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# PERFORMANCE INVESTIGATION OF A BOOST CONVERTER DRIVING A SEPARATELY EXCITED DC MOTOR USING RC FILTER

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**Abstract**— Because boost converter circuits allow for precise speed regulation, frequent starting, flexible speed control, and support for stopping and reversing operations, they are becoming more and more common in industrial and electrical systems for powering DC motors. However, because these converters are made of non-linear devices, they introduced harmonic distortions that lowered the system's power quality and decreased the performance of the DC

MATLAB/Simulink,
RC Filter,
Separately Excited DC Motor

motor that was connected to them. This paper presents a low-cost and effective boost chopper circuit that drives a separately excited DC motor by combining it with an RC filter. Matlab/Simulink was used to simulate an RC filter model based on a boost converter that has a 120 V input DC voltage, a 50% duty ratio, and a 50 kHz switching frequency. The separately excited DC motor is powered by the boost converter's average output voltage and current. The RC filter significantly reduced total harmonic distortion (THD) from 37% to 11.8%. In addition to harmonic mitigation, this study investigated the efficiency of a separately excited DC motor, and a significant improvement in the motor’s efficiency from 74.42% without the filter to 91.42% with it was observed. This research underscores the effectiveness of integrating an RC filter with a boost chopper circuit to enhance power quality and optimize the performance of a DC motor system.

## I. Introduction

A wide range of devices, including DC motor drives and power supplies for laptops, desktop computers, office equipment, spacecraft power systems, and telecommunications equipment, use DC-DC power converters [1]. Separately excited direct current (DC) motors are widely used in many industrial domains, when the DC motor is running, the load torque and network voltage may cause the real speed and current to become unstable

[2]-[3]. Controlling the speed and current of the DC motor is therefore a crucial area of research. While there are a few techniques to regulate and improve individually stimulated DC motor performance, using a Boost Converter circuit is the most widely used method. This study investigates how to improve the DC Motor's performance when powered by the boost converter by utilizing an efficient filtering circuit.

There are several works and investigations that proposed their techniques on filter, boost converter and separately excited DC motor speed control, starting with R. Nagarajan et. al [2] that utilized a neural net controller and a proportional integral (PI) controller to control the speed of the DC motor [4], furthermore a different approach to modelling pulse width modulated (PWM) dc/dc converters with basic converter units (BCUs) and focused on applying this suggested method to simplify the modelling of quasi-resonant converters and multi-resonant converters [5]. Authors in [6] proposed and put into use a separately excited DC motor speed control system with a chopper circuit and two distinct control loops, or a speed controller and a current controller. [2] Proposed method of speed control for a separately excited DC motor fed by a chopper circuit, the circuit provides a variable voltage to the motor's armature so that the required speed can be reached using a PI controller. DC-DC converter with PID controller aimed to keep voltage and current constant, the proportional Kp, integral Ki and derivative Kd were set by choosing appropriate resistor R and capacitor C [7], moreover, improvement and management of the speed of a separately excited DC motor with an IGBT-based chopper by altering the field flux and armature voltage was studied by George [8]. In order to reduce the size and expense of the current passive EMI filters and to attenuate common mode conducted noise in the DC/DC converter's input bus, [9] proposed an approach that combines passive and active electromagnetic interference (EMI) filtering technologies.

