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Fuzzy Gain Scheduled Pi Controller for Resonant Power Converter Fed Hybrid Electric Vehicle with Bldc Motor Drive

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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 earlier designs into a fraction of their size and weight. At present, a novel attack is upon us the resonant mode converter and while extending new benefits in performance, size and cost, this new technology brings with it an added dimension of complexity. The aim 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. 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 An MATLAB/Simulink software tool. PI controller and Fuzzy Gain Scheduled PI controller are used for closed-loop control of the projected scheme.

Key words: BLDC motor · Electric vehicle · Fuzzy Gain Scheduled PI controller · PI controller · Resonant Inverter

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 [1, 2]. For the next-generation EVs must be secure and perform well. The propulsion force generation which strongly influences the base hit 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 a simple construction, high efficiency, higher speed range, large starting torque, noiseless operation, etc., [3, 4, 5].

The invention and evolution 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 elements. 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 deficiency of a DC blocking element before the isolation transformer. Hence, an RC with three reactive components is suggested for better regulation [6-10].

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In this paper, 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 analyzed.

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

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 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 detect without sensors.

The BLDC motor is the magnetic field produced by the stator and the magnetic field produced by the rotor rotation is 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 [11-13]. 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 [11, 14, 15].

Resonant Inverter: In Fig. 3, there is shown a block scheme 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 branch 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].

PI Controller: A Proportional – Integral (PI) control is a special case of the classic controller family known as Proportional – Integral – Derivative (PID). These types of controllers are up to date the most common way of controlling industrial processes in a feedback configuration. More than 95% of all installed controllers are PID [17]. Fig. 4 shows the structure of the proposed converter with PI controller. The proportional part is responsible for following the desired set-point while the integral part accounts for the accumulation of past errors. In spite of the simplicity, they can be used to solve even a very complex control problem, especially when combined with different functional blocks, filters (compensators or correction blocks), selectors etc.

The closed loop simulation using the PI controller for the Resonant Converter fed HEV system is carried out using MATLAB/Simulink software. Depending on an error and the change in error, the value of change of switching frequency is calculated. Set parameter instruction and function blocks available in MATLAB are used to update the new switching frequency of the pulse generators.

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.

