Power Electronics Project:
Report

Speed Control in a Brushless DC motor with the help of a Zeta Converter

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Aim of the Project:

Simulating a Zeta DC-DC Converter in both open-loop and closed-loop control fed Brushless DC motor and studying the system for speed control.

Abstract

The utilization of driving systems with variable speed is increasing in different applications like vehicle industries, domestic appliances and manufacturing industries, etc. And in product manufacturing companies motors with both variable speed and constant speed is required. For such requirements, the proposed circuit fed BLDC motor can be used effectively. This project simulates sensored control of BLDC motors using Zeta converters. The circuit operates in both open loop and closed loop. The sensored speed control scheme of the BLDC motor is designed. Since brushes are absent in the motor, for the commutation purpose response from hall sensors is used to commutate the BLDC motor. Zeta converter is used for obtaining regulated dc output voltage.

Two-stage PFC converters are widely in practice in which the first stage is used for the power factor correction which is preferably a boost converter and the second stage for voltage regulation which can be any converter topology depending upon the requirement. This two-stage topology is complex, results in higher cost and more losses. Hence a single-stage Zeta converter is proposed which is used for DC-link voltage control, power factor correction, and bucking and boosting the voltage. It is a naturally isolated structure. ZETA converter is designed to control using a PI controller and the corresponding output response is simulated using MATLAB software. Also, the response of the ZETA converter, when it is subjected to the line and load variations is simulated. The project presents the study of the Zeta converter operating in continuous conduction mode for power factor correction.

INTRODUCTION TO BRUSHLESS DC MOTOR

Brushless dc motors are available in single-phase, two-phase, and three-phase configurations. Most types of motors used are of three-phase type. These motors are a special type of permanent magnet synchronous motors. The magnetic field created by the stator and the rotor rotates at the same frequency. It does not operate directly by a dc voltage source. To supply power to stator windings it requires a voltage source inverter. The rotor is made up of permanent magnets and the stator is made up of windings. It is an electronically commutated motor. Some of the BLDC motors contain position sensors like hall sensors. Hall sensors detect the rotor position and perform input commutation based on it.

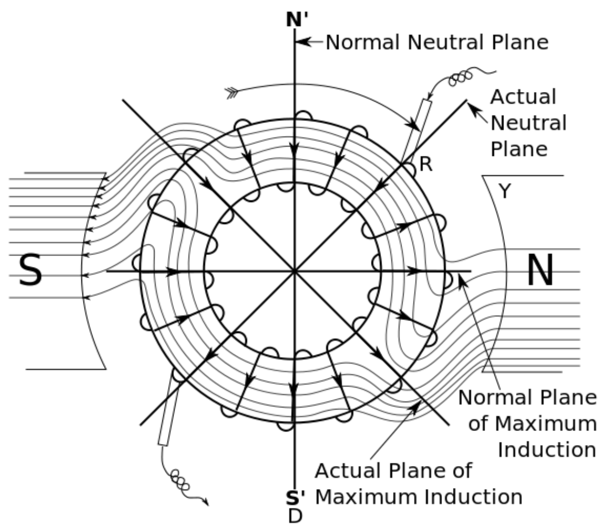


Fig. PMBLDC Motor

Stator: The stator present in the BLDC motor consists of stacked steel laminations slots, the windings are placed in these slots which are axially cut along the inner periphery of the slot as in Figure 1. Windings of a stator can be arranged in two shapes which are a star connection (Y) or delta connection(Δ). BLDC motors mostly have three stator windings connected in star connection. The stator windings can be classified into two types which are trapezoidal and sinusoidal motors.

Rotor: The BLDC motor rotor is made up of permanent magnets. The number of poles in the rotor varies and is chosen based on application requirements. As the number of poles increases, it gives better torque but speed reduces. The maximum torque is also impacted by the material used for the construction of a permanent magnet; the higher the flux density of the material, the higher the torque.

The main advantage of the brushless configuration of this type of motor is the removal of the brushes, which exclude the maintenance of brushes and sparking associated with brushes. And the conduction of heat takes place from the armature windings as it is placed on the stator and no winding on the rotor. Electrical losses in the rotor are, thus minimized. The PMBLDC motor compares favorably with induction motors in the fractional horsepower range.

BLDC motors are a type of synchronous motor, Magnetic field generated by the rotor and magnetic field generated by stator at the same frequency. Hence does not show any slip, which normally occurs in induction motors. BLDC motors are available in 1-phase, 2-phase, and 3-phase configuration, out of these, 3-phase motors are the most used. The stator has the same number of windings corresponding to its phase.
Various techniques can be used to control BLDC motor, among them two methods; ***sensor control** and ***sensorless control.** We are using sensor control technique i.e. hall sensors for commutation.

The Voltage Source inverter (VSI) is made of power semiconductor switches, which are used for commutation and also for controlling the motor terminal voltage. As the rotor speed is directly proportional to the terminal voltage of the motor. Closed-loop control is used with a PI controller to control the speed using which we compare the actual speed and reference speed, and the error signal produced by this method is used to drive the motor. This offers improved reliability, longer life, smaller size, and lower weight to BLDC motors.

INTRODUCTION TO ZETA CONVERTERS

The zeta converter is a fourth-order DC-DC converter that operates in both continuous and discontinuous current conduction mode and performs a non-inverting buck-boost function. And operating either in step-up/ step down mode. It is made up of 2 inductors, 2 capacitors, a resistor, and MOSFET as a switch. The circuit diagram of the zeta converter is shown below in the figure.

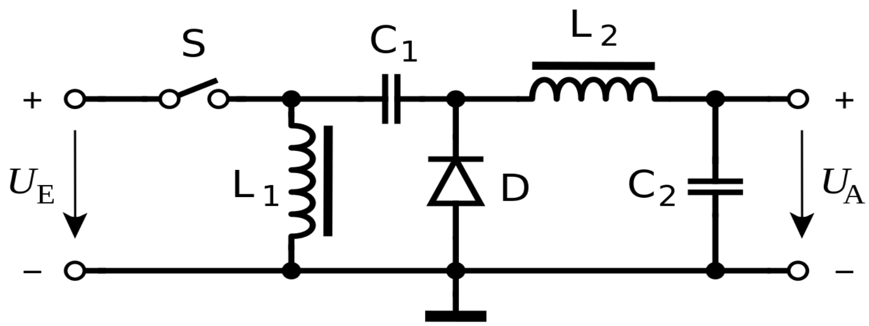


Fig. The circuit diagram of the zeta converter

The zeta can be operated in both continuous and discontinuous conduction modes. In this way, the zeta operating in the continuous conduction mode with a constant duty cycle and switching frequency behaves as a resistance to the ac line, which assures the high input power factor.
The ZETA Converter is the heart of the proposed system, which rectifies and improves the power quality of the entire system. The DC output of the Diode Bridge Rectifier (DBR) is fed to the Zeta converter circuit. The DC supply from DBR has some ripples which are being eliminated by the low pass filter Cf in the Zeta converter. Thus, eliminating harmonic distortion in the circuit. The MOSFET acts as a switch here, the gate signals for the MOSFET are given from the driver circuit using the Pulse Width Modulation method. In Zeta converter,

Mode 1: The first mode is obtained when the switch is ON (closed) and instantaneously, the diode D is OFF. During this period, the current through the inductor L1 and L2 is drawn from the voltage source Vs. This mode is the charging mode.

