its car nonlinearly according to traffic demand so as to avoid any collision with neighboring front and back cars. A traffic congestion scenario with more than 50 vehicles is considered to calculate variable acceleration and velocity of electric vehicle, the braking rate of the driver is also considered since in such traffic congestion use of brake by the driver will be quite high. To make the result more accurate the author has taken 10 different velocity and acceleration values at 10 different time interval and for each time interval the author has calculated the power of the motor and finally taken the average of all 10 values to calculate more accurate value of power of a motor. The author also used a variable gear drive train since a variable gear drive train offers more energy efficiency, high acceleration , more top up speed . All type of opposing forces and losses like gravity force, air drag, rotational inertia, gear losses has been considered to model the power train of the electric vehicle in the paper.

Keywords

Electric vehicles, Brush DC motor, Controller, Drive train, Torque, Power, Resistance forces, Gear loss.

Introduction

Electric vehicles technology is advancing and becoming popular with [2] every passing year. People either buying electric vehicles or they are converting [14, 16] their existing petrol vehicles into electric vehicles Still researcher around the globe is finding difficulties in finding solution of existing problem in electric

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vehicles like cost and miles per charge . Lot of research has been done in past to reduce the cost and increase the miles per charge of the electric vehicles. The author tries another and a novel way to solve both these problems in electric vehicles through a novel propulsion system describe in this paper. This propulsion system not only reduces cost with the help of brush DC motor [1, 3, 4] and its controller but also reduces cost by reducing number of batteries as this propulsion system can give high output voltage with small input voltage so we need fewer batteries and using fewer batteries also reduces the weight of the vehicle and light weight vehicles gives more miles per charge as compared to heavy vehicles. The power of a motor is calculated under city traffic conditions. Considering a complex city traffic scenario [29, 30, 31] the main thing to observe is that the velocity and acceleration are not constant and keep on changing non-linearly, this can be concluded by various urban drive cycles. Calculating power of a motor for electric vehicles under city traffic and dynamic conditions is quite complex and challenging. Most people assume steady state conditions and other linear and simple scenario to calculate power of a motor for electric vehicles. This paper tries to dig deep on all possible scenarios while calculating power of a motor for electric vehicles under city traffic condition. All the necessary calculations of calculating power of the motor and gear loss are done in MATLAB [17, 18, 19, 20].

Battery

The batteries used in this propulsion system are lithium ion batteries since lithium ion batteries [11] has certain advantages as compared to lead acid batteries, some of the advantages are mention below:

1. Higher voltage in Lithium Ion over Lead Acid,
2. Greater Energy Density per unit Weight, Volume
3. Lighter / smaller providing more portability, less storage
4. Space, could even eliminate storage boxes
5. Tolerates Higher Temp and no Air Conditioning required
6. Faster recharge time
7. Higher turnaround charge efficiency
8. More Discharge Cycles

9. Deeper Discharge Tolerance
10. State of health and state of charge can be readily and
11. Remotely monitored
12. Longer time between service
13. Li-Ion batteries average replacement time is 5-7 years while
14. Lead Acid batteries replacement time is 1.5 - 2 years

This propulsion system uses a high boost converter which is capable to give high output voltage with small input voltage so the amount of batteries require in such propulsion system will be less and thus we require less number of lithium ion battery thus the cost of entire propulsion system will be less and it also neutralizes high cost of lithium ion batteries.

Controller

The controller consists of an IC 555 Timer and High Boost converter [6, 7]. The output voltage which goes to motor through High Boost converter depends on duty ratio and duty ratio can be varied through IC 555 Timer circuit by varying one of the resistances which connected to the brakes of the electric car. Entire method is explained in detail. The main reason of using IC 555 Timer is its stability, cheap cost and easy availability. This method of controlling DC Motor speed is cost affective. Refer figure 1, 555 Timer is used as an astable circuit. Astable 555 Timer produces a square wave output with transitions between low (0 V) and high (+ V1) as shown in figure 1. The output is continuously changing between low and high. During T_{ON} the capacitor will charge through Ra and a high pulse with amplitude (V1) is generated, during T_{OFF} the capacitor discharges through Rb generating low pulse.

