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Experimental Analysis of Hybrid Electric Vehicle with BLDC Motor Drive

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Abstract: This report suggests a power circuit for DC-AC conversion and voltage boosting using a voltage multiplier to control the velocity of a Brushless DC motor (BLDC) in a Hybrid-Electric Vehicle. In this proposed system, a voltage multiplier introduced for the substitution of traditional inverter and converter. A Zeta converter used in a DC-DC converter to determine the DC voltage and fed into the BLDC motor through a motor driver circuit. PI controller used to check the speed and regulate the DC output voltage from Zeta Converter. The Hybrid-Electric Vehicle system performances analysed with a PI controller using MATLAB/ Simulink software platform. The experimental validation of the proposed system is verified using Arduino controller.

Key words: BLDC motor · Electric vehicle · PI controller · Zeta converter · Voltage multiplier

INTRODUCTION

Recently because environmental pollution and the energy crisis are growing globally, most industrialized nations have been attempting to cut their addiction on petroleum as an 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 secure and perform well. The propulsion force generation that 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 structure, high efficiency, higher speed range, large starting torque, noiseless operation, etc., [3-5].

In this paper, we proposed a circuit of voltage multiplier topology for replacement of conventional inverters and converters of BLDC motor control for a hybrid electric vehicle using a voltage multiplier and the zeta converter with PI control strategy.

Proposed System Description: Fig. 1 shows the block diagram representation of the voltage multiplier based Hybrid-Electric Vehicle system. It consists of four sections, Battery supply, Voltage multiplier, DC-DC converter and BLDC driver circuit.

DC Voltage Section: Fig.2 shows the DC voltage section of the Electric Vehicle. It consists of a battery unit and a single phase inverter circuit to convert the battery DC supply to an AC supply. The inverter AC voltage fed to voltage multiplier for further processing.

Voltage Multiplier: Voltage multipliers are AC-DC power converters, comprised of diodes and capacitors, which create a high potential DC voltage from a lower voltage AC source. Multipliers made up of multiple levels, each level comprised of one diode and one capacitor. The most commonly used multiplier circuit is the half-wave series multiplier. All multiplier circuits can be inferred from its basic operating rules. Therefore, the half-wave series multiplier circuit is shown in Fig. 3 to exemplify general multiplier operation. The model shown in Fig. 3 assumes no losses and represents sequential reversals of transformer (T_S) polarity.

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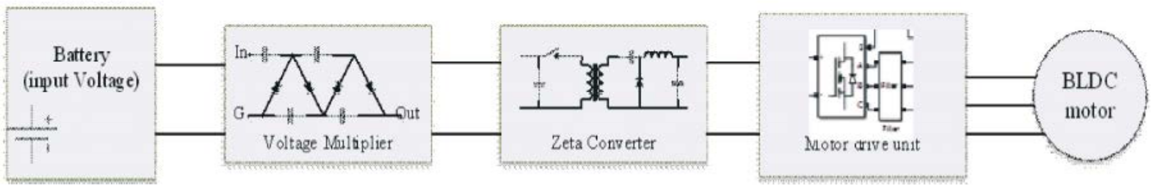


