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Hardware Implementation of Field-Weakening Algorithm for BLDC Motor Drives

[1]Dr.I.Gerald Christopher Raj, [2]Mr.G.Praveenraj, [3]Mr.R.Baladhandapani, [4]Mr. J. Velmurugan

[1]Professor, [2,3] Assistant Professor, [4]Associate Professor

[1,2,3,4] Department of EEE,PSNA CET, Dindigul, Tamilnadu, India.

[1]gerald@psnacet.edu.in, [2]praveenrajmw@psnacet.edu.in, [3]balasree86@psnacet.edu.in, [4]vel@psnacet.edu.in

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Abstract

Brushless DC (BLDC) motors and their drives have been progressively considered in an expansive scope of uses because of their noteworthy highlights. The construction and uncommon highlights of these motors have arranged a reason for easier control and reduced size contrasted with different motors with a similar power. This exploration work shows an improved Field Weakening (FW) calculation for BLDC motor.

The proposed technique is robust to the parametersof d-and q-axis inductances. Furthermore, this proposed procedure is joined with the DTC technique to achieve angreat performance drive in the FW area. A recreation model of proposed drive has been created utilizing MATLAB and equipment model was produced for the proposed BLDC drive. The reenactment and equipment results are given in this report to demonstrate the adequacy of the proposed approach..

I. INTRODUCTION

Brushless DC (BLDC) motors are progressively solid with low support,extendedlife,high effectiveness contrasted with different motors. The Direct Torque Control (DTC) conspire has been broadly inquired about for synchronous motors. The vector Control is less noteworthy than old style type of DTC. Variable exchanging recurrence, high torque and transition swells are created because of the usage of DTC with hysteresis controllers.

Subsequentlythe controls over the torque and transition straightforwardly and freely, it is advantageous to execute Field Weakening on the Direct Torque Control. The greater part of the exploration works is done on the Field Oriented Control rather on Field Weakening.

The benefits of the traditional Direct Torque Controltechniques are utilized in the projected strategy. In the proposed technique, the references of stator transition sufficiency and electromagnetic torque are altered based on the investigation of torque and motion blunders. FW activity is consequently begun when a back to back number of torque expanding endeavors are seen as fruitless. Hence, a smooth progress into the FW district can be normal without the use of parameter-subordinate base speed.

Moreover, a torque-restricting component is given to improve the security and strength of the proposed calculation. Off base torque limits controlled by the engine conditions will be balanced by the sequential examination of torque blunders. This instrument ensures quick and dynamic alterations of torque limits for stable fast activities. The reproduction and trial results included demonstrate the veracity of the proposed calculation.

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II. SIMULATION BLOCK DIAGRAM

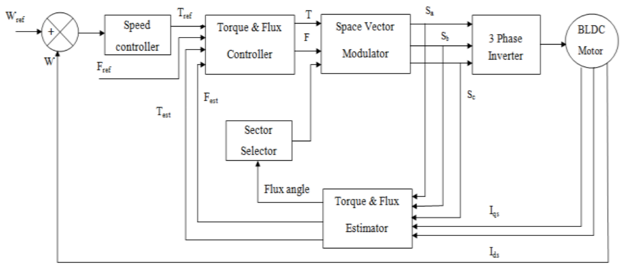

Fig.1. Block diagram

The Fig.1 shows the block diagram of proposed system. The DTC control is executed alongside Field Weakening calculation. The DTC - SVM plans are proposed here so as to progress the old-style DTC. The DTC-SVM procedures work at a constant switching frequency. SVM algorithm is used in the control structures. The category of DTC-SVM technique can be identified based on the applied flux and torque control technique. in this proposed system, controllers calculate the necessary stator current vector which is acknowledged by SVM method.

A. Direct Torque Control Of Bldc Motor

A basic DTC control layout can be seen in Fig.2.

