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Performance Analysis of Open Loop and Closed Loop Control in BLDC Drives for Electrical Vehicle Applications

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Abstract— This paper deals with analysis implementation of open loop and closed loop speed control for a Brushless dc (BLDC) motor drive using Hysteresis and MRAC. Mostly BLDC drives are used for electrical vehicle applications. Generally control algorithms which are developed for the motor drive might show good simulation results during steady state and transient conditions. Model reference adaptive system is a control strategy to drive electrical machine. Conventional cascade PI controllers are often used to control speed, torque and current. Adaptive PI controller for speed and current of a low inertia machine, change in speed set point should be slowly applied in order avoid stability problem. Hysteresis current control is used to eliminate voltage stability problem. In order to improve the performance compare to hysteresis current control the new model reference adaptive system used in speed control block. So, here initially open loop and closed loop system of BLDC drive using hysteresis current control is simulated and results are verified, after that MRAC is introduced to analysis improvement and dynamic behaviour of system and performance are analysed using MATLAB/ SIMULINK software. Hardware implementation of open loop BLDC drive system performance is validated by using DSP processor. In this project detailed procedure of effectively controlled the BLDC drive real time is presented.

Keywords— BLDC motors, PI controller, Model Reference Adaptive Control (MRAC)

I. INTRODUCTION

An electric motor or an electric generator's performance efficiency is generally determined by their speed of rotation. The machine's speed can be easily controlled by applying voltage and frequency of the source current. By implementing the concept of drive in electric motor or generator the motor's speed can be controlled more accurately. The main advantage is motion control is optimized easily. These types of motors are generally used in robots, fans, mills, pumps, industries etc. These drives are also used as prime movers for diesel or petrol engines, gas turbines and hydraulic motors. These motors are used for vehicle and hybrid electric vehicles to improve energy efficiency [1] [2].

Generally Brushless DC motor requires a DC source which is in available form of AC. When an AC supply is given to motor, the supplied AC supply gets converted into rectified DC and it is provided to BLDC drive. The diode bridge rectifier carries the process of rectification. To obtain position of a rotor and speed, hall sensors are used. The usage of DC link capacitor is to provide DC supply to the electronic commutation of brushless DC motor and also to maintain constant DC voltage. This is to be fed to inverter input circuit. BLDC motor has the advantage of high starting torque, high efficiency and high density compared to other motors. BLDC motor is a open loop system where the current is not controlled. Hysteresis current controller is also used for utility applications like low and medium voltage. This project mainly involves in implementing control strategy for speed control in BLDC motor drive. Comparing with other techniques hysteresis current control has advantage of eliminating voltage stability problem[3] [4] [5].

In this paper, we have discussed about the single phase half bridge rectifier harmonic content through some analytical expressions which employs either fixed or variable hysteresis current control and organised as follows Section I contains the introduction of BLDC motor and its control strategy, Section II contains Closed loop control of BLDC motor by harmonic output of fixed band hysteresis current control is derived, Section III contains BLDC drive using MRAC and hysteresis controller by harmonic output derivations of variable band hysteresis band, Section IV contains simulation models are developed by MATLAB Simulink and the results are taken, section V concludes research work.

II. CLOSED LOOP CONTROL OF BLDC DRIVE

Usually, BLDC motor drive requires control strategy to operate a motor at different speeds. Hence a closed loop system is proposed. The proposed system ensures BLDC motor drive runs at variable speed. Also here reference speed gets changed at any time which operates at desired speed. In a closed loop system, the motor speed is given to the input side. Then it gets compared with reference speed to produce an error signal. The produced error signal is fed to PI controller. Here the PI controller controls the speed of BLDC motor drive using the gain value of PI. The error occurred in present and past are nullified by PI controller. This proportional and integral controller also provides value for reference torque. The general structure of BLDC motor with AC supply is shown in Fig 1[7].