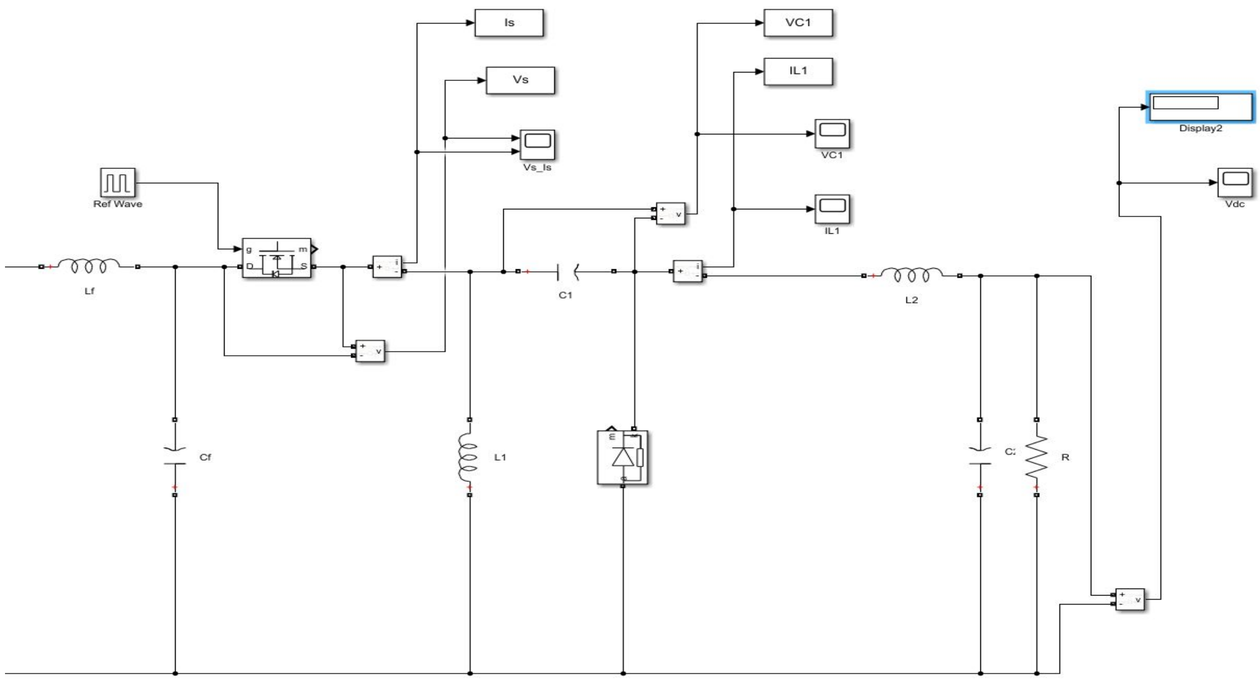


Fig. Operations in zeta converters.

Mode 2: The second mode of operation starts when the switch is OFF and the diode D is in ON position, This stage or mode of operation is known as the discharging mode since all the energy stored in L2 is now transferred to the load R.

Mode 3: The freewheeling stage lasts until the start of a new switching period. In this mode, both Diode and the switch do not conduct. The voltage applied across both inductances is zero and their currents are constant until the new cycle starts.

DESIGN OF ZETA CONVERTER PARAMETERS

Unlike the buck-boost and Cuk converter, it doesn't give the inverted output voltage, the output voltage is of the same polarity and this can be either higher or lower than the input voltage depending upon the duty cycle of the PWM given to the MOSFET. The output voltage of the zeta converter is given like this:

$$Vo = Vin*D/(1-D)$$

Where D is the duty cycle which is the ratio of pulse width to the period or ratio of time a load or circuit is ON compared to the time the load or circuit is OFF.

Where, Vin is the average output voltage of the DBR for a given ac input voltage(Vs) related as

$Vin = 2\surd 2 * Vs/ \pi$

The zeta converter uses a boost inductor (L1) and capacitor (C1) for energy transfer. Their values are given as

$L1 = D*Vin/2\{Fs(\Delta IL1)\}$

$C1 = D*Idc/\{Fs(\Delta Vc1)\}$

Where $\Delta IL1$ is a specified inductor current ripple, $\Delta Vc1$ is a specified voltage ripple in the intermediate capacitor (C1) and Idc is the current drawn by the PMBLDC motor from the dc link.

A ripple filter is designed for ripple-free voltage at the dc-link of the zeta converter. The inductance of the ripple filter restricts the inductor peak to peak ripple current($\Delta IL2$) within a specified value for the given switching frequency (Fs), whereas the capacitance (C2) is calculated for the allowed ripple in the dc-link voltage($\Delta Vc2$). The values of the ripple filter inductor and capacitor are given as

$L2 = (1-D)*Vdc/2\{Fs(\Delta IL2)\}$

$C2= Idc/(2\omega \Delta Vc2)$

SYSTEM PARAMETERS	VALUES
Source voltage (V_s)	220V
Source current (I_s)	4.12 A
Frequency (F_s)	50 Hz
Inductance (L_f)	10^{-3} H
Capacitance (C_f)	330 * 10^{-9} F
Inductance (L_1)	3.6 * 10^{-3} H
Capacitance (C_1)	239 * 10^{-9} F
Inductance (L_2)	0.85 * 10^{-3} H
Capacitance (C_2)	935 * 10^{-6} F
Resistance (R)	400 Ω
Motor stator phase resistance (R_s)	2.8750 Ω
Motor stator phase inductance (L_s)	8.5 * 10^{-3} H