$$T_{ON} = 0.69 * Ra * C_4 \tag{1}$$

$$T_{OFF} = 0.69 * Rb * C_4 \tag{2}$$

$$T_S = T_{ON} + T_{OFF} \tag{3}$$

$$T_{ON} = DT_s \tag{4}$$

$$T_{OFF} = (1 - D)T_s \tag{5}$$

$$DutyRatio(D) = \frac{T_{ON}}{(T_{ON} + T_{OFF})} \tag{6}$$

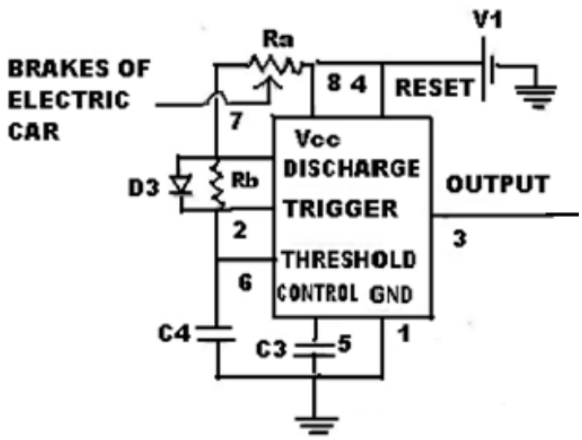

Figure 1: *IC 555 Timer Circuit*

$$DutyRatio(D) = \frac{Ra}{(Ra + Rb)} \tag{7}$$

T_{OFF} is fixed while TON can be varied by varying resistance of potentiometer

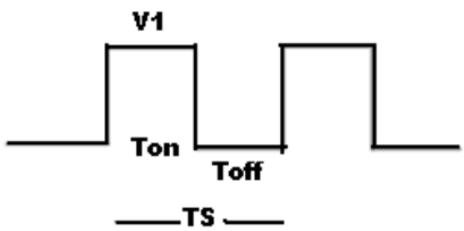

Figure 2: *Output through IC 555 Timer*

Ra. To achieve variable duty cycle a diode is added in parallel with Rb as shown in the figure 2. This bypasses Rb during the charging part of the cycle so that TON depends only on Ra and C4. Figure 3 shows a High Boost converter, its working is as follows:

During time DT_s or T_{ON}

Here S1 and S4 are ON and S3 and S2 are OFF. The voltage across L1 is given as:

$$V_{L1} = V_{input} + V_{C1} \tag{8}$$

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The inductor stores energy during this time. During this time, the capacitor C1 reverses bias diode D2 and forward bias D1.The voltage across L2 is given as:

$$V_{L2} = V_{C1} V_{output} \tag{9}$$

During time $(1 - D)\, T_s$ or T_{OFF}

In this case S1 and S4 are turned OFF and S3 and S2 are ON. The energy in the inductor L1 charges up the capacitor C1 through the diodes S3 and S2. The voltage across L1 is given as:

$$V_{L1} = V_{input} V_{C1} \tag{10}$$

During the time, the current in L2 through D2 transferring energy from L2 to C2. The diode D1 is reverse-biased during this time and is therefore OFF. The voltage across L2 is given as:

$$V_{L2} = -V_{output} \tag{11}$$

Applying the volt-second balance rule for L1:

$$(V_{input} + V_{C1}) T_{ON} + (V_{input} V_{C1}) T_{OFF} = 0 \tag{12}$$

$$V_{C1} = \frac{V_{input}}{1 - 2D} \tag{13}$$

Applying the volt-second balance rule for L2,

$$(V_{C1} V_{output}) T_{ON} + (-V_{output}) T_{OFF} = 0 \tag{14}$$

$$V_{output} = V_{C1} D \tag{15}$$

The following input-output relationship results:

$$V_{output} = \frac{V_{input} D}{1 - 2D} \tag{16}$$

$$I_{input} = \frac{I_{output} D}{1 - 2D} \tag{17}$$

The above relation clearly shows that we can get high amplification in input voltage using a High Boost converter [21, 6]. The IC 555 Timer output is fed to switches S1 and S4 of High Boost Converter. During T_{ON} when a high pulse from IC 555 Timer is giving to S1 and S4, S1 and S4 will be in ON state while during T_{OFF} a low pulse from IC 555 Timer is giving to S1 and S4, S1 and

