© 2014 IJIRT | Volume 1 Issue 4 | ISSN : 2349-6002

PERFORMANCE EVALUATION AND DRIVE SELECTION FOR HYBRID ELECTRIC VEHICLES

Ms. Vaishali Bakshi, Prof. Mrs. V.S. Jape,
P.E.S. Modern college of Engineering, Pune

***Abstract*—Today's automobile world is turning towards Electric and Hybrid Electric Vehicles (EV and HEV) due to their numerous advantages over a conventional vehicle such as reduced emissions, higher efficiency etc. Different motors are used to provide the total propulsion power for an EV and combined with engine for HEV. For these motors, various control strategies can be implemented to improve the motor performance and hence the enhanced performance of EV/HEV. In this paper, HEV model is analyzed for their performances by considering the cases of Permanent magnet Synchronous Motor (PMSM) and induction Motor (IM) drivetrains. First, the HEV models are integrated in MATLAB/SIMULINK environment along with PMSM and induction motor drives in different operating conditions. The motor controllers and supervisory controllers are appropriately tuned to achieve the required speed-torque demands and vehicle performance. The HEV model developed in LMS imagine.lab AMESim is considered to have a comparison with the results obtained with that in MATLAB/SIMULINK. The results are compared to analyze the relative performances in terms of efficiency, response and fulfilling load demands of the respective motor drives under various operating conditions. This will enable choosing the appropriate drive for the Hybrid Electric Vehicle application. Based on the comparative results appropriate motors are suggested for different requirements and under various operating conditions for HEV.**

***Index Terms*— HEV, Induction motor, *PMSM*, vector control**

I. INTRODUCTION

Presently, air pollution concerns, oil dependence on politically unstable regions and high oil prices are some of the biggest problems. The United Nations estimated that over 600 million people in urban area worldwide were exposed to traffic-generated air pollution with immense quantities of cars which targeted the Internal combustion (IC) engines for global warming issues [10]. These have caused a flurry of activity in the areas of efficient EV and HEV contributing to the development of an environment friendly transportation sector.

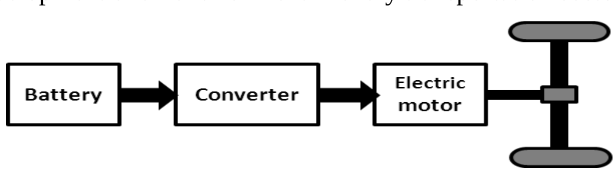

Fig. 1. EV architecture

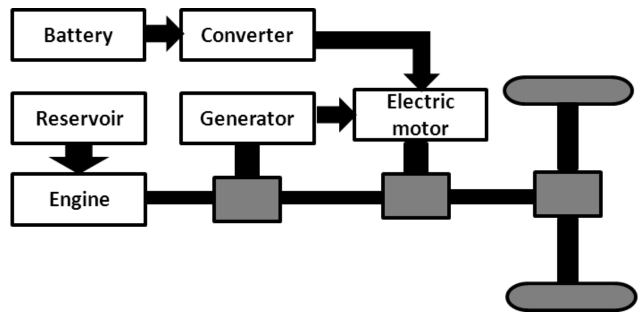

Fig. 2. HEV architecture

The EV architecture is given in Fig. 1 which shows the electric motor powered EV energized through a battery. The use of battery accounts certain problems such as huge battery mass and more charging time requirement. Also total available propulsion power is restricted due to limited battery range. These limitations of EV have laid the use of hybrid vehicles. Hybrid electric vehicles use electric motor in association of engine to provide the total propulsion power [11].

Fig. 2 shows the series-parallel architecture of HEV which is similar to the Toyota Prius Hybrid system. In series-parallel architecture, the HEV operation is divided in different modes which offer shutting the engine off when not required [8]. The improvements come from regenerative braking and shutting down the engine when not required, can improve the fuel economy and reduce tailpipe emissions with a smaller and more efficient engine.

