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BLDCM CEILING FAN WITH CUK CONVERTER SWITCHED INDUCTOR

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ABSTRACT:-

In order to achieve unity power factor (UPF) functioning at the supply input, the switched-inductor Cuk (SICuk) converter fed permanent magnet brushless direct current motor (PMBLDCM) is presented in this work. One uses the SI-Cuk converter as a front-end to address the power quality (PQ) issues with the current CF. The continuous conduction mode (DCM) operation of the SI-Cuk converter is intended to provide a variable output with built-in power factor correction (PFC). A potential divider is used to estimate the voltage output of the converter. To generate high frequency PWM pulses for the converter switch, the reference voltage is approximated based on the CF reference speed. This minimizes the number of sensors needed and their associated costs. The changeable The converter's voltage output allows the inverter to run at the commutation frequency, reducing inverter losses and increasing CF efficiency. By doing away with the necessary position sensors, the back-EMF sensorless control substantially lowers the cost of CF. In the result section, simulated results are displayed to validate the SI-Cuk converter's design.

I.INTRODUCTION

Green electrification is gaining attention from industry and researchers due to rising fuel prices and carbon emissions. The need for electricity is growing as the enormous innovations in the world of electricity. There are commercial, industrial, agricultural, and household uses for these inventions. The industrial and residential sectors are evident in the substantial role that electrical power consumption plays. Residential and commercial applications use roughly 65.92% of the power, while residential applications use about 24.76% of the power [1]. Only by reducing these needs can energy surplus be produced for industrial and home uses of energy-efficient equipment. Energy-efficient technology for homes and businesses is the only way to meet these demands and create excess energy. In emerging nations like India. Ceiling fans (CFs), which are utilized in both home and commercial settings, are among the most popular uses [2]. Particularly in the summer, when summers are long in tropical nations like India, this application is becoming more and more significant. Having a linear relationship between current-torque and voltage-rpm, permanent magnet brushless direct current motors (PMBLDCMs) are DC motors with electronic commutation that can be used in CF applications. It lowers the energy that the CFs use extensively [3], which lowers carbon dioxide emissions.

The majority of consumers like using ceiling fans with single-phase induction motors (SPIM-CF). The SPIM-CF is inexpensive and simple to care for. But the SPIM-CF requires between 60 and 70W of an input power that is greater than twice as much as the power used by the CFs based on PMBLDCM [2]–[3]. In comparison to SPIM-CF, the BLDCM-based CF is more expensive. But, a one-time investment pays for itself in less than a year thanks to energy savings and a lower power bill. The increased torque to weight ratio, reduced electromagnetic interference (EMI), and noiseless operation of BLDCM-based CFs are contributing to their growing popularity [2]–[3]. Because of the converter design and inverter control to achieve the regulated CF speed, the standard PMBLDCM CFs has consumed a significant amount of power. There are problems with electricity quality in the traditional CF as a result of the inverter and converter's functioning. This study uses the voltage and speed linear relation to regulate the CF speed. The inverter may run at a fundamental frequency thanks to the voltage and speed's linearity, which results in lower switching losses. In order to provide controllable speed and intrinsic power factor correction (PFC) at the supply input, the frontend SI-Cuk converter is constructed in discontinuous conduction mode (DCM) with variable voltage output [4]. Because of its high switching frequency (200 kHz) design, the converter has less passive parts.

There is a wealth of information about AC-DC and DC-DC converters in [4]–[12]. The DCDC PWM converter was created by the author in [4] using a transformer less construction. But the author hasn't spoken about the analysis and design. among those converters. The DC-DC Cuk converter family for high voltage gain, comprising switched capacitor-based and transformer less switched inductor models, is documented in [5]–[6]. These topologies result in higher losses and worse efficiency since they employ two switches and a higher number of components. Low switching frequency (< 40kHz) and a high component count in the non-isolated transformer less DC-DC buck-boost converter described in [7] result in low efficiency and huge passive component sizes. A report on the SI-Cuk converter for the battery charging application may be found in [8].

The improved dual output Cuk and PFC Cuk converters, which are utilized for the BLDCM and switching reluctance motor driving, are documented in [9]–[10]. These adapters are using a low switching frequency (20 kHz) while running in DCM. Furthermore, these converters have a modest gain. According to [11], the Cuk converter features a bridgeless design, operates at a low switching frequency (40 kHz), and has a low voltage gain.

The high voltage gain bridgeless SI-Cuk converter for charging applications is described in [12]. Its low operating frequency (20 kHz) results in a big converter size since the passive component utilized is substantial in size.

In typical PMBLDCM based CF, the SI-Cuk converter is employed at the front end to address power quality issues. The front-end converter has a high-performance DCM design. switching frequency operation to obtain the built-in PF correction and to minimize the size of passive components. In order to lead inverter operation at a fundamental frequency, lower switching loss, and obtain the controller CF speed, the converter works with a variable voltage output.

II. CONFIGURATION AND OPERATION OF THE CF

Fig.1 illustrates the SI-Cuk converter fed PMBLDCM drive for the CF. To increase the converter's gain and achieve a transformer less design, one inductor and one diode are added. The converter performs better and may run at a very low voltage output with the proper duty (d) thanks to this gain enhancement. The converter's efficiency increases and losses are decreased when the transformer is removed.