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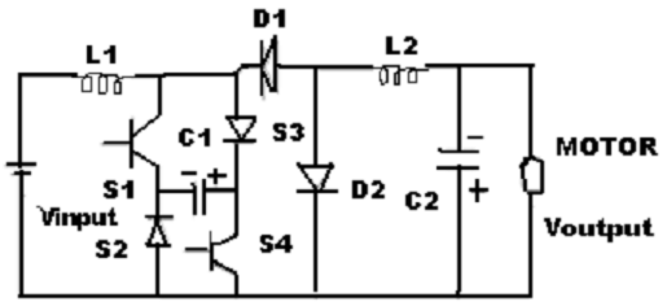

Figure 3: *High Boost Converter*

S3 will be in ON state while S1 and S4 will be in OFF state. In the given circuit the Duty Ratio can be varied by varying T_{ON} and T_{ON} can be varied by varying resistance of potentiometer Ra which is connected to brake of electric car. Thus resistance of Potentiometer can be varied by movement of brake. The voltage is varied to vary the speed of the motor while the current is varied to vary the torque of the motor. In this propulsion system as the voltage increases the speed of the motor increases while the current decreases, decreasing the torque of the motor.

Motor

This propulsion system uses a permanent magnet Brush DC Motor. Figure 4 shows the characteristics of permanent magnet Brush DC Motor [3].

Variable Acceleration

The acceleration of the vehicle can be calculated by equations 18, 19 and 20.

$$X(\beta) = \frac{Y}{\beta} - Z(\beta)^2 \tag{18}$$

$$Y = \frac{746 * H_p}{M} \tag{19}$$

$$Z = \frac{D * A * C_D}{M} \tag{20}$$

where, X is the variable acceleration of the vehicle, Y is the constant, Z is also a constant, β is the variable velocity of the vehicle, M is the mass of the vehicle and

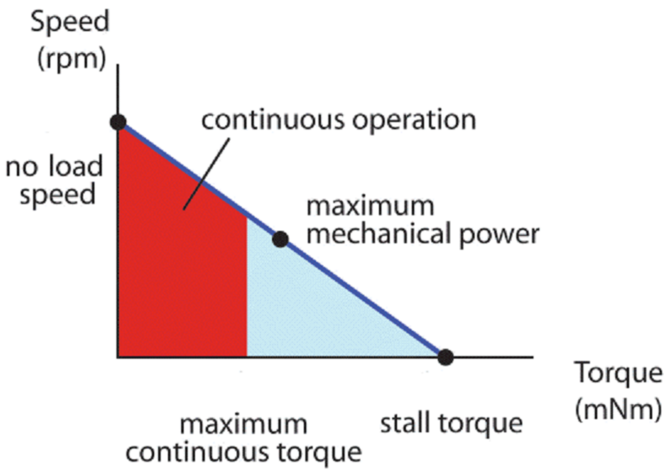

Figure 4: *Characteristics of Permanent Brush DC Motor*

A is the frontal area of the vehicle, D is the density of the air, C_D is the air drag.

To calculate the variable acceleration from above equations first the variable velocity is calculated, for calculating variable velocity we use intelligent driver model. The intelligent driver model [25, 26, 27, 28, 29, 30, 31] is defined by equations as shown below:

$$\frac{d\beta}{dt} = X * (1 - (\frac{\beta}{\beta_0})^4 - (\frac{\gamma}{\gamma_1})^2) \tag{21}$$

where,

$$\gamma = \gamma_0 + \beta S + \frac{\beta \Delta \beta}{2(XN)^{1/2}} \tag{22}$$

In the equations 21 and 22, γ_0 is the minimum distance kept between stand still in a traffic jam, β_0 is the velocity of the vehicle in free traffic, N is the braking deceleration and $\Delta\beta$ is the variation or fluctuation in the velocity.

All the values will dependent on a particular city traffic condition. The acceleration in terms of velocity defined in equation 18 is put in equation 21 and the equation 21 is integrated, after calculating the net velocity we can calculate the variable acceleration. The value of both variable velocity and acceleration can be matched with standard value given in some urban cycles shown in figure 3, 4 and 5. The velocity and acceleration is calculated for all 50 vehicles.