Various papers have been published in the literature on drive selection as well as modeling of EV/HEV. Drive selection is associated with a comparison (for different parameters) of commonly used motors in case of EV/HEV and selecting the appropriate motor based on their performance characteristics [1], [2]. The control strategies are implemented to improve the motor performance. The control strategy preferably used for AC motors is based on vector control which is studied in detail and verified using MATLAB/SIMULINK [3]. Along with a vector controlled motor drive the HEV is modeled in SIMULINK based on Toyota Prius Hybrid system and its performance is evaluated [5]. Similarly Electric go-kart is modeled with induction motor for the performance evaluation [6]. Comparison of PMSM and induction motor for HEV applications is done to conclude the design considerations [4].

In this paper, HEV models are analyzed for their performances by using Permanent magnet synchronous motor

(PMSM) and induction motor drivetrains in MATLAB/SIMULINK environment. The drive selection criterion for EV/HEV is studied in section II. Section III is associated with model descriptions. The supervisory controller is integrated to have a controlled vehicle operation under different operating conditions. The results of simulation under different case examples of motor types are compared to analyze the relative performance (in terms of efficiency, response and fulfilling load demands) and the behavior of the controllers under various operating conditions in section IV. Section V is associated with the comparison of results obtained with the two different software platforms which offer the validation of the results obtained. Finally based on the results, this paper concludes the best suitable drive in case of HEV considering the different operating conditions in section VI. Also the vehicle performance can be evaluated with the mentioned drives.

II. Selection Criterion For Drives Used In EV/HEV

In parallel and series– parallel hybrid vehicles, the electric motor is one of the torque sources that contribute to the peak torque (power) to meet the vehicle performance requirements. Thus, the development of compact, lightweight, high efficiency and proper torque-speed profile becomes crucial [2].

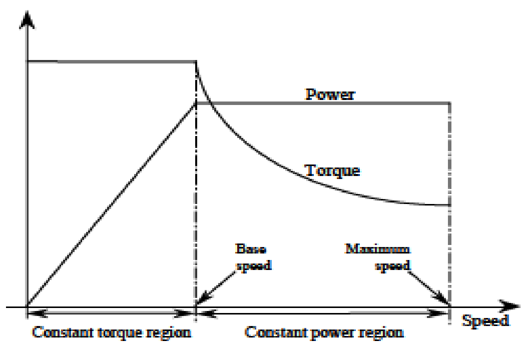

Fig. 3. Required drive characteristics for EV/HEV

A well-controlled electric motor drive has the torque-speed profile close to the ideal one as shown in Fig. 3 [2]. It includes two distinguishable regions namely constant torque and constant power. The corner speed is usually called base speed. The lower base speed results in a larger max torque at a given power and maximum speed rating. It clearly shows that a motor drive with a long constant power range is preferred [1]. The constant power profile can maximize the vehicle acceleration performance at given power rating or minimize the power rating at given vehicle acceleration performance [2].

With reference to above drive characteristics, commonly used motors for EV/ HEV applications are DC motor, Induction motor, Permanent magnet synchronous motor (PMSM), Brushless DC motor (BLDC) and Switched reluctance motor (SRM). These drives can be compared for their performances in EV and HEV [1], [2].

With the primary comparison, PMSM and induction motor drives are preferably used for vehicle applications due to their suitable characteristics and developed control strategies [1]. The PMSM motors and induction motors are also compared for their designs. There is common perception that the permanent magnet motor is the correct solution for the application and offers considerable advantages in terms of performance and efficiency. But proper design considerations can offer the use of induction motors for vehicle applications [4]. This paper offers a direct comparison of EV and HEV performances for alternate PMSM and induction motor drives along with the evaluation of individual motor drive performances in order to choose the suitable drive based on vehicle performance.

III. HEV Model Descreption Using Simulink And AMESIM

The HEV models are integrated in AMESim and MATLAB/SIMULINK environment. The ratings of various components and their respective parameters are mentioned in Appendix A.

A. HEV Model using SIMULINK

The HEV simulation model based on [5] having series-parallel architecture as shown in Fig. 2 is supplied with constant DC source. The new model is modified with a battery source which enables the performance evaluation of HEV in regenerative braking mode of operation. The model incorporates different subsystems namely Energy management subsystem (EMS), Electrical subsystem, IC engine, Planetary gear subsystem and Vehicle dynamics. The EMS is associated with a supervisory controller which is responsible for hybrid mode on/off and reference signal generations for electric motor drive, electric generator drive and IC engine in order to have efficient distribution of the power from different sources. Hybrid mode on/off is controlled to operate the engine efficiently depending on mode of operation. The vehicle is supplied via battery to power up the motor when hybrid mode is off.

