Australian Journal of Basic and Applied Sciences, 9(27) August 2015, Pages: 311-316

ISSN:1991-8178

Australian Journal of Basic and Applied Sciences

Journal home page: www.ajbasweb.com

Resonant Power Converter fed Hybrid Electric Vehicle with BLDC Motor Drive

[1]Balamurugan A. and [2]Ramkumar Subbhuram

[1]*Assistant Professor, Department of EEE, Surya College of Engineering & Technology, Villupuram – 605 652, Tamil Nadu, India*
[2]*Professor and Head, Department of EEE, Sri Krishna College of Engineering and Technology, Coimbatore – 641008, Tamil Nadu, India*

ARTICLE INFO

Article history:
Received 23 June 2015
Accepted 25 August 2015
Available online 2 September 2015

Keywords:
BLDC motor, Electric vehicle, PI controller, Resonant inverter.

ABSTRACT

This paper proposes a new scheme for control the speed of a Brushless DC motor (BLDC) in a Hybrid-Electric Vehicle. This system introduces a new circuit for the replacement of the DC boost converter and traditional inverter. A resonant inverter used for DC-AC conversion with current resonance. The inverter used to regulate voltage and fed into the BLDC motor through a motor driver circuit. In this paper open loop and closed loop response of the resonant inverter fed BLDC motor drive for hybrid electric vehicle system simulated using MATLAB/Simulink software tool. PI controller is utilized for closed loop control of the projected scheme.

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To Cite This Article: Balamurugan A, Ramkumar Subbhuram., Resonant Power Converter fed Hybrid Electric Vehicle with BLDC Motor Drive. ***Aust. J. Basic & Appl. Sci.,*** *9(27): 311-316, 2015*

INTRODUCTION

Recently because environmental pollution and the energy crisis are rising globally, most industrialized countries have been trying to reduce their dependence on oil as an electric cars, scooters, bicycles, wheelchairs, etc. Electric vehicles (EVs) are becoming important, not only as an environmental measure against global warming but also as an industrial policy (Xiaohong Nian and F. Peng, 2014, J. F. Gieras and M. Wing, 2002). For the next-generation EVs must be safe and perform well. The propulsion force generation which strongly influence the safety and running performance of the vehicle. The faster, more efficient, less noisy and more reliable Brushless dc motors (BLDCMs) have many advantages over brushed dc motors and induction motors. It has simple construction, high efficiency, higher speed range, large starting torque, noiseless operation, etc., (F. Fang et.al, 2012, F. Fang et.al, 2013, M. Muruganandam, M. Madheswaran, 2013). In this paper, a new circuit of resonant inverter fed BLDC motor control for hybrid-electric vehicle is proposed with PI control strategy. The detailed process is described as follows.

Proposed Resonant Inverter Fed Ehv System:

Fig. 1 shows the block diagram representation of the resonant inverter fed Hybrid-Electric Vehicle system.

Fig. 1: Resonant inverter fed hybrid electric vehicle system.

A. BLDC Motor drive:

A brushless DC (BLDC) motor is a rotating electric machine, where the stator is a classic 3-phase stator like that of an induction motor, and the rotor has surface-mounted permanent magnets shown in Fig.2. The BLDC motor equal to a reversed DC commutator motor, in which the magnet rotates while the conductors remain stationary. In the DC commutator motor, the current polarity altered by the commutator and brushes. However, in the brushless DC motor, polarity reversal performed by power transistors switching in synchronization with the rotor position. Therefore, BLDC motors often incorporate either internal or external position sensors to sense the actual rotor position, or the position can detected without sensors.

Corresponding Author: Balamurugan A., Assistant Professor, Department of EEE, Surya College of Engineering & Technology, Villupuram – 605 652, Tamil Nadu, India.
E-mail: balamurugana@suryagroup.edu.in

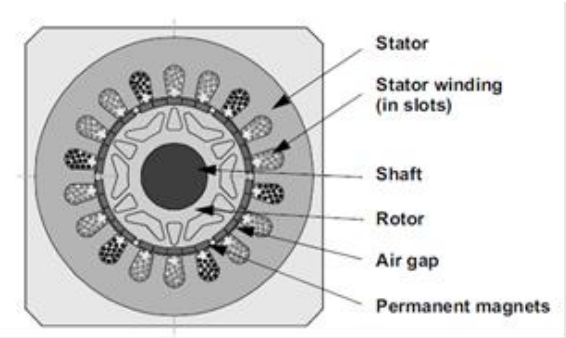

Fig. 2: BLDC Motor - Cross Section.