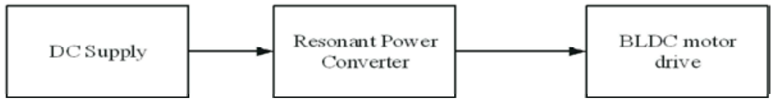

Fig. 1: Resonant inverter fed hybrid electric vehicle system

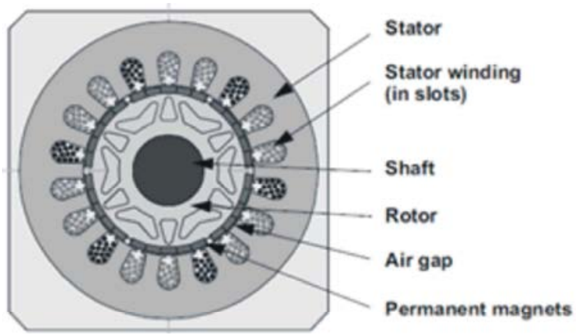

Fig. 2: BLDC Motor - Cross Section

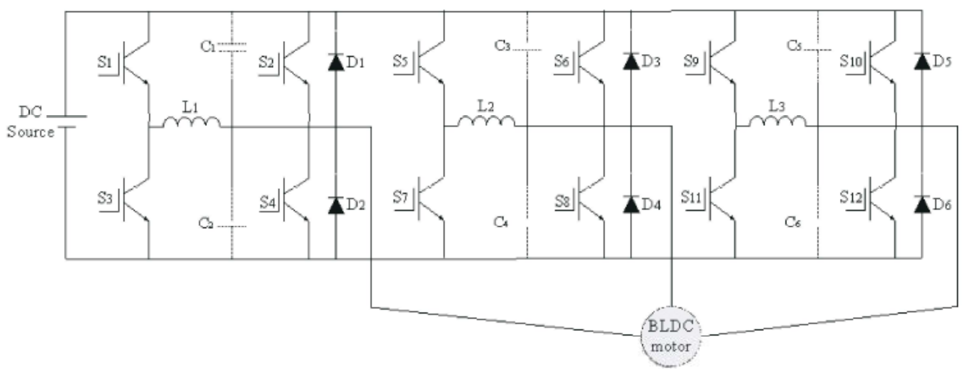

Fig. 3: Three phase resonant inverter

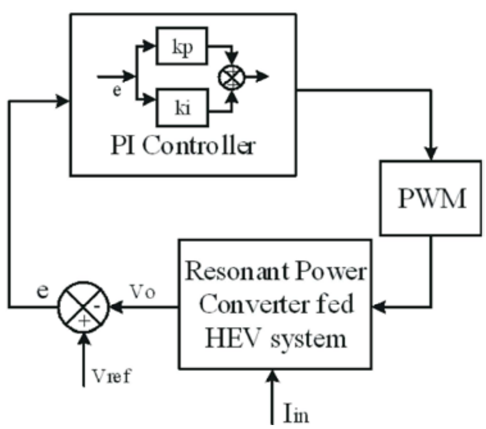

Fig. 4: Structure of PI controller with HEV system

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 amount of rules 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 in order to achieve a non-linear response. The switching in this controller is achieved with a fuzzy logic section that depends on the input $V_{in}(t)$.

