BLDC Motor drive fed Hybrid Electric Vehicle using Resonant Converter with Fuzzy PI controller

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Abstract: Over the years, it has seen the power conditioning move from simple, but extravagant linear regulators, through early low-frequency pulse-width modulated systems, to high-frequency square wave converters, which pack the same power handling capabilities of previous designs into a fraction of their size and weight. At present, a novel attack is upon us the resonant mode converter, and while extending innovative benefits in size, and cost and performance wise this new topology brings with it an added dimension of complexity. The main purpose of this paper is to provide a system for manipulating the speed of a Brushless DC motor (BLDC) in a Hybrid-Electric Vehicle fed resonant mode inverter. The resonant inverter is 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, the resonant inverter fed BLDC motor drive for hybrid-electric vehicle system simulated using A MATLAB/Simulink software tool. Fuzzy Gain Scheduled PI controller are used for closed-loop control of the projected scheme.

Keywords: BLDC motor; Electric vehicle; Fuzzy Gain Scheduled PI controller; Resonant Inverter.

INTRODUCTION

Recently because environmental pollution and the energy crisis are growing globally, most industrialized nations have been attempting to cut their addiction on oil as electric cars, scooters, bikes, wheelchairs, etc. Electric vehicles (EVs) are becoming important, not just as an environmental measure against global warming, but also as an industrial policy [1, 2]. For the next-generation EVs must be safe and execute good. The propulsion force generation which strongly influences the base hit and moving 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 delivers a simple construction, high efficiency, high speed, High starting torque, noiseless operation, etc., [3, 4, 5].

The conception and development of various resonant power converters (RPC) have been focused on telecommunication and aerospace applications. It has been set up that these converters experience high switching losses, reduced reliability, electromagnetic interference (EMI) and acoustic noise at high frequencies. The series and parallel Resonant Converter circuits are the basic resonant converter topologies with two reactive components. The RC is found to be desirable, due to various inherent advantages. The merits of SRC include better power conversion efficiency due to the series capacitor in the resonant network and the inherent DC blocking capability of the isolation transformer. Nevertheless, the load regulation is poor and output-voltage regulation at no-load is not possible by switching frequency variations. On the other hand, the PRC offers better no-load regulation, but suffers from poor power conversion efficiency due to the inadequacy of a DC blocking element before the isolation transformer. Hence, an RC with three reactive components is suggested for better regulation [6, 7, 8, 9, 10].

In this report, a new circuit of resonant inverter fed BLDC motor control for hybrid-electric vehicle closed loop control is implemented using PI and fuzzy gain scheduled PI controller, performance parameters like steady state and transient analysis are studied.

PROPOSED SYSTEM DESCRIPTION

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

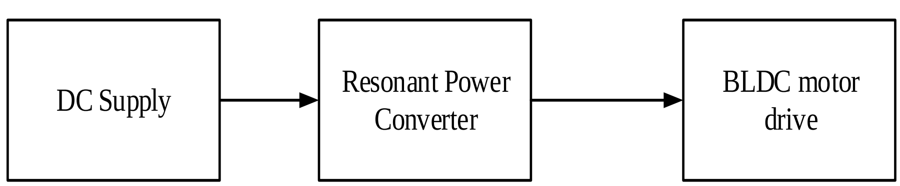

Fig.1: Resonant inverter fed hybrid electric vehicle system

BLDC Motor

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 surfaced-put on 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 detect without sensors.

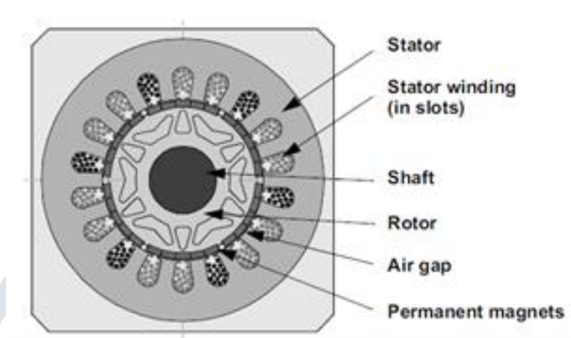

Fig.2: BLDC Motor - Cross Section

The BLDC motor is the magnetic field made by the stator and the magnetic field generated by the rotor rotation is the same frequency. Brushless DC (BLDC) motors are ideally suitable for EVs because of their high-power densities, excellent 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 [11, 12, 13]. Nevertheless, a BLDC motor needs complex electronics for control. The BLDC motor, permanent magnets mounted on the rotor, with the armature windings fixed to the stator with a laminated steel core. Revolution began and kept in sequentially energy opposite pairs of pole windings that called as formative phases. Knowledge of rotor position is critical to suffering the apparent movement 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 going near the sensors [11, 14, 15].

Resonant Inverter

In Fig.3, there is depicted a block system of the power part of the used three-phase resonant inverter. The inverter consists of a conventional voltage source inverter with zero (reverse) diodes. Each leg of the inverter bridge contains four switches (S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, S11, and S12). The switches activate circuits L1, C1 and C2, respective L2, C3 and C4 and L3, C5, and C6. These circuits are initialized in the instants when the current of the load is too low for fast overcharging or wrong polarity for overcharging of resonant capacitors. If the current of the 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 [12,13,16].