The performance of a nonlinear autoregressive moving average controller and the conventional traditional controller were evaluated for the purpose of controlling the speed of SEDM [10], likewise in [11] authors demonstrated how the converter regulation and input filter interact with each other and proposed a way to stabilize the filter, converter, and control system [12]. Moreover, [13] designed and assessed a boost chopper with a high conversion efficiency, low weight, and volume for the HFC hybrid railway system. Shaoru Zhang et. al [14] proposed high gain DC-DC converter is designed to enhance the converter's performance, also [15] investigated Photovoltaic (PV) as the feed source for the Boost converter the idea of a brushless DC (BLCD) mixer grinder motor was put into practice. [8] achieved a PID controller that allows for more accurate and efficient speed control of a DC motor with reduced noise, overshoot, and improved steady-state error [17]-[18]. The DC motor drive in hybrid electric vehicles (HEVs) with intricate control systems was examined and simulated in a variety of torque scenarios. A converter's built-in passive filter was intended to reduce harmonic distortion, and a power capacitor bank was specifically included to offset any voltage loss [19]-[21]. Two common issues that LCL-filtered voltage source converters deal with are active damping and harmonic correction, in order to handle them comprehensively [22] suggested using a virtual RC damper in tandem with the passive filter capacitor. The developed and designed process that allows tuning through resistor trimming alone was proposed, along with a methodical RC-active network synthesis process for the realization of second-order transfer functions, additionally [23]. A circuit design approach that makes it possible to implement broadly programmable high-frequency active RC filters in CMOS technology [24].

Most of the works focused on speed control of DC motor with Boost converter employing different types of control system such as proportional integral PI, proportional integral differential PID fuzzy logic controllers for efficient and reliable operation, others addressed the harmonic mitigation of the converter by implementation of filter. Few works integrate both in achieving efficient results. However, evaluation of the performance of DC motor with respect to the filter type is yet to be addressed, also investigation of different types filtering circuit of boost converter that feeds DC motors is also important and improvement of the performance of boost converter and DC motor output in the most cost-effective way is another challenge that need to be addressed. Therefore, this study aimed to contribute to addressing the aforementioned issues.

## II. Materials and Methods

In this study MATLAB was used in designing and simulation of boost converter incorporating LC filter that drives separately excited DC motor. The procedures followed are;

- Modelling of boost converter circuit
- Modelling of RC filter circuit
- Modelling of separately excited DC motor
- Integrating the above model together
- Simulation of the complete model
- Efficiency evaluation of the DC motor

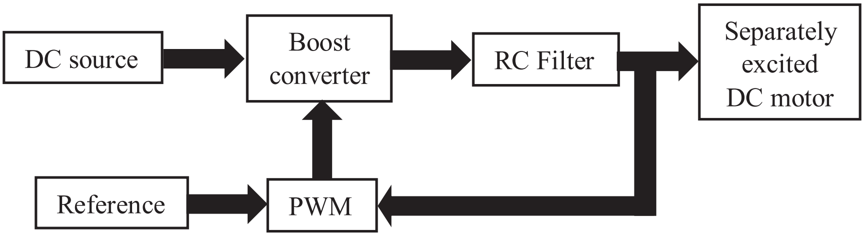


Figure 1: Block diagram of Boost Converter with RC filter feeding separately excited DC motor

Boost converters are DC-DC converters that use PWM controllers, power switches, diodes, inductors, and capacitors to raise the input voltage to a higher output voltage. They have phases of charging and discharging, where the capacitor voltage rises during charging and the inductor retains energy. The diode allows the stored energy to be released while discharging, increasing output voltage. The output quality is enhanced by adding an RC filter, which smoothens the voltage waveform and lowers ripples. A separately excited DC motor is powered by this filtered voltage, and it is managed by varying the duty cycle of the PWM controller to efficiently control the average output voltage and motor speed. For a variety of applications, this integrated technique ensures accurate and consistent motor speed control.

### A. Modelling of Boost Converter Circuit

The circuit for the boost converter circuit shown in Figure 2 deviates from traditional designs in that it employs a novel method for handling harmonic reduction. Unlike traditional boost converters, which consider the resistor only as a load element, this model introduces a novel configuration that uses both resistance and capacitance to form an RC filter. This deviation from the norm highlights a deliberate strategy to address harmonic distortions in the output voltage.