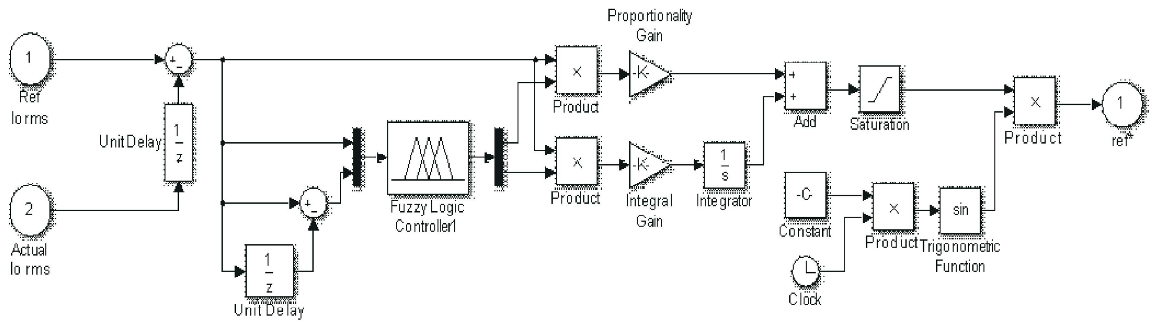

Fig. 5: Fuzzy Gain Scheduled PI controller

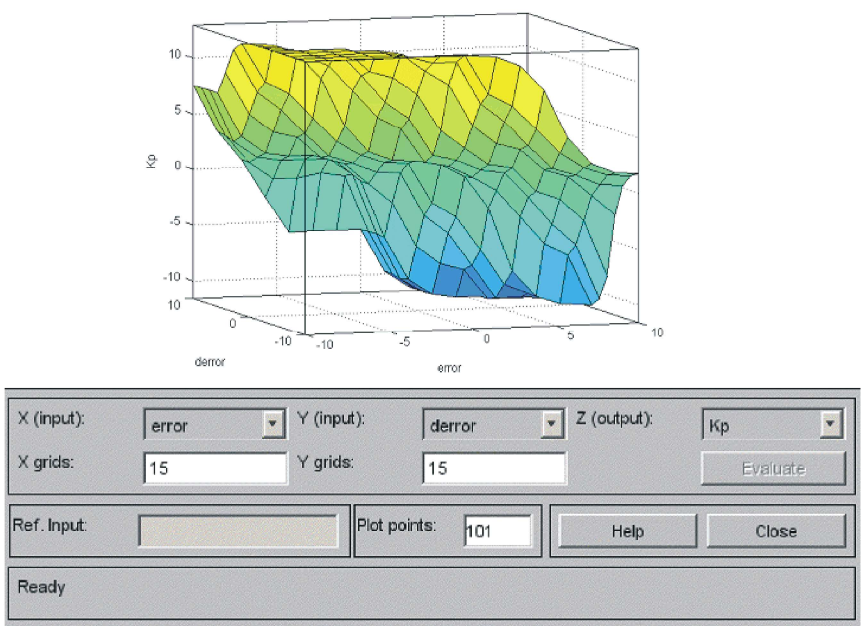

Fig. 6: Fuzzy Proportionality gain response over error and change in error

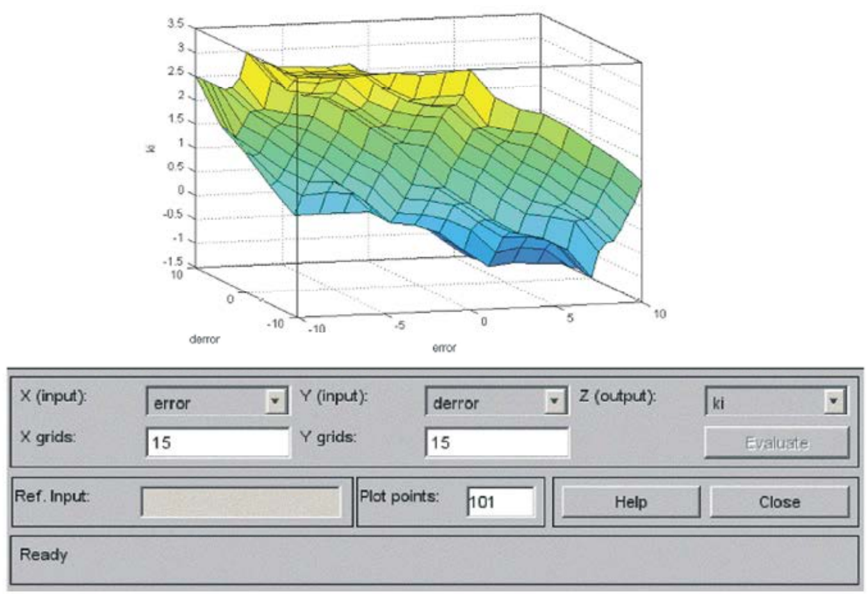

Fig. 7: Fuzzy Integral gain response over error and change in error

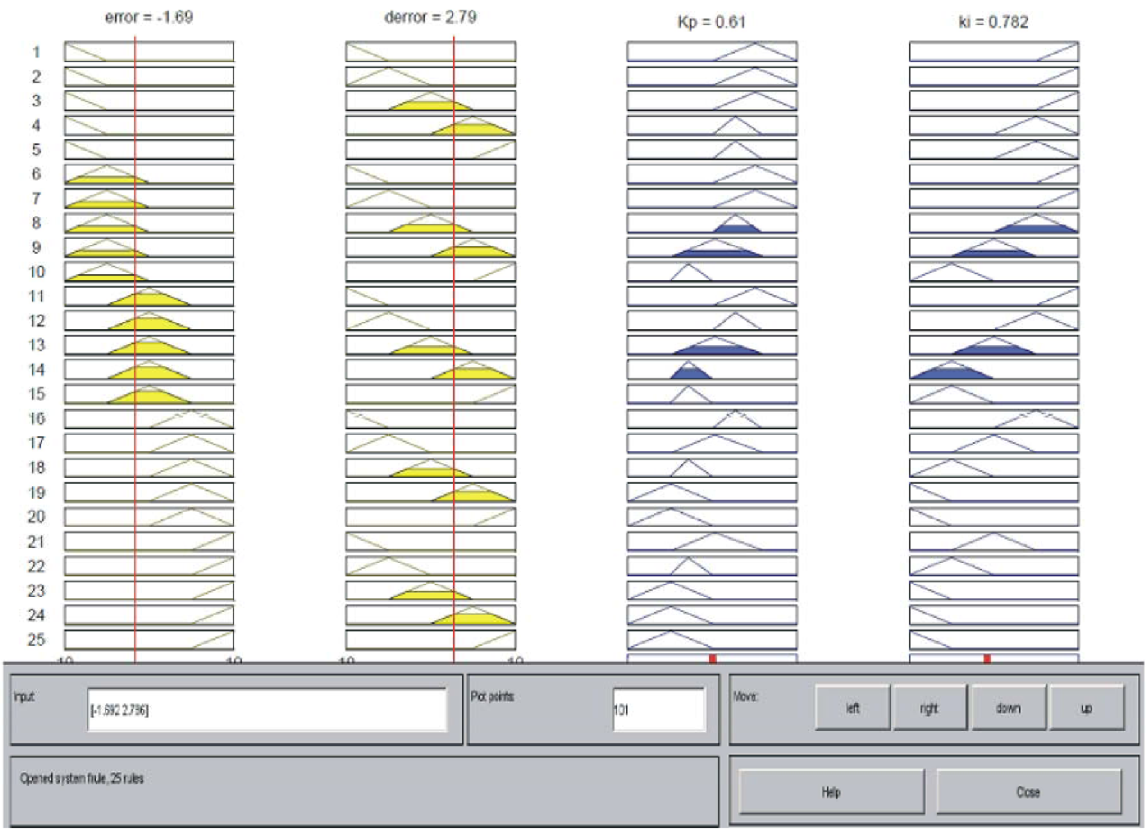

Fig. 8: Fuzzy rule base response over error, change in error and gains

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 in order to achieve a suitable non-linear response. The switching in this controller is achieved with a fuzzy logic section that depends on the input $I_{in}(t)$. Fig. 5 shows a diagram of the proposed Fuzzy-PI controller.

Figs. 6, 7 and 8 show the Fuzzy Proportional and Integral gain response over error and change in error and fuzzy rule respectively.

RESULTS AND DISCUSSION

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