Fig. System Parameters

The block diagram of the system is shown below,

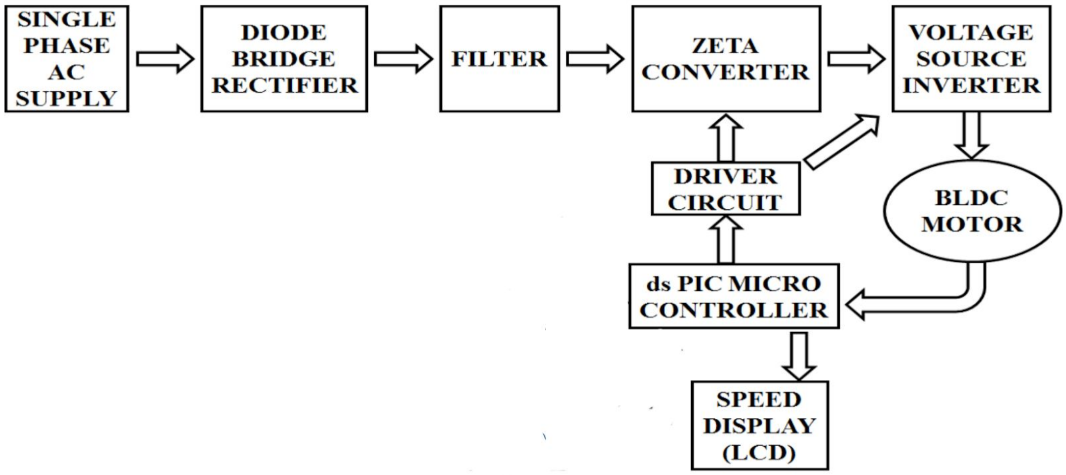


Fig. Block Diagram

SIMULATION:

BLDC Motor

The output of the zeta converters is connected to the BLDC motor through a three-phase voltage inverter. The figure of the BLDC motor as used in the simulation is shown below,

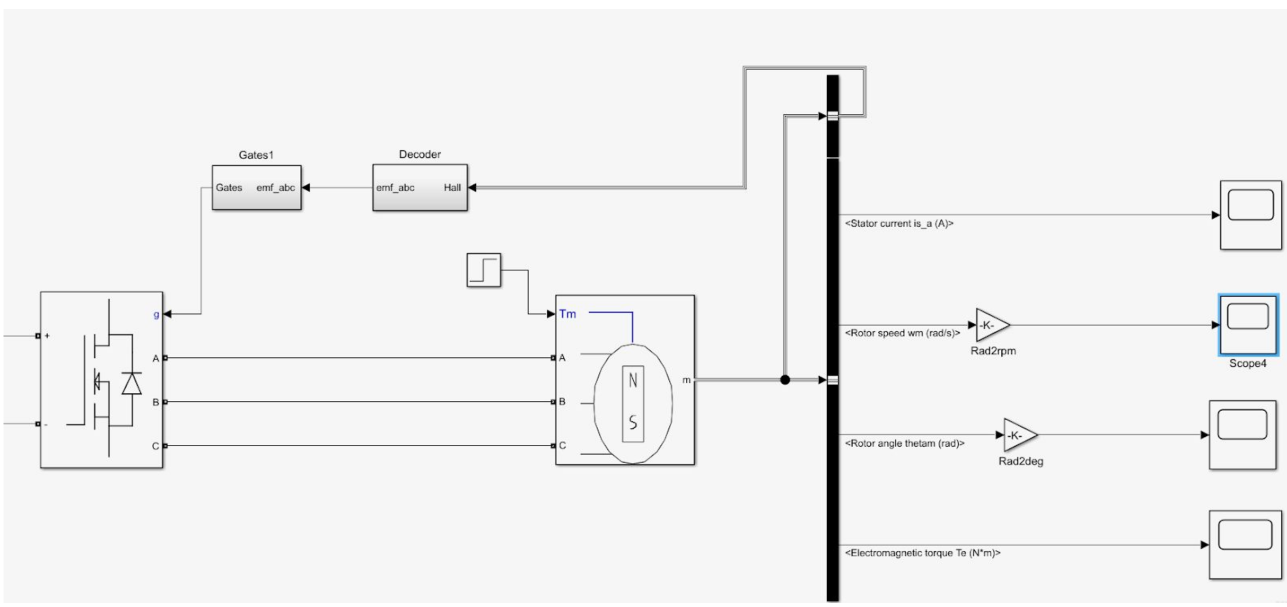


Fig. BLDC Motor System

The decoder and gate circuits used to provide electronic commutation are shown below,