In normal operating conditions engine power is divided by the power split device which turns the generator on to drive the motor and rest of the power drives the wheels directly. Extra power needed for additional acceleration is supplied from the battery, while the engine and high-output motor provide smooth response, for improved acceleration characteristics. The motor acts as a generator, driven by the vehicle’s wheels in braking application in which system recovers kinetic energy as electrical energy further stored in the battery. The engine drives the generator to recharge the battery when necessary. Supervisory controller controls the power allocation to maximize efficiency.

The Battery management system maintains the State-Of-Charge (SOC) between prescribed limits. Electrical subsystem consists of a motor along with its controller. The motor control strategy used is based on vector control. The controller is tuned to achieve the required performance. The vehicle dynamic subsystem is associated with longitudinal vehicle dynamics, the differential and tire dynamics. Engine and planetary gears are also modeled. The HEV model is altered by using PMSM and induction motor to observe their relative performances.

B. *HEV Model using AMESim*

HEV model based on Toyota prius hybrid system [12] is modified as per the requirements given in Appendix A. The model consists of different subsystems for hybrid strategy control, engine control, motor control along with different models of engine, motor, generator, battery, driver profile etc. The hybrid mode on/off is controlled through hybrid strategy control. Depending on different requirements of demand power and battery SOC hybrid mode is switched on/off when exceeding their predetermined limits. Engine and motor are associated with different control units. The vehicle is supplied via battery to develop required propulsion power when hybrid mode in off. The operation is divided in different operating modes as per the Toyota prius hybrid system [8].

IV. SIMULATION RESULTS AND ANALYSIS

The simulation results with PMSM and induction motor drive for HEV are plotted and the comparison is done to evaluate their respective performances in vehicles. For simulating different operating conditions, accelerator pedal is started and maintained at 70% (starting) for 4s, 10% (cruising) for 4s, 85% (acceleration) for 5s and finally set to -70% (braking) till the end of simulation time.

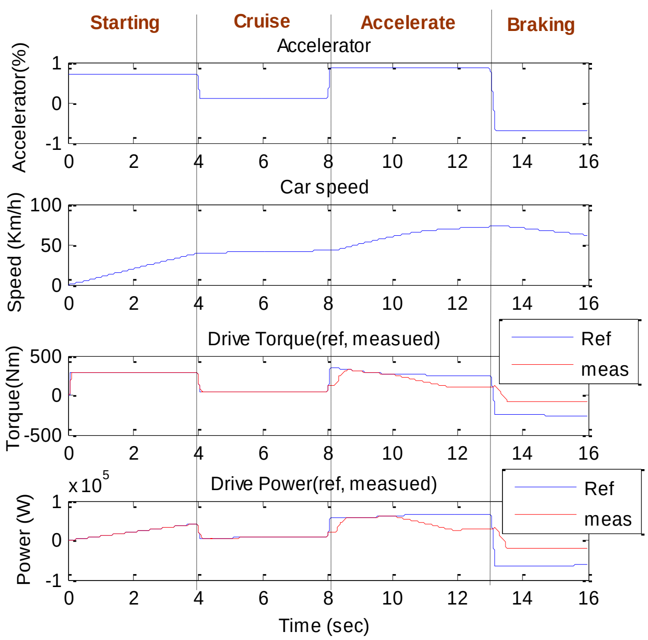

Fig. 4. Car speed profile and Vehicle Torque and power depending on the accelerator percentage with PMSM drive