Figs. 9 and 10 shows the closed-loop three-phase resonant inverter fed HEV system using PI and FGSPI controllers respectively. The system steady state and transient responses implemented with controllers are shown in Figs. 10-16.

Fig. 11 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. 11. 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 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.

Figs. 13 and 15 show the servo response of the proposed system. 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 0.0108 sec with PI

Table 1: Performance evaluation of 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%	
Controller	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)
PI	0.0096	0.013	29.21	0.220	-	0.010	-	0.0108	2.68	0.169	2.70	0.179
FGSPI	0.0080	0.013	4.96	0.0473	-	0.007	-	0.0068	4.80	0.071	4.60	0.076

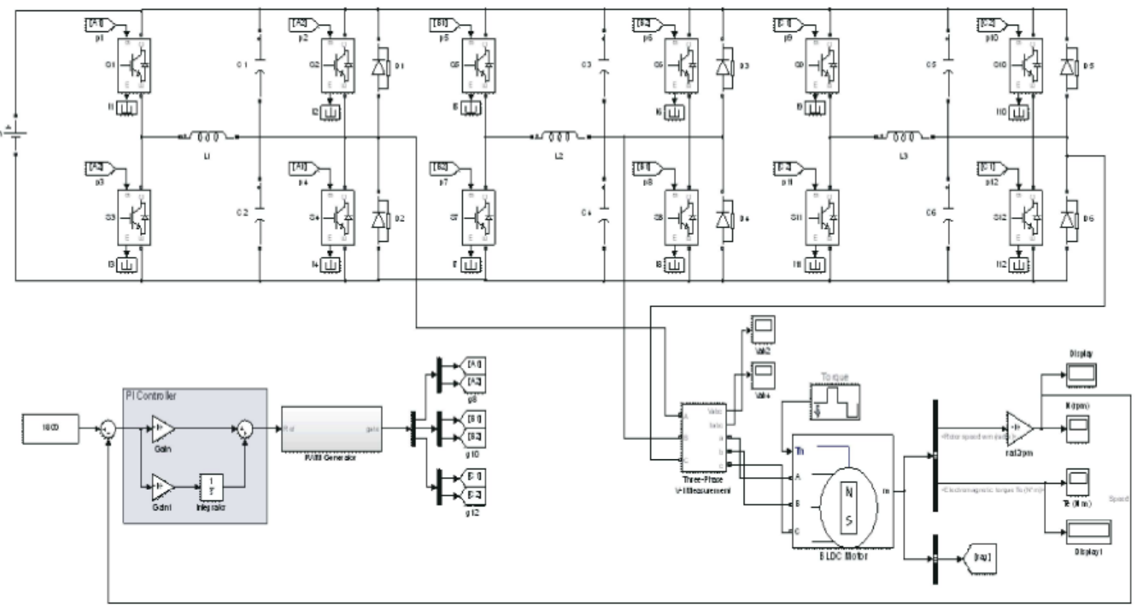

Fig. 9: Three phase resonant inverter fed HEV system using conventional PI controller