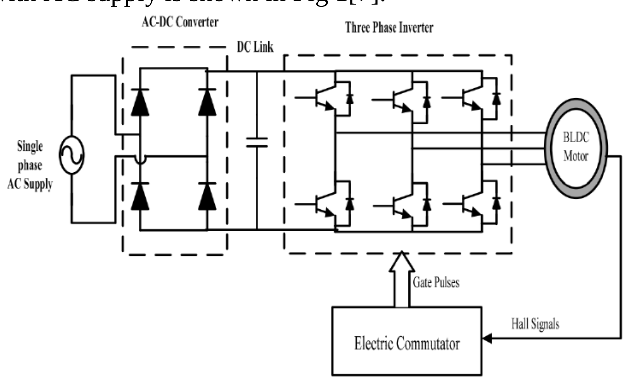

Fig 1. BLDC motor with AC supply

An input filter has used in a closed loop system to avoid noise produced by input switching elements. This input filter crosses 50/60 Hz and attenuates high noise and frequency. Reactive elements such as capacitors and inductors play a major role in suppressing frequency. Capacitors are connected in series and act as a high pass filters which DC is blocking. To avoid spikes at high voltage in electric power, voltage dependent resistor is included in filter circuit. Fig 2 shows inverter control diagram of input filter.

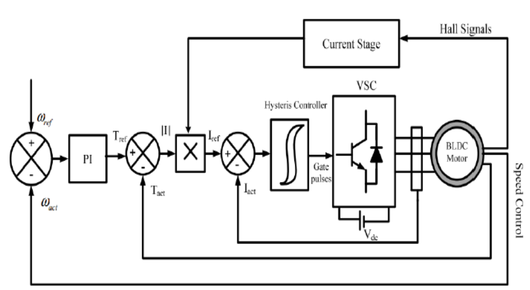

Fig 2. Closed loop control of BLDC motor

The working of voltage source converter is to convert AC supply into DC. To improve the efficiency of VSC, power factor correction is needed. Here single stage PFC is used. Rectifiers are used by implementing semiconductor devices like diode, SCR or TRIAC. These semiconductor devices get turned on when gate signal is triggered. Commutation is done either by natural or forced. Here capacitor is incorporated so that the energy is stored between input and output power. The three phase star connected BLDC motor can be described as the following four eqations:

$$v_{ab} = R(i_a - i_b) + L\frac{d}{dt}(i_a - i_b) + e_a - e_b \quad (1)$$

$$v_{bc} = R(i_b - i_c) + L\frac{d}{dt}(i_b - i_c) + e_b - e_c \quad (2)$$

$$v_{ca} = R(i_c - i_a) + L\frac{d}{dt}(i_c - i_a) + e_c - e_a \quad (3)$$

$$e_a = \frac{k_e}{2} w_m F(\theta_e) \quad (4)$$

In a three phase supply, phase voltages, phase currents and phase back emf are denoted by v, I and e. the electrical torque is represented as T_e and load torque as T_L. Inductance L and Resistance R are used as per the phase required. Here rotor inertia is denoted as J and friction constant constant as K_f. The rotor speed is represented as w_m. By using the above parameters, the back emf and torque are expressed by following mathematical expressions[8]

$$e_b = \frac{k_e}{2} w_m F(\theta_e - {}^{2\pi}/_3) \quad (5)$$

$$e_c = \frac{k_e}{2} w_m F(\theta_e - {}^{4\pi}/_3) \quad (6)$$

$$T_e = \frac{K_t}{2}\left[F(\theta_e) i_a + F\left(\theta_e - \frac{2\pi}{3}\right) i_b + F\left(\theta_e - \frac{4\pi}{3}\right) i_c \right] \quad (7)$$

PI controller with zero initial condition is given by

$$\frac{U(s)}{E(s)} = K_p[1 + \frac{1}{T_i\, s} \quad (8)$$

In integral error compensation, the actuating signal depends on the integral of the error. Proportional-integral controller is a special type of PID controller. Here the error derivative (D) is not used. Integral error compensation is to eliminate steady state error but the system become sluggish due to increase in order.