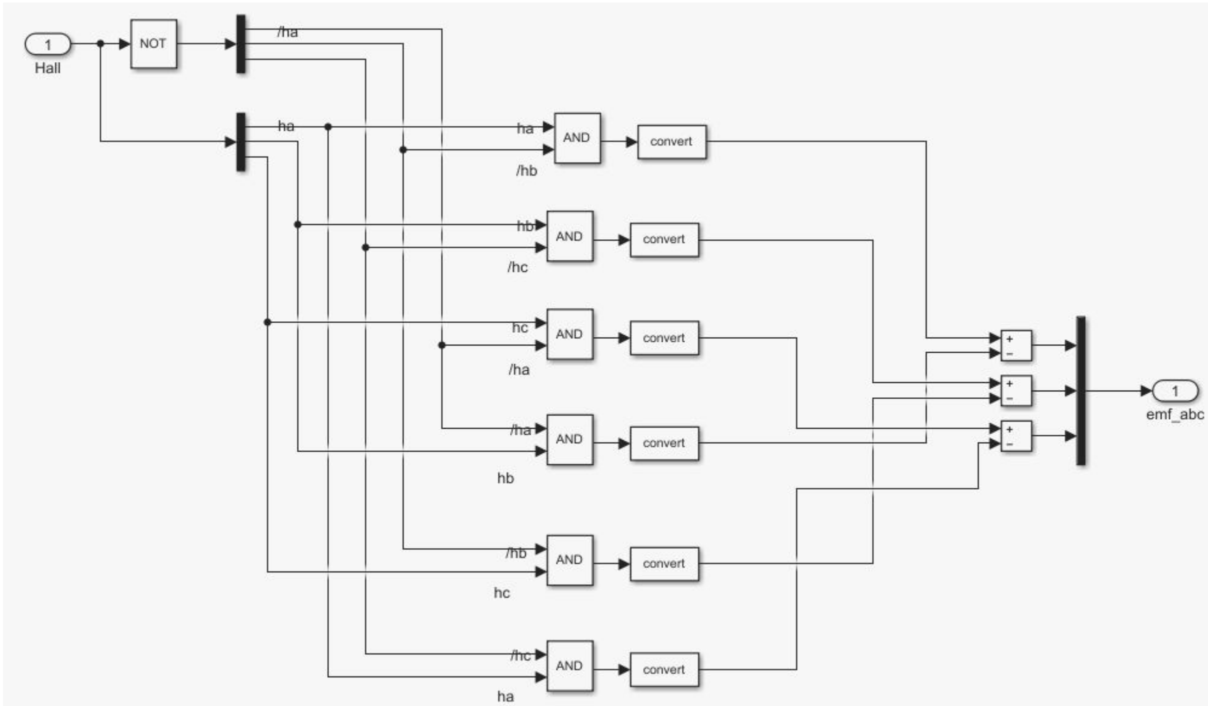


Fig. Decoder Circuit

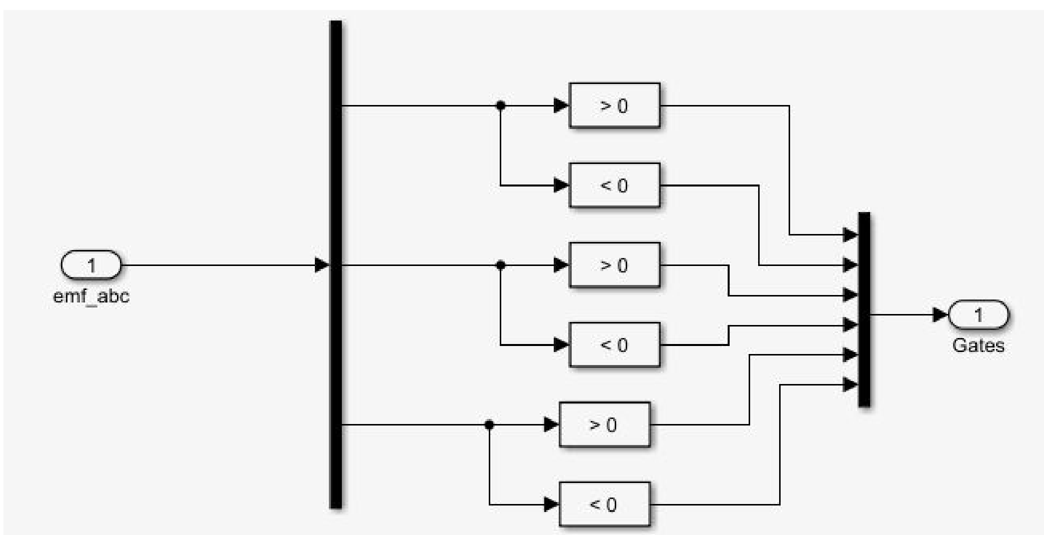


Fig. Gate Circuit

Open Loop System

The open-loop zeta converter as used in the simulation is given below,

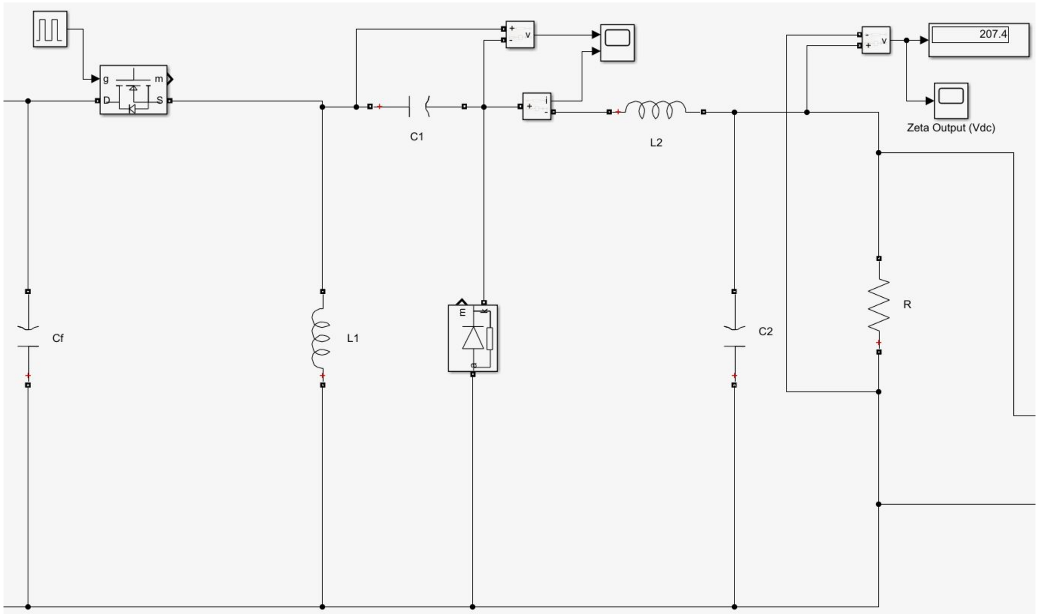