The basic torque equation of BLDC Motor is given by

$$T_e = \left(\frac{3P}{4}\right)\left(\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds}\right)$$

Torque delivered is proportional to stator flux, because of permanent magnet in the rotor and has constant rotor flux. Subsequently by controlling the amplitude and speed of stator flux, torque is controlled. The following equation is used to obtain the stator flux.

$$\lambda_{qs} = L_q i_{qs}$$

$$\lambda_{ds} = L_d i_{ds} + \lambda_m$$

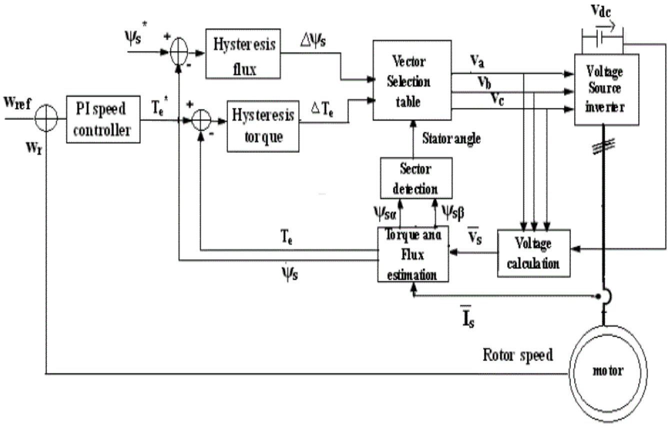

Fig.2. Basic DTC control design

B. Line to Line Values and Modified Clarke's Transformation

Since the neutral point of BLDC motor is not available at out in real cases, we can't use phase values for the3×3 park and Clarke transformation. So the transformation prefers line to line values instead of phase value measurements. Also a balanced system doesn't require a zero sequence term and the equation is given by

$$\begin{bmatrix} X_\alpha \\ X_\beta \end{bmatrix} = \begin{bmatrix} -\frac{1}{3} & -\frac{1}{3} \\ \frac{1}{\sqrt{3}} & -\frac{1}{\sqrt{3}} \end{bmatrix} \begin{bmatrix} X_{ba} \\ X_{ca} \end{bmatrix}$$

Where X represents flux, currents, voltages etc.

C. Electromagnetic Torque Equation

The stationary reference frame model torque equationis given by

$$T_{em} = \frac{3P}{4}\left[\frac{d\varphi_{r\alpha}}{d\theta_e} i_{s\alpha} + \frac{d\varphi_{r\beta}}{d\theta_e} i_{s\beta}\right]$$

Where

$$\frac{d\varphi_{r\alpha}}{d\theta_e} = \frac{e_\alpha}{\omega_e} and \frac{d\varphi_{r\beta}}{d\theta_e} = \frac{e_\beta}{\omega_e}$$

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D. Sector Selection

The stator voltages in stationary reference frame is used to calculate the stator flux linkages in the same reference frame

$$\varphi_{s\alpha} = (V_{s\alpha\_}Ri_{s\alpha})dt$$

$$\varphi_{s\beta} = \left(V_{s\beta\_}Ri_{s\beta}\right)dt$$

The location of stator flux linkage and sector is used to calculate$Vs\alpha$ and $Vs\beta$.The stator flux amplitude is expressed as

$$\varphi_s = \sqrt{{\varphi_{s\alpha}}^2 + {\varphi_{s\beta}}^2}$$

The elimination of resistance in the stator flux estimation algorithm induces the change in stator flux linkage that makes dependency only on the applied voltage vector.

The sector can be found by the following equation

$$\theta_s = tan^{-1}\frac{\varphi_{s\beta}}{\varphi_{s\alpha}}$$

Where θs = stator flux linkage,

$\varphi S\beta$ = α-β stator flux linkages.