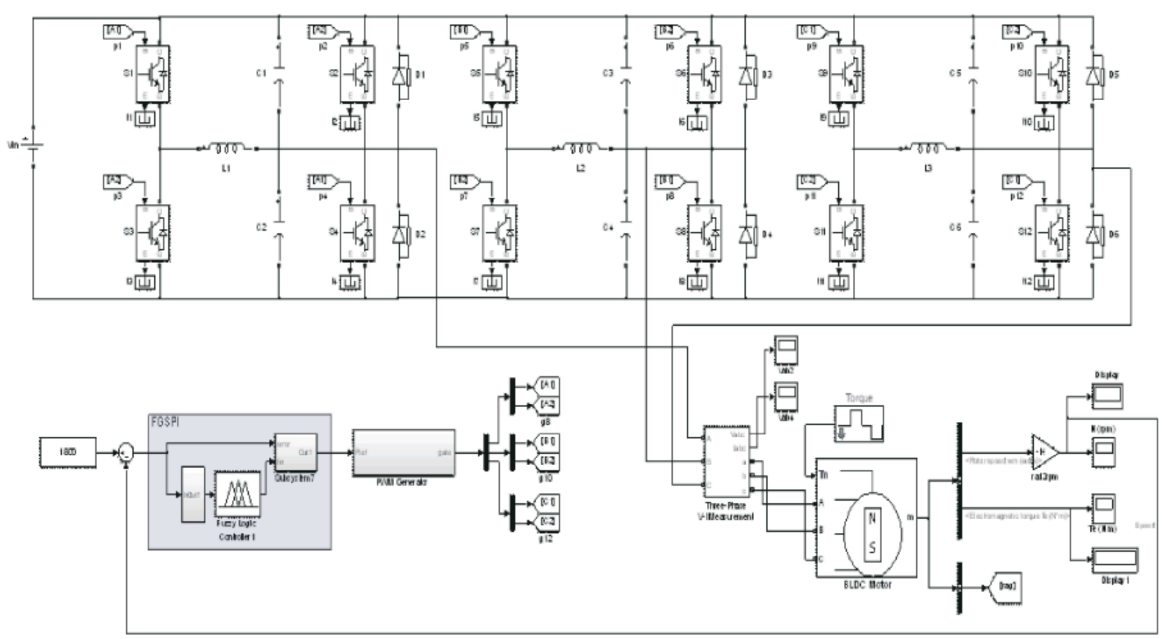

Fig. 10: Three phase resonant inverter fed HEV system using FGSPI controller

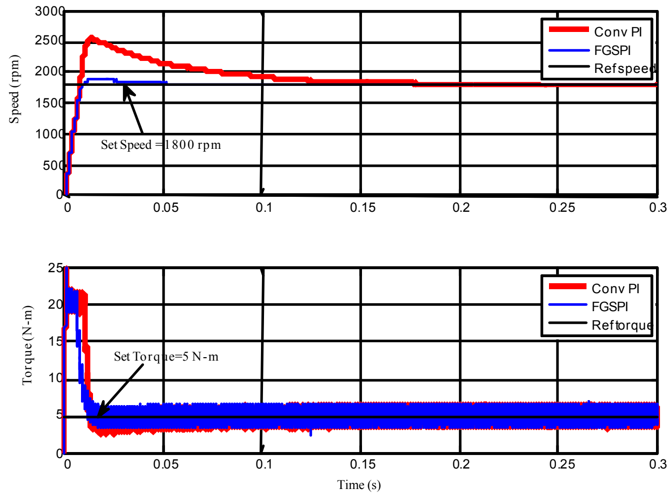

Fig. 11: Steady state response of HEV system speed and torque (N=1800 rpm, T=5N-m)