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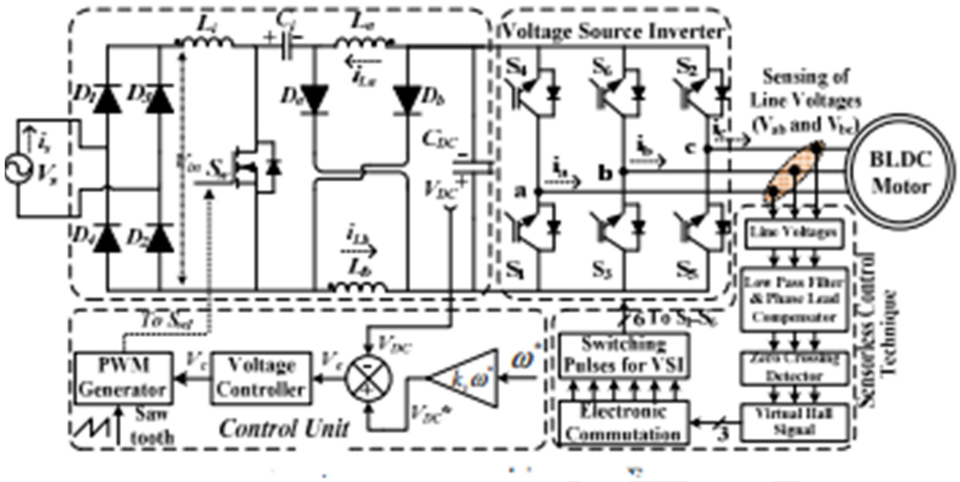
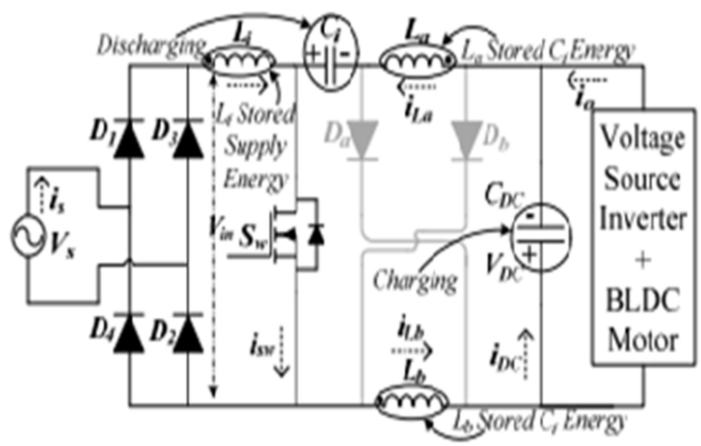
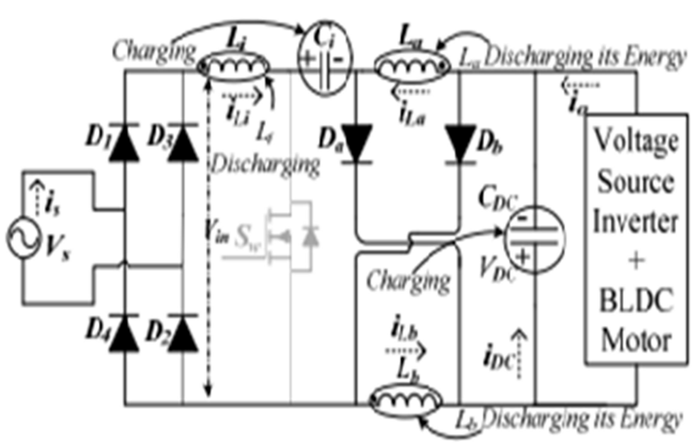


Fig. 1 PMBLDCM drive fed by SI-Cuk converter for CF.



(a)



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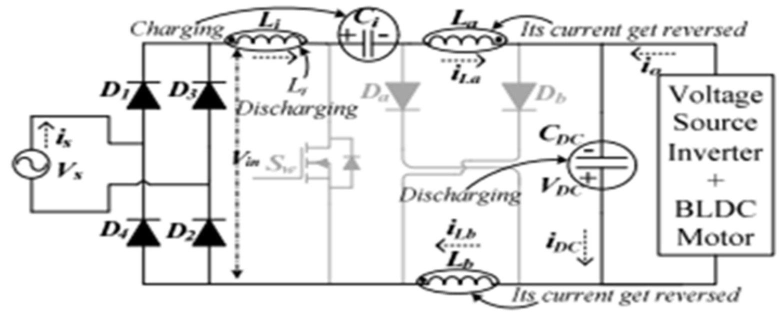


(c)

Fig. 2: SI-Cuk converter operating modes.

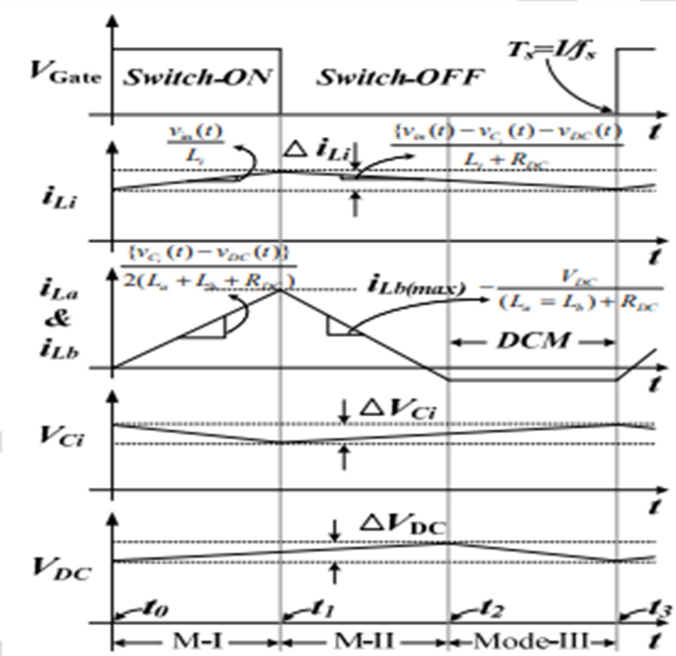


Fig. 3: SI-Cuk converter operational waveforms associated.

To obtain the regulated CF speed, the variable voltage output idea is applied. To lower the inverter's switching losses, it runs it at the transition frequency, which enhances the CF's overall efficiency. The potential divider does away with the need for a sensor by providing the controller with feedback converter voltage. The CF reference speed is used to estimate the controller reference voltage. A voltage controller for the converter switch (Sw) produces the high frequency (200 kHz) PWM pulses.

Supply voltage variations are handled by this control during its operation. In order to execute the back-EMFbased sensor less control, the line voltages are measured. It gets rid of the necessary sensors to detect the position of the rotor for the electronic commutation and generate the PWM pulses at the fundamental frequency for the VSI switches. It lowers the CF system's overall cost. Figures 2 and 3 depict how the SI-Cuk converter works. The SI-Cuk converter's output inductors, La and Lb, are designed in

DCM, while the input inductor, Li, is designed in CCM. There is equal current flow via the output inductors La and Lb. flowing in opposite and equal directions through them. The following operating modes and related equations for a single switching period (Ts) provide insight into the SI-Cuk converter's operation. M-I (from t0 to t1): This mode begins when switch Sw enters its conduction period. Fig. 2(a) shows that the diodes Da and Db are reverse biased. The output capacitor CDC is charged while the capacitor Ci's energy is stored in the inductors La and Lb.

$$v_{L_a} = v_{L_b} = \frac{v_{C_i} - v_{DC}}{2}$$
$$v_{L_a} = L_a \frac{d\,i_{L_a}}{dt} = v_{L_b} = L_b \frac{d\,i_{L_b}}{dt}$$
$$L_a = L_b = \frac{(v_{C_i} - v_{DC})}{2\Delta i_{L_a}} dT_s \text{ and } v_{DC} = \frac{1}{C_{DC}} \int_0^{dT_s} i_{DC}\, dt \qquad (1)$$