The BLDC motor is magnetic field produced by the stator and the magnetic field produced by the rotor rotation are the same frequency. Brushless dc (BLDC) motors are ideally suitable for EVs because of their high-power densities, good speed-torque characteristics, high efficiency, wide speed ranges, and low maintenance. BLDC motor is a type of synchronous motor. BLDC motors do not experience the "slip" which is available in induction motors (B. Singh, 1997, N. Mohan et.al, 2003 and F. Z. Peng et.al, 2004). However, a BLDC motor needs complex electronics for control. The BLDC motor, permanent magnets mounted on the rotor, with the armature windings fixed on the stator with a laminated steel core. Rotation began and kept by sequentially energy opposite pairs of pole windings that called as form phases. Knowledge of rotor position is critical to suffering the motion of the windings whereas the rotor shaft position sensed by a Hall Effect sensor, which provides signals to the respective switches. Whenever the rotor magnetic poles pass near the Hall sensors they give a high or low signal, showing either N or S pole is passing near the sensors (G. H. Jang et.al, 2002, Jahn et.al, 1996 and B. Singh, 1997).

Resonant Inverter:

In Fig. 3 there is shown a block scheme of the power part of used three-phase resonant inverter. The inverter consists of a conventional voltage source inverter with zero (reverse) diodes. Each branch of the inverter bridge contains four switches (S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11} and S_{12}). The switches activate circuits L_1, C_1 and C_2, respective L_2, C_3 and C_4 and L_3, C_5 and C_6. These circuits are initialized in the instants, when the current of load is too low for fast overcharging, or wrong polarity for overcharging of resonant capacitors. If the current of load is high enough and right polarity it is possible to overcharge without resonant circuit utilization. The main switches of the converter use zero voltage switching and the auxiliary switches use zero current switching. In the case there are no losses concerning a conventional converter using hard switching (N. Mohan et.al, 2003, F. Z. Peng et.al, 2004 and K. M. Smith, K. M. Smedley, 1997).

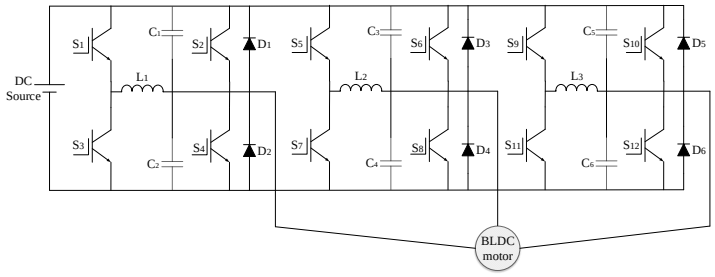

Fig. 3: Three Phase Resonant Inverter.

Simulation Results:

Fig.4 shows the open loop Simulink diagram of Hybrid Electric Vehicle with BLDC motor drive fed through resonant inverter. The proposed system open loop analysis has been done with R load and motor load analysis. The output voltage, current and its harmonic analysis are shown in Figs.5-8.

From the open loop responses the motor load connected three phase inverter produced high harmonic distortion compared with R load, the motor load harmonics increased due to the absence of control mechanism. Then we used a closed loop PI controller for the proposed organization to validate the performance analysis of the same. Fig.9 shows the closed loop three phase resonant inverter fed HEV system using PI controller. The output waveforms of the system steady state and transient responses are presented in Figs. 10-15.

Fig. 10 shows the output voltage and current response of resonant inverter fed HEV BLDC motor drive system using PI controller. Fig.11 shows the steady state response of resonant inverter fed HEV

system, BLDC motor speed (N=1800 rpm) and torque (T=5 N-m.) for steady state analysis. From the figure 11, it is observed that the speed of the motor controlled by PI controller and it has made its steady state and determined with the reference speed of 1800 rpm at 0.22 sec with overshoot of 29.21% shown in Table.1.