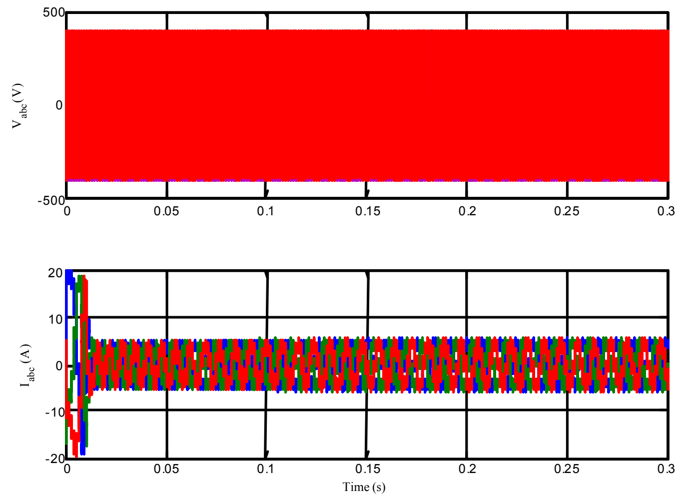

Fig. 12: Output voltage and current response of HEV system speed and torque (N=1800 rpm, T=5N-m)

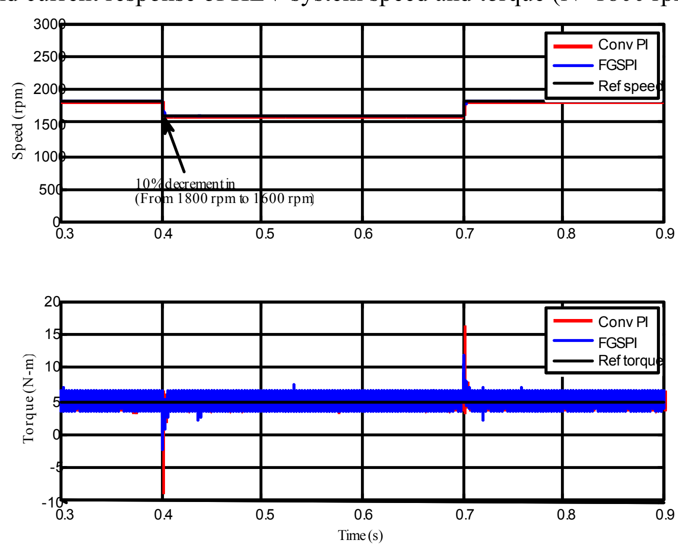

Fig. 13: Output voltage and current response of HEV system speed and torque (N=1800 rpm, T=5N-m)

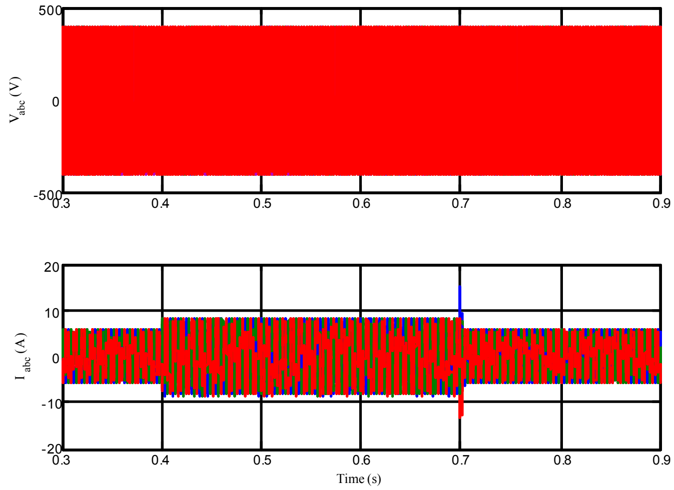

Fig. 14: Voltage and current responses of HEV system for change in speed (up to 0.4sec, N=1800 rpm, T=5N-m; t= 0.4 – 0.7sec, N=1600 rpm, T=5N-m; t= 0.7 - 1sec, N=1800 rpm, T=5N-m)

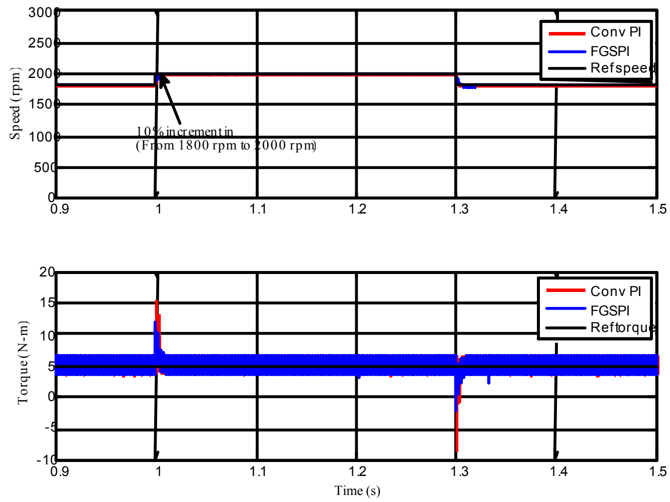

Fig. 15: Speed and torque responses of HEV system for change in speed (N=1800 rpm up to 1 sec, T=5N-m; t= 1 – 1.3sec, N=2000 rpm, T=5N-m; t= 1.3 – 1.5sec, N=1800 rpm, T=5N-m)