III. BLDC DRIVE USING MRAC AND HYSTERESIS CONTROLLER

A.MRAC

The proposed system with MRAC (Model Reference Adaptive Control) consists of controller with closed loop where the parameters are desinged such that it can change the response of the system at any desired time. The system output gets compared with reference model of the desired response. The control parameters of a closed loop controller gets updated based on the error produced.

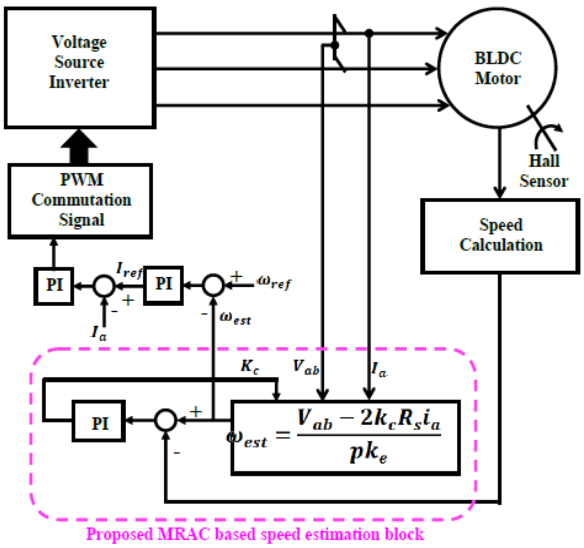

Fig.3 Control flow diagram of MRAC

The control flow diagram of MRAC is shown in fig 3. Model reference adaptive control (MRAC) is a direct adaptive control method that has controller parameters and mechanisms which are adjustable. By comparing the PID controllers and adaptive controllers, these adaptive controllers are much efficient and also they are easy to handle changes in environment and unknown parameters. This type of adaptive controller has two loops named as inner and outer loop. This paper mainly deals with adaptive controller. Control system is a process that regulates dynamics in system. Adaptive controller is a one of the control strategy method that are popularly used. Generally, BLDC motor with three phase supply operates in two phase that produces high torque when the third phase is in off state. The position of rotor are always dependent on the energized two phases. In MRAC position sensors are used where the signals are produced for every 60º of rotation. The rotor and stator field lines are 120º apart every interval time and gets end when the rotor and stator field lines are 60º. When the stator and rotor field lines are in perpendicular, maximum torque is achieved. The P-Controller is more complicated than ON-OFF control process rather simple than PID controller which are used in automobile control[9].

B.Hysteresis Current Controller

Hysteresis current controller is mainly used in low and medium voltage applications. Here the inverter line current tracks sinusoidal reference voltage with error margin. Line harmonics from inverter depends upon switching pattern. These switching patters are generated from line harmonics feedback. Hysteresis current controller classified as follows:

a) Fixed band hysteresis control

b) Variable ban hysteresis control

Fixed band hysteresis control produces error current using frequency modulated triangular wave. These results with time varying characteristics that are computed from system.

Fig 4 shows as the control flow of hysteresis current controller.

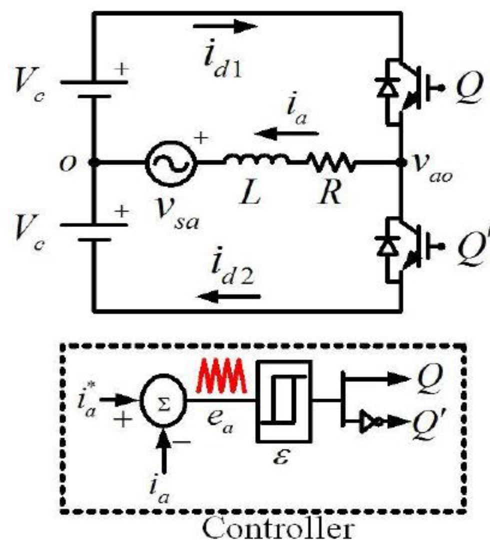

Fig 4. Control flow of hysteresis current controller

The harmonic performance analysis of hysteresis inverter of both AC and DC system are analysed. These harmonics which is present in AC and DC voltages will affect the frequency of inverter.