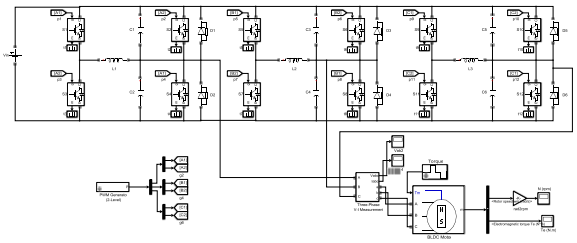

Fig. 4: Open Loop Simulink of Resonant Inverter Fed Electric Vehicle with BLDC Motor Drive.

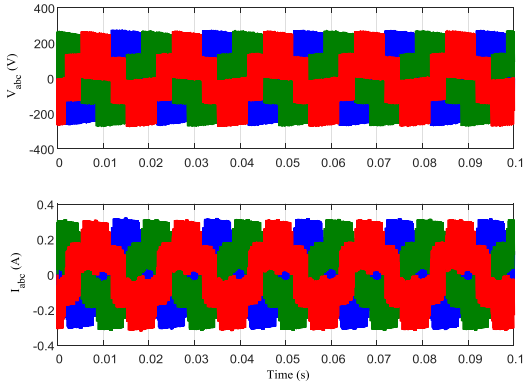

Fig. 5: Open Loop Output Voltage and Current Waveform of Three Phase Resonant Inverter with R-Load.

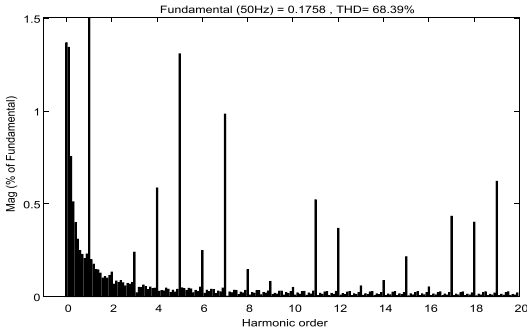

Fig. 6: Open Loop % THD Performance of Three Phase Resonant Inverter with R-Load.

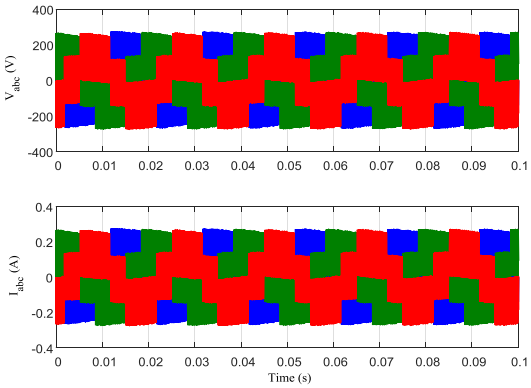

Fig. 7: Open loop output voltage and current waveform of three phase resonant inverter with motor load.

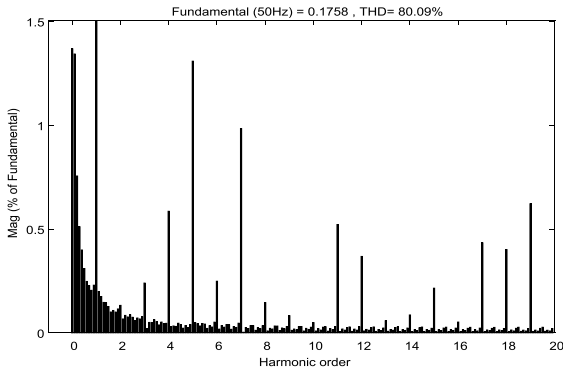

Fig. 8: Open loop % THD performance of three phase resonant inverter with motor load

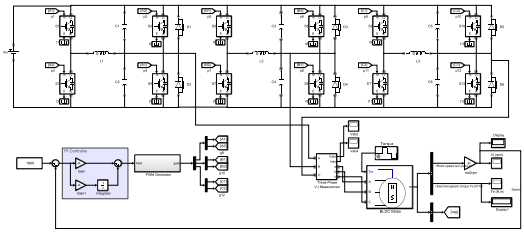

Fig. 9: Closed loop Simulink diagram of three phase resonant inverter fed HEV system using PI controller.