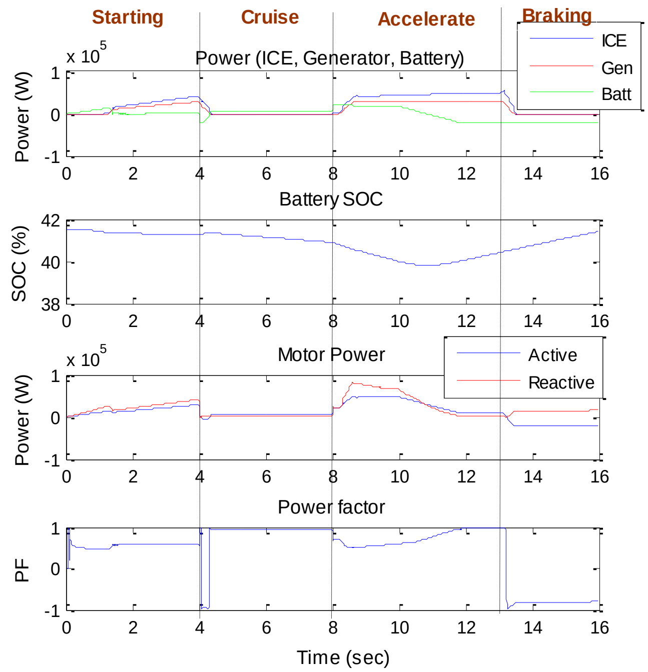

Fig. 5. Engine, genereator, battery power variation along with motor active, reactive power and power factor with PMSM drive.

Fig. 4 and Fig. 5 shows the results for PMSM driven HEV model while Fig. 6 and Fig. 7 shows the results with induction motor drive. The simulation shows different operating modes of the HEV over one complete cycle including accelerating, cruising, recharging the battery while accelerating and regenerative braking.

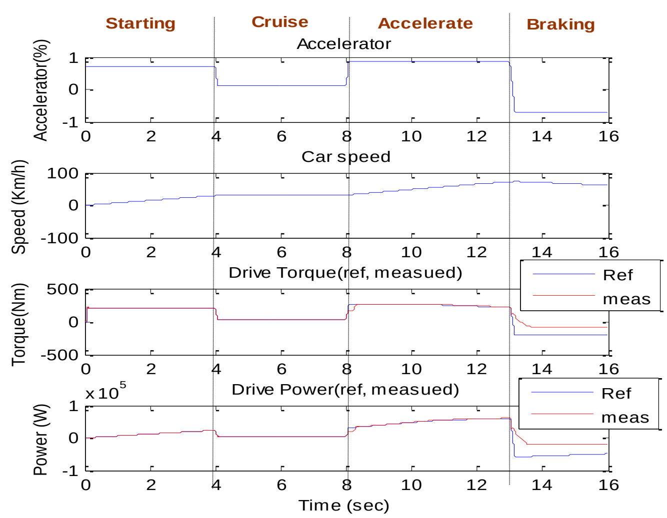

Fig. 6. Car speed profile and Vehicle Torque and power depending on the accelerator percentage with induction motor drive

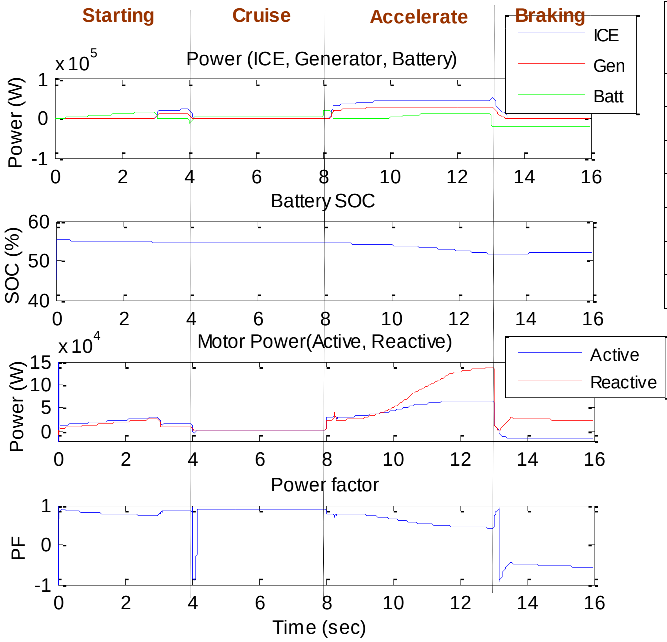

Fig. 7. Motor, genereator, battery, engine power variation along with throttle position and hybrid mode on/off requirement with induction motor drive.

