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PFC Cuk Converter Fed BLDC Motor Drive using Artificial Neural Network

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***Abstract*—In this paper a Power Factor Correction Cuk converter fed Brushless DC Motor Drive using a Artificial Neural Network is used. The Speed of the Brushless dc motor is controlled by varying the output of the DC capacitor. A Diode Bridge Rectifier followed by a Cuk converter is fed into a Brushless DC Motor to attain the maximum Power Factor. Here we are evaluating the three modes of operation in discontinuous mode and choosing the best method to achieve maximum Power Factor and to minimize the Total Harmonic Distortion. We are comparing the conventional PWM scheme to the proposed Artificial neural network. Here simulation results reveal that the ANN controllers are very effective and efficient compared to the PI and Fuzzy controllers, because the steady state error in case of ANN control is less and the stabilization if the system is better in it. Also in the ANN methodology the time taken for computation is less since there is no mathematical model.The performance of the proposed system is simulated in a MATLAB/Simulink environment and a hardware prototype of the proposed drive is developed to validate its performance.**

Keywords — Brushless dc motor, Discontinuos input inductor mode , Discontinuous output inductor mode, Discontinuous intermediate capacitor mode ,Cuk converter,Power Factor Correction,Total Harmonic Distortion, Artificial Neural Network,Pulse width modulation

I. INTRODUCTION

Brushless Dc Motor is recommended for many low cost applications such as household application, industrial, radio controlled cars, positioning and aeromodelling, Heating and ventilation etc. ,because of its certain characteristics including high efficiency, high torque to weight ratio, more torque per watt , increased reliability, reduced noise, longer life, elimination of ionizing sparks from the commutator, and overall reduction of electromagnetic interference(EMI) etc. With no windings on the rotor, they are not subjected to any centrifugal forces, and because the windings are supported by the housing, they can be cooled by conduction, requiring no airflow inside the motor for cooling purposes. The motor's internals can be entirely enclosed and protected from dust, dirt or any other foreign obstacles.

The two main factors that determine the power quality of a motor are the Power Factor (PF) and the total harmonic Distortion (THD). The Power Factor determines the amount of useful power being consumed by an electrical system. The term THD is defined as the ratio of the harmonic components of voltage (or current) to the voltage (or current) of the fundamental. So the Power Factor Correction (PFC) is the best method of improving the PF by making the input to the power supply purely resistive or else due to the presence of non linear loads the input will contain phase displacement which causes harmonic distortion and thus the power factor gets degraded.

The main aim of all papers is to improve the power quality according to the standards recommended ,But in the conventional schemes for example diode bridge fed Brushless Dc Motors due to the presence of huge capacitor value it draws a non sinusoidal current from the ac mains which increased the THD to 65% and power factor to 0.8.The other conventional schemes by using many of the converters fed BLDC motors like Sepic ,Buck, Boost ,Buck Boost etc. by using high frequency pulse width modulation increases the switching losses. Bridgeless configuration of these converters were also existed ,even though they reduces the switching losses ,the no of active and passive components were more which increases the complexity in designing the circuit and the overall cost. The Power Factor in these cases is very less and a high value of THD which reduces the power quality. In this paper we are using a Cuk converter for PFC correction to the maximum value and to attain a low value of THD using Artificial neural network.

There are some draw backs in using conventional Power Factor Correction Methods, By using a Boost converter in Discontinuous Current Mode leads to a high ripple output current. The Buck converter input voltage does not follow the output voltage in DCM mode and the output voltage is reduced to half which reduces the efficiency.In our proposed system front-end Cuk converter is used in both continuous and discontinuous mode because of its certain advantages like easy implementation of the transformer isolation ,protection against high inrush current ,low current ripple and also low electromagnetic interferences.

The two modes of operation for the front-end converter are continuous conduction mode and discontinuous conduction modes of operations. The current multiplier approach is used in continuous mode with low voltage and current stresses but which make use of three sensors(One voltage sensor and twocurrent sensors) and increase the cost. But in the case of discontinuous mode of operation we use voltage control follower with comparatively more voltage and current stresses but only one voltage sensor is used .