Fig. Open Look Zeta Converter

Open Loop Results

The zeta output and rotor speed are given below,

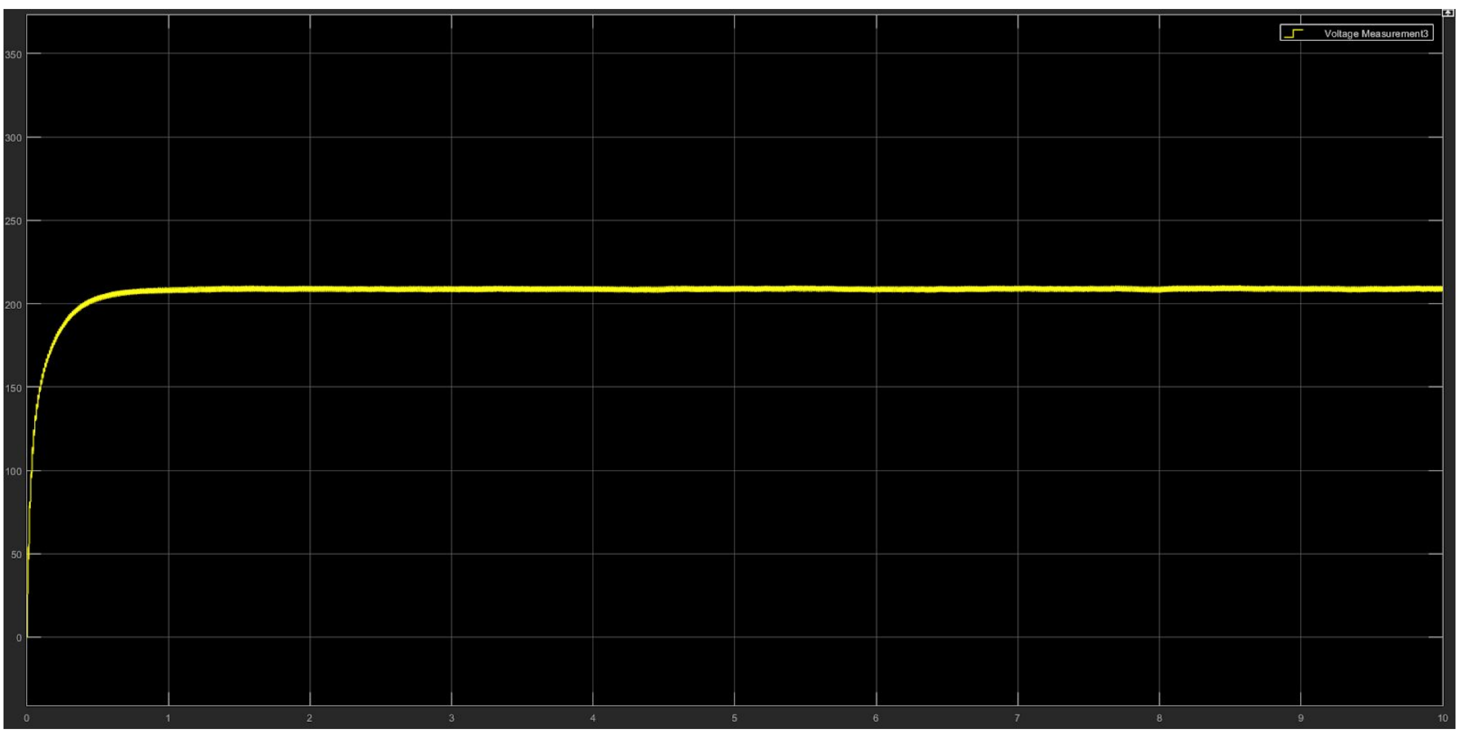


Fig. Zeta Output

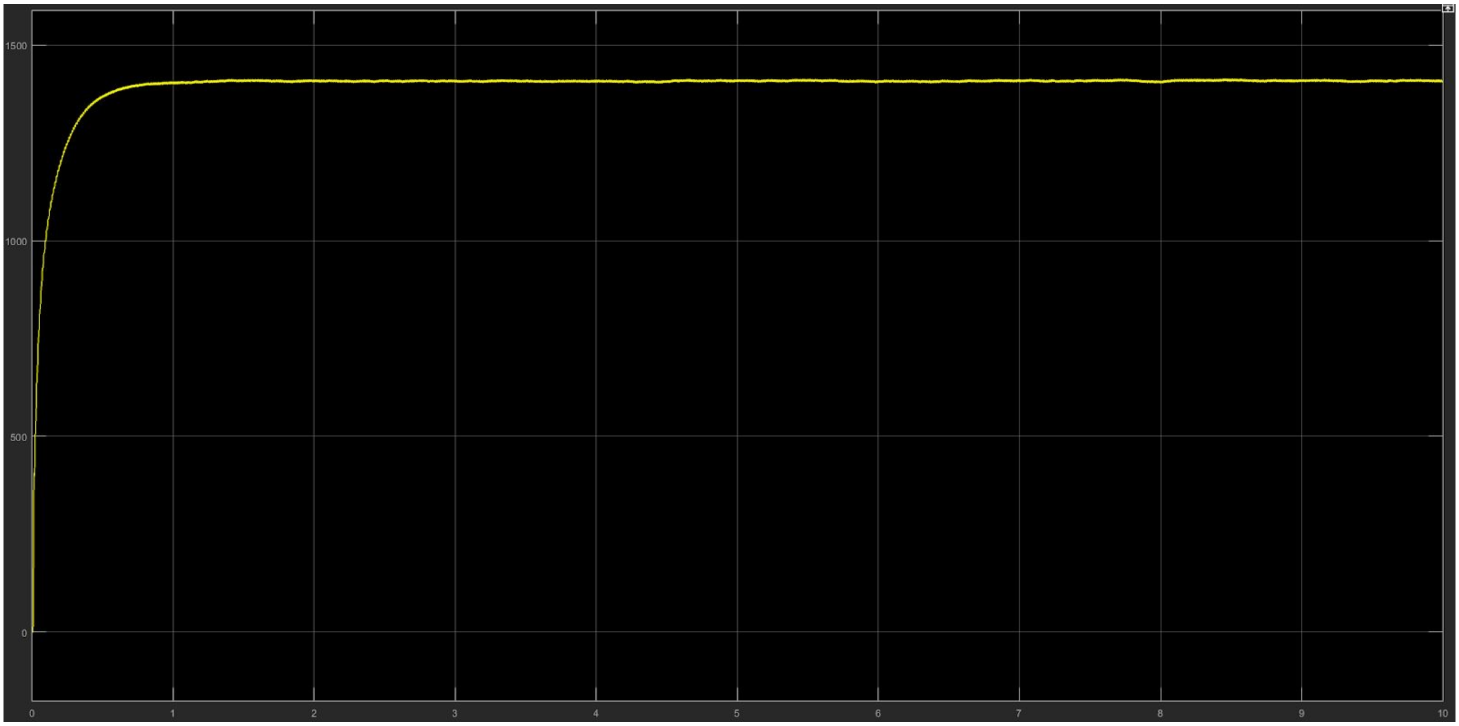
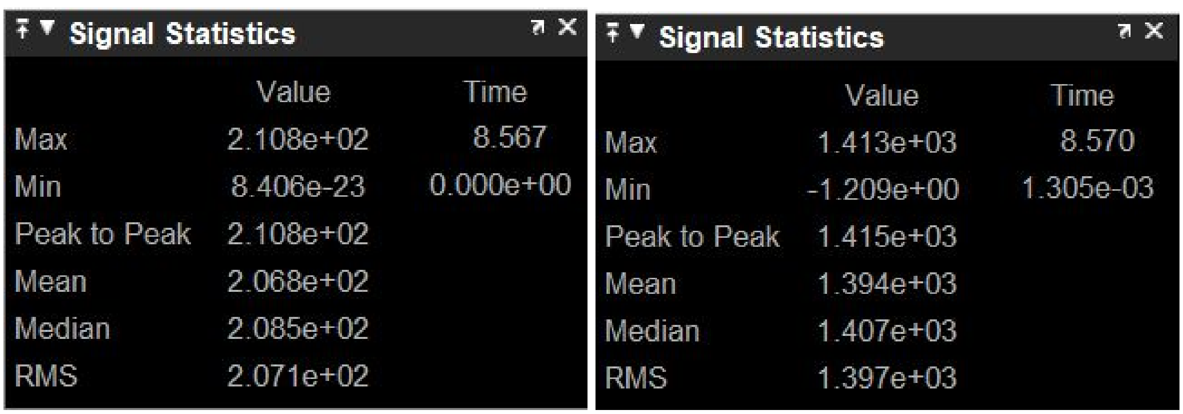