The supply energy is stored in the input inductor Li, and its current, iLi, increases linearly. The voltage across the linearly decreasing and growing capacitors Ci and CDCas seen in Figure 3.

$$\left.\begin{aligned} v_{in} &= v_{L_i} = L_i \frac{d\,i_{L_i}}{dt} \Rightarrow L_i = \frac{v_{in}}{\Delta i_{L_i}} dT_s \\ v_{C_i} &= \frac{1}{C_i} \int_0^{dT_s} i_{C_i}\, dt \end{aligned}\right\} \qquad (2)$$

M-II (t1 to t2): As shown in Fig. 2(b), the second mode begins when switch Sw is switched OFF and diodes Da and Db begin conducting. The inductors for the input and output are released. and they are linearly decreasing in current. As seen in Fig. 3, the capacitors Ci and CDC are charging and their voltages are rising linearly.

$$v_{L_i} = (v_{in} - v_{C_i} - v_{DC}) \text{ and } L_i = \frac{v_{L_i}}{\Delta i_{L_i}} (1-d) T_s$$
$$L_i = \frac{(v_{in} - v_{C_i} - v_{DC})}{\Delta i_{L_i}} (1-d) T_s \qquad (3)$$

M-III (t2 to t3): As shown in Fig. 2(c), in this mode, the switch Sw and the diodes Da & Db are OFF. The output inductors La and Lb are fully discharged, and the reverse-flowing currents from them, iLa and iLb, enter DCM. The capacitor Ci is charged by the input inductor Li, which is still discharging energy. The output is receiving its energy from the capacitor CDC, and its voltage VDC is dropping linearly.

$$\left.\begin{aligned} -v_{in} + v_{L_i} + v_{C_i} - (v_{L_a} + v_{L_b}) - v_{DC} = 0 \\ i_{L_i} = i_{C_i} = i_{L_a} = i_{L_b} \text{ and } i_{DC} = (i_{L_a} = i_{L_b}) + i_{L_b} \end{aligned}\right\} \qquad (4)$$

III SI-CUK CONVERTER DESIGN

The variable voltage output of the SI-Cuk converter is designed to range from 15V to 48V. To achieve unity PF operation with variable voltage output, the input inductor Li is functioning in CCM while the output inductors La and Lb are running in DCM. The voltage of the rms supply is stated as

$$v_s(t) = \sqrt{2} V_s \sin(2\pi f_l) t \qquad (5)$$

In CCM mode, the input inductor Li is in operation. It transmits its energy in (1-d)Ts time in one switching period (Ts) after storing it in dTs time. By voltage-second balance, therefore, the average voltage across the inductor at steady-state for one switching period is provided by [13].

$$\begin{aligned} &\bar{V}_{in} dT_s + (\bar{V}_{in} - V_{Ci} - V_{DC})(1-d)\bar{T}_s = 0 \\ &V_{in} dT_s + (-2V_{DC})(1-d)T_s = 0 \end{aligned} \qquad (6)$$

The SI-Cuk converter's gain from equation (6) is as follows:

$$\frac{V_{DC}}{V_{in}} = \frac{d}{2(1-d)} \text{ and } V_{in} = \frac{2\sqrt{2}}{\pi} V_s \Rightarrow 0.9V_s$$

For the variable voltage output, the operational duty (d) of the SI-Cuk converter using (7) is as follows:

$$d = \frac{2V_{DC}}{2V_{DC} + V_{in}} \qquad (8)$$

$$d_{(\max)} = \frac{2\times 48}{2\times 48 + 0.9\times 220} = 0.3265$$

$$d_{(\min)} = \frac{2\times 15}{2\times 15 + 0.9\times 220} = 0.1316$$

The working duty range that yields variable voltage is 0.3265 to 0.1316. The input inductor Li's critical value to obtain its current in CCM is determined using the provided equation [13].,

$$L_{i(Critical)} = \frac{2\{1-d_{(\max)}\}^2 T_s V_{DC}^{\ 2}}{(P_{in} = P_{out}) d_{(\max)}} \qquad (9)$$

$$L_{i(Critical)} = \frac{2\times\{1-0.3265\}^2 \times 5\times 10^{-6} \times 48^2}{30\times 0.3265} = 1.07mH$$

Using equation (9) to obtain the input inductor's critical value, 1.07 mH was selected as the value to operate iLi in CCM. 1.4mH is the selected value. The output inductors, La and Lb, have the same design and have a maximum current in DCM.

The purpose of these inductors is to prevent the maximum duty CCM functioning of currents iLa and iLb. The following equation is used to build the inductors La and Lb [13].

$$L_{a,b(Critical)} = \frac{(1-d_{(\max)}) V_{DC}^{\ 2}}{f_s P_{out}} \qquad (10)$$

$$L_{a,b(Critical)} = \frac{(1-0.3265)\times 48^2}{200{,}000\times 30} = 258.6\mu H$$

Both inductors' computed values, which come out to be 258.6µH, are comparable. In order for these inductors to function in DCM in all circumstances, the value is selected to be lower than the computed value of 150µH.

The supplied equation [13] is used to build the capacitor Ci so that its voltage (VCi) form resembles the supply voltage (Vs).

$$C_i = \frac{1}{(4\pi^2 f_c^2)\times L_{eq}} \text{ and } L_{eq} = (L_i+L_a+L_b) \quad (11)$$

$$C_i = \frac{1}{(4\pi^2 \times 100,000^2)\times(1.4\times10^{-3}+2\times150\times10^{-6})} = 1.49nF$$

where the cut-off frequency, fc, is. Capacitor Ci has been developed and selected to have values of 1.49nF and 2nF at 400V.The voltage output capacitor CDC of the SI-Cuk converter is designed to obtain the output voltage (VDC) with the least amount of voltage ripple. The provided equation is used to create it [9].

$$C_{DC} = \frac{I_o}{2\omega_l \Delta V_{DC}} \quad (12)$$

$$C_{DC} = \frac{(30/48)}{2\times(2\pi\times50)\times0.02\times48} = 1036.2\mu F$$

The voltage output capacitor (CDC) has a selected value of 1200 µF and 63V, although its intended value is 1036.2µF with a 2% voltage ripple.

IV. COMMAND OF THE CF SYSTEM

Simple control of the PMBLDCM drive fed by the SI-Cuk converter is covered separately. There is no voltage or current sensor needed for these controls to function. The following controls are examples of how they may be used in both software and hardware.