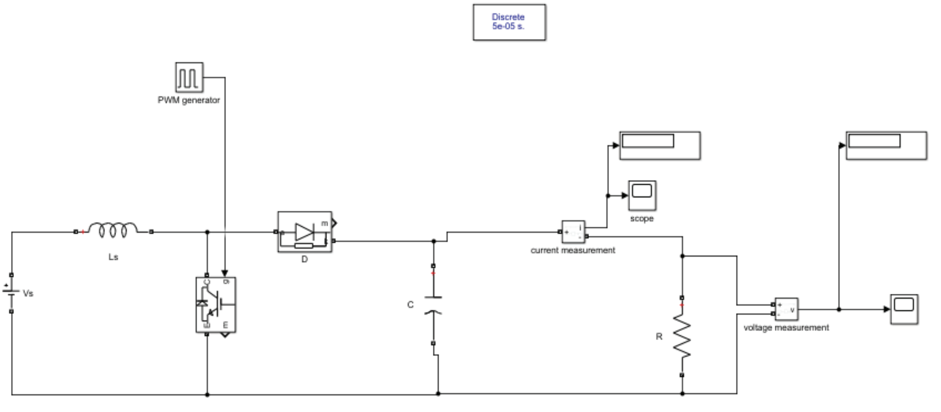


Figure 2: Boost converter with RC filter model

The RC filter, which in this case is made up of a capacitor (*C*) and a resistor (*R*), is essential because it works together to lower the output voltage's harmonic content. In this design, the resistor works in tandem with the capacitor to reduce voltage fluctuations, as opposed to traditional designs where the resistor serves as the only load. The equations used in this model are as follows.

Output voltage equation of the converter,

$$V_{out} = \frac{V_{in} - V_{Trans}D}{1-D} - V_D \quad (1)$$

$$V_{out} = \frac{V_{in}}{1-D} \quad (2)$$

Inductor equation,

$$L = \frac{V_S \times D}{f_S \times \Delta I_O} \quad (3)$$

Capacitor equation,

$$C = \frac{I_O \times D}{f_S \times \Delta V_O} \quad (4)$$

Efficiency equation of converter,

$$\eta = \frac{P_{out}}{P_{in}} = \frac{V_{out}(1-D)I}{V_{in}I} = \frac{V_{out}(1-D)}{V_{in}} \quad (5)$$

Filter equation,

$$\frac{V_{out}}{V_{in}} = \frac{1}{\sqrt{1+(2\pi f_S RC)^2}} \quad (6)$$

where:
$D$ = Duty ratio
$V_{in}$ = Voltage input
$V_{out}$ = Converter voltage output
$L$ = Inductor, $C$ = Capacitor
$R$ = Resistance, $f$ = frequency
$V_{trans}$ = Transistor voltage
$V_D$ = Diode voltage
$I$ = Source current
$\Delta I_o$ = Ripple current which must not exceed 20% to 30% of the average output current (Io)
$\Delta V_o$ = Ripple voltage which must not exceed 20% to 40% of average output

The equations of motor are given below,

$$R_a I_a + L_a \frac{di_a}{dt} + E = V \quad (7)$$

At steady state condition, Equation (7) becomes

$$V_a = E + I_a R_a \quad (8)$$

$$E = K\omega_m \quad (9)$$

$$V_a = \frac{V_{in}}{1-D} \quad (10)$$

By equating (7), (8) and (9)

$$\frac{V_{in}}{1-D} = E + I_a R_a = K\omega_m + I_a \quad (11)$$

By simplification,

$$\omega_m = \frac{1}{K}\left(\frac{V_{in}}{1-D} - I_a R_a\right) \quad (12)$$

where:
$D$ = duty ratio
$V_{in}$ = Voltage input
$V_{out}$ = Converter voltage output
$L$ = Inductor, $C$ = Capacitor
$f$ = frequency
$\omega_m$ = Speed of the motor in rpm
$I_a$ = Armature current
$R_a$ = Armature resistance
$P_{in}$ = Power input to DC motor
$P_{out}$ = Output power of the motor
$V_{trans}$ = Transistor voltage
$I_o$ = Average output current
$\Delta V_o$ = Ripple voltage must not exceed 20% to 40% of average output voltage
$I_a$ = Armature current
$V_a$ = Armature voltage
$R_a$ = Armature resistance
$K$ = Motor constant
$E$ = Back emf
$R$ = filter resistance