E. Switching Table

Table I.Switching Table

Torque τ	Flux φ	Sector(Θ) 1	2	3	4	5	6
1	1	V_1 (100001)	V_2 (001001)	V_3 (011000)	V_4 (010010)	V_5 (000110)	V_6 (100100)
	0	V_2 (001001)	V_3 (011000)	V_4 (010010)	V_5 (000110)	V_6 (100100)	V_1 (100001)
	-1	V_3 (011000)	V_4 (010010)	V_5 (000110)	V_6 (100100)	V_1 (100001)	V_2 (001001)
0	1	V_1 (100001)	V_2 (001001)	V_3 (011000)	V_4 (010010)	V_5 (000110)	V_6 (100100)
	0	V_0 (000000)	V_0 (000000)	V_0 (000000)	V_0 (000000)	V_0 (000000)	V_0 (000000)
	-1	V_3 (011000)	V_4 (010010)	V_5 (000110)	V_6 (100100)	V_1 (100001)	V_2 (001001)

The stator Flux Linkage amplitude and direction of rotation can be controlled by the above mentioned switching table I.

F. Estimation of Rotor Position

The following equation can be used for determining the rotor position, since we are using position sensorless approach

$$\theta_{re} = tan^{-1}\left(\frac{\varphi_{s\beta} - L_s i_{s\beta}}{\varphi_{s\alpha} - L_s i_{s\alpha}}\right)$$

Where θ = electrical rotor position,

$\varphi S\beta$ = α-β stator flux linkages

$is\beta$ = α-β stator current

Ls = stator phase inductance.

G. Field Weakening Methodology

The considerable losses of DC motor are core losses, winding copper losses and mechanical losses. Out of which the copper losses is dominant as the speed decelerates below the base speed and the core losses increases as the speed accelerates above the rated value. In order to reduce the winding copper losses the following maximum torque per ampere (MTPA) control methodology is used. The speed of the motor will get increased if the apparent magneto motive force generated by the permanent magnets is reduced. This is found from the manipulation of the stator currents generating the demagnetization MMF.This technique is known as field-weakening (FW).

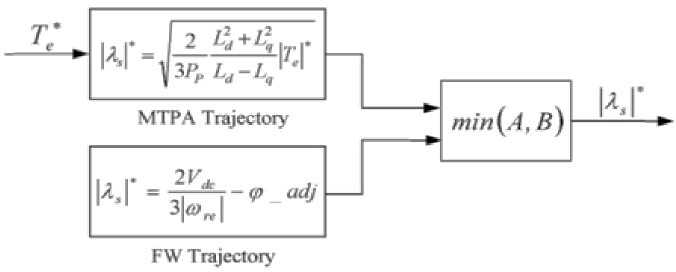

Fig.3. Block diagram of the proposed flux calculation

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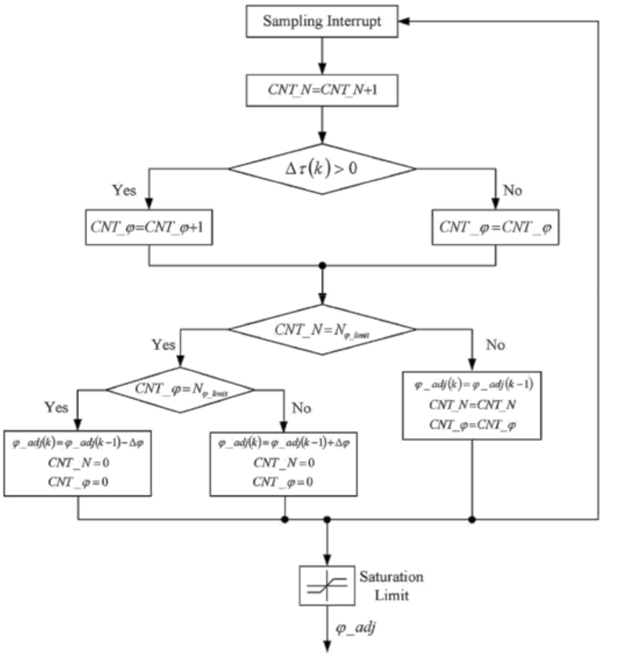