Fig. Rotor Speed



Signal Statistics

	Value	Time
Max	2.108e+02	8.567
Min	8.406e-23	0.000e+00
Peak to Peak	2.108e+02	
Mean	2.068e+02	
Median	2.085e+02	
RMS	2.071e+02	

Signal Statistics

	Value	Time
Max	1.413e+03	8.570
Min	-1.209e+00	1.305e-03
Peak to Peak	1.415e+03	
Mean	1.394e+03	
Median	1.407e+03	
RMS	1.397e+03	

Fig. Signal Stats for Zeta Output (Left) and Rotor Speed (Right)

The zeta output from the open-loop system has a lot of ripples. After stabilizing, the ripples range from 206.9V at the minimum to 210.8V at the maximum. The median voltage of the signal is 208.5V. We’ll use this as the reference voltage for the closed-loop zeta converter.

Also, the BLDC motor takes about a second to stabilize. This is a lot of time according to industry standards.

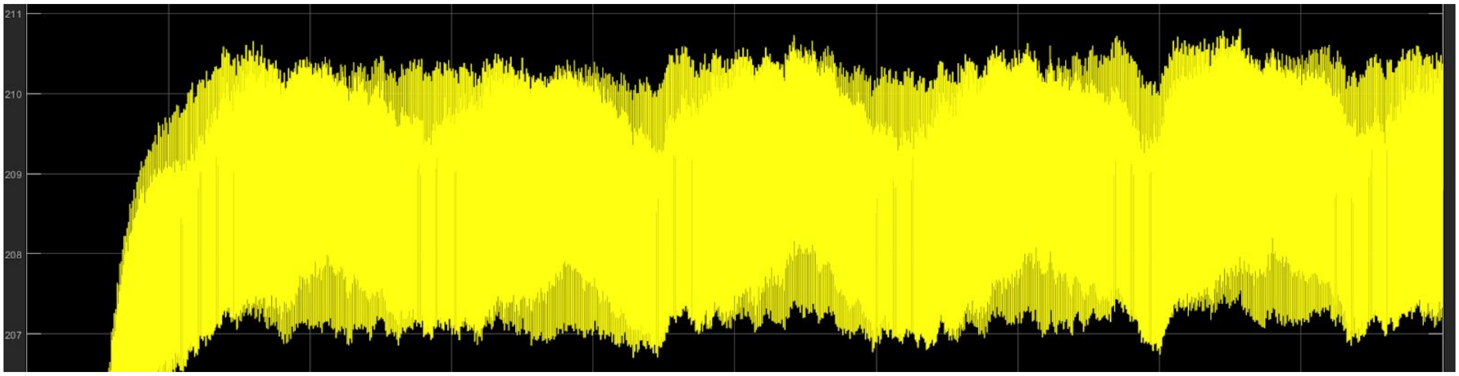


Fig. Voltage Ripples

Closed-Loop System

We'll take reference voltage as 208.5V for our closed-loop zeta converter and the controlled voltage source.