A. Control of SI-Cuk Converter

The control of SI-Cuk converter is taken care of supply voltage fluctuations, and it controls the converter voltage output corresponds to the CF reference speed (ω*). The CF speed (ω) is controlled corresponding to the converter voltage output (VDC) variation. The controller estimates the operating pulses for the converter switch (Sw) by desired speed (reference speed) with appropriate gain (kv), and it is given as

$$V_{DC}^* = k_v \omega^* \quad (13)$$

$$V_e(n) = V_{DC}^*(n) - V_{DC}(n) \quad (14)$$

$$V_c(n) = V_c(n-1) + k_p\{V_e(n) - V_e(n-1)\} + k_i V_e(n) \quad (15)$$

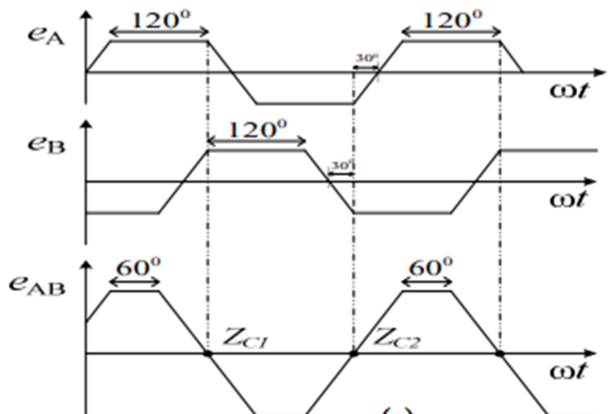
Where ki and kp are the PI controller's gains. A fixed high frequency (200 kHz) carrier signal mk(n) is compared to these samples of regulated voltage Vc(n) to create As seen in Fig. 1, the converter control unit, the high frequency PWM pulses for the SI-Cuk converter switch (Sw) regulated the converter voltage output (VDC). The following are the converter switch (Sw) operations:

$$\left.\begin{aligned} m_k(n) < V_c(n)\,;\, S_w \text{ is } ON \\ m_k(n) \ge V_c(n)\,;\, S_w \text{ is } OFF \end{aligned}\right\} \quad (16)$$

B. PMBLDCM Sensor less Control

The position sensor-equipped PMBLDCM control is expensive and needs a single auxiliary power source. To solve this issue, the back EMF-based sensor less control is utilized; line voltages are detected in order to do this. The stage As seen in Fig. 4(a), the zero-crossing locations of voltages are causing a 30° phase shift, which is difficult to correct for. Line voltage zero-crossing points are proportional to the necessary Hall-effect signals. The low pass filter, or LPF, is utilized to lessen the commutation ripple present in these detected voltages. The phase lead compensator, or PLC, is used to offset the line voltages' LPF delay.

Consequently, as shown in Fig. 4(b), the filtered voltages yield the accurate moment of zero crossing, from which the virtual Hall signals (Ha, Hb, and Hc) are computed. These virtual Hall signals produce the six switching pulses (S1 to S6) with commutation frequency, which are then used to switch the inverter switches. By doing away with position sensors and increasing commutation accuracy from low to high speed, this sensor less control approach lowers the cost and dimensions of the motor.



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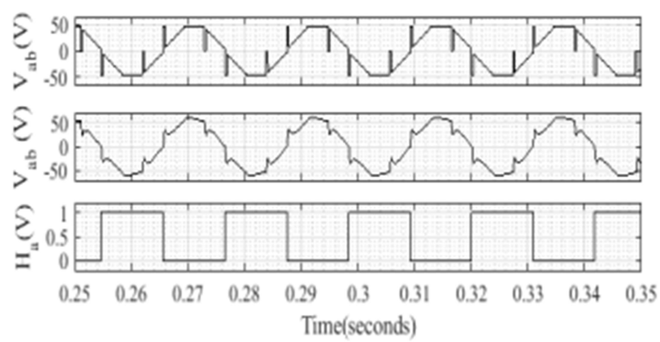


(b)

Fig4 Sensorless control of BLDCM; (a) line voltage detection of the zero crossing point and (b) virtual Hall signal (Ha, Hb, a nd Hc) estimate

V. OUTCOMES AND SUGGESTIONS

Figs. 6–10 display the SI–Cuk converter fed PMBLDCM based CF performances. In MATLAB, these results are simulated at 350 rpm and 0.565 Nm of torque. The transcriber The Appendix contains the design values for the passive parts and the motor parameters that were utilized in the simulation. Here, the specific performances of CF are spoken about.

a)Assessment of SI-Cuk Converter Performance

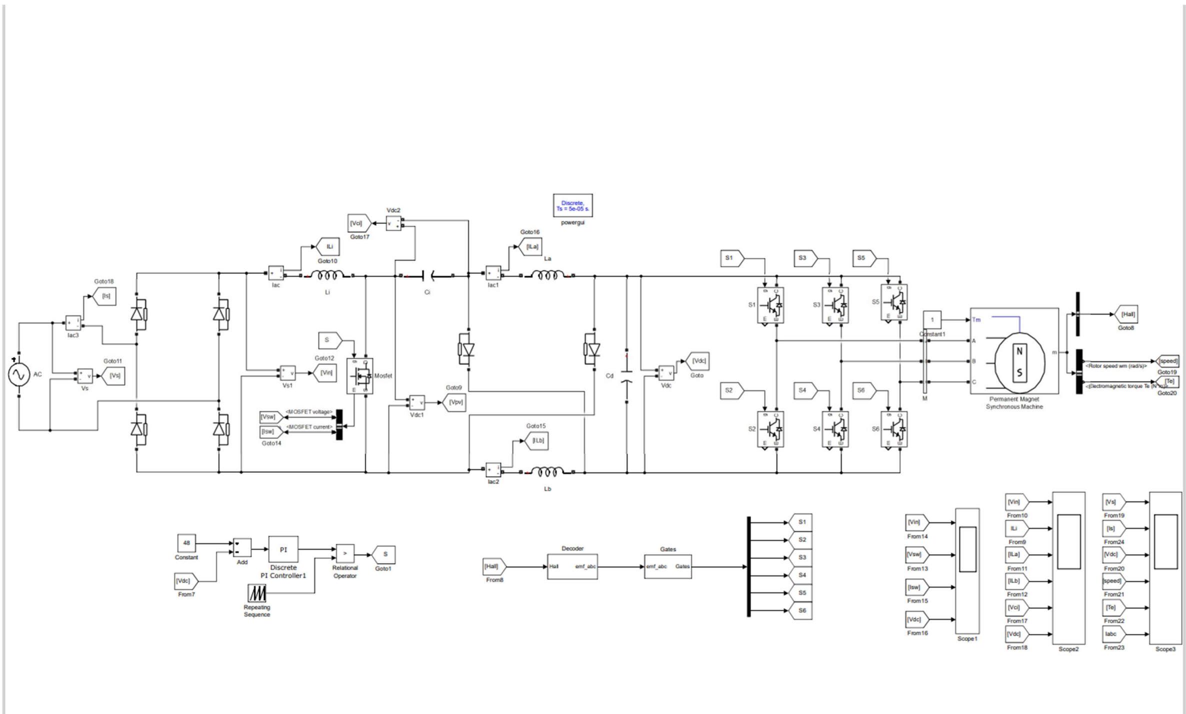


Fig 5.Similink model of the proposed system

The SI-Cuk converter's performance is displayed in Fig. 6. The input voltage (Vin) keeps the source voltage in its original form to get the supply voltage (Vs) and supply current (is) in phase. As shown in Fig. 6(a), the converter voltage output is 48V, and the switch current and voltage stresses are less than 2.5A and 450V. The converter input voltage (Vin) is followed by the input inductor current (iLi), and the output inductors La and Lb, with their peak currents of 2A, are running in DCM. As shown in Fig. 6(b), the capacitor Ci voltage VCi keeps the converter input voltage in the same form such that the supply current (is) sinusoidal.