Fig.4. Flowchart of the proposed technique

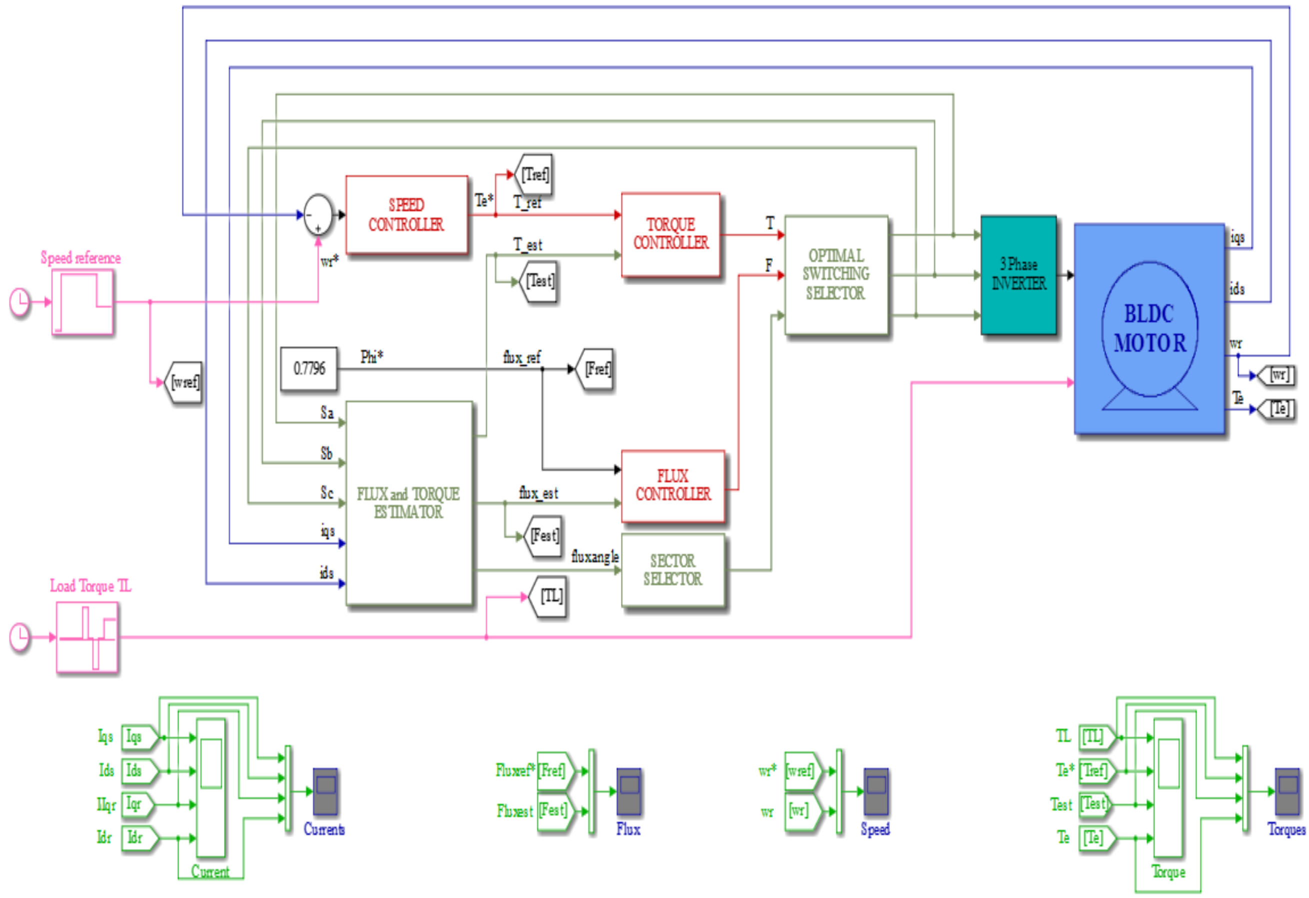

Fig.5.Simulation Model

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III. SIMULATION RESULTS

The validity of the DTC with field weakening has been checked in MATLAB/SIMULINK. The specifications used for the modelling of the drive system are shown in table II.