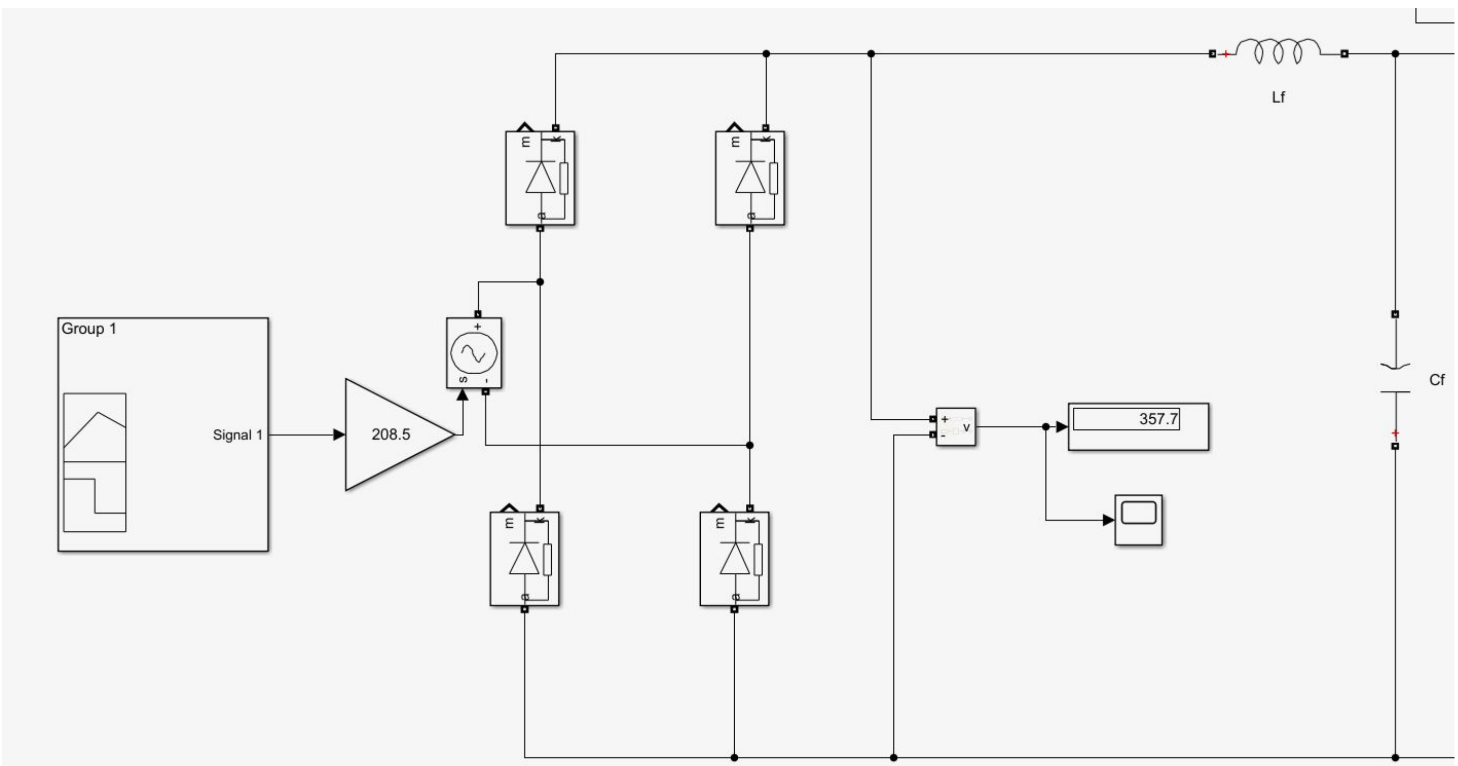


Fig. Controlled Voltage Source

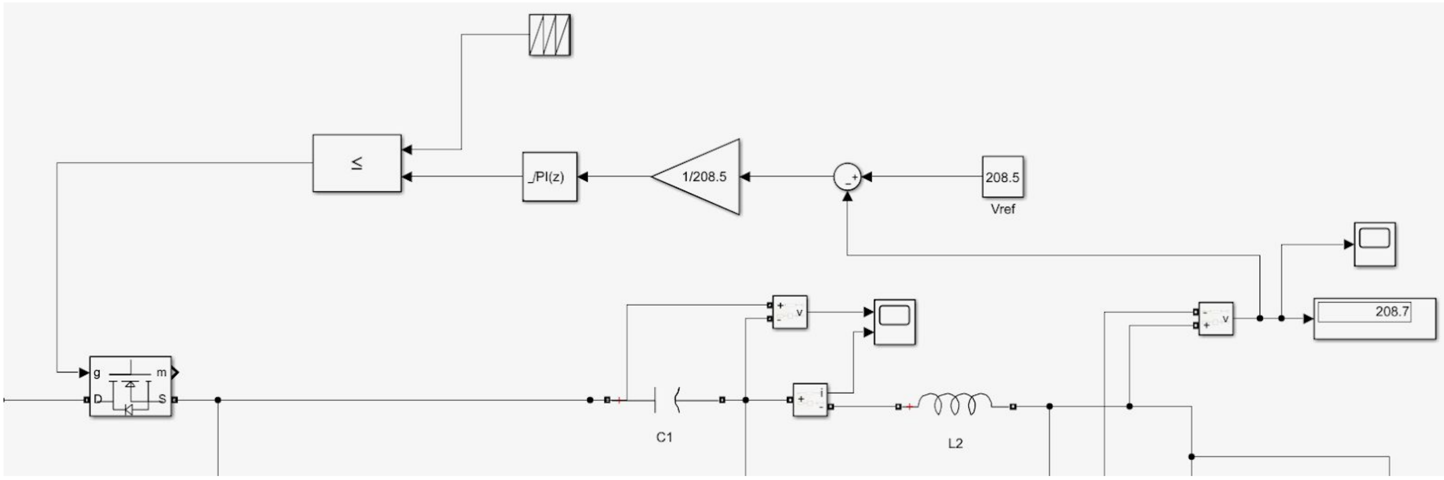


Fig. Closed-loop Control in Zeta Converter

Closed Loop Results

The zeta output and rotor speed for the closed-loop system is given below,

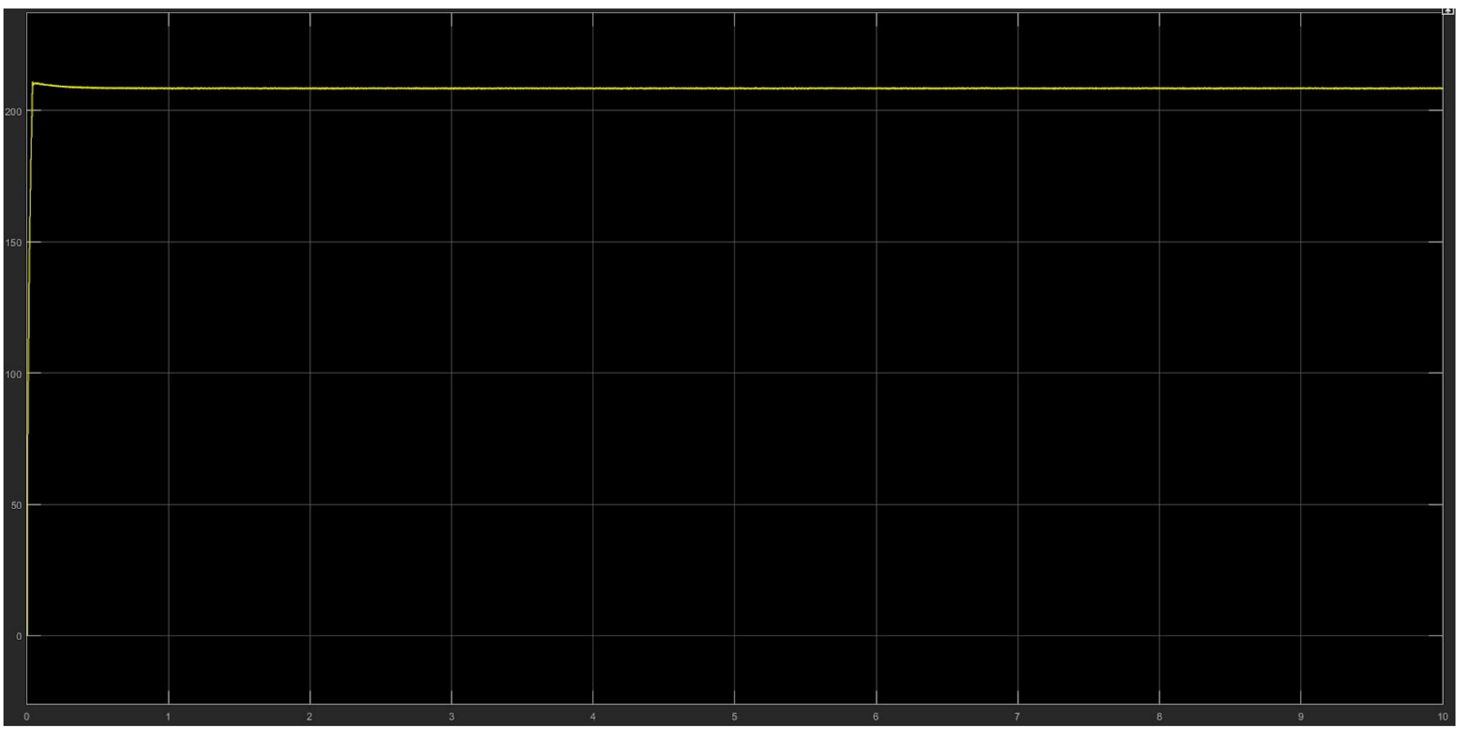


Fig. Zeta Output for Closed-loop system

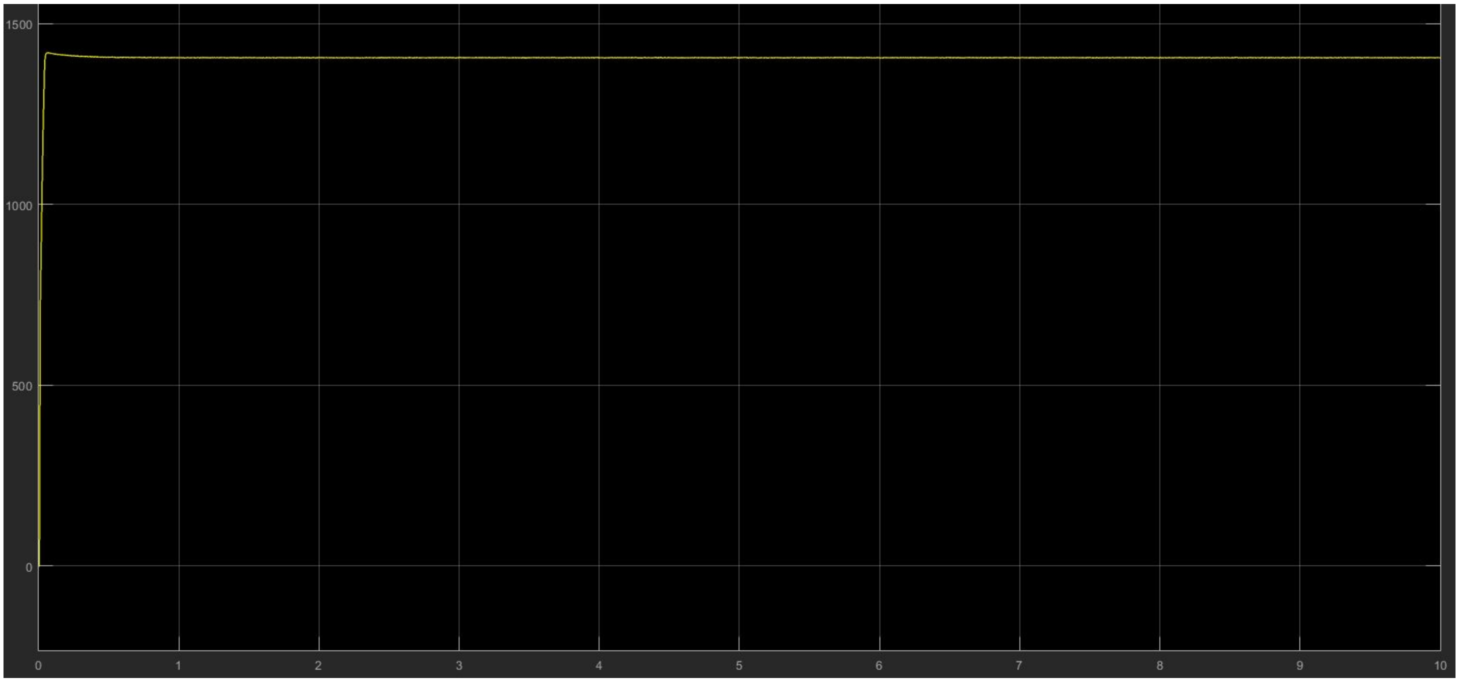


Fig. Rotor Speed for Closed Loop System

The zeta output for the closed-loop system has a lot less rippled response. The mean value of the zeta voltage output is 208.3V and the median is 208.5V. The system reaches stability in mere 0.05 seconds as opposed to 1 second in the open-loop control.

Signal Statistics

	Value	Time
Max	2.111e+02	0.039
Min	3.469e-08	0.000e+00
Peak to Peak	2.111e+02	
Mean	2.083e+02	
Median	2.085e+02	
RMS	2.084e+02	

Signal Statistics

	Value	Time
Max	1.420e+03	0.065
Min	-6.662e-01	7.300e-04
Peak to Peak	1.421e+03	
Mean	1.405e+03	
Median	1.406e+03	
RMS	1.405e+03	

Fig. Signal Stats for Zeta Output (Left) and Rotor Speed (Right)

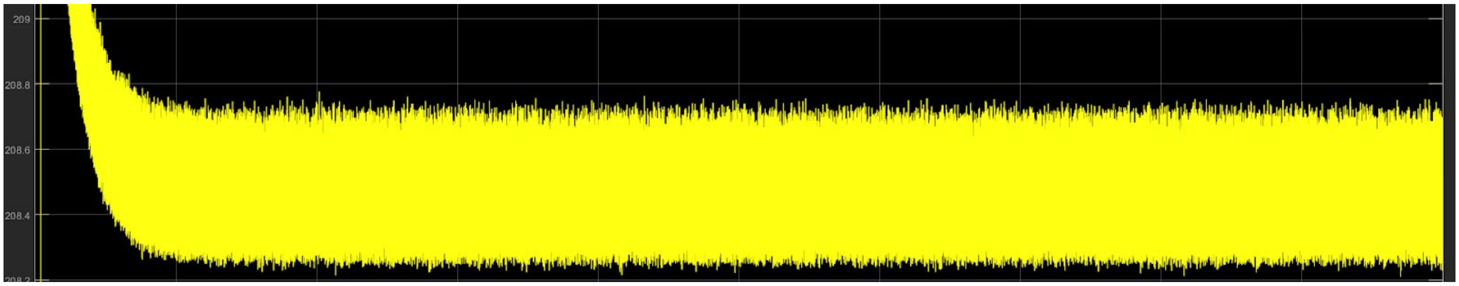


Fig. Voltage Ripples in CLosed-Loop System

After the steady-state is reached, the voltage output of the zeta converter stays between the maximum of 208.75 and a minimum of 208.25. This is considered tolerable under industry standards.

Conclusion:

The responses of open-loop and closed-loop zeta converters fed into the BLDC motor were recorded. We found out that we were able to acquire a stable voltage output with a tolerable amount of voltage ripples after implementing closed-loop control in the system. We were also able to reach the desired speed and voltage within t=0.05 seconds in the case of the closed-loop zeta converter as opposed to the open-loop zeta converter which took t=1 second to stabilize.

Attachments:

The Github repository, containing both open and closed-loop MATLAB simulation files, is attached in the link below.

[Simulation Files]

References:

1. G.Ranjitham, V.Poompava, M.Rohini, S.Thangamani, (2017), Zeta Converter Fed Brushless DC Motor for Power Factor Correction and Speed Control
2. S. Naga Pavithra, Dr. S. Umamaheswari, (2016), Zeta converter fed BLDC motor for power factor correction and speed control
3. Banashankari Hosur, Hemalatha J N, (2019), Design and Simulation of Zeta Converter for Speed Control of BLDC Motor