Using the demodulation technique of the inverter, the hysteresis current controller passes harmonic AC supply to the DC side of inverter. The switching fuction is not desingned inverter in hysteresis current controller so that harmonic currents are desinged by balancing DC input and AC output power equations[10],[11].

IV. SIMULATION RESULTS AND DISCUSSION

It should MATLAB Simulink models are designed and implemented for BLDC drive which operates without current control and also for BLDC drives at fixed and variable speed in a closed loop.

A.BLDC Motor without Current Control

The initial model designed is BLDC motor drive without current control. The Simulink model design is a open loop system where the simulation results of BLDC drive stator current and back EMF is shown in figure 5. At the output side of motor, trapezoidal back EMF can be taken. Figure 6 shows speed of BLDC motor drive without current control in open loop system and figure 7 gives its toque waveform.

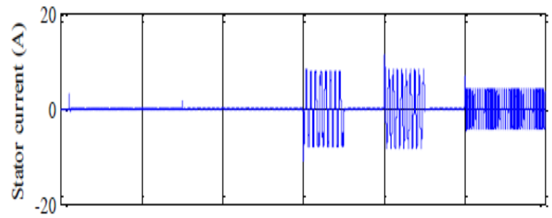

Fig 5. Simulation of stator current with out current control

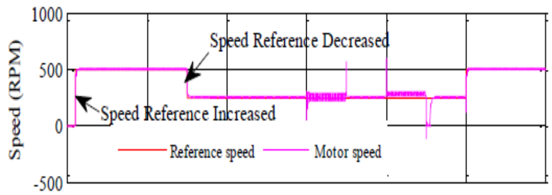

Fig 6. Simulation response of speed without current control

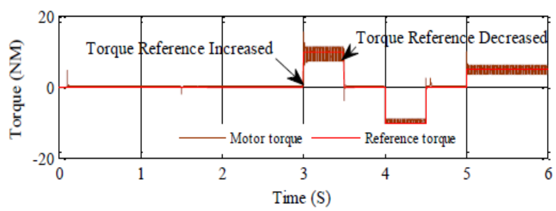

Fig 7. Simulation of torque response with out current control

B.Closed Loop BLDC Motor With Fixed Speed

This Simulink is designed for brushless DC motor with closed loop system that runs in constant speed is shown in figure 8. In figure 9, BLDC motor drive with current control is shown. The BLDC motor drive stator current and EMF is shown in figure 10.

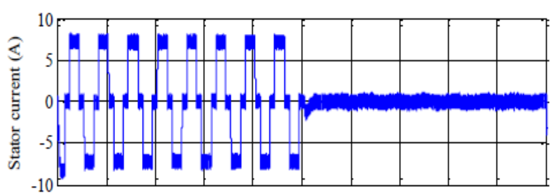

Fig 8. BLDC motor with current control

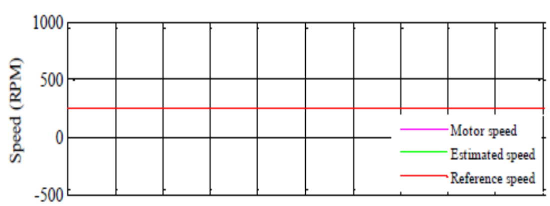

Fig 9. BLDC motor drive with fixed speed

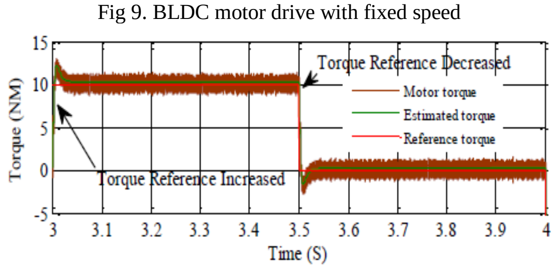

Fig 10. Torque response at step time 3.5 sec

C. *Open Loop BLDC Motor with Variable Speed*

This Simulink is designed for brushless DC motor with closed loop system that runs in variable speed is shown in figure 11. This model is designed as BLDC motor drive with current control. The BLDC motor drive stator current and EMF is shown in figure 12. At the output side of motor, trapezoidal back EMF can be taken. The corresponding torque waveform was shown in figure 13.