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Drive Train

The figure 5 shows a block diagram of variable gear drive train used in the propulsion system of electric vehicle. The figure 6 shows the various forces considered in calculating the power of a motor. The various resistance forces

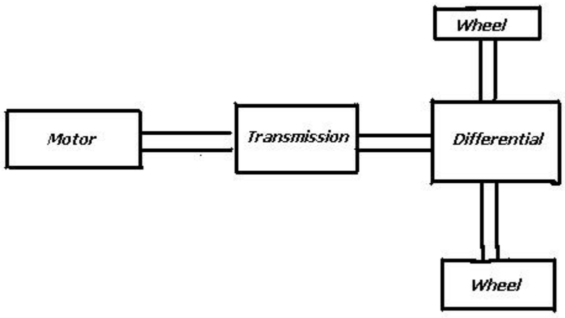

Figure 5: *Drive train of an electric vehicle*

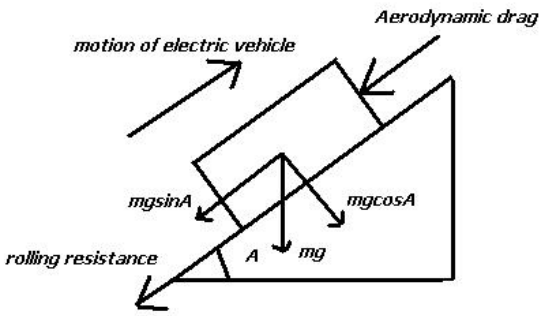

Figure 6: *Road load force components*

as shown in figure 6 are:

1. Rotational inertia
2. Gravity force
3. Aerodynamic drag
4. Rolling resistance

Rotational Inertia

The torque loss due to inertia [15] of rotating parts are calculated in equation 23.

$$C_{net} = C_{initial} - I\mu \tag{23}$$

Where, $C_{initial}$ - initially torque given by the motor, I is the moment of inertia of motor and μ is the angular acceleration of the motor.

Gear ratio amplifies the torque but again the torque is decreased by the inertia losses due to gear and shafts. So net torque delivered to drive shaft will be equal to as shown in equation 24.

$$C_{net1} = (C_{net} - I_1\mu_1)\alpha_1 \tag{24}$$

Where, C_{net1} is the torque left after transmission losses and I_1 is the moment of inertia of transmission and α is the gear ratio.

Torque delivered at axle is reduced by the inertia present at drive shaft but amplified by final drive ratio. Torque delivered at axle is shown in equation 25.

$$C_{net2} = (C_{net1} - I_2\mu_2)\alpha_2 \tag{25}$$

Where, I_2 and μ_2 are the moment of inertia of drive shaft and rotational inertia of the wheels.

The relation between rotational accelerations of the motor, transmission, and driveline and gear ratios is shown in equation 26.

$$I = I_1\alpha_1 = I_1 I_2\alpha_2 \tag{26}$$

The above equations 23 to 26 can be combined to calculate the rotational inertia, which is also known as mass factor and its value, is taken as 1.1.

Gravity Force

Gravity force is given as

$$MgsinA. \tag{27}$$

Rolling Resistance

The rolling resistance is calculated by equation 28.

$$R_r = \frac{(D_r(D_2V + D_3) * MgCosA)}{1000} \tag{28}$$

where D_r, D_2 and D_3 are rolling coefficient of resistance.

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Aerodynamic Drag

The aerodynamic drag is given as shown in equation 29.

$$D_A = \frac{1}{2\rho V * C_D * A_{rea}} \tag{29}$$

where, ρ is the air density, A_{rea} is the frontal area of vehicle and C_D is the aerodynamic drag coefficient.
Some of the values used to calculate to calculate these values are shown in Table 1.

Table 1: *Values of various parameters used*

M	1000 Kg
C_D	0.3
r	0.28m
D_r	1(Concrete Pavement)
D_1	0.0472
D_2	0.0328(Radial Tyres)
ρ	1.19Kg/m3
η	0.8 or 0.9
sinA	0.0665
Gear ratios	1.12, 1.67, 2.73, 4.6, 5.75

Gear Losses

The Gear losses three types of components:

1. Oil churing losses,
2. Air windage losses and
3. Mechanical losses which mainly consists of sliding losses and rolling losses.