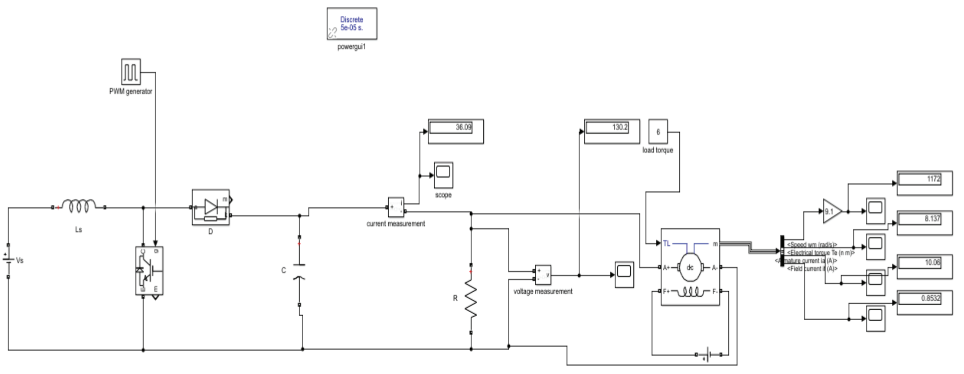


Figure 4: Boost converter with RC filter feeding separately excited DC motor

Table 1: Input parameter of the simulation

| Symbols | Parameters | Specification |
|---|---|---|
| $V_{in}$ | Voltage input | 70 V |
| $L$ | Inductance of converter | 1.0 mH |
| $D$ | Duty cycle | 50 % |
| $C$ | Capacitance of converter | 0.5 $\mu F$ |
| $f_s$ | Switching frequency | 50 kHz |
| $V_{trans}$ | Transistor voltage | 0.6 V |
| $V_D$ | Diode Voltage | 0.2 V |
| $R$ | Filter resistance | 5. 0 Ω |
| $C_0$ | Filter capacitance | 1.0 $\mu F$ |
| $V_f$ | Field voltage | 120 V |

Following the execution of simulations and their observation through a SCOPE, a number of parameters as tabulated in Table 1 were collected and examined.

## III. Results and Discussion

The simulation model of chopper circuit with RC filter driven separately excited DC motor was developed using MATLAB/Simulink package. The supply voltage was applied to the chopper circuit; however, the operation of the circuit relies solidly on switching of IJBT and this was achieved using PWM technique. The PWM generator was use in generating pulse which switch ON and OFF the switch.

### A. Simulation Results

The square function that is used to generate a PWM signal that represents the ON and OFF states of the switch is shown in Figure 5. This PWM signal is used by the Boost Converter Simulation Function to compute the input and output voltage and current over time. For PWM generation in this study, a frequency of 50 KHz and a duty cycle of 50% were used.

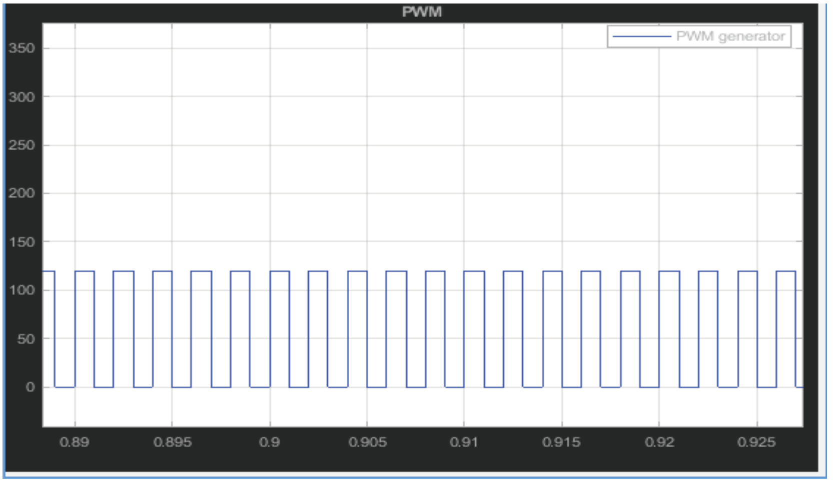


Figure 5: Pulse width modulation MATLAB

Regulated average voltage output of 130.2V from 70V input with minimal harmonic distortion was observed in