Fig. 4 shows the operation of HEV in battery recharging mode while acceleration. After 10s the battery SOC falls below 40%. Part of generator power is used to charge the battery. Hence the drive power is not following the reference in case of PMSM as shown in Fig. 4. However in case of induction motor SOC level is maintained above 50% in acceleration mode hence HEV follows the reference drive power as shown in Fig. 6. The comparative results of performance values are shown in Table. I.

The maximum speed achieved by HEV with PMSM is 1.5% more as compared to that with induction motor drive. The maximum torque and power delivered by PMSM is 20% and 7% more respectively as compared to that of induction motor. Induction motor consumes more active as well as the reactive power in all operating modes as compared to PMSM. Hence, the power factor in case of induction motor drive is 16% lower. Also the speed and torque response time is 23% more in case of induction motor driven HEV. The efficiency of both the motors is also estimated. The efficiency of PMSM is 20% higher as compared to induction motor. The performance of PMSM motor shows better results as compared to induction motor but its cost is very high.

TABLE I. RESULT OF COMPARISON WITH DIFFERENT DRIVES

Sl. No	HEV Results		
	Parameters	***PMSM***	***Induction motor***
1	Max Car speed achieved (Kmph)	73	72
2	Max Torque achieved by vehicle (Nm)	320	260
3	Max power achieved by vehicle (Kw)	58	60
4	Max Motor power delivered (Kw)	47	44
5	Max Generator power delivered (Kw)	30	30
6	Max Battery power delivered (Kw)	21	21
7	Max Motor torque (Nm)	280	210
8	Motor current (A)	230	290
9	Power factor	0.96	0.8
10	Response time for speed & torque (sec)	0.1215	0.15

V. RESULT COMPARISON

The model is simulated for a part of standard drive cycle over the different operating modes such as starting, accelerating in hybrid mode, cruising and braking mode. The results for different powers can be plotted as shown in Fig. 8. Fig.8 shows different powers associated with vehicle performances.

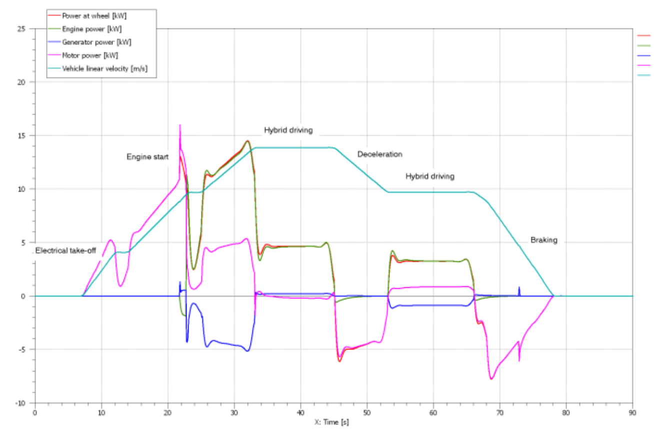

Fig. 8. Power at wheel, engine power, generator power, motor power, drive cycle plotted with AMESim HEV model

The simulation results are obtained for power at wheel, generator power, motor power, engine power in different modes of operation. This model also evaluates fuel consumption and emissions over a complete drive cycle and the respective plots can be generated. Table II shows the comparison of results obtained with AMESim and SIMULINK. In similar way several other quantities can be compared to validate the obtained results.

TABLE II. WHEEL POWER OBTAINED IN DIFFERENT OPERATING MODES

Sl. No	Wheel power obtained in different modes			
	Mode of operation	***Parameters***	***Results in AMESim***	***Results in SIMULINK***
1	Starting mode	Power at wheels (kW)	3.8518 kW	4.054 kW
		Hybrid mode	Off	Off
2	Accelerati	Power at wheels (kW)	11.34 kW	9.69 kW

Sl. No	Wheel power obtained in different modes			
	Mode of operation	***Parameters***	***Results in AMESim***	***Results in SIMULINK***
	on mode	Hybrid mode	On	On
3	Braking mode	Power at wheels (kW)	-6.108 kW	-6.26 kW
		Hybrid mode	Off	Off

VI. CONCLUSION

In this paper the performance of PMSM and induction motors along with HEV models is analyzed. It is observed that PMSM motor in general offers various advantages over induction motor such as higher achievable maximum car speed, less active and reactive power consumption resulting in high power factor and efficiency. The lower motor efficiency will affect the engine loading. Also response time is more in case of induction motor hence it takes more time for power development resulting in poor acceleration and hence the pick-up performances. However, the SOC level in an HEV using induction motor does not fall substantially during acceleration mode as compared to PMSM. To achieve better performances in HEV PMSM motors can be preferred. But the cost of PMSM is higher as compared to induction motor. To have cost effective HEVs at moderate performance induction motors can be preferred.