Fig. 1: Hybrid Electric Vehicle system

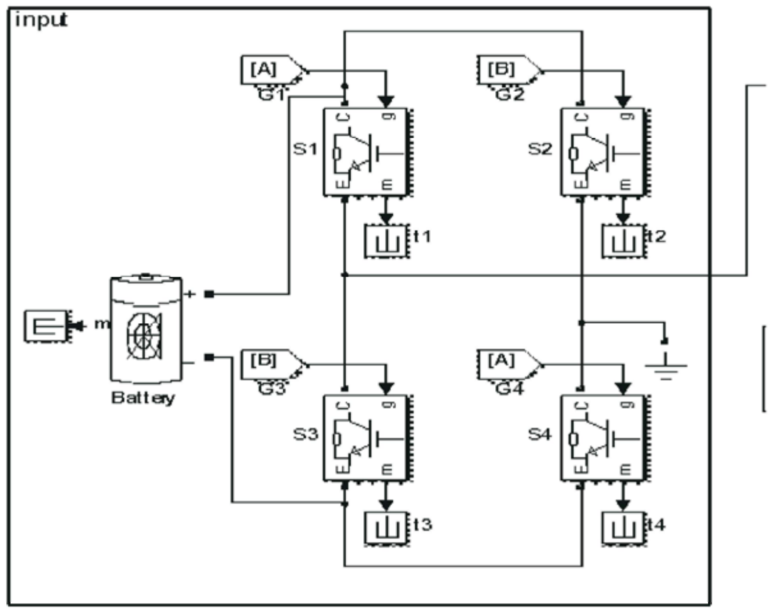


Fig. 2: DC voltage section of Hybrid Electric Vehicle system

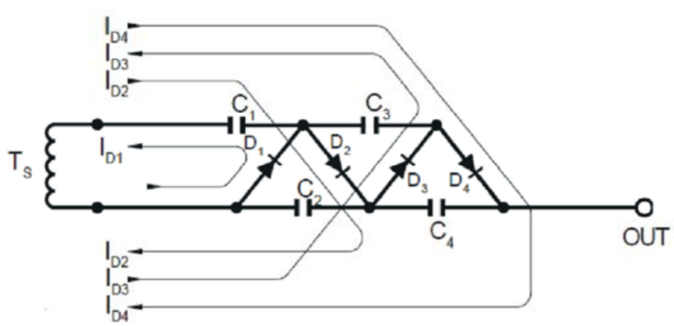


Fig. 3: Series half wave voltage multiplier

Originally used for television CRT's, voltage multipliers are now used for lasers, x-ray systems, traveling wave tubes (TWT's), photomultiplier tubes, ion pumps, electrostatic systems, copy machines and many other applications that utilize high voltage DC. DC output voltage drops as DC output current is increased. Regulation is the drop, from the ideal, in DC output voltage at a specified DC output current (assuming AC input voltage and AC input frequency are constant). A close approximation for series half-wave multipliers can be expressed as:

$$V_{reg} = \left[I\left(N^3 + \left(9N^2/4\right) + \left(N/2\right)\right)\right] \Big/ 12FC \qquad (1)$$

where, N is no. of stages (I capacitor and I diode = 1 stage
F is AC input frequency (Hz)
C is Capacitor per stage (F)
I is DC output current (A)

Ripple voltage is the magnitude of fluctuation in DC output voltage at a specific output current. A close approximation for series half-wave multipliers can be expressed as:

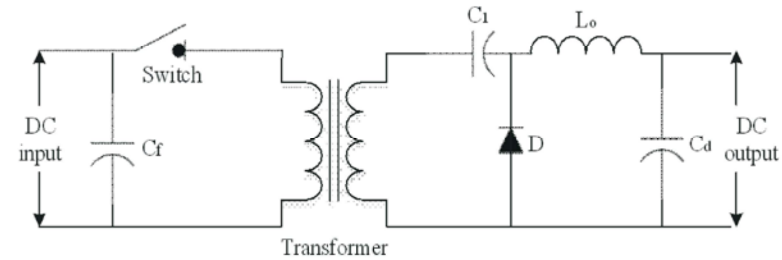


Fig. 4: Circuit diagram of zeta converter

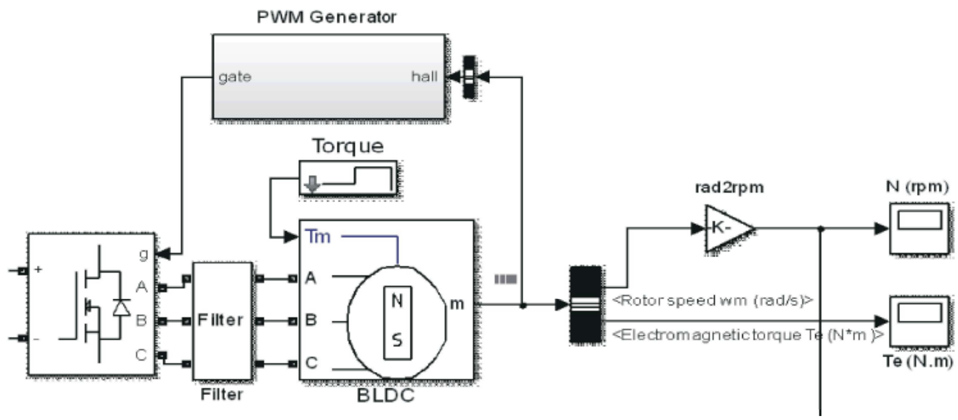


Fig. 5: BLDC motor drive of the proposed Electric Vehicle

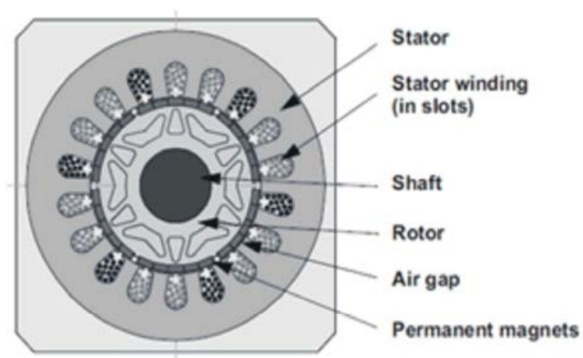


Fig. 6: BLDC Motor - Cross Section

$$V_{rip} = I\left(N^2 + N/2\right)\Big/8FC \tag{2}$$

DC-DC Converter: Dissimilar types of AC-DC converters have introduced to fulfil the demanded power conversion, such as Sepic, Cuk converters and so on. From the available converters the Zeta Converter (Buck-Boost type) employed in the proposed study. The zeta converter has advantages such as, safety, flexibility, isolation and output adjustment. Zeta converter usually has a high transfer voltage gain and produce high insulation at both positions. The addition of the Zeta Converter always depends on the transformer turn ratio N, which can be thousand times. The zeta converter is a transformer based converter with a low-pass filter. Its output voltage ripple value is small [6-7]. Fig. 4 shows the circuit diagram of Zeta Converter.

The output voltage of zeta converter is,

$$V_o = \frac{k}{1-k} N V_{in} \tag{1}$$

where N is the turn ratio of transformer and k is the conduction duty cycle k= T_{on}/T.

Bldc Motor Drive: Fig. 5 shows the BLDC motor drive, it consists of a three phase inverter and BLDC motor. Sinusoidal PWM used as a switching strategy of the inverter. The speed and torque of the motor controlled using a PI controller with the reference speed and duty cycle of DC-DC converter.

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. 6. 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.

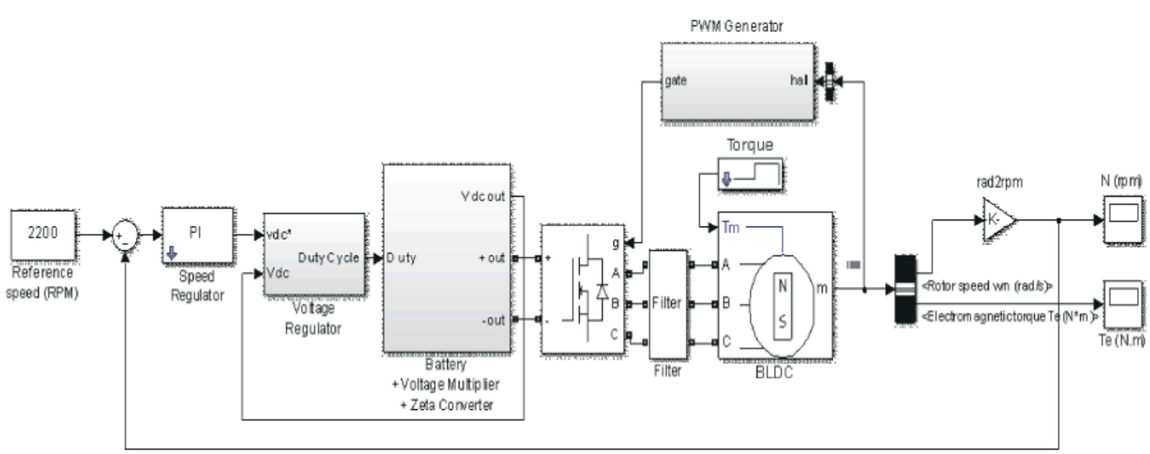
The BLDC motor is the magnetic field made by the stator and the magnetic field created by the rotor rotation is the same frequency. Brushless DC (BLDC) motors are ideally suitable for EVs because of their high-power densities, good speed-torque characteristics, high efficiency, wide speed ranges and low maintenance. BLDC motor is a type of synchronous motor. BLDC motors do not experience the "slip" which is available in induction motors [8-10]. 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 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].