Figure 6. When the simulation was run without filter, 112.06V voltage was obtained. The voltage waveform has undergone total harmonic distortions (THD) reduction from 37% to 11.8%.

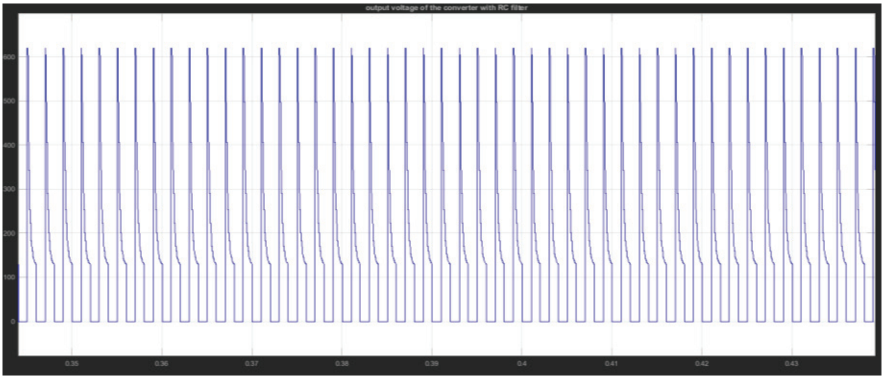

Figure 6: Chopper Circuit Output Voltage with RC filter driven separately excited DC Motor

Efficiency of the motor is,

$$\gamma = \frac{\text{Power output}}{\text{power input}} \tag{13}$$

$$P_{in} = V_{out} I_{out} \tag{14}$$

where:

$P_{in}$ = Power input to the DC motor from the converter

$V_{out}$ = Average voltage output of the converter

$V_{in}$ = Average output current of the converter

$\gamma$ = Efficiency of the separately excited DC motor

$$P_{out} = T_L \omega_m \tag{15}$$

where:

$P_{out}$ = Output power of the motor

$T_L$ = Load torque

$\omega_m$ = speed of the motor

By substituting the values of the simulated result in Equation (13) and (14)

$P_{in}\ without\ RC\ filter = V_{out} I_{out} = 112.06V \times 40.31\text{A} = 4517.139\text{VA}$

$P_{out}\ without\ RC\ filter = T_L \omega_m = 29.0 \times 1107 \times \frac{2\pi}{60} = 3361.818\text{W}$

Now efficiency without RC filter,

$\gamma_{without\ RC} = \frac{3361.818}{4517.139} = 0.7442 = 74.42\%$

$P_{in}\ with\ RC\ filter = V_{out} I_{out} = 130.2V \times 36.09\text{A} = 4698.918\text{VA}$

$P_{out}\ with\ RC\ filter = T_L \omega_m = 35 \times 1172 \times \frac{2\pi}{60} = 4295.604\text{watt}$

Now efficiency with RC filter, $\gamma_{with\ RC} = \frac{4295.604}{4698.918} = 0.9142 = 91.42\%$

## B. Discussion

The outcomes derived from the simulations are concisely summarized in Table 2. Table 2 presents a comprehensive compilation of the obtained results. This table effectively encapsulates all pertinent information garnered throughout the investigation.