APPENDIX A

Sl. No	Component specifications for HEV		
	Component	***Parameter***	***Values (units)***
1	Vehicle	Mass	1325 kg
		Frontal area	2.57 m^2
		Drag coefficient	0.26
2	Permanent magnet Synchronous Motor	Maximum dc voltage	500 V
		Maximum power	50 kW
		Maximum torque	400 Nm
3	Induction Motor	Maximum ac voltage	460 V
		Maximum power	50 kW
		Maximum torque	300 Nm
4	Battery	Capacity	6.5 Ah
		Initial voltage	201.6 V
		Initial state-of charge	33.33 %
		Maximum power	21 kW
5	Engine	Maximum power	57 kW
		Speed at maximum power	523.33 rad/s
		Maximum speed	628 rad/s

ACKNOWLEDGMENT

The authors would like to acknowledge the Automotive Research Association of India (ARAI) and staff member Dr. Somnath Sengupta, who contributed towards the integration of the EV and HEV models used in this paper and the writing of this paper.

REFERENCES

[1] Mounir Zeraoulia, Mohamed El Hachemi Benbouzid, and Demba Diallo, "Electric Motor Drive Selection Issues for HEV Propulsion Systems: A Comparative Study", *IEEE transactions on vehicular technology*, vol. 55, no. 6, november 2006, pp. 1756-1764.

[2] Xue, X.-D.; Cheng, K. W E; Cheung, N.C., "Selection of electric motor drives for electric vehicles," *Power Engineering Conference, 2008. AUPEC '08. Australasian Universities* , vol., no., pp.1,6, 14-17 Dec. 2008

[3] Joshi, R.P.; Deshmukh, A.P., "Vector Control: A New Control Technique for Latest Automotive Applications (EV)," *Emerging Trends in Engineering and Technology, 2008. ICETET '08. First International Conference on* , vol., no., pp.911,916, 16-18 July 2008 doi: 10.1109/ICETET.2008.235

[4] Dorrell, D.G.; Popescu, M.; Evans, L.; Staton, D. A.; Knight, A.M., "Comparison of permanent magnet drive motor with a cage induction motor design for a hybrid electric vehicle," *Power Electronics Conference (IPEC), 2010 International* , vol., no., pp.1807,1813, 21-24 June 2010 doi: 10.1109/IPEC.2010.5543566

[5] Mahapatra, S., Egel, T., Hassan, R., Shenoy, R. et al., "Model-Based Design for Hybrid Electric Vehicle Systems," SAE Technical Paper 2008-01-0085, 2008, doi:10.4271/2008-01-0085

[6] Emma grunditz, Emma Jansson, "Modelling and Simulation of a Hybrid Electric Vehicle for Shell Eco-marathon and an Electric Go-kart," *Master of Science Thesis in Electric Power Engineering,* Chalmers university of technology, Göteborg 2009, Sweden

[7] Evaluation of 2004 Toyota Prius Hybrid Electric Drive System, Interim Report C.W. Ayers, J.S. Hsu, L.D. Marlino, C.W. Miller, G.W. Ott Jr., C.B. Oland, Oak Ridge National Laboratory Report ORNL/TM-2004/247

[8] Toyota Hybrid System II. [Brochure] Tokyo : Toyota Motor Company; 2003

[9] B. K. Bose, "Power Electronics & AC drives", Prentice Hall, New Jersey, 1986

[10] Xianglu Han, Luke P. Naeher, "A review of traffic-related air pollution exposure assessment studies in the developing world," Environment International 32 (2006) 106 – 120

[11] http://en.wikipedia.org/wiki/Hybrid_vehicle_drivetrain

[12] AMESim reference