II OPERATION OF THE CONVENTIONAL SCHEME

A. *PFC CUK CONVERTER FED BLDC MOTOR*

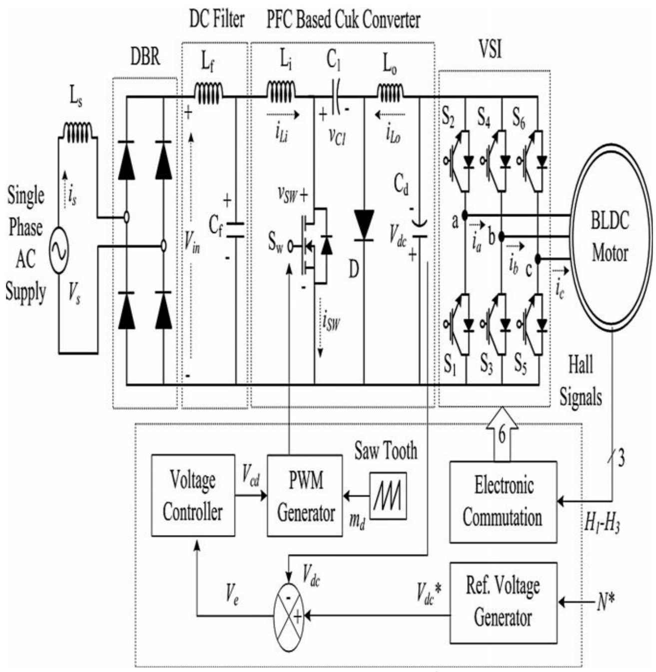

Fig.1.Conventional scheme using voltage follower approach

In this operation a diode bridge rectifier is used to convert the given ac source to a dc, which is fed into a Cuk converter to improve the Power Factor and THD.The Voltage follower approach is used to evaluate the scheme in three different discontinuous mode of operation. In the first method DICM (Li),the input inductor is made discontinuous while all other parameters are made continuous. In the DICM(Lo),the output inductor is made discontinuous while other parameters are continuous.In DCVM,the output capacitor is made discontinuous while the other parameters are continuous. The speed of the BLDC motor is sensed using the hall effect position sensors mounted on the shaft. Electronic commutation is used to trigger the switches in the inverter according to the information from the hall effect position sensors to turn on/off the switches with low frequency which reduces the switching losses. It means that proper switching of the VSI in such a way that asymmetrical current is drawn from the dc link capacitor for 120˚ and placed symmetrically. The output of the cuk converter(Vc) is feed back and compared with a reference voltage(Vf) to produce the voltage error(Ve) and is given to the PI controller .The proportional constant(kp) determines the reaction to the current error and the integral constant (ki) determines the reaction based recent error. The output of the PI controller is compared with the high frequency signals from the sawtooth generator to trigger the front-end Cuk converter switch

III PFC CUK CONVERTER FED BLDC MOTOR USING ARTIFICIAL NEURAL NETWORK

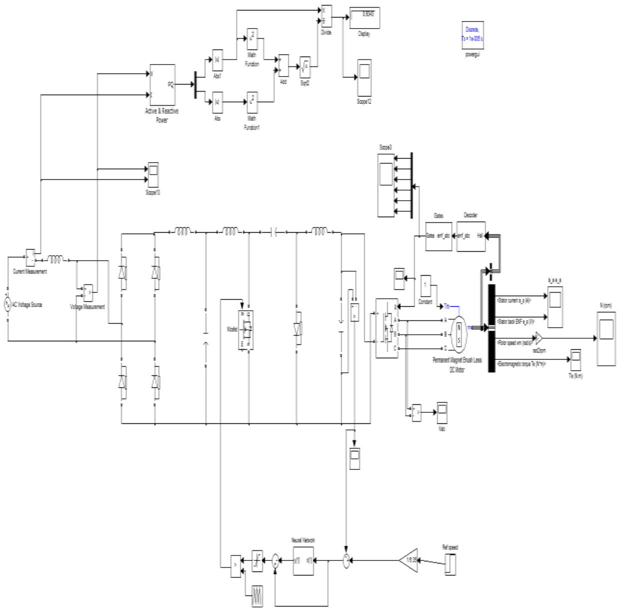

Fig.2.Proposed scheme using Artificial Neural Network

In this proposed scheme using Artificial Neural Network (ANN),The AC source followed by a diode bridge rectifier to convert AC source to DC is boosted or bucked using the switching pulse given to the MOSFET switch of a cuk converter is fed to a inverter fed Brushless DC motor. Here the power factor is made approximately to the unity by using the cuk converter. Here the speed is not sensed ,only the cuk converter output voltage is sensed and compared with the reference speed 2000rpm the output is given to a Artificial neural network which consist of two main functions Transig and Purelin. The error signal is given to the first layer Transig which removes the complex, imaginary minimized values and only allows the real values p. This p is given after a delay is given to various constant weights their product is given to a mux is compared with the biased value and produce the output a(1).This function a(1) is given to the next neural layer called Purelin with the same process as same as Transig layer.The only difference is that in Transig layer the weighted values are compared with many biased values.but in the case of purelin only 1 bias value is used for the comparison.From the purelin only the real values are permitted and removes all constants,imaginary,complex values etc.This output y(1) is compared with the feed back signal and the error signal is undergone a comparison with the repeating sequence to produce the gating signal for triggering the mosfet. The ANN controllers are very effective and efficient compared to the PI and Fuzzy controllers, because the steady state error in case of ANN control is less and the stabilization if the system is better in it. Also in the ANN methodology the time taken for computation is less since there is no mathematical model

