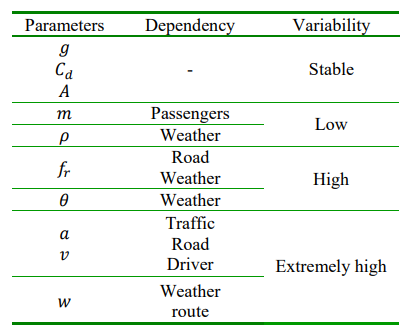
Literature Review

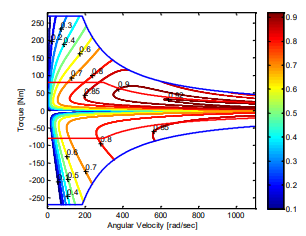
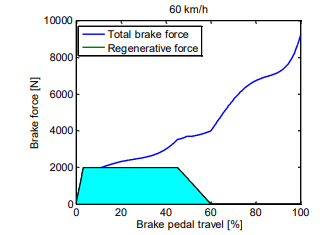
The project is a comparative study of Regenerative Braking Energy recovery between three motors IM, BLDC and SynRM. The project can be broken down into two main segments, the first segment primarily deals with the electric vehicle modelling and driver influence with braking. The second segment comprises of the comparison of the three motors.

Several studies have been performed to develop model and simulate hybrid electric vehicles and Electric vehicles[x12]-[x13]. The paper by J.Wang, I.Besselink and H.Nijmeijer [x11] proposes the energy consumption modelling and prediction based on road information. It takes into account the dependency of characteristic vehicle parameters on different driving and weather conditions as shown in table 1.

Table 1: Dependency of Characteristic Parametres.



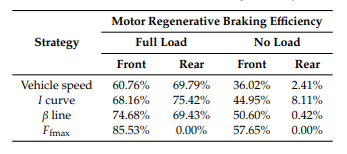
It implements a parallel braking system. It discusses the safe use of the Regenerative braking in the EV. The regenerative braking is a function of the percentage of brake pedal depression. Arguing that at speeds greater than 60km/hr, when the brake pedal is depressed more than 60%, the regenerative braking is reduced to zero and mechanical braking is only applied to ensure braking stability in case of emergency. It also highlights the powertrain efficiency in traction and regenerative braking mode.

A problem regenerative braking Is that current is limited to safe operating region of the batteries, as high currents during regenerative braking decreases the life of the batteries [8]-[9]. A solution to this issue is using flywheel and ultracapcitors for regenerative braking as discussed in this paper by S.Bhurse and A.Bhole which conclues that this combination would lead to an increase of range by 16.25%[x1].

There are many regenerative braking strategies, several papers are published comparing different approaches[x2]-[x3]. The paper by W.Zhang, J.Yang, W.Zhang and Ma[x4] compares four different regenerative braking control strategies for Pure Electric Mining Dump Truck. Vehicle Speed based control strategy, which is parallel braking strategy in which the regenerative braking force increases as the speed of the vehicle increases. This seems a bad approach for braking due to the fact that at high speeds, to maintain braking controllability for safe operation mechanical braking should be engaged. The paper restricts the speed of the vehicle to 15km/hr. I-Curve based control strategy this control strategy is maximum driver feel braking strategy, It follows the I-Curve for front and rear braking forces. β Line control strategy is based on the distribution of axle braking forces are a constant β ratio. The last control strategy is Ffmax based strategy. The paper concludes that Ffmax based strategy improves braking energy recovery compared to other strategies.

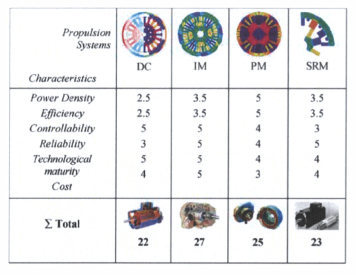
Table 2: Front and rear motor braking efficiency



The experience of the driver also affects the power and energy consumption. An unexperienced driver increases the power need by 36.74% and range by 4.95% in FTP75 cycle. Whereas, an experienced driver reduces the power need by 2.13% in FTP75 cycle and 7.92% in WLTP cycle[x5].