RESULTS

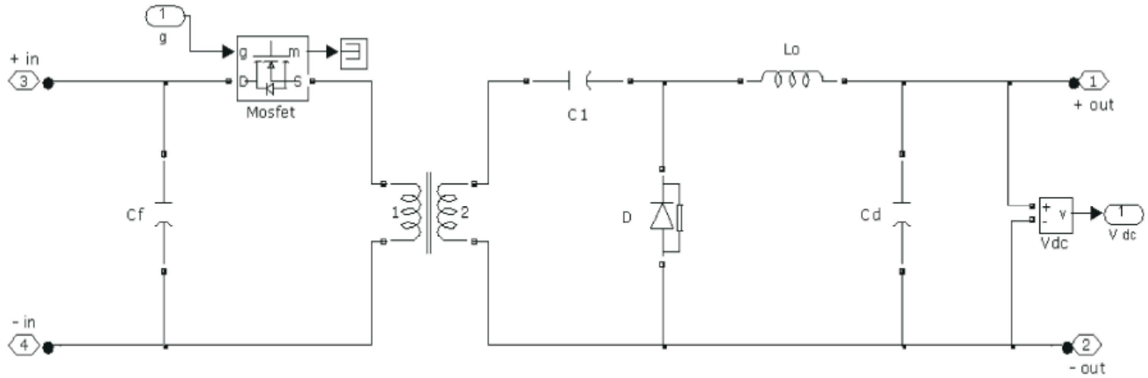
Fig. 7 shows the overall Simulink diagram of Hybrid Electric Vehicle with BLDC motor drive. The Simulink consist of various sections as inverter, voltage multiplier and motor drive as discussed above.

Fig. 7 shows the Simulink model of the voltage multiplier circuit. The battery voltage 12Vdc converted to AC using inverter in the input section, further the voltage multiplied by voltage multiplier cells to boost the low level voltage to a higher degree and delivered the voltage to the motor driver circuit in the form of AC voltage. In our proposed system the 12Vdc multiplied by the voltage multiplier and converted to 120Vac. The PI controller approach used in two positions in this Electric Vehicle. One is to control the speed and another is to control the DC voltage of zeta converter. The uncontrolled DC voltage of voltage multiplier controlled by the zeta converter by controlling duty of the converter using PI controller. The reference speed of the vehicle achieved by PI controller. Figs. 8 -10 shows the simulated responses of the hybrid electric vehicle system using BLDC motor drive.

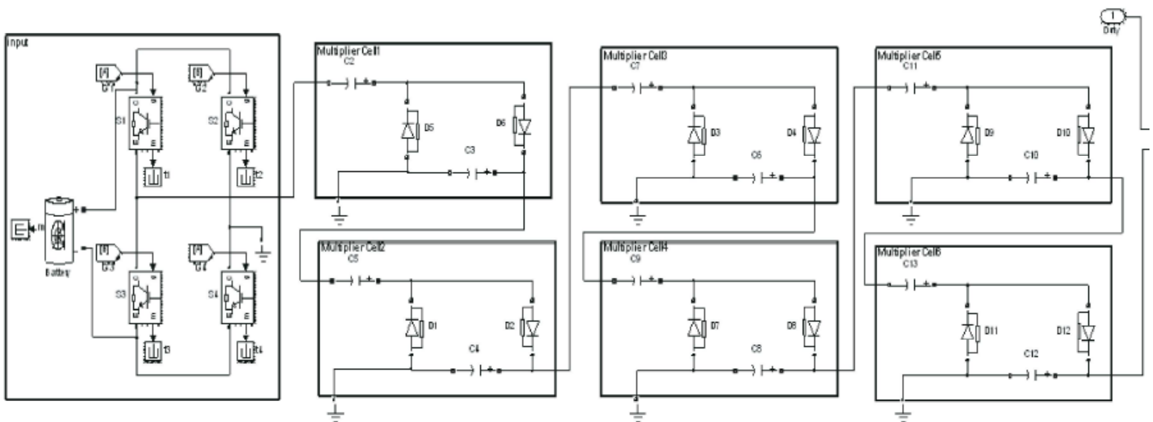
Fig. 8 shows the Steady state response of voltage multiplier, DC-DC converter, BLDC motor speed (N=2200 rpm) and torque (T=5 N-m.) for nominal case. From the figure it is observed that the speed of the motor controlled by PI controller and it has reached its steady state and settled with the reference speed at 0.75 sec. Fig. 9. Load disturbance response of voltage multiplier, DC-DC converter, BLDC motor speed and torque. This figure shows the regulatory response of the proposed system. During this performance the load is suddenly increased from 5 N-m to 10 N-m at 0.4 sec and decremented to 5 N-m at 0.7 sec. Due to this sudden increment and decrement of the load the speed slightly varied of 200 rpm from its actual speed. Similarly Fig.10 shows the Servo response of voltage multiplier, DC-DC converter, BLDC motor speed and torque. This figure shows the disturbance in the input side of the system.