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VI OPERATING MODES OF THE PROPOSED CONVERTER

There are mainly three modes of Discontinuous operation:

A) DICM(Li)

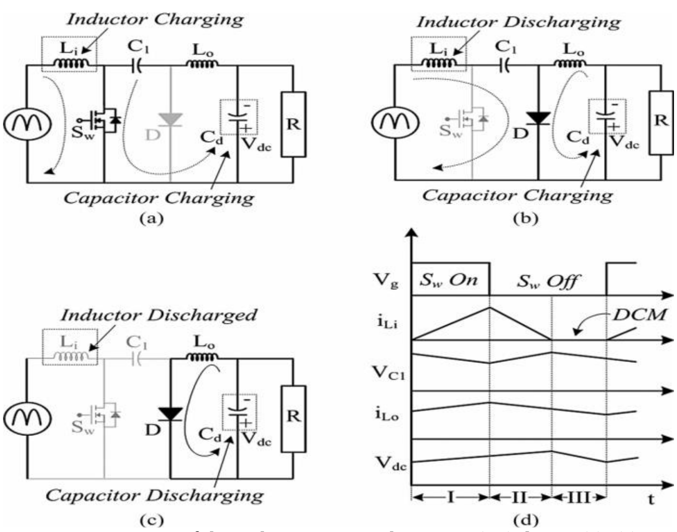


Fig. 4. Operation of the Cuk converter in the DICM (*Li*) during (a)–(c) different intervals of switching period and (d) associated waveforms. (a) IntervalI. (b) Interval II. (c) Interval III. (d) Waveforms.

Interval I The swithch Sw is turned on and the inductor Li will store energy and the capacitor Ci will start discharging through the switch Sw to the dc link capacitor Cd .So the voltage across the capacitor Cd will start increasing and the current iL1 will be decreasing in this interval.
Interval II The switch Sw is turned off and the energy stored across the inductor will start discharging through diode D to the dc link capacitor Cd.
Interval III At this moment no energy will be left back in the inductor and the inductor Lo will be in continuous conduction mode to transfer its energy to the Dc link capacitor.

B) DICM(Lo)

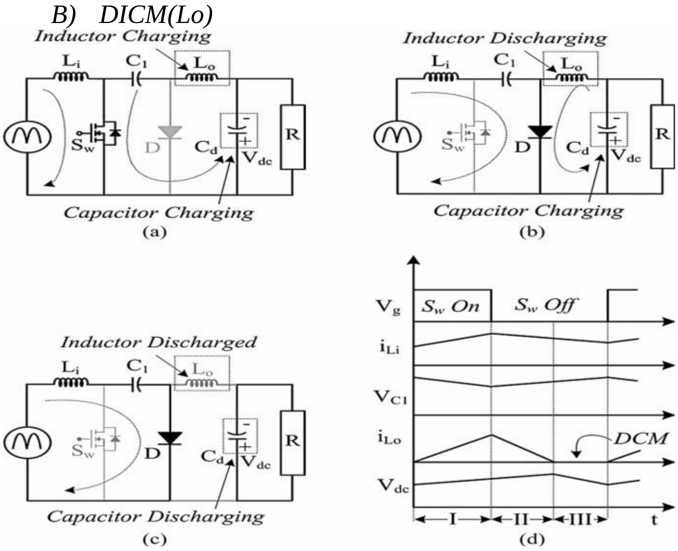


Fig. 5. Operation of the Cuk converter in DICM (*Lo*) during (a)–(c) different intervals of switching period and (d) associated waveforms. (a) Interval I.(b) Interval II. (c) Interval III. (d) Waveforms

Interval IThe swithch Sw is turned on and the inductor Li will store energy and the capacitor Ci will start discharging through the switch Sw to the dc link capacitor Cd .So the voltage across the capacitor Cd will start increasing and the current iL1 will be decreasing in this interval .
Interval II The switch Sw is turned off and the energy stored across the inductor Li and Lo will start discharging through diode D to the dc link capacitor Cd and capacitor Ci.
Interval III At this moment no energy will be left back in the inductor Lo and the inductor Li will be in continuous conduction mode to transfer its energy to the intermediate capacitor.