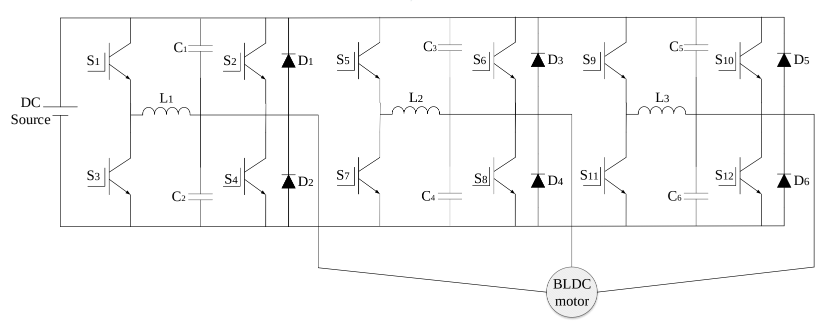

Fig.3: Three phase resonant inverter

Fuzzy Gain Scheduling PI Controller (FGSPI)

Fuzzy logic is a part of artificial intelligence or machine learning which interprets a human's actions. Computers can interpret only true or false values, but a human being can reason the degree of truth or degree of falseness. Fuzzy models interpret the human actions and are also called intelligent systems. Fuzzy logic is not logic that is fuzzy, but the logic that is used to describe fuzziness. Fuzzy logic is the theory of fuzzy sets, sets that calibrate vagueness. It is based on the idea that all things admit of degrees. In other words, fuzzy logic is a set of mathematical principles for knowledge representation based on degrees of membership. Fuzzy logic reflects how people think. It attempts to model our sense of words, our decision making, and our common sense. As a result, it is leading to new, more human, intelligent systems.

Fuzzy Logic Toolbox available in MATLAB used in this research work for implementation of the Fuzzy controller. It allows several things to be done, but the most important things are to be a place where a fuzzy inference system can be created or edited. For this Resonant Converter control simulation system, the fuzzy boundaries can be considered according to the rules that are going to be used. As the number of rules are increased, the degree of membership will become more accurate. The designed Fuzzy Proportional Integral (Fuzzy-PI) controller is a hybrid controller that utilizes two sets of PI gains to achieve a non-linear response. The switching in this controller is obtained by a fuzzy logic section that depends on the input $V_{in}(t)$. At every sampling interval, the instantaneous RMS values of the sinusoidal reference voltage and load voltage are used to calculate the error (e) and change in error (ce) signals that act as the input to the gain of PI controller.

The designed Fuzzy Proportional Integral (Fuzzy-PI) controller is a hybrid controller that utilizes two sets of PI gains to achieve a suitable non-linear response. The switching in this controller is obtained by a fuzzy logic section that depends on the input $I_{in}(t)$. Fig.4 shows a diagram of the proposed Fuzzy-PI controller.

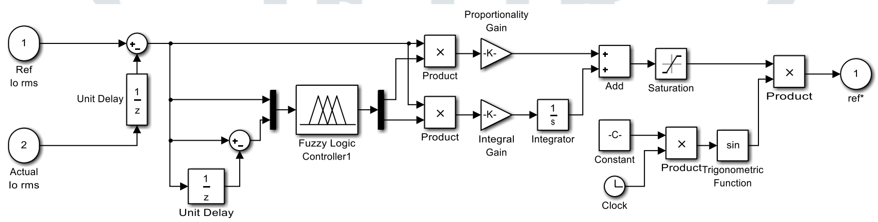

Fig.4: Fuzzy Gain Scheduled PI controller

Figs. 5-7 show the Fuzzy Proportional and Integral gain response over error and change in error and fuzzy rule respectively.

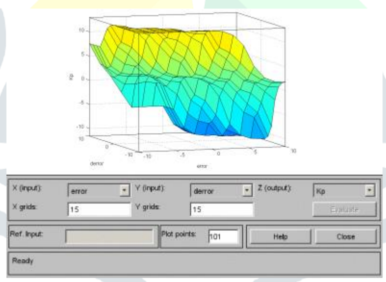

Fig.5: Fuzzy Proportionality gain response over error and change in error

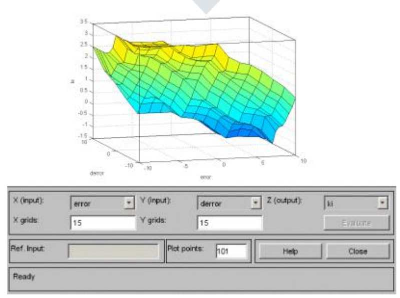

Fig.6: Fuzzy Integral gain response over error and change in error

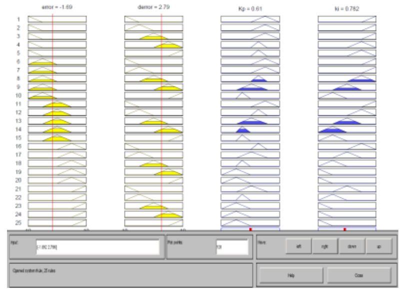

Fig.7: Fuzzy rule base response over error, change in error and gains

SIMULATION RESULTS AND DISCUSSION

The inverter used to regulate voltage and fed into the BLDC motor through a motor driver circuit. A MATLAB/Simulink tool utilized for the performance evaluation of this scheme with conventional PI controller and fuzzy gain scheduled PI controllers and validated the same.