(a)



(b)



(c)

Fig. 7: (a) Overall Simulink of Hybrid Electric Vehicle with BLDC Motor drive (b) Zeta Converter (c) Voltage Multiplier circuit

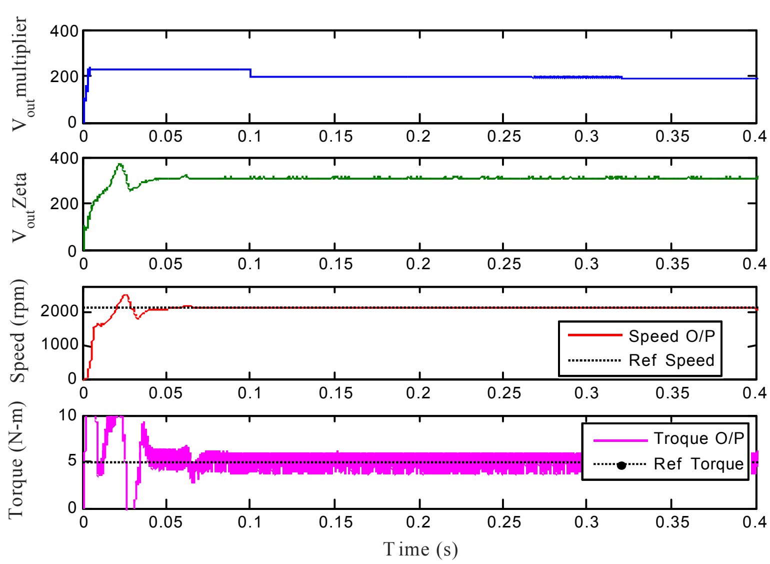


Fig. 8: Steady state response of voltage multiplier, DC-DC converter, BLDC motor speed and torque (N=2200 rpm, T=5N-m)

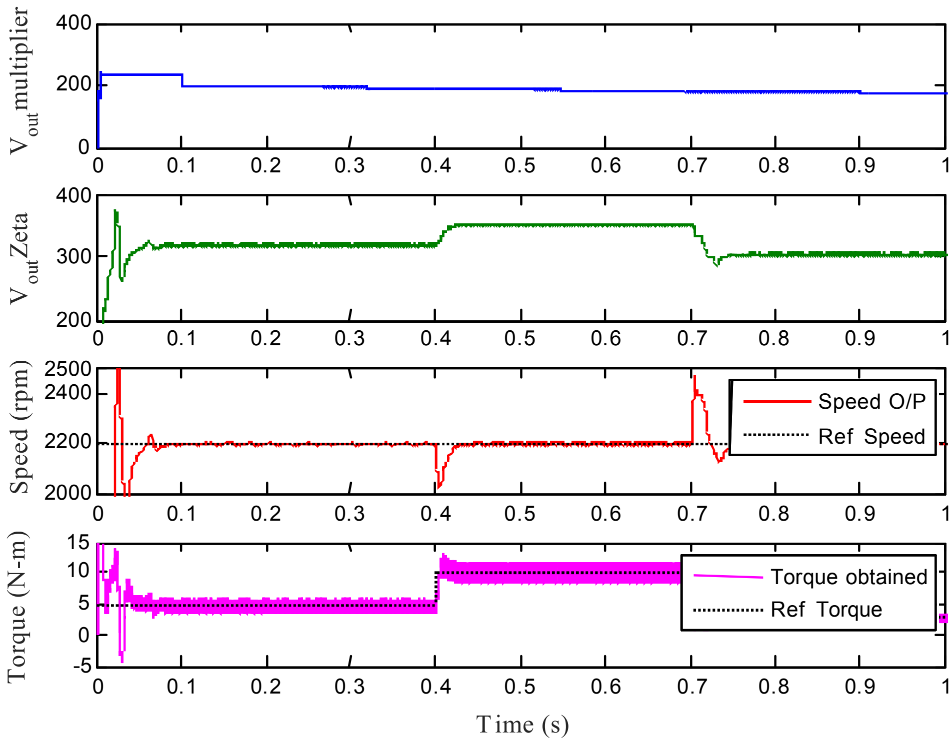


Fig. 9: Load disturbance response of voltage multiplier, DC-DC converter, BLDC motor speed and torque (t= 0 – 0.4s, N=2200 rpm, T=5N-m; t= 0.4 – 0.7s, N=2200 rpm, T=10N-m; t= 0.4 - 1s, N=2200 rpm, T=5N-m)