b)Assessment of CF's Performance with Speed Variation

Figs. 7-8 show the performances of CF at varying speeds. The supply voltage (is) followed by the supply current.as shown in Figs. 7(a)–(c), and it has a converter output voltage of 48V, 35V, and 15V. It is in phase with the supply voltage (Vs).

Operating modes	Vdc	W(rpm)	Is(mA)	PF	%THD	CF
mode-1	15	110	26.04	0.977	7.60	1.342
mode-2	20	160	36.28	0.989	4.21	1.389

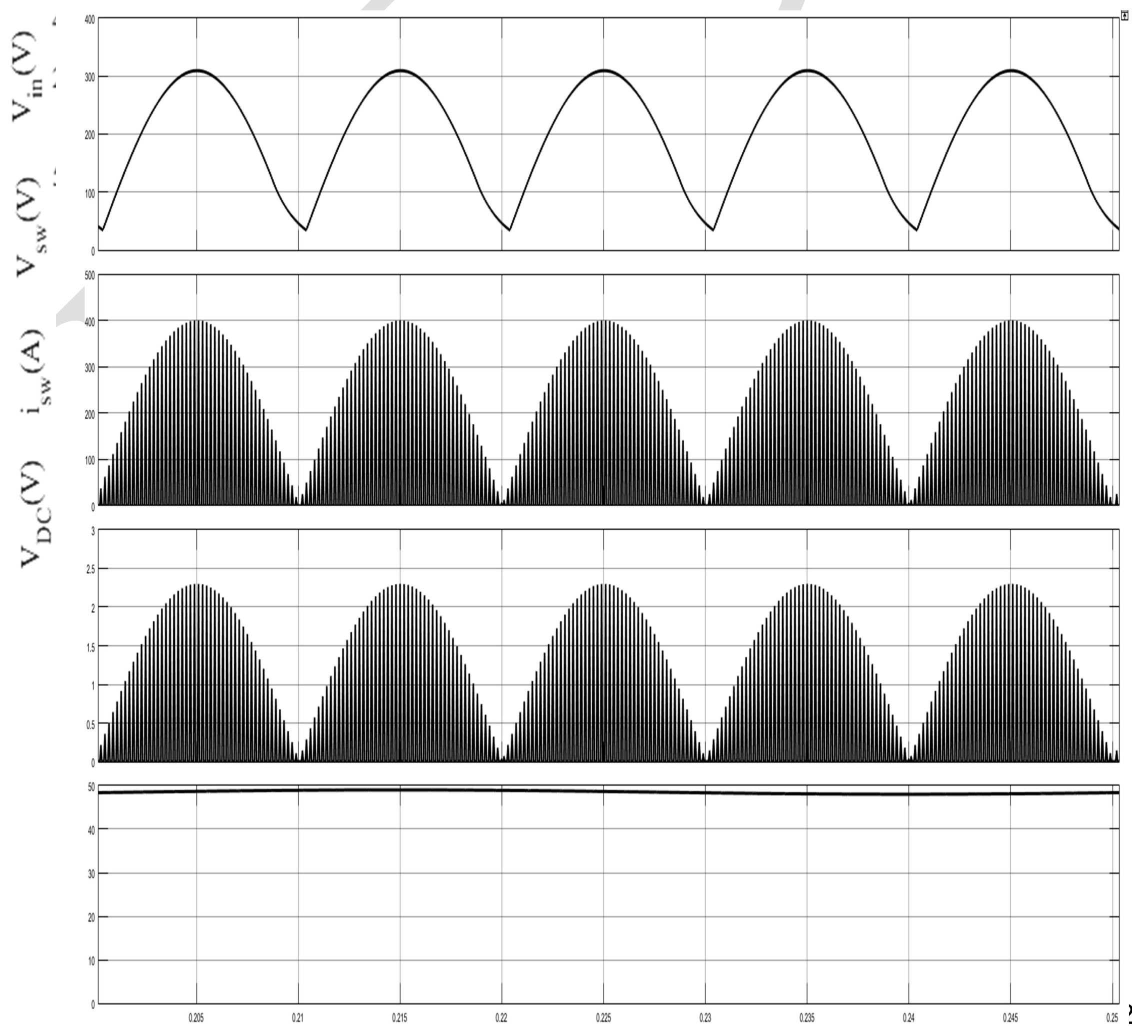
mode-3	25	215	52.31	0.998	3.15	1.398
mode-4	30	245	72.09	0.999	2.01	1.399
mode-5	35	275	101.12	0.999	1.82	1.399
mode-6	40	305	121.75	0.999	1.59	1.399
mode-7	45	335	139.43	0.999	1.41	1.399
boost mode	48	350	142.20	0.999	1.39	1.399

Table 1:Performances of Speed Control

When the motor's torque (Te) and phase current (ia) are adjusted, the converter voltage output (VDC) and variations in speed (ω) match. As seen in Figs. 8(a)–(c), the supply current THDs are 1.39%, 1.82%, and 7.6%, which correspond to the converter voltage output of 48V, 35V, and 15V. The converter voltage output (VDC) variations in relation to the CF performances with speed changes are summarized in table 1

C. CF Performance Changing Supply Voltage

Figs. 9–10 display the CF's performances when the supply voltage changes. The supply voltage (Vs) fluctuates between 220V and 90V and 220V and 270V. The supply current (is) also fluctuates in tandem with the supply voltage (Vs) and is in-phase. When these source voltages fluctuate, the converter output voltage (VDC) remains constant, which keeps the motor torque (Te) and speed (ω) constant as well. According to IEC standard 61000-3-2, the current THDs with supply voltage variations are 0.95% at 90V and 1.43% at 270V [14].