Oil churing losses

The churing loss [22] is defined by the equation 30.

$$P_{churing} = \frac{1}{2} * C_m * \rho * \omega * S_m * r^3 \tag{30}$$

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Where, S_m is surface area in contact with the gear, C_m is 20/Re where Re is Reynolds number and its value is < 2000, r is the gear pitch radius and ρ is lubricant density.

Air Windage losses

The air windage [23] losses is defined by the equation 31.

$$P_{windage} = \frac{1}{2} * C_t * \rho * \omega^3 * r^5 \tag{31}$$

with With $C_t = C_f + C_l$

$$C_f = 2.301 * \frac{((3.10)^5)^{4.5}}{r^5} + 0.1011 * [\frac{1}{Re^{0.2}} - \frac{((3.10)^5)^{4.8}}{r^5}] \tag{32}$$

$$C_1 = \epsilon * \frac{Z}{4} * (\frac{b}{r}) * [\frac{1 + 2(1 + x)}{z}]^4 * (1 - cos\theta) * (1 + cos\theta)^3 \tag{33}$$

Where, ϵ is the coefficient for obstacles 0.5 for no obstacles, x is profile shift coefficient, θ is $\frac{\pi}{z-2} * (\frac{1}{\alpha_P} - \frac{1}{\alpha_A})$
α_P and α_A are pressure angle at pitch point and at tooth tip.

Sliding losses

Sliding losses [24] is defined by the equation 34. (Rolling losses are quite small so they are neglected).

$$\Sigma\mu(k) * F(N, K) * V(N, K) \tag{34}$$

With k: teeth whom come in contact .

$$\Sigma F(N, K) * V(N, K) = P_i * \pi * \frac{i + 1}{z1 * i * cos\beta} * (1 - (\epsilon A) + (\epsilon 1)^2 + (\epsilon 2)^2) \tag{35}$$

With P_i is input power, ϵ_A profile contact ratio and ϵ_1, ϵ_2 are tip contact ratio.

$$\mu(k) = 0.048 * (\frac{\frac{F_{bt}}{b}}{V\Sigma c} * \rho_{redc}) * \eta oil * R_a * X_1 \tag{36}$$

Where, F_{bt} is tangential force at the base circle, R_a is arithmetic mean roughness, X_l is lubricant factor, $V_{\Sigma c}$: sum speed at operating pitch circle and ρ_{redc} is reduced radius of curvature at pitch point.

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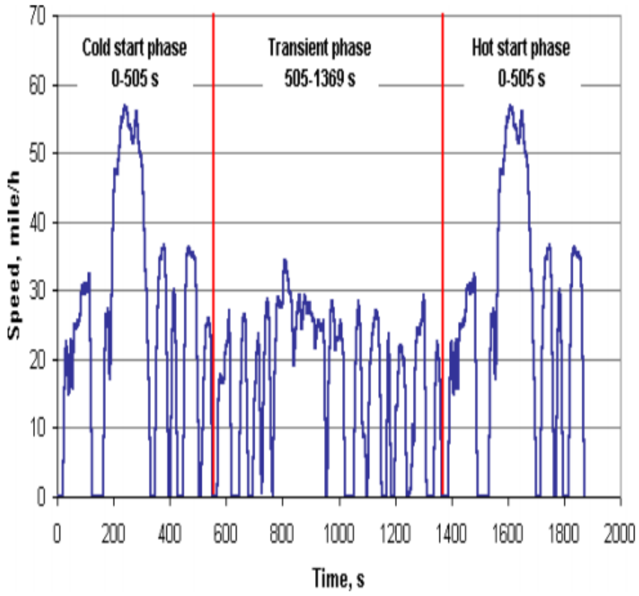

Figure 7: *FTP-75 test driving cycle established by the EPA*

Total gear loss is equal to sum of churing loss + windage loss+ sliding loss.