C) DCVM

Interval I The swithch Sw is turned on and the inductor Li will store energy and the capacitor Ci will start discharging through the switch Sw to the dc link capacitor Cd .So the voltage across the capacitor Cd will start increasing and the current iL1 will be decreasing in this interval.
Interval II The switch Sw is turned off ,the capacitor Cd will be completely discharged,The inductor Lo will give supply to the dc link capacitor Cd
Interval III At this moment Li will start charging the intermediate capacitor Ci and the inductor Lo will be in continuous conduction mode to transfer its energy to the Dc link capacitor.

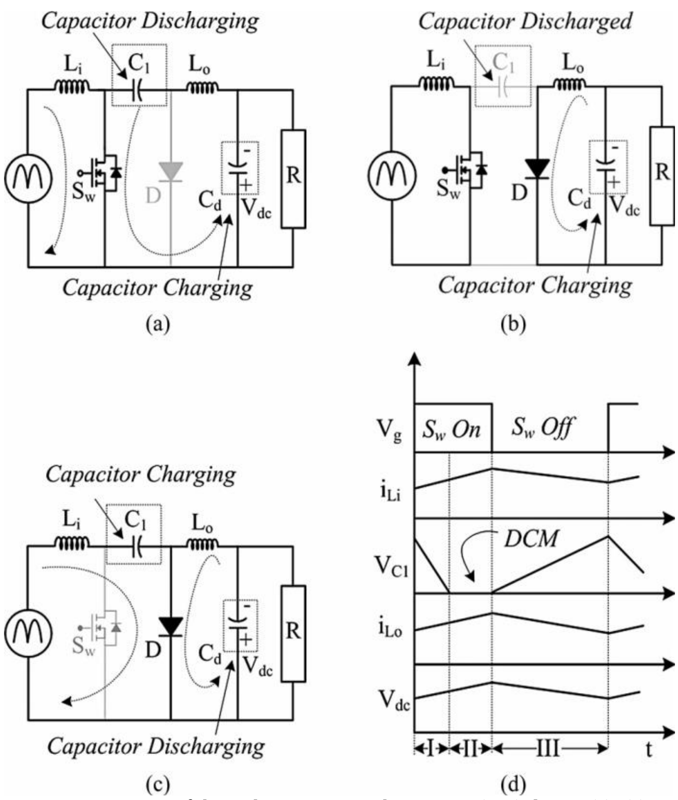


Fig. 6. Operation of the Cuk converter in the DCVM (*C*1) during (a)–(c) different intervals of switching period and (d) associated waveforms. (a) IntervalI. (b) Interval II. (c) Interval III. (d) Waveforms.

D) DESIGN PARAMETERS

TABLE I
SPECIFICATIONS OF A BLDC MOTOR

S. No.	*Parameters*	*Values*
1.	No. of Poles (P)	4 Poles
2.	Rated Power (P_{rated})	251.32W
3.	Rated DC link Voltage (V_{rated})	200V
4.	Rated Torque (T_{rated})	1.2Nm
5.	Rated Speed (ω_{rated})	2000rpm
6.	Back EMF Constant (K_b)	78V/krpm
7.	Torque Constant (K_t)	0.74Nm/A
8.	Phase Resistance (R_{ph})	14.56Ω,
9.	Phase Inductance (L_{ph})	25.71mH
10.	Moment of Inertia (J)	1.3x10^{-4}Nm/s^2

Table2
DESIGN PARAMETERS IN DIFFERENT MODES OF OPERATION

Specifications ↓	***Values***			
Supply Voltage (V_s)	Rated: 220V, (Universal Mains: 85-270V)			
DC Link Voltage (V_{dc})	Rated: 200V, (40V-200V)			
Power (P)	Rated: 350W, (70W-350W)			
Switching Frequency (f_s)	20kHz			
Operation ↓	L_i	L_o	C_1	C_d
CCM	2.5mH	4.3mH	0.66µF	2200µF
DICM (L_i)	100µH	4.3mH	0.66µF	
DICM (L_o)	2.5mH	70µH	0.66µF	
DCVM (C_1)	2.5mH	4.3mH	9.1nF	