Table 2: Results obtained after the simulation

| Output variables | Symbols | Chopper without filter | Chopper with *RC* filter |
|---|---|---|---|
| Average output voltage | $V_o$ | 112.06 V | 130.02 V |
| Average output current | $I_o$ | 40.31A | 36.09 A |
| Total Harmonic Distortion | *THD* | 37 % | 11.8 % |
| Efficiency of the motor | $\gamma$ | 74.42 % | 91.42 % |
| Speed of the motor | $W_m$ | 1107 rpm | 1172 rpm |
| Load torque | $T_L$ | 29.0 $Nm^2$ | 35.0 $Nm^2$ |
| Electrical torque | $T_e$ | 5.295 $Nm^2$ | 8.137 $Nm^2$ |
| Armature current | $I_a$ | 38.21 A | 35.63 A |
| Field current | $I_f$ | 0.8532 A | 0.8532 A |

Table 2 offers a comprehensive evaluation of the system's operation both with and without the *RC* filter in the chopper circuit. First, with the *RC* filter, the average output voltage (*Vo*) shows a significant rise from 112.06V to 130.02V as depicted in Figure 6. This improvement indicates more stable and regulated voltage, which is important for reliable operation of the DC motor. Conversely Figure 7, the average output current (*Io*) drops with the *RC* filter from 40.31A to 36.09A, demonstrating ripples reduction which improved the system efficiency and current control. Meanwhile, with the *RC* filter, the motor's speed (*Wm*) increases noticeably, going from 1107 rpm to 1172 rpm as shown in Figure 8. This improvement is indicative of better speed stability and regulation, which is important for applications requiring accurate motor control.

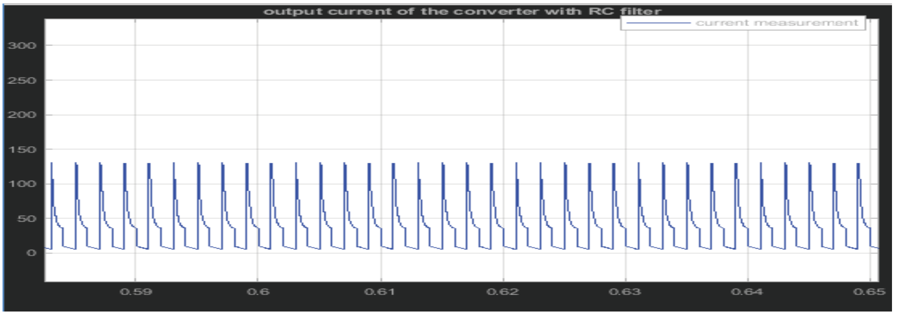

Figure 7: Output current of the chopper circuit with *RC* filter MATLAB (Simulink)


Figure 8: Speed of DC Motor Response when fed by Chopper Circuit with *RC* Filter

Furthermore, the load torque (*TL*) increases from 29.0Nm$^2$ to 35.0Nm$^2$ upon installation of the *RC* filter, suggesting the improvement in torque delivery and system resilience. Additionally, with the *RC* filter, the electrical torque (*Te*) increases significantly from 5.295 Nm$^2$ to 8.137 Nm$^2$, indicating better torque output and motor performance as

Figure 9 depicted. As a result of the *RC* filter, the average armature current (*Ia*) drops from 38.21A to 35.63A, indicating better current control and system efficiency as shown in Figure 10. Interestingly, whether the RC filter is present or not, there is no effect on the field current (*If*), which stays constant at 0.8532A as shown in Figure 11.

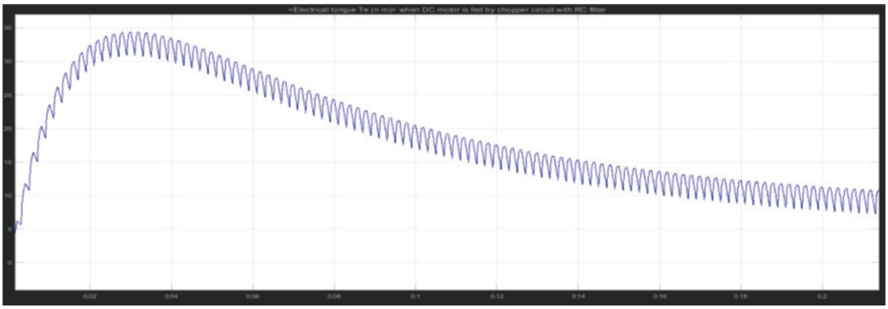

Figure 9: Electrical Torque of DC Motor when fed by Chopper Circuit with *RC* Filter