The figure 7, describe a urban drive cycle. This is a standard drive cycle and recorded in day to day normal traffic conditions: The table 1 and figure 7 shows various values of different components and the drive cycle considered to calculate the total power of Brush DC Motor.

Results

Considering all the parameters and components as shown in table 1, the total power of a Brush DC Motor ranges from 10 KW to 15 KW. The output of the controller is shown in table 2.

Conclusion

This paper shows a novel propulsion system for a plug in electric vehicles. The input voltage used is 35 Volt to generate a power excess of 10 KW at the output thus this propulsion help reducing number of batteries, thus reduces the overall weight of the electric vehicle and gives more space to passenger as the space

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Table 2: *Results*

V_{input} (in Volts)	I_{input} (in Amp)	Duty Ratio (D)	V_{output} (in Volts)	I_{output} (in Amp)
35	300	0.46	201.25	52.17
35	300	0.47	274.16	38.31
35	300	0.48	420	25

generally get reduce in electric vehicles since a lot of space is covered by the batteries. Light weight vehicle gives more miles per charge as compared to heavy vehicles. This system uses a Brush Dc Motor with variable gear drive train. The cost of this system is less and its design is also simple. Some body looking for a lost cost and simple design propulsion for plug in electric vehicle this is the ideal choice. The variable gear drive train gives more acceleration, top up speed and more energy efficiency. This propulsion system can be used in a four seater plug in electric car. Entire propulsion system is shown in figure 8.

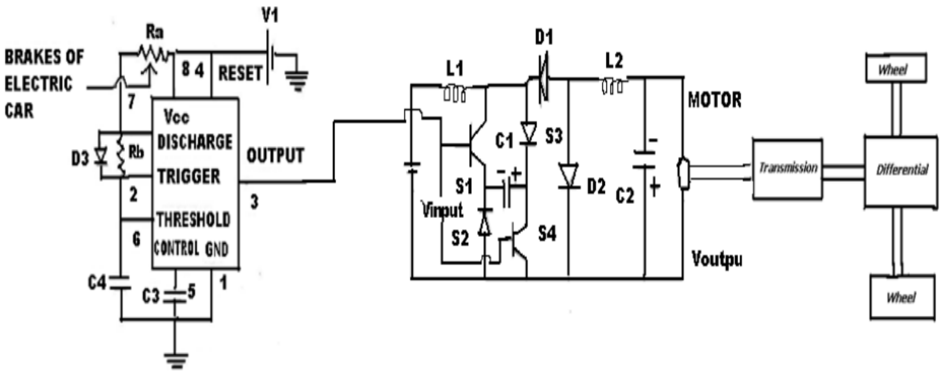

Figure 8: *Novel Propulsion system for plug in Electric vehicles*

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References

[1] Microchip, Application notes on brushed DC motors, AN905, 2004, pp.1-7.

[2] Chan CC and Chau K T, Modem Electric Vehicle Technology, oxford University press, 2001.

[3] P. C. Sen, Electric Motor Drives and Control: Past, Present and Future, IEEE Transaction on Industrial Electronics, Vol. IE37, No. 6, 1990, pp-562-575.

[4] G.K. Dubey, Power Semiconductor controlled Drives, Englewood, Cliffs, N.J: Prentice Hall, 1989

[5] ST Microelectronics, Application notes on brushed DC motors, AN380, 2003, pp.1-14.

[6] L. Umanand, Power Electronics: Essentials & Application, Wiley India,2009, pp.263-265.

[7] Muhammad H. Rashid, Power Electronics Circuits, Devices, And Applications, Pearson Education, 2004, pp.190-191.

[8] P. S. Bimbhra, Generalized Theory of Electrical Machines, Khanna Publishers, Delhi, India, 2001, pp. 93-98.

[9] E. Afjei, M.A. Saati, M.M. Nezamabadi, S. Ataei, New Converter Topology for a Hybrid Brushless DC Motor Without Permanent Magnet, ICEM Conf., Greece, pp. 20-25 ,2006.

[10] B.C. KUO and J. TAL, Incremental Motion Control, Vol. 1, DC Motors and Control Systems, SRL Publishing Co., Champaign, IL, 1979.