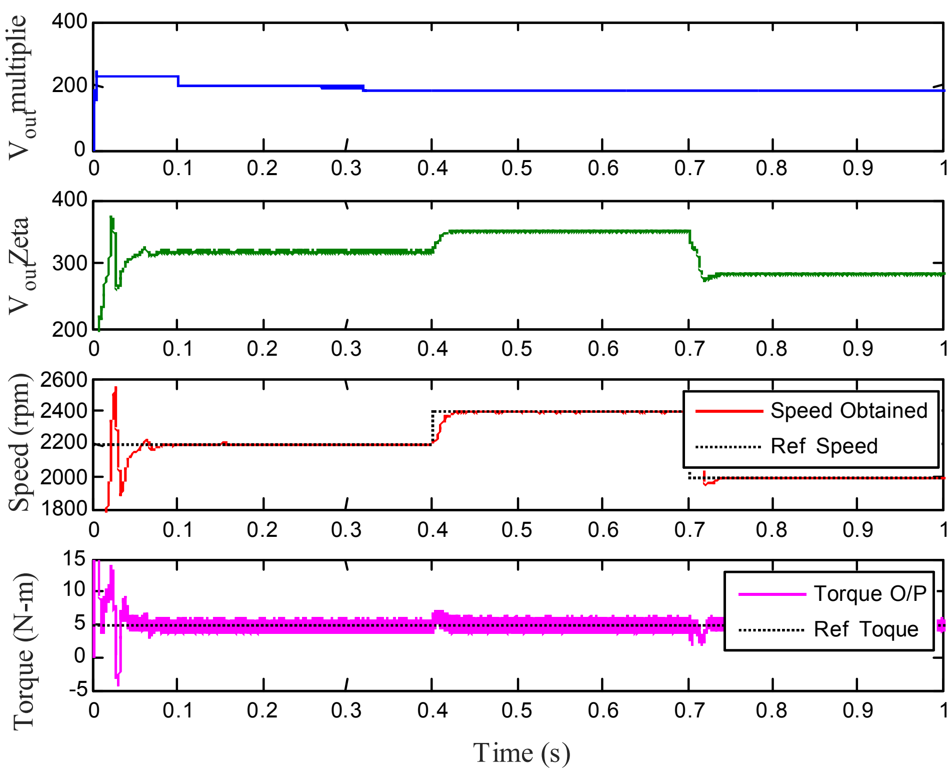


Fig. 10: Servo response of voltage multiplier, DC-DC converter, BLDC motor speed and torque (t= 0 – 0.4s, N=2200 rpm, T=5N-m; t= 0.4 – 0.7s, N=2400 rpm, T=5N-m; t= 0.4 - 1s, N=2000 rpm, T=5N-m)

Due to this sudden disturbance the speed of the motor slightly varied at 0.4 sec with increment of 2200 rpm to 2400 rpm and at 0.7 sec with decrement of 2400 rpm to 2000 rpm respectively. The speed will not get any oscillation because of the presence of PI controller.

Experimental Results: Proposed Hybrid Electric Vehicle system using voltage multiplier and zeta converter have verified experimentally with Arduino and PIC controllers. The PIC controller used for controlling pulse generation of three phase voltage source inverter in associated with the Arduino controller. Because the Arduino controller used for PI controller for controlled PWM generation and control the duty of zeta converter. Voltage multiplier and zeta converter responses are shown in Fig. 11 and 12. The BLDC motor output speed response has been studied as a feedback using speed sensor and current using current sensor respectively. Experimentally taken digital values of the speed and current sensor output are changed into a graphical representation using Matlab software. The graphical representation of current, speed, torque and flux are shown in Fig. 13, 14, 15 and 16 respectively.