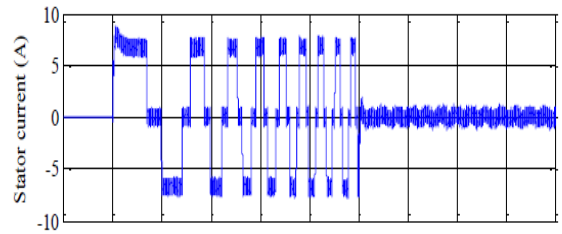

Fig 11. The Stator Current of BLDC motor drive

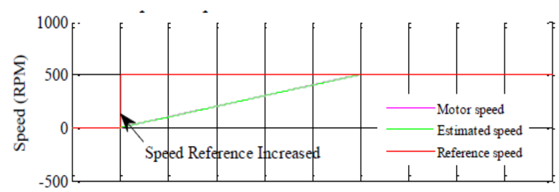

Fig 12. The speed of the open loop control for BLDC motor

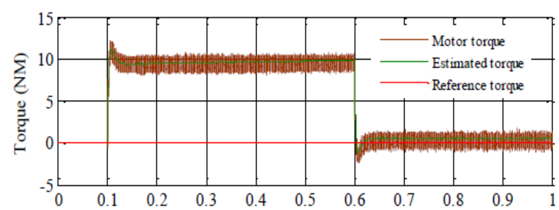

Fig 13. Torque response at step time 0.6 sec

D. *Closed Loop Control Of BLDC Motor Using MRAC*

The model of BLDC motor drive with closed loop control using MRAC is designed and terminal voltage of BLDC motor drive is shown in figure 14. The simulation results of closed loop system rectifier current and back EMF of BLDC motor is shown in figure 15.

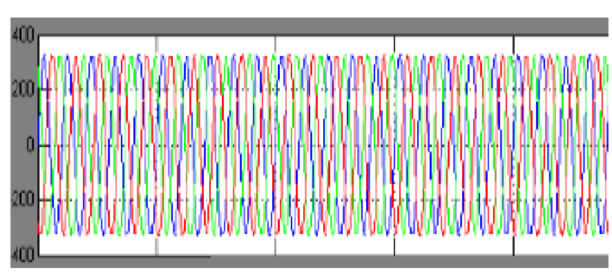

Fig 14. Terminal voltage of BLDC motor using MRAC

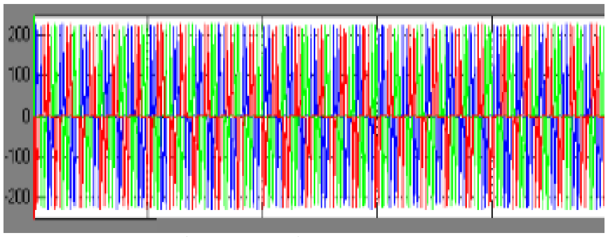

Fig 15. Rectifier current of BLDC motor using MRAC

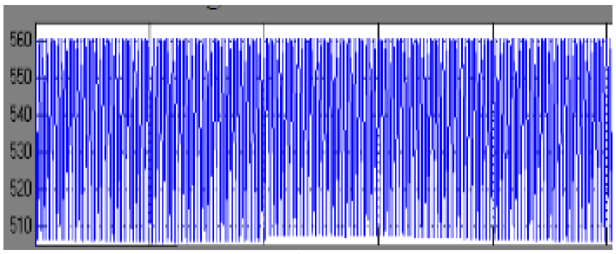

Fig 16. Inverter voltage of BLDC motor using MRAC

V. CONCLUSION

This works evaluate the different controlling strategies in the BLDC motor to obtain better simulation results by using PI controllers. This helps in obtaining the controlled speed, torque and current with better improvements. Here initially open and closed loop system of BLDC drive using hysteresis current controller helps