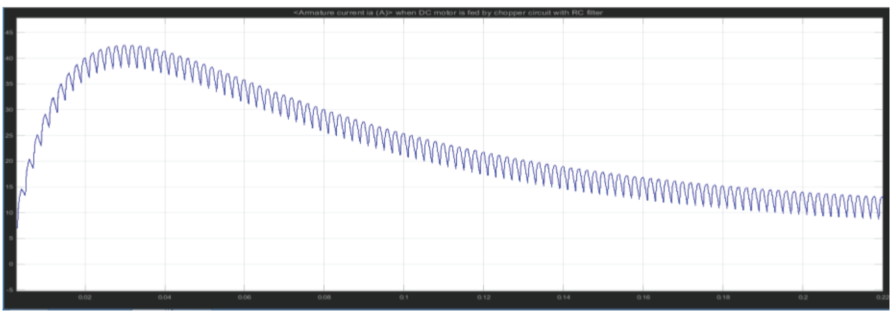

Figure 10: Armature Current of the DC Motor when fed by Chopper Circuit with *RC* Filter

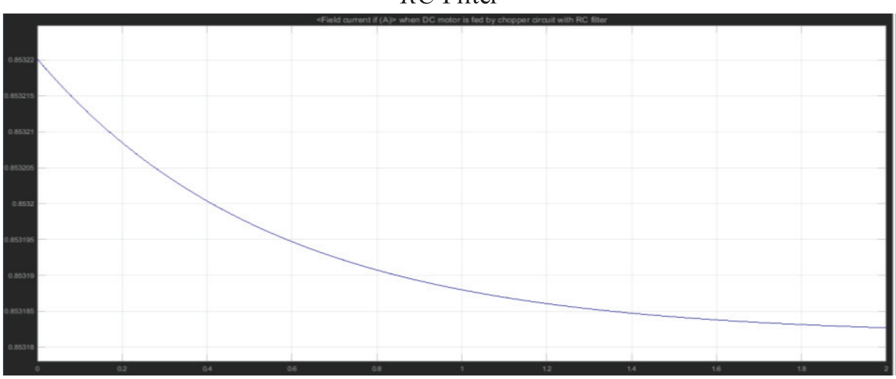

Figure 11: Field Current of DC Motor when fed by Chopper Circuit with *RC* Filter

A significant improvement is observed in the total harmonic distortion (*THD*), which decreases substantially from 37% to 11.8% with the *RC* filter. This reduction underscores the effectiveness of the filter in mitigating harmonic components, contributing to improved power quality and reduced electrical noise.

Furthermore, the efficiency of the motor ($\gamma$) experiences a remarkable increase from 74.42% to 91.42% with the *RC* filter, highlighting enhanced energy conversion efficiency and minimized losses within the system.

## IV. Conclusion

The low-cost, high-efficiency boost chopper circuit coupled with *RC* filter that drives separately excited DC motor was effectively designed and developed and the simulation model was presented. With less harmonic content, this combination produced noticeably better responsiveness. When the converter circuit was used in conjunction with the *RC* filter, the overall harmonic distortion (*THD*) dropped dramatically, from 37% to 11.8%. Furthermore, the motor's efficiency increased significantly with the *RC* filter, going from 74.42% without it to 91.42% with it. This accomplishment highlights how well an effective filter can be integrated into the converter to further enhance system performance. Notably, the investigation did not look at the responses of different DC motors, different filters, or other converter configurations leaving gaps for further research to be conducted.

## V. Acknowledgement

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