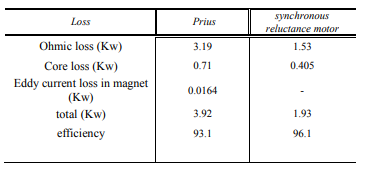
There have been many papers comparing the perfomance of the three electric motors. SynRM has seen increased popularity by researcher due to the increases in the price of high-strength sintered neo magnets which are used in BLDC motor[x6]. Many studies in which comparision of motors for electric vehicle don’t include SynRM due to its recent insurgence[x7]. The paper compares five electric motors for EV application. The motors under the study are Dc motor, IM, PM synchronous motor, Switched Reluctance Motor, and BLDC motor. Because of the presence of a permanent magnet in the rotor, PM motors have highest power density and highest efficiency. DC motors and Induction Motors have high controlability due to the fact that their flux and torque can be decoupled and controllled. Induction Motors are also have robust and rigid construction.

Table : Comparision of Motors



The paper concludes that Induction Motors is the best candidate for Electric Vehicle application due to its mature technology, robust construction, less maintenance and less cost compared to other motors.

Due to the scarcity of permanent magnets, BLDC motor have higher cost. An alternative to PM motors that has recently gain popularity is SynRM. It uses the stator similar to Induction Motor, hence the developed assembly line of IM can be used. The paper by A.Siadatan, M.Kholousi Adab and H. Kashian compares the permanent magnet motor in toyota prius and Synchronous Reluctance motor[x8]. Both motors have same torque and maximum output power, because of this SynRM motor is 1.69 times heavier than toyota prius motor. The SynRM costs 100$ less than toyota motor in material costs. The fem analysis leads to these results. First both motors have similar flux density. SynRM has twice the torque ripple. Surprisingly, toyota motor has 2kw more motor losses compared to SynRM. The paper concludes that SynRM is more favourable for EV and HEV applications.



Compared to IM, SynRM with same stator frame and with same power dissipation(same stator windings temperature) have a higher rated torque about (10%-15%). This is due to absense of rotor losses in SynRM[x9]. IM motor has better performance in middle torque and rated speed region, SynRM has a wider region of maximum efficiency. The highest efficiency of IM is 95% where as for SynRM is 97.5%[x10].

References:  
[8] Pay, S., Baghzouz, Y., “Effectiveness of battery-supercapacitor combination in electric vehicles,” Power Tech Conference Proceedings, 2003 IEEE Bologna, vol.3, no., pp. 6 pp. Vol.3, 23-26 June 2003

[9] Gagliardi, F., Pagano, M., “Experimental results of on-board batteryultracapacitor system for electric vehicle applications,” Industrial Electronics, 2002. ISIE 2002. Proceedings of the 2002 IEEE International Symposium on, vol.1, no., pp. 93- 98 vol.1, 2002

[x1] A Review of Regenerative Braking in Electric Vehicles Sneha S. Bhurse A.A. Bhole

[x4 ]Research on Regenerative Braking of Pure Electric Mining Dump Truck Wei Zhang \* , Jue Yang , Wenming Zhang and Fei Ma

[x2] Switched Robust Control of Regenerative Braking of Electric Vehicles Xie Jing1, 2, Cao Binggang1 , Zhang Huarong1 , Xu Dan

[x5] A Method to Analyze Driver Influence on the Energy Consumption and Power Needs of Electric Vehicles Rayad Kubaisi, Frank Gauterin, and Martin Giessler

[x6] Thomas Jhans,” Getting Rare-Earth Magnets Out of EV Traction Machines: A review of the many approaches being pursued to minimize or eliminate rare-earth magnets from future EV drivetrains”, 2017

[x7] Comparative Study of Using Different Electric Motors in the Electric Vehicles Nasser Hashernnia and Behzad Asaei

[x8] Compare Motors of Toyota Prius and Synchronous Reluctance for Using in Electric Vehicle and Hybrid Electric Vehicle

[x9] Aldo Boglietti, Michele Pastorelli, “Induction and synchronous reluctance motors comparison”,2009

[x10] Efficiency Map Comparison of Induction and Synchronous Reluctance Motors Anton Rassõlkin, Hamidreza Heidari, Ants Kallaste, Toomas Vaimann

[x11] Electric vehicle energy consumption modelling and prediction based on road information Jiquan Wang , Igo Besselink , Henk Nijmeijer

[x12] D. W. Gao, C. Mi and A. Emadi, "Modeling and Simulation of Electric and Hybrid Vehicles," in Proceedings of the IEEE, vol. 95, no. 4, pp. 729-745, April 2007, doi: 10.1109/JPROC.2006.890127.

[x13] M. Yaich, M. R. Hachicha and M. Ghariani, "Modeling and simulation of electric and hybrid vehicles for recreational vehicle," 2015 16th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering (STA), 2015, pp. 181-187, doi: 10.1109/STA.2015.7505098.