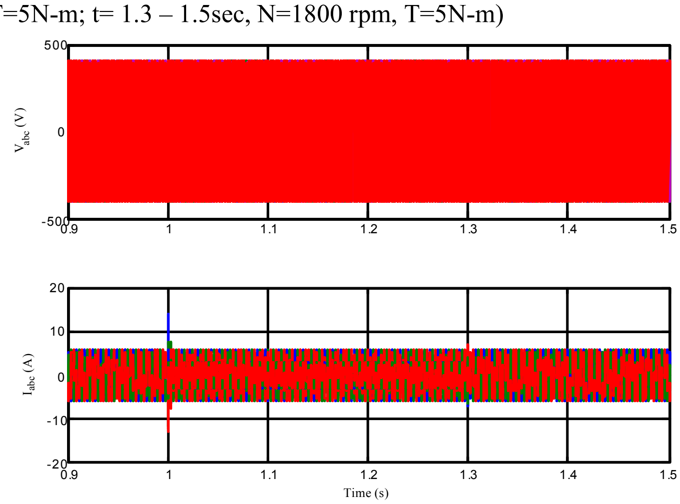

Fig. 16: Voltage and current responses of HEV system for change in speed (N=1800 rpm up to 1 sec, T=5N-m; t= 1 – 1.3sec, N=2000 rpm, T=5N-m; t= 1.3 – 1.5sec, N=1800 rpm, T=5N-m)

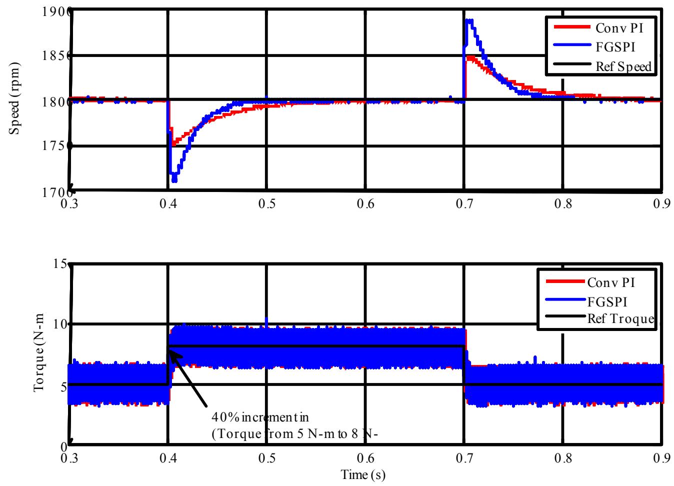

Fig. 17: Speed and torque responses of HEV system for change in load (up to 0.4sec, T=5N-m, N=1800 rpm; t= 0.4 – 0.7sec, T=8 N-m, N=1800 rpm; t= 0.7 - 1sec, T=5 N-m, N=1800 rpm)

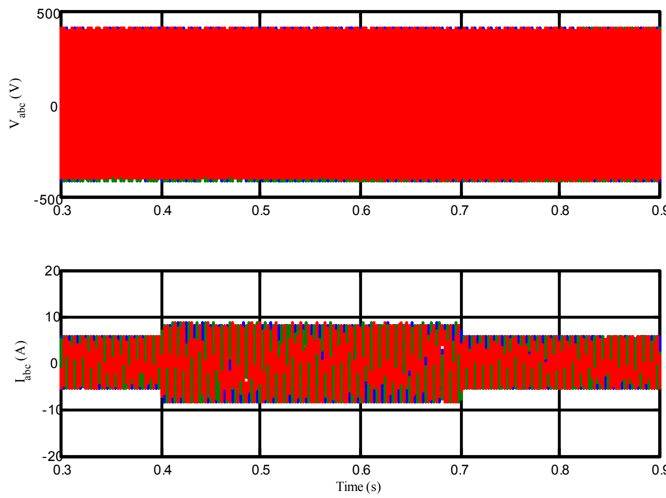

Fig. 18: Voltage and current responses of HEV system for change in load (up to 0.4sec, T=5N-m, N=1800 rpm; t= 0.4 – 0.7sec, T=8 N-m, N=1800 rpm; t= 0.7 - 1sec, T=5 N-m, N=1800 rpm)