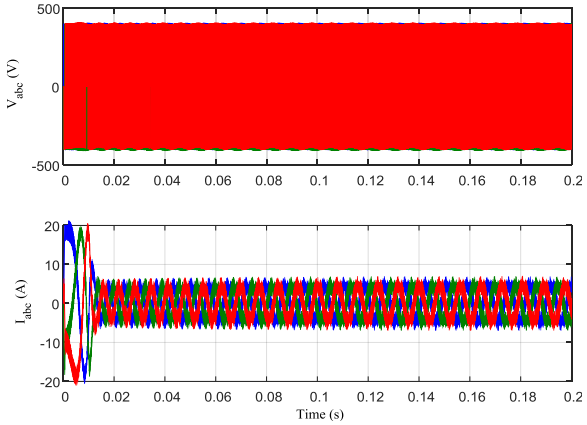

Fig. 10: Closed loop output voltage and current waveform of three phase resonant inverter fed HEV system.

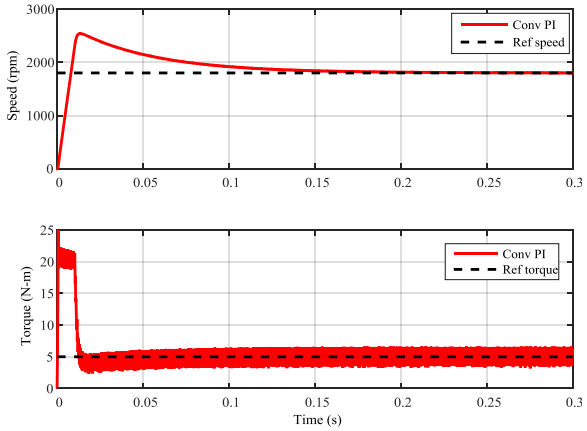

Fig. 11: Steady State Response of Resonant Inverter fed HEV System, BLDC Motor Speed and Torque (N=1800rpm, T=5N-m).

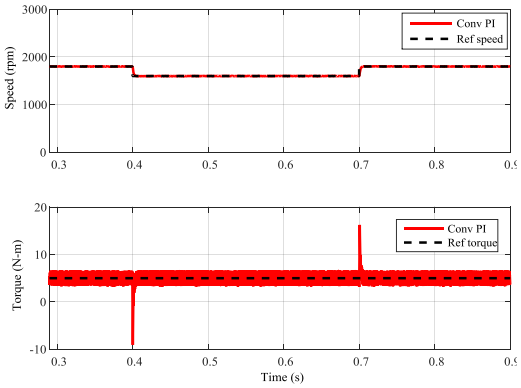

Fig. 12: Change in speed response of resonant inverter fed HEV system, BLDC motor speed and torque (up to 0.4sec, N=1800 rpm, T=5N-m; t= 0.4 – 0.7sec, N=1600 rpm, T=5N-m; t= 0.7 - 1sec, N=1800 rpm, T=5N-m).

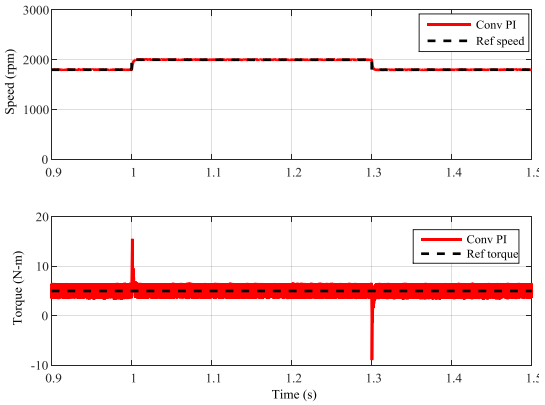

Fig. 13: Change in speed response of resonant inverter fed HEV system, BLDC motor speed and torque(N=1800 rpm up to 1 sec, T=5N-m; t= 1 – 1.3sec, N=2000 rpm, T=5N-m; t= 1.3 – 1.5sec, N=1800 rpm, T=5N-m)

Figs. 12 and 13 show the servo response of the proposed scheme. These figures show the disturbance on the input side of the system. Fig. 13 shows the sudden change in speed (10% decrement) from 1800 to 1600 rpm at the interval of 0.4 to 0.7 sec and settled with a decremented speed of 1600 rpm at 0.471 sec without any shoot. Besides the change in speed (10% increment) from 1800 to 2000 rpm at 1.0 sec and settled its reference speed of 2000 rpm at 1.008 sec without any configuration. The speed settled very fast with respect to its reference value and the torque response did not change speed during the disturbances due to the presence of PI controller.