TABLE II. Parameters of BLDC motor used in Simulation

Number of pole pairs	Pp	2
Stator resistance	Rs	0.9Ω
d-axis inductance	Ld	0.323 H
q-axis inductance	Lq	0.0595 H
Moment of inertia	J	0.03116 kg m2
Damping coefficient	Bm	0.00317N.m.s
Mutual inductance	Lm	0.071919 H

Simulation results of the DTC based BLDCwhen the speed is increased from 0 to 140 r/min using the proposed method is shown in Fig.6.

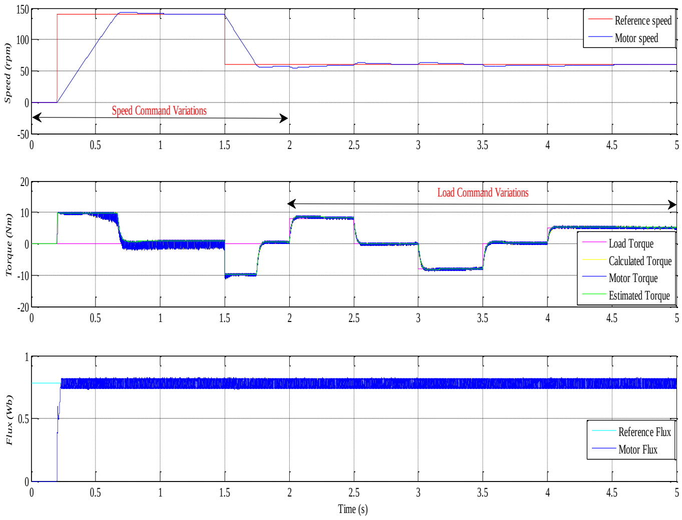

Fig.6. a) DTC based BLDCwhen the speed is increased from 0 to 140 r/min b) Torque c) Flux

The above results show the simulated outputs of the rotor Speed, Electromagnetic torque and flux comparison with the references. When the full load speed is obtained, the motor speed tends to track the reference value with a delay of 0.7s.As the motor speed rises, the torque starts to diminish and tries to track the reference torque. Also the motor flux tracks the reference flux for the changes in motor speed and motor torque.

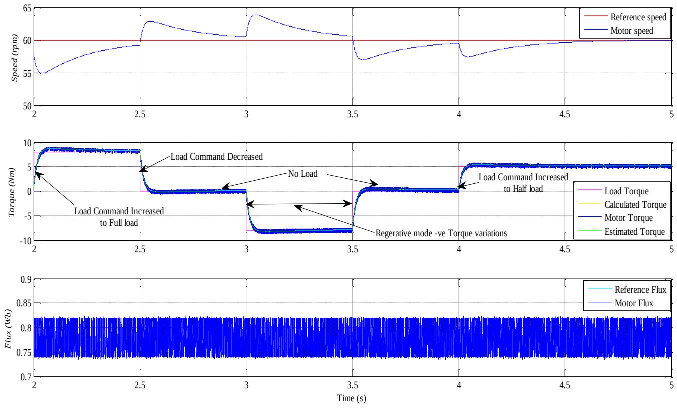

Fig.7. a)DTC based BLDC when the machine is under loaded conditions during the 2 to 5 seconds b) Torque c) Flux

Fig. 7. shows the simulated outputs of the motor speed, electromagnetic torque and flux for loaded condition. It is clear that the load and torque values are directly proportional as the load increases the torque also show as hike and while the load reduces there is a dip in the motor torque. Also during unloaded condition the torque remains zero with speed changes from maximum to reference value. But the flux remains constant throughout the operation.