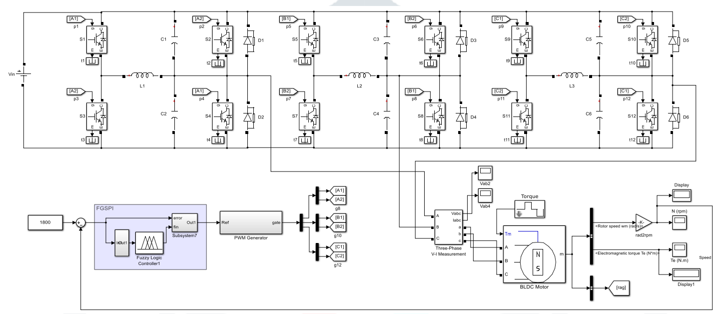

Fig.8: Three phase resonant inverter fed HEV system using FGSPI controller

Fig.8 shows the closed-loop three-phase resonant inverter fed HEV system using FGSPI controllers respectively. The system steady state and transient responses implemented with controllers are shown in Figs.9-10.

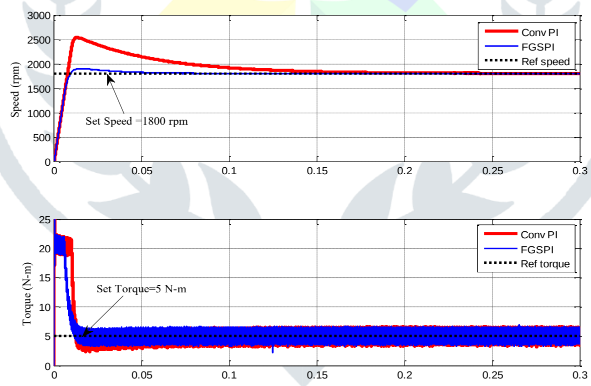

Fig.9 Steady state response of HEV system speed and torque (N=1800 rpm, T=5N-m)

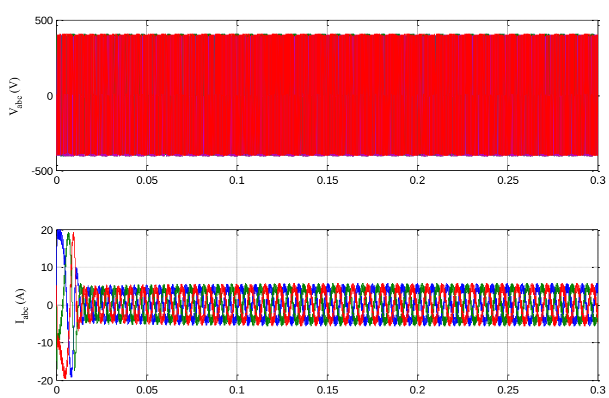

Fig.10: Output voltage and current response of HEV system speed and torque (N=1800 rpm, T=5N-m)

Fig.9 shows the steady state response of resonant inverter fed HEV system speed (N=1800 rpm) and torque (T=5 N-m.) for steady state analysis. Also, the output voltage and current responses are shown in Fig.10. From the figure 10, it is observed that the speed of the motor controlled by PI and FGSPI controllers and it has reached its steady state and settled with the reference speed of 1800 rpm at 0.22 sec with an overshoot of 29.21% and 0.0473 sec with overshoot 4.96% respectively shown in Table.1. From the observation of the table, the FGSPI controller reached its steady state value faster than conventional PI controller with less overshoot.

The response of the FGSPI controller is superior to conventional PI controller shown in Table.1

Table.1 Performance evaluation of resonant inverter fed HEV BLDC motor using MATLAB

Controller	**Steady state analysis**			
	Rise Time (sec)	Peak Time (sec)	Over Shoot (%)	Settling Time (sec)
PI	0.0096	0.013	29.21	0.220
FGSPI	0.0080	0.013	4.96	0.0473

CONCLUSION

The simulated results showed the performance analysis of the three-phase resonant inverter fed hybrid-electric vehicle using the BLDC motor drive with conventional PI and Fuzzy Gain Scheduled PI (FGSPI) controllers. The controllers regulated the voltage of the 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 and FGSPI controllers. From the simulated analysis, the overall performance of FGSPI controller is superior to conventional PI controller. The speed settled very fast on its reference value, and the torque response did not change speed during the disturbances due to the presence of the proposed FGSPI controller.

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