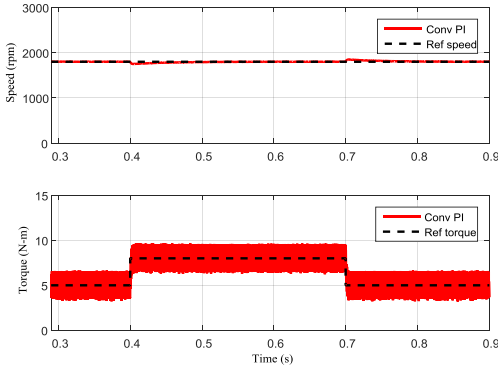

Fig. 14: Change in load response of resonant inverter fed HEV system, BLDC motor speed and torque (up to 0.4sec, T=5N-m, N=1800 rpm; t= 0.4 – 0.7sec, T=8 N-m, N=1800 rpm; t= 0.7 - 1sec, T=5 N-m, N=1800 rpm).

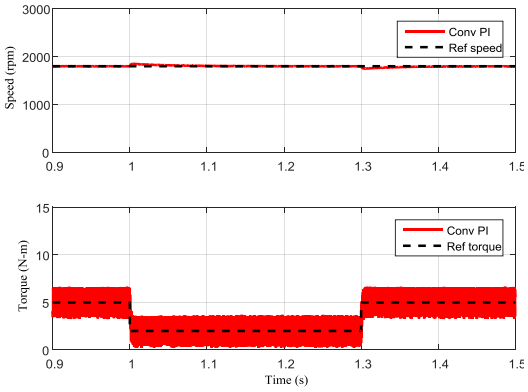

Fig. 15: Change in load response of resonant inverter fed HEV system, BLDC motor speed and torque (up to 1.0sec, T=5N-m, N=1800 rpm; t= 1.0 – 1.3sec, T=2 N-m, N=1800 rpm; t= 1.3 – 1.5sec, T=5 N-m, N=1800 rpm).

Figs.14 and 15 show the regulatory response of the proposed scheme. These figures show the disturbance on the load side of resonant inverter fed HEV BLDC motor speed and torque. During this performance the load is suddenly increased from 5 N-m to 8 N-m at 0.4 sec and decremented to 5 N-m to 2 N-m at 1.0 sec in figure 14 and 15 respectively. Due to this sudden change of the load the speed slightly deviated of 48-50 rpm from its real speed. The performance analysis also tabulated in Table.1.

Table 1: Performance evaluation of the PI controller for resonant inverter fed HEV BLDC motor using MATLAB.

Steady state analysis				Servo Response (Input)				Regulatory Response (Load)			
				speed Increase 10%		speed Decrease 10%		Load Increase 40%		Load Decrease 40%	
Rise Time (sec)	Peak Time (sec)	Over shoot (%)	Settling Time (sec)	Over shoot (%)	Settling time (sec)	Under shoot (%)	Settling time (sec)	Under shoot (%)	Settling time (sec)	Over shoot (%)	Settling time (sec)
-	0.013	29.21	0.220	-	0.010	-	0.0108	2.68	0.169	2.70	0.179

Conclusion:

The simulated results shown the performance analysis of the three phase resonant inverters fed hybrid electric vehicle using the BLDC motor drive with PI controller. The PI controller regulated the voltage of three phase resonant inverter and controlled the BLDC motor speed equal to the reference speed. The motor speed reached its steady-state level with fewer oscillations by the control of PI controller. Further, in the future the conventional PI controller may replace by an intelligent controller to determine the performance of the proposed scheme.

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