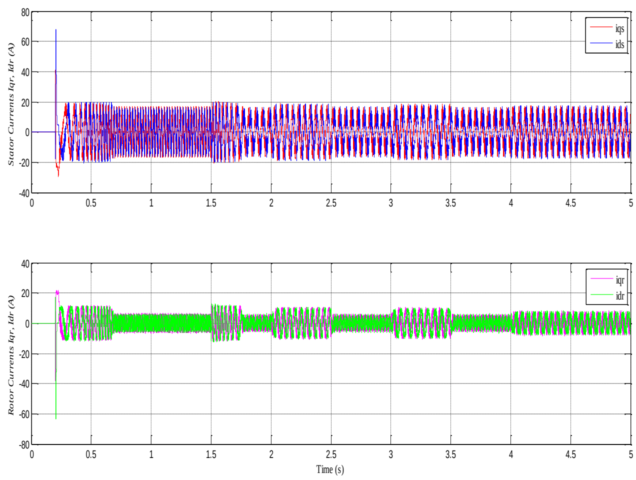

Fig.8. BLDC direct torque-controlled drive's d-q axis stator and rotor eddy currents during speed and torque command variations

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The simulation result shown above depicts the variation of d-q axis stator and rotor eddy currents during load and no-load condition.

IV. EXPERIMENTAL RESULTS

This chapter deals with the design and implementation of Field-Weakening Algorithm for BLDC Motor Drives using Arduino Pro-Mini microcontroller and Electronic Speed Controller (ESC). The sequence of tasks in hardware implementation is explained as follows. First the Input 230V AC voltage is stepped down to 12V AC signal, then rectified and regulated to get 12V and 5V DC supply. These DC voltages were given to potentiometer, Arduino Pro-Mini microcontroller and Electronic Speed Controller (ESC) as input supply. The potentiometer was connected to microcontroller, the microcontroller was linked to Electronic Speed Controller (ESC). The ESC act as the driver circuit to the BLDC motor. The above developed board is tested. The Arduino Pro-Mini microcontroller coding is programmed to generate the gate pulses for triggering the inverter circuit in Electronic Speed Controller. The sequences of steps include the development and testing of power supply board. The development and testing of rectifier and regulator circuit is done to supply potentiometer, Arduino Pro-Mini microcontroller and Electronic Speed Controller. The above developed and tested circuits are coupled. Now in this chapter, we have explained the hardware requirements, the pin diagram of various IC's, the quantity of the components used and the respective connection diagrams of circuits.