Table3
SWITCHING STATES OF VSI CORRESPONDING TO HALL-EFFECT ROTOR POSITION SIGNALS

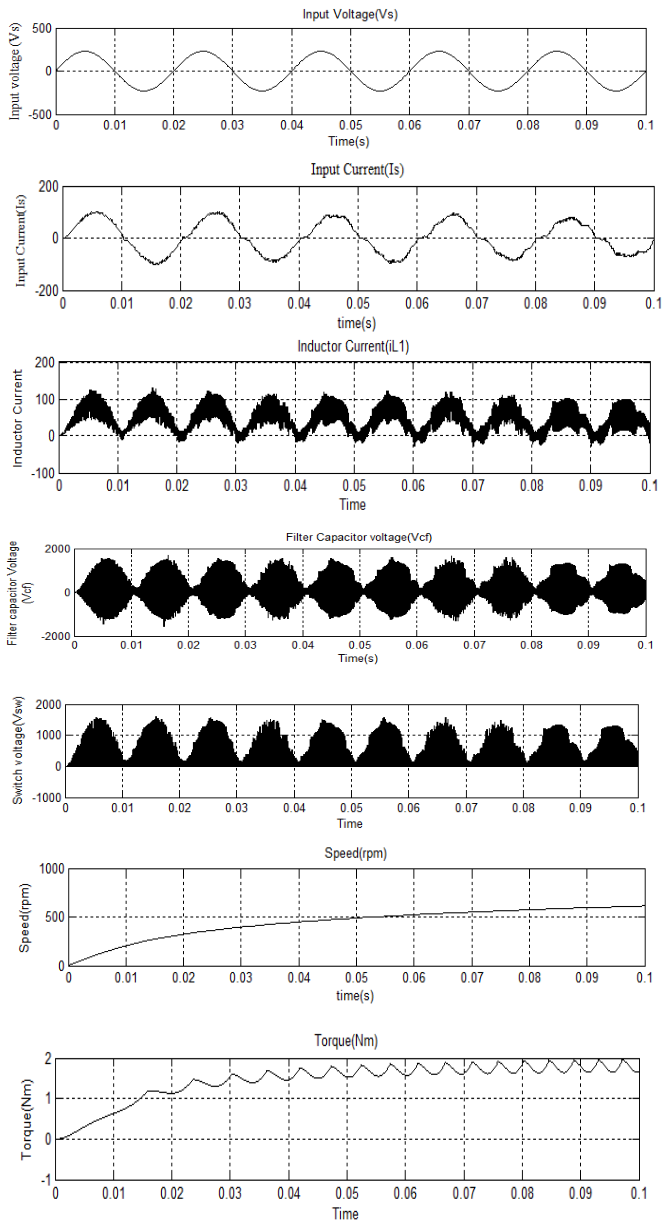
Hall signals			Switching states					
H_1	H_2	H_3	S_1	S_2	S_3	S_4	S_5	S_6
0	0	0	0	0	0	0	0	0
0	0	1	1	0	0	0	0	1
0	1	0	0	1	1	0	0	0
0	1	1	0	0	1	0	0	1
1	0	0	0	0	0	1	1	0
1	0	1	1	0	0	1	0	0
1	1	0	0	1	0	0	1	0
1	1	1	0	0	0	0	0	0

V. SIMULATION RESULTS OF CONVENTIONAL SCHEME

The simulation of the PFC Cuk converter fed BLDC motor drive is done in the environment of MATLAB/SIMULINK at a switching frequency 20khz.The input voltage 230V is given to a diode bridge rectifier where rectification process is done which convert AC to DC and fed to a Cuk converter which is used for power factor correction and to reduce the THD. The speed of the BLDC motor drive is controlled by using the dc capacitor voltage. Here Electronic commutation is used by sensing the rotor position by using the hall effect position sensors to trigger the low frequency IGBT switches of the Vol

A)PERFORMANCE OF BLDC MOTOR DRIVE USING DICM MODE(Li)

In the DICM(Li) mode by simulating at a frequency of 20khz The maximum power factor obtained is .927 and the THD obtained is 6.36%. In DICM mode the input inductor will be discontinuous while all other parameters will be continuous.The design value of parameters are Input inductor L_i = 100 μH, output inductor L_o = 4.3 mH, intermediate capacitor C_1 = 0.66 μF, and dc-link capacitor C_d = 2200 μF