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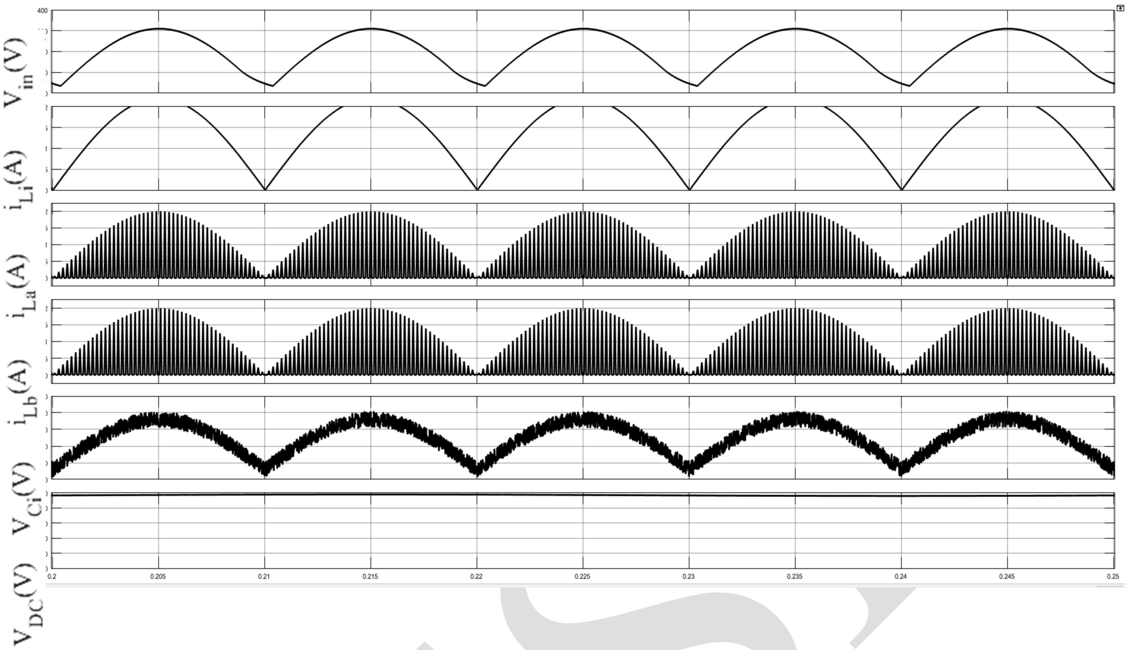
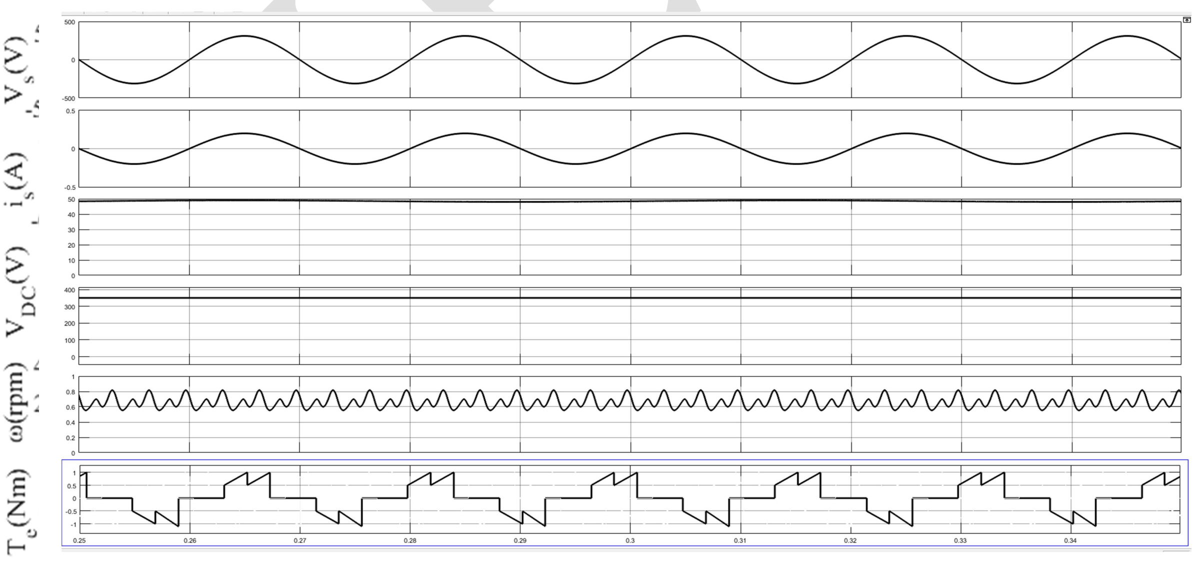


(b)

Fig .6 shows the SI-Cuk converter's steady-state performance at Vs = 220V and VDC = 48V.



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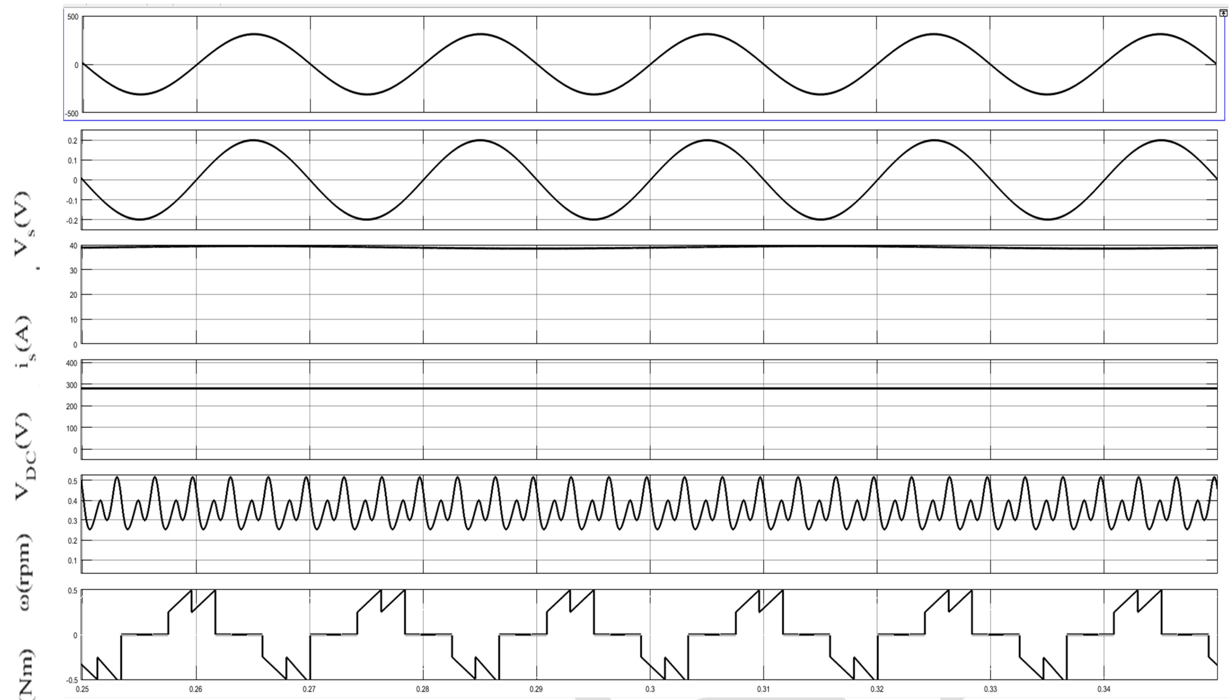