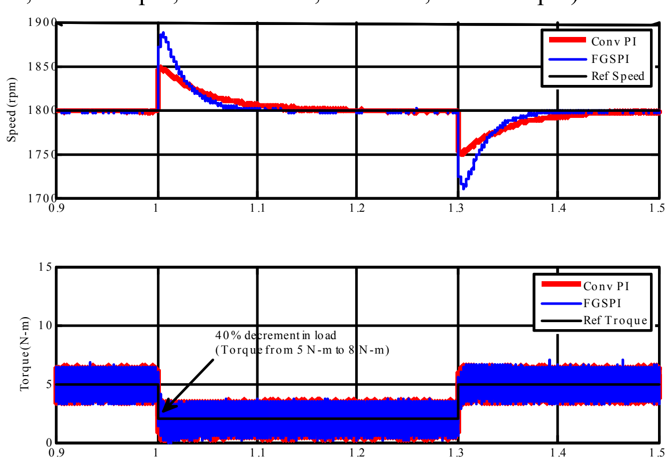

Fig. 19: Speed and torque responses of HEV system for change in load (up to 1.0sec, T=5N-m, N=1800 rpm; t= 1.0 – 1.3sec, T=2 N-m, N=1800 rpm; t= 1.3 – 1.5sec, T=5 N-m, N=1800 rpm)

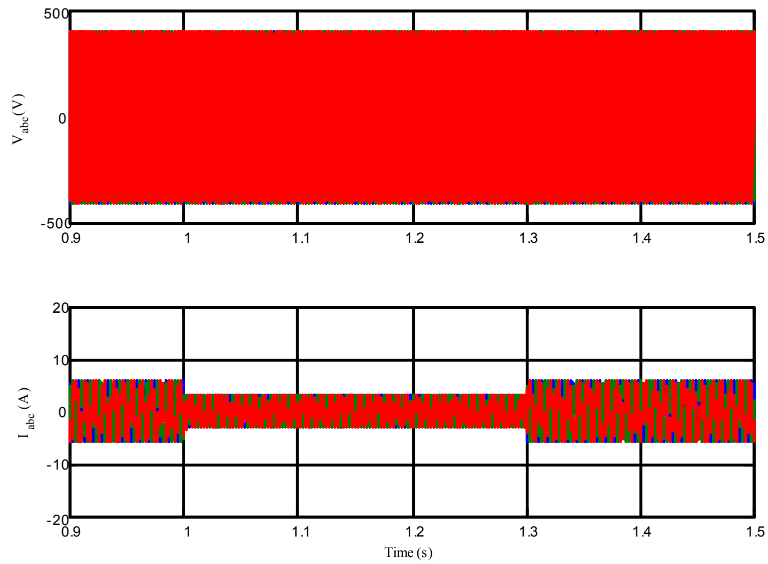

Fig. 20: Voltage and current responses of HEV system for change in load (up to 1.0sec, T=5N-m, N=1800 rpm; t= 1.0 – 1.3sec, T=2 N-m, N=1800 rpm; t= 1.3 – 1.5sec, T=5 N-m, N=1800 rpm

controller and 0.0068 sec with FGSPI controller without any shoot. Likewise the change in speed (10% increment) from 1800 to 2000 rpm at 1.0 sec and settled its reference speed of 2000 rpm at 0.010 sec with PI controller and 0.007 sec with FGSPI controller without any form shown in Fig. 15.

Figs. 17 and 19 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 (40%) from 5 N-m to 8 N-m at 0.4 sec and decremented (40%) from 5 N-m to 2 N-m at 1.0 sec in Figure 17 and 19 respectively. The response of the FGSPI controller is superior to conventional PI controller, but the overshoot value of the FGSPI controller is slightly higher than PI controller shown in Table 1.

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 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 with respect to 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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