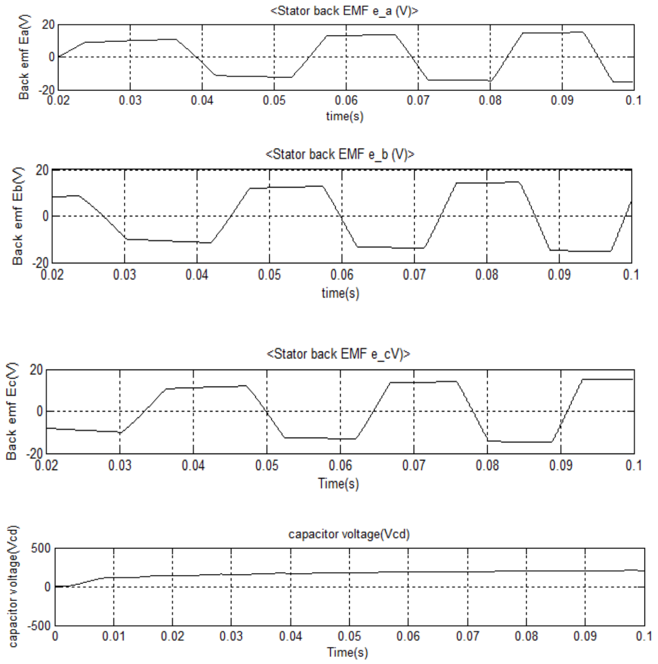
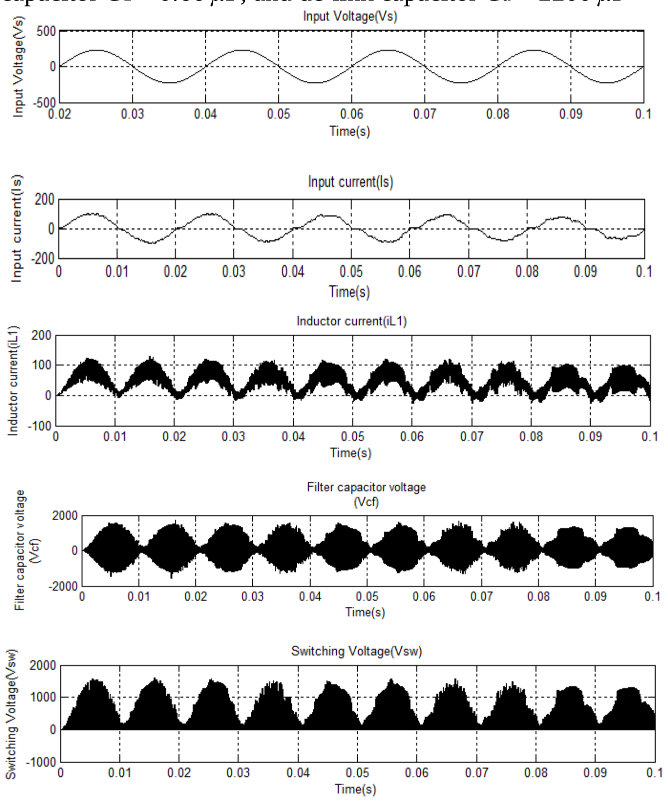


Fig 7.Waveforms in DICM (Li) mode

B.PERFORMANCE OF BLDC MOTOR DRIVE USING DICM MODE(Lo)

In the DICM(Lo) mode by simulating at a frequency of 20khz The maximum power factor obtained is .91 and the THD obtained is 10.39%..In DICM(Lo) the output inductor is discontinuous will all the other parameters are continuous.The design value of parameters are Input inductor L_i = 2.5 mH, output inductor L_o = 70 μH, intermediate capacitor C_1 = 0.66 μF, and dc-link capacitor C_d = 2200 μF



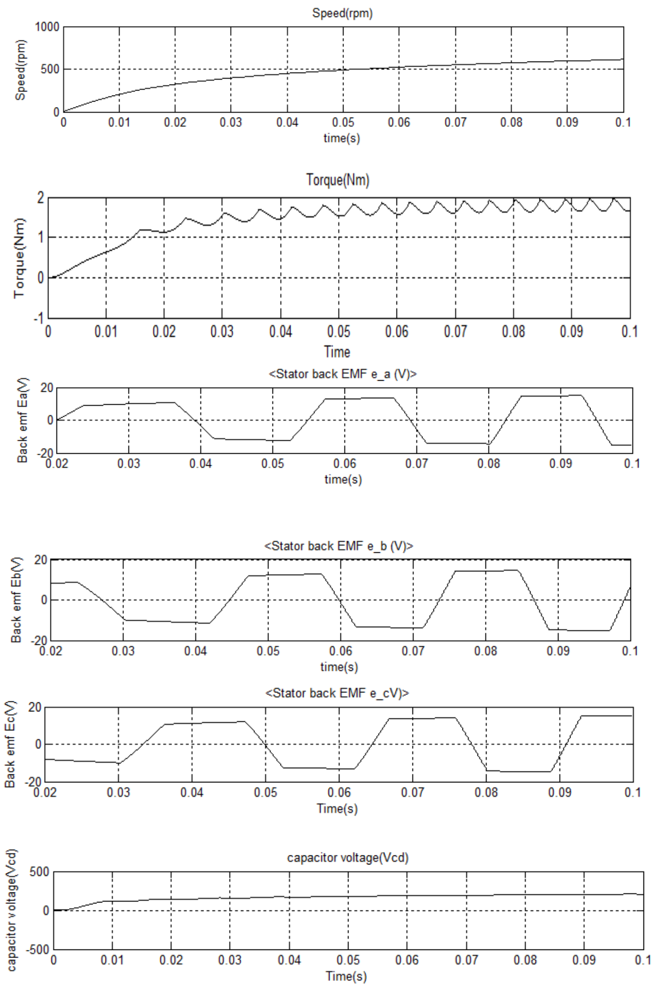
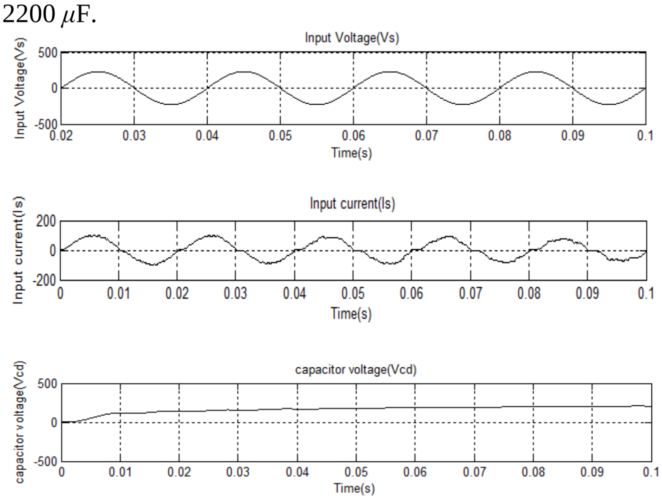