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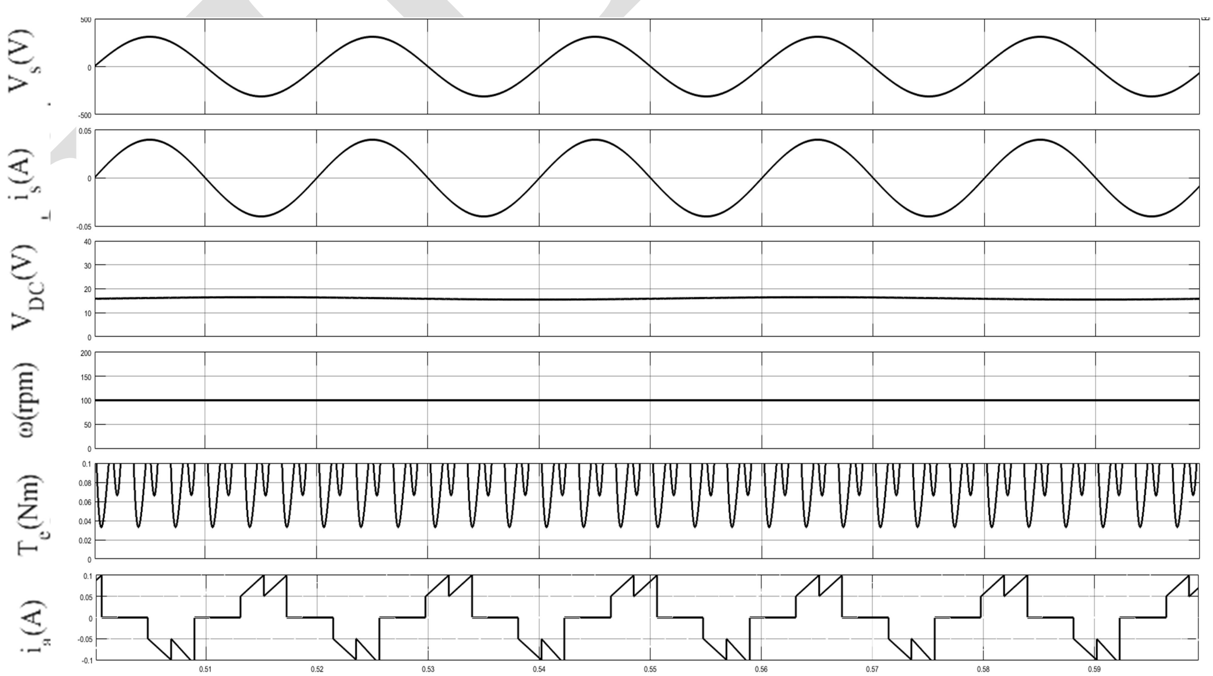
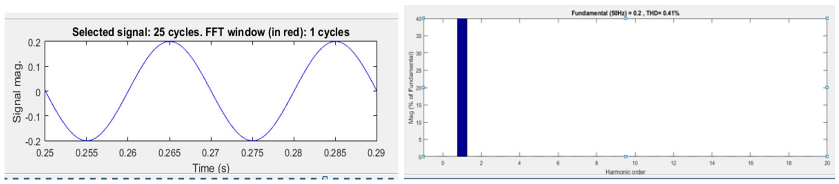


(c)

Fig..7 Performances with 48V, 35V, and 15V converter voltage output



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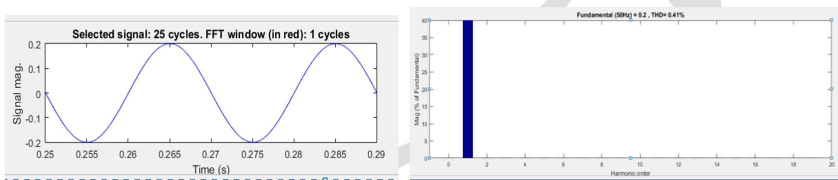

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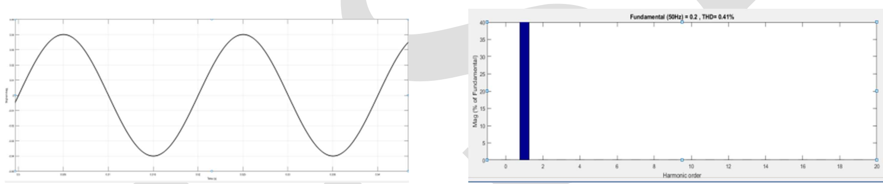
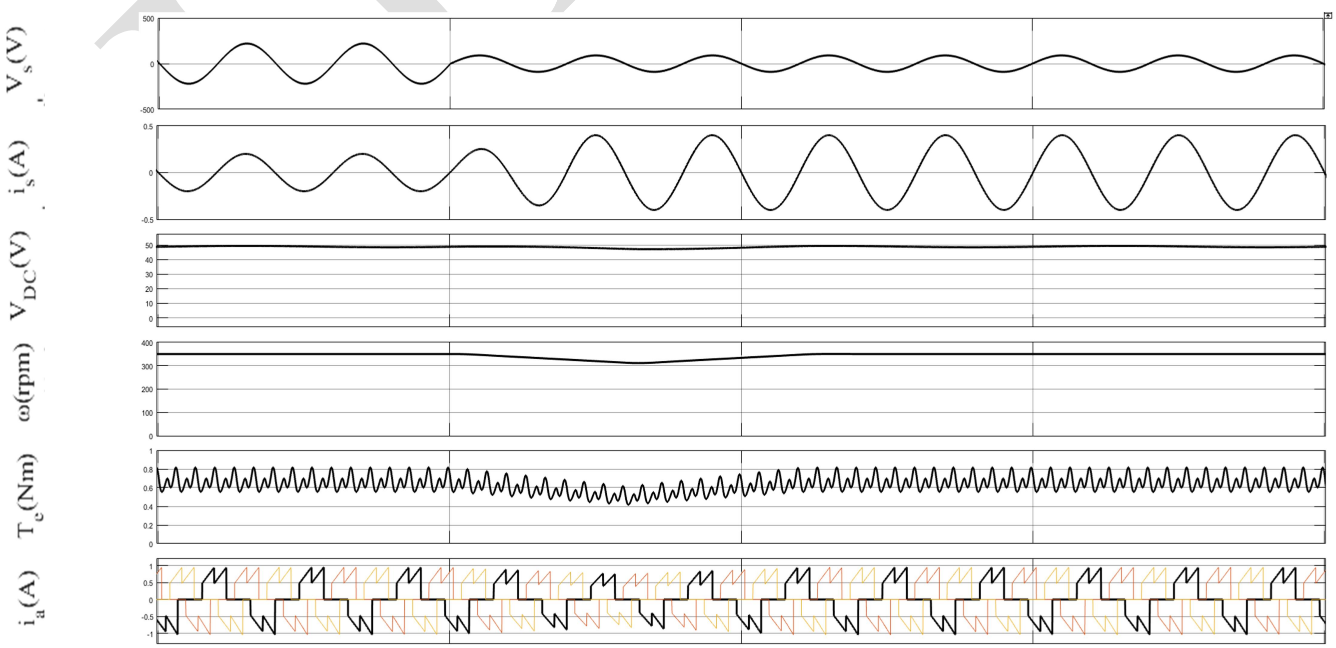