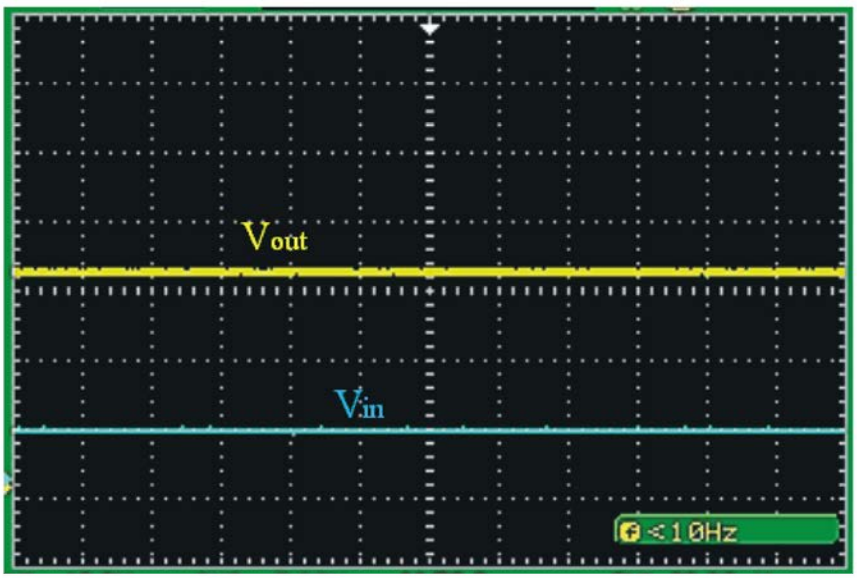


Fig. 11: Voltage multiplier response of Hybrid Electric Vehicle system

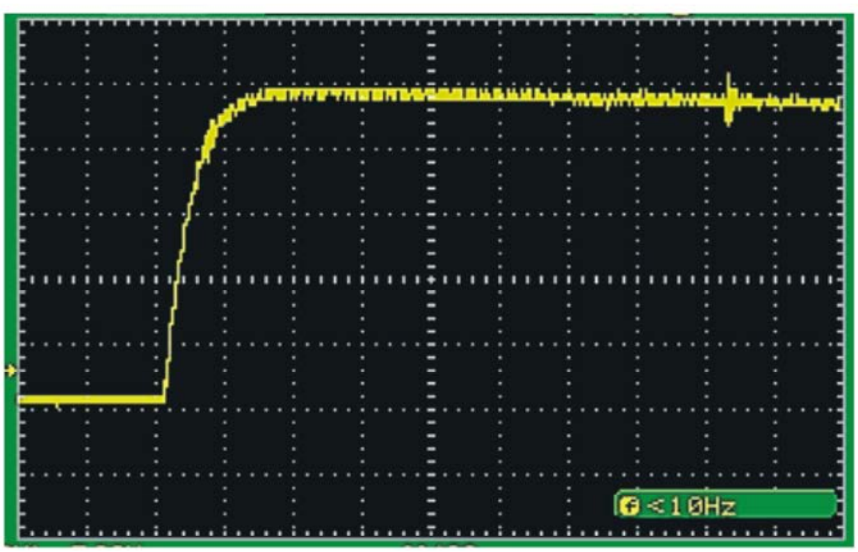


Fig. 12: Zeta converter response of Hybrid Electric Vehicle system

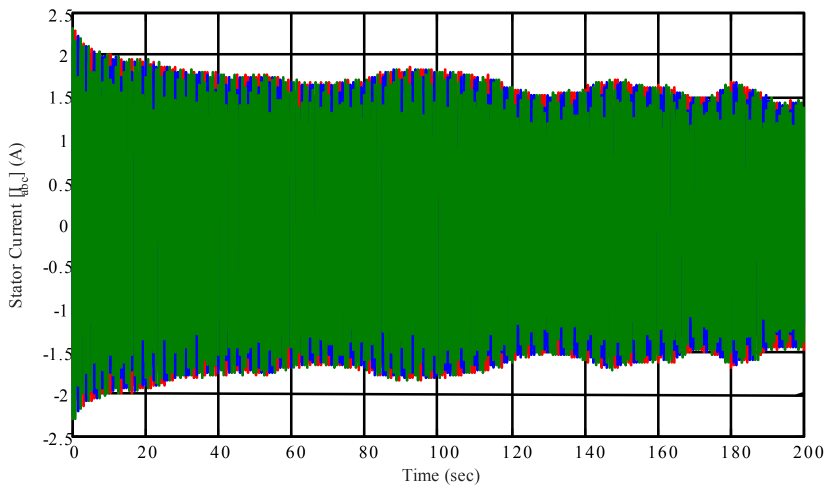


Fig. 13: Output current response of HEV system

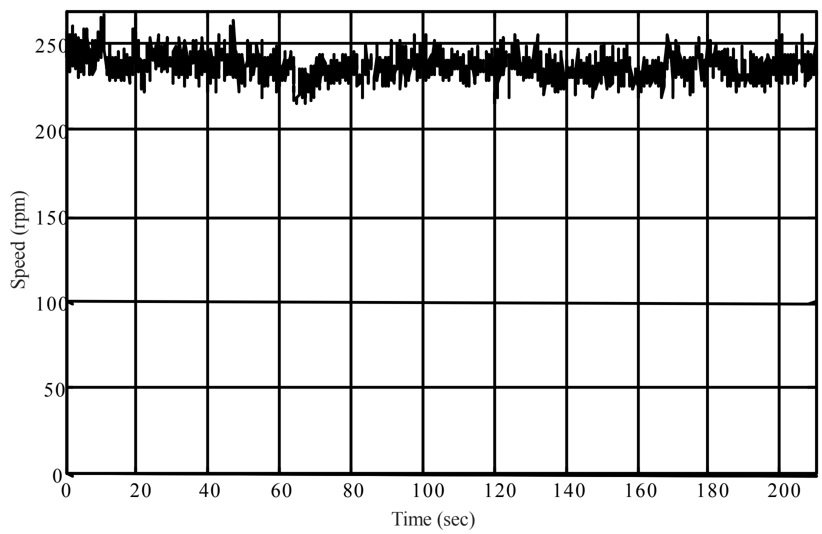


Fig. 14: BLDC motor speed response of HEV system

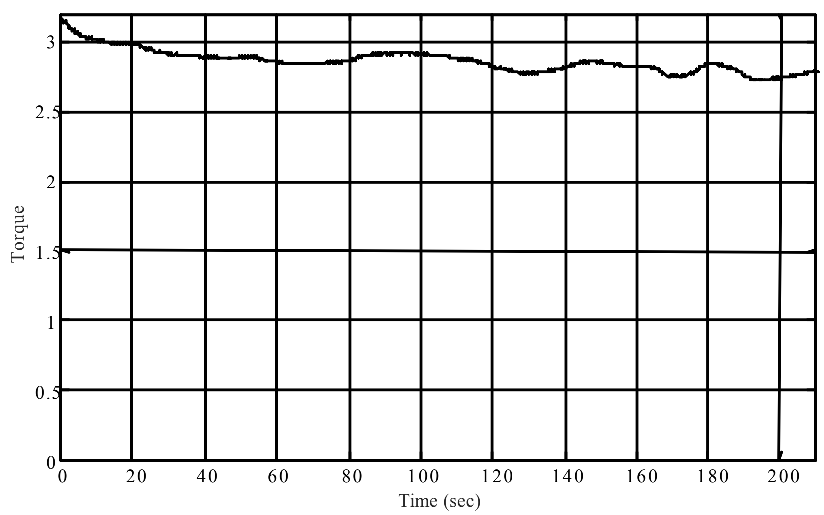


Fig. 15: BLDC motor torque response of HEV system

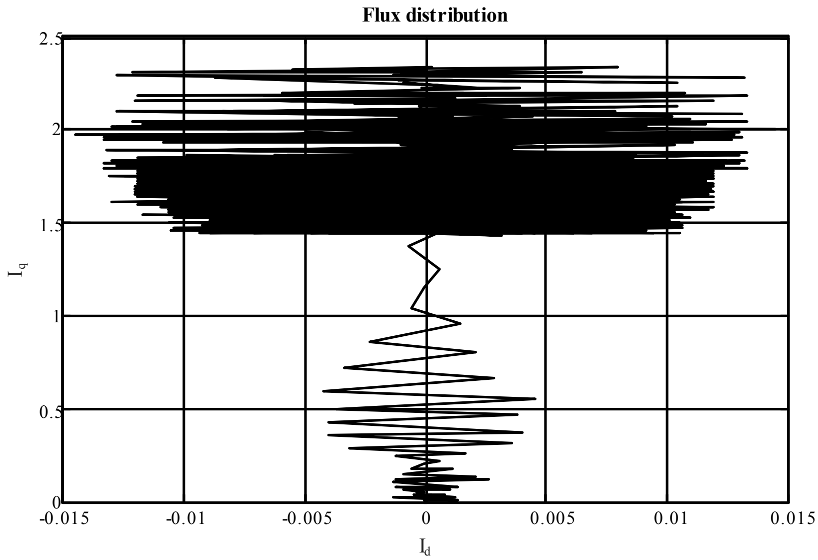


Fig. 16: BLDC motor flux response of HEV system

CONCLUSION

The simulated results shown the potency of the voltage multiplier and PI controller. The PI controller regulated the DC voltage of Zeta converter 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. The battery voltage converted and multiplied to a higher voltage using the voltage multiplier to run the motor of the electric vehicle. The three-phase equivalent voltage obtained because of the comportment of the voltage multiplier than traditional converters. The experimental results also proved the performance the proposed system with simulation results.

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