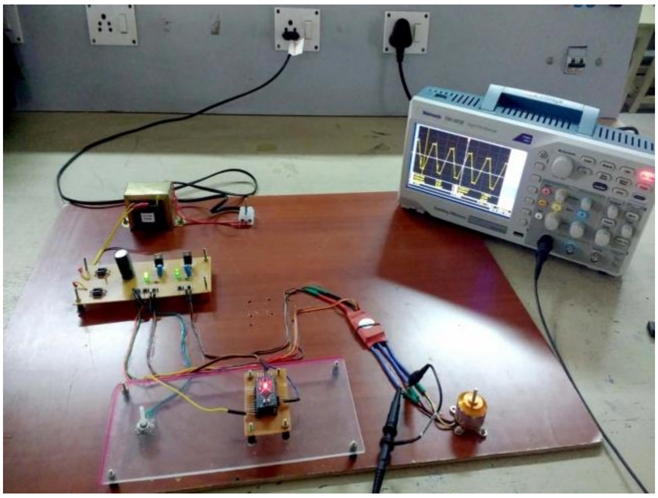

Fig. 9. Proposed Hardware Model

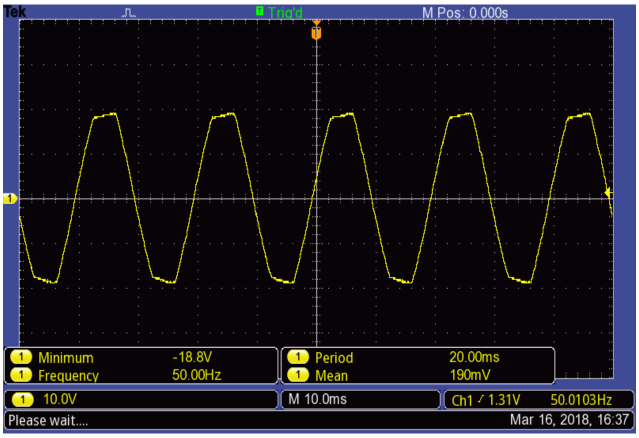

Fig. 10. 230V power supply is step down to 12V

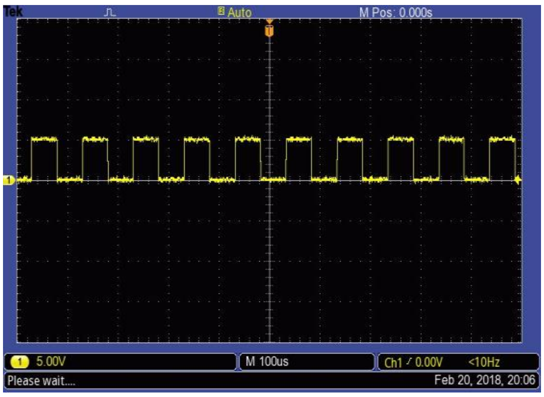

Fig. 11. 12 V sinusoidal voltage is rectified to 5V

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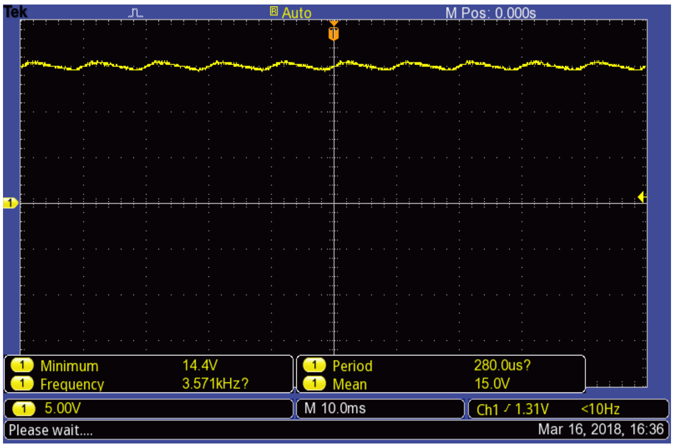