(c)

Fig.8 Supply current THD with three different converter voltage outputs: 48V, 35V, and 15V.



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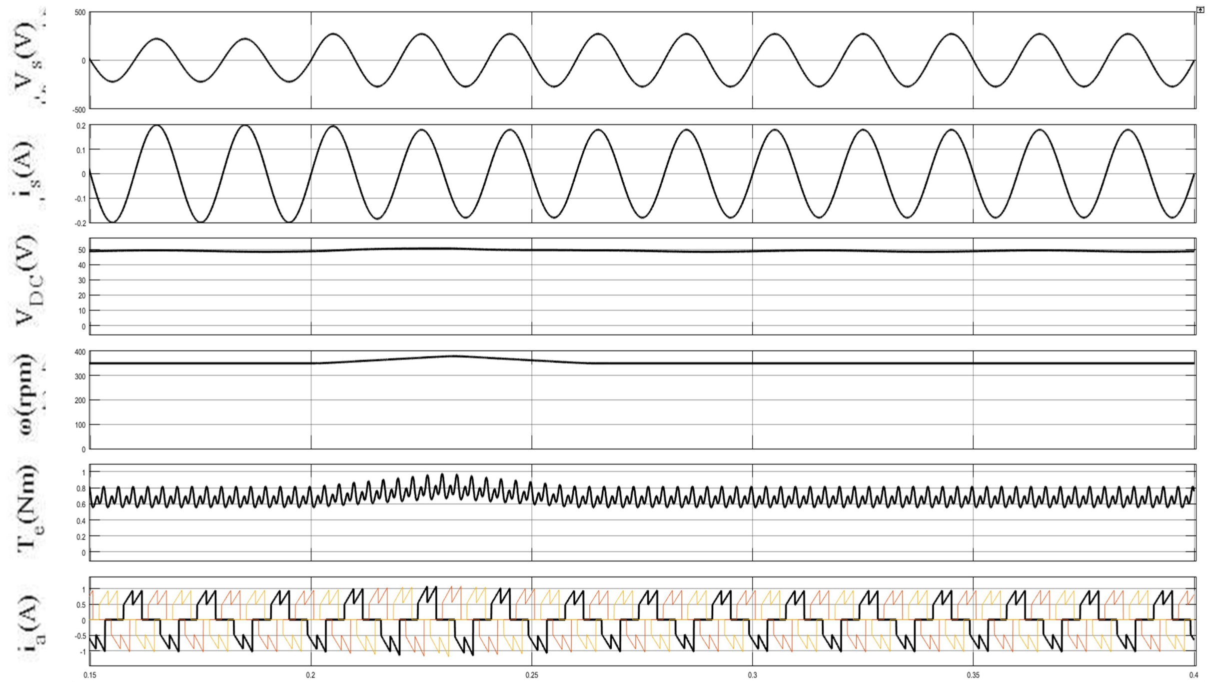

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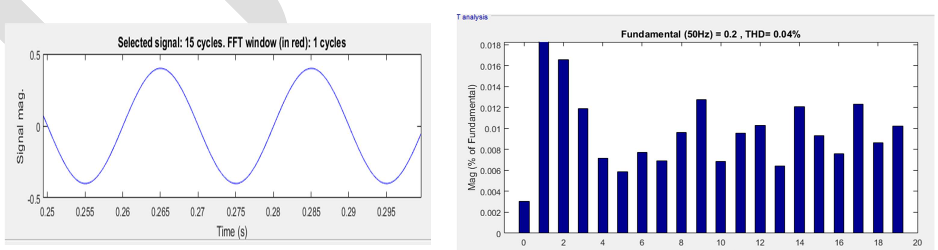
Fig 9 Performance with a Supply Voltage Alteration



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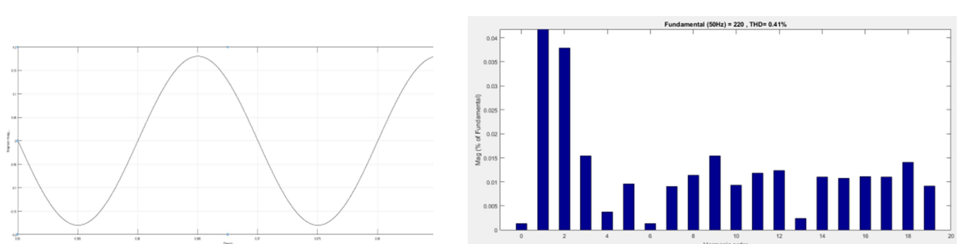

(b)

Fig.10 Supply current THD as a function of supply voltage (Vs); (a) 90V, (b) 270V

VI. CONCLUSIONS

The CF performances with SI-Cuk based on PMBLDCM converters are examined in this section. The controller has done a good job. when the voltages of the source and converter output fluctuate. The PQIs are fairly excellent at the supply input. It has confirmed the controller performance and converter design. The transcriber runs at a high switching frequency, lowering the dimensions of the passive parts that are employed. The speed limiter featuring The inverter's variable converter voltage output operating at the frequency of commutation, lowering the switching reductions and increasing CF effectiveness. The sensor-free management of CF costs are reduced by the converter and motor.

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