Fig 8.Waveforms in DICM (Lo) mode

C.PERFORMANCE OF BLDC MOTOR DRIVE USING DCVM MODE(Vco)

In the DCVM(Vco) mode by simulating at a frequency of 20khz The maximum power factor obtained is .92 and the THD obtained is 6.93%. The design parameters values are Input inductor L_i = 2.5 mH, output inductor L_o = 4.3 mH, intermediate capacitor C_1 = 9.1 nF, and dc-link capacitor C_d = 2200 μF.



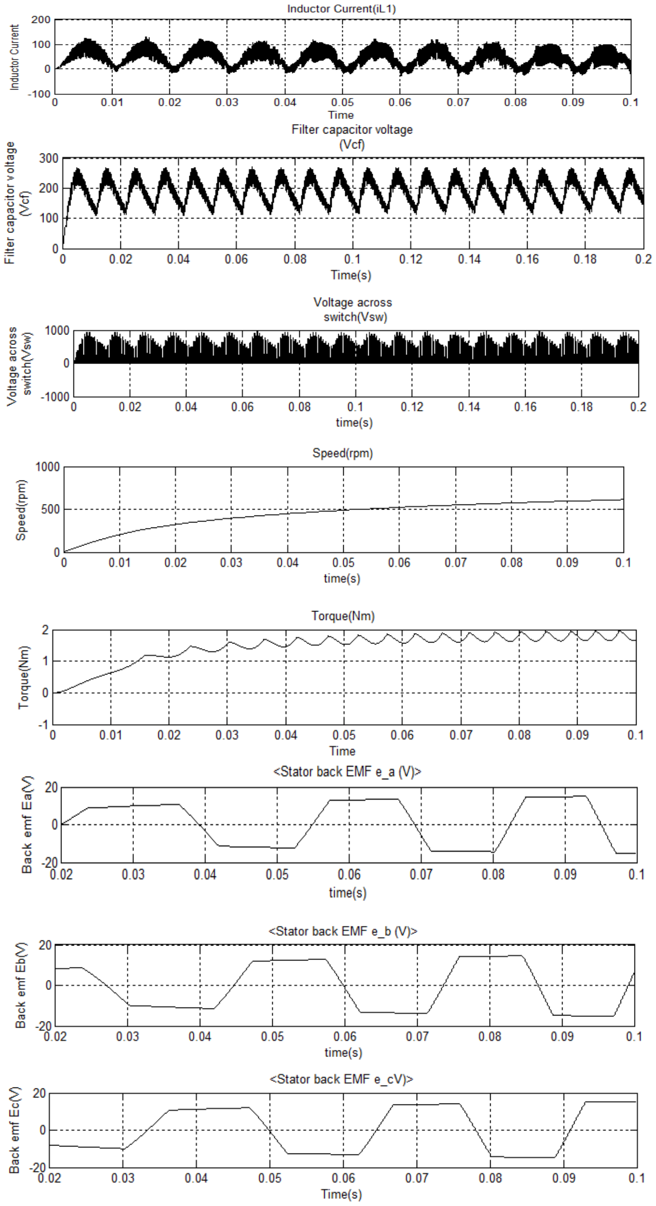


Fig 9.Waveforms in DICM (Vco) mode

SIMULATION USING ARTIFICIAL NEURAL NETWORK(DICM Li)