[11] M.Ehsani, Y.Gao, S.E. Gay, and A.Emadi, Modern Electric, Hybrid Electric, and Fuel Cell Vehicles, London: CRC Press LLC,2005.

[12] Wei Zhan, Make Mc Dermott, Behbood Zoghi, and Muhammad Hasan, Requirement Development for Electrical Vehicles Using Simulation Tools, Proceedings of the World Congress on Engineering and Computer Science 2009 Vol II WCECS 2009, October 20-22, 2009, San Francisco, USA.

[13] W. Gao, E. Solodovnik, and R. Dougal, Symbolically-aided model development for an induction machine in virtual tset bed, IEEE Transactions on energy Conversion,Vol 19, No. 1, March, 2004, pp.125-135.

[14] J.Dave and J.Dong, Conversion of an existing car to a rechargeable electric vehicle. ASEE Annual Conference,2009.

[15] T.D. Gillespie, Fundamental of Vehicle Dynamics, Society of Automotive Engineers, Inc., Warrendale, PA, 1992.

[16] T. Lucasand, F. Riess, How to convert to an electric car, Crown Publishers Inc., New York, 1980.

[17] R.Pratap, Getting Started with MATLAB 7: A Quick Introduction for Scientists and Engineers, Oxford University Press, 2006.

[18] Iqbal Husain and Mohammad S. Islam, Design, Modelling and Simulation of an Electric Vehicle System, SAE International Congress and Exposition Detroit,Michigan,1999.

[19] The MathWorks Inc. Matlab/Simulink, version 6, 1990-2005. Natick, MA: The MathWorks Inc.

[20] Butler KL, Ehsani M, kamathP, Matlab-based modelling and simulation package for electric and hybrid electric-vehicle design,IEEE Trans Vehicular Technology 1999;48(6):1770-8.

[21] Vikas Gupta, Anindya Deb, Speed control of Brush DC Motor for low cost electric cars, in proceedings of IEEE IEVC 2012.

[22] R. Bones (1989), Churning losses of discs and gears running partially submerged in oil, Proc. ASME Int. Power Trans Gearing Conf., Chicago

[23] Y. Diab, F. Ville, P. Velex, Windage losses in high speed gears, Journal of mechanical design, (2004)

[24] B. Hhn,K. Michaelis, R. Dbereiner, Load carrying capacity properties of fast biodegradable gear lubricants. J STLE Lubr Eng. (1999).

[25] M. Treiber, A. Hennecke, and D. Helbing, Congested traffic states in empirical observations and microscopic simulations, Phys. Rev. E, vol. 62, pp. 18051824, 2000.

[26] A. Kesting, M. Treiber, and D. Helbing, `General lane-changing model MOBIL for car-following models`, Transport. Res. Record, vol. 1999, pp. 8694, 2007.

[27] M. Treiber, A. Kesting, and D. Helbing, `Three-phase traffic theory and two-phase models with a fundamental diagram in the light of empirical stylized facts`, Transport. Res. B, Methodol., vol. 44, pp. 9831000, 2010.

[28] M. Treiber and A. Kesting, `Verkehrsdynamik und-SimulationDaten, Modelle und Anwendungen der Verkehrsflussdynamik`. Berlin: Springer- Verlag, 2010.

[29] A. Kesting, M. Treiber, M. Schnhof, and D. Helbing, `Adaptive cruise control design for active congestion avoidance`, Transport. Res. C, Emerging Technol., vol. 16, no. 6, pp. 668683, 2008.

[30] A. Kesting, M. Treiber, and D. Helbing, `Enhanced intelligent driver model to access the impact of driving strategies on traffic capacity`, Philos. Trans. Royal Soc. A, vol. 368, pp. 45854605, 2010

[31] A. Kesting, M. Treiber, and D. Helbing, `Connectivity statistics of store-and-forward inter-vehicle communication`, IEEE Trans. Intell. Transport. Syst., vol. 11, no. 1, pp. 172 181, 2010

[32] Vikas Gupta, `Computation of Power of a Motor in Electric Vehicle under City Traffic and Dynamic Conditions`, HCTL Open International Journal of Technology Innovations and Research, Volume 3, May 2013, ISSN: 2321-1814, ISBN: 978-1-62776-443-8.