Fig. 12. 12V rectified output is converted to 12V regulated output

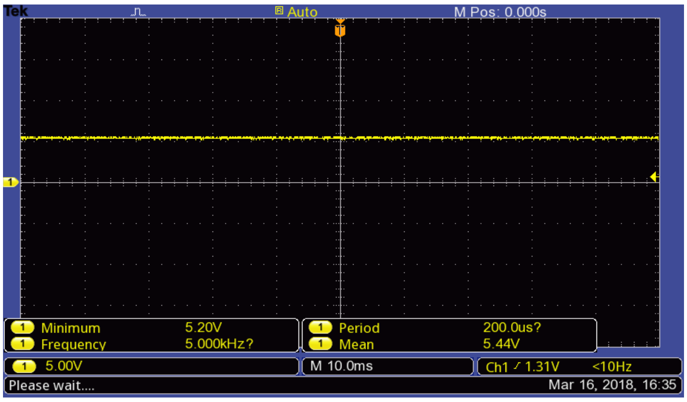

Fig.13. 5V rectified output is converted to 5V regulated output

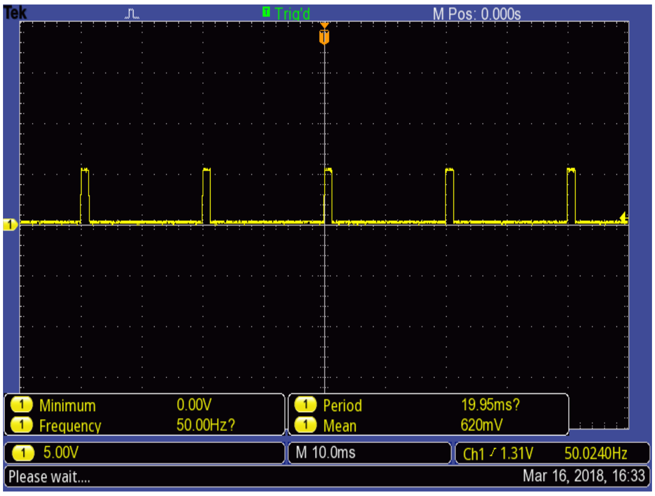

Fig. 14. By varying the potentiometer the Amplitude and Time Period of the PWM Pulse is varied, here PWM pulse amplitude is 5V

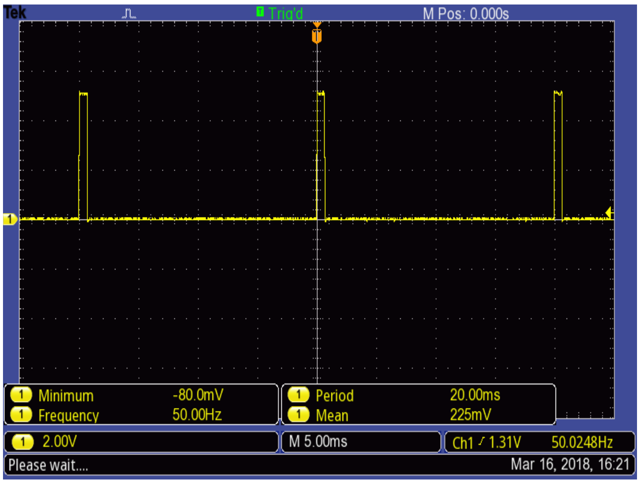

Fig.15. By varying the potentiometer the Amplitude and Time Period of the PWM Pulse is varied, here PWM pulse amplitude is 2V

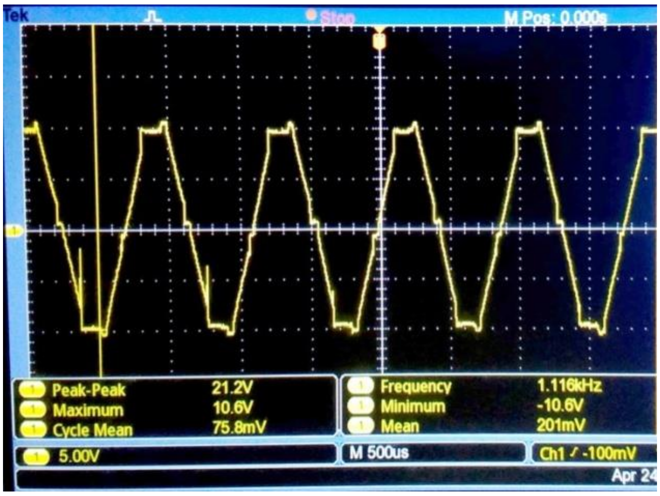

Fig.16. Motor Input Voltage Vab

Fig.17. Parameter Values of Input Voltage Vab

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V. CONCLUSION

This paper proposes a field weakening algorithm for BLDC motor derived from the knowledge of the same algorithm stated for a DTC-SRM motor for achieving a stable operation of the motor under various speed ranges. This method is more suitable for and BLDC motor drives which requires increased efficiency even under higher speed ranges. Hence this proposed algorithm pays a way for dynamic control if the motor torques under high speed changes.Depending on the torque error the proposed algorithm modifies the flux reference values also. The change between the MTPA and the Field Weakening regions are smooth in the proposed algorithm. Further a torque limiting algorithm is also proposed for the improvement of the torque parameters in the MPTA control. The adequacy of the proposed algorithm is broke down utilizing MATLAB and results are introduced for confirmations. Further, the work is advanced with improvement of model equipment for the proposed algorithm. The consequences of created model were likewise approved with that of the simulated results.

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