The simulation is carried out in the environment of MATLAB/SIMULINK with a switching frequency Fs=20Khz.Here an AC source of 230V is converted to DC by using a Diode bridge rectifier.The power factor is corrected by using a Cuk converter and fed to a Brushless DC motor. Here we are using Discontinuous input inductor mode (DICM Li) using the following parameters Input inductor L_i = 100 μH, output inductor L_o = 4.3 mH, intermediate capacitor C_1 = 0.66 μF, and dc-link capacitor C_d = 2200 *M*f

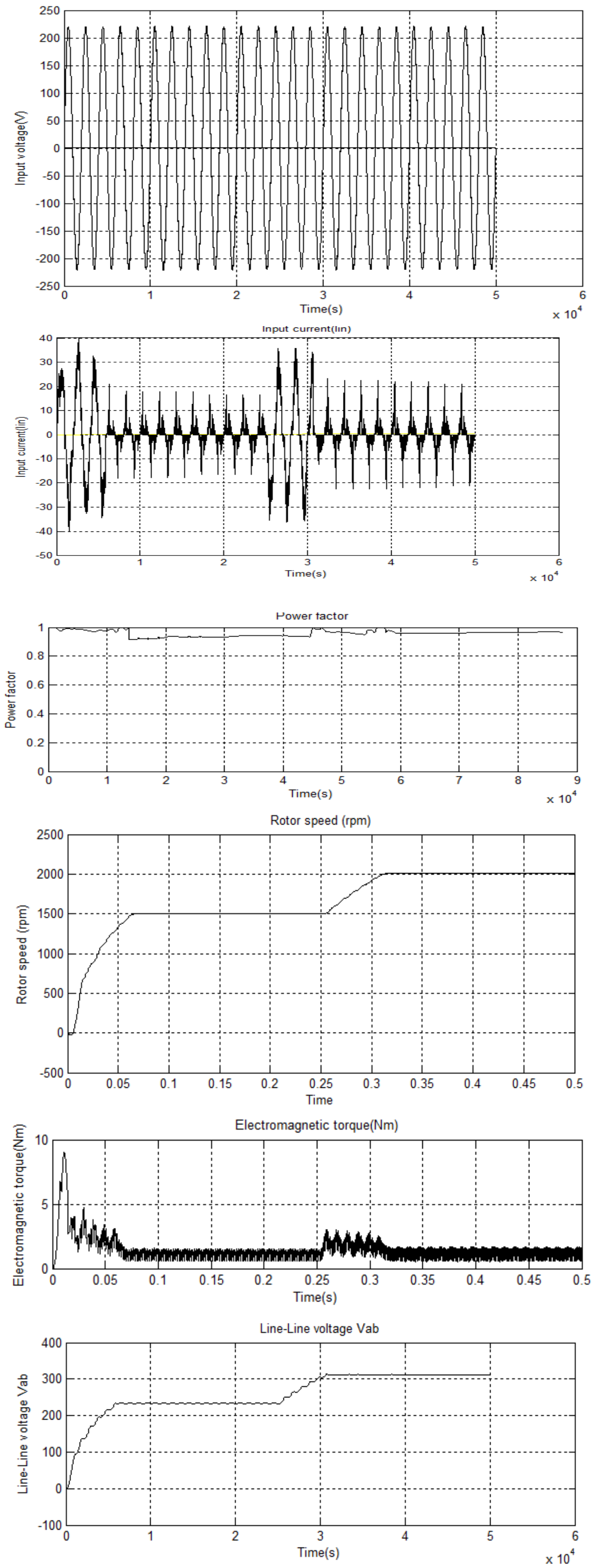


Fig 10.Waveforms in DICM (Li) mode in ANN

By comparing the graphs of the conventional DICM Li and the proposed scheme we can see that for the same input voltage the power factor is improved and approximately equal to the unity .967.The main advantage of using Artificial neural network is that in conventional PI only one value that is feed back is selected and comparing and producing the gating pulse but in our proposed scheme a set of values is compared and we are choosing the best out of them.

V1 CONCLUSION

A Power Factor Corrected Cuk converter fed BLDC motor using Artificial neural network is simulated in the environment of MATLAB. The three modes of Discontinuos DICM(Li),DICM(Lo),DCVM(Vco) is simulated at the given switching frequency 20Khz.The diode bridge followed by a Cuk converter is used here for maximum Power Factor Correction. . Here simulation results reveal that the ANN controllers are very effective and efficient compared to the PI and Fuzzy controllers, because the steady state error in case of ANN control is less and the stabilization if the system is better in it. Also in the ANN methodology the time taken for computation is less since there is no mathematical model. The main advantage of using Artificial neural network is that in conventional PI only one value that is feed back is selected and comparing and producing the gating pulse but in our proposed scheme a set of values is compared and we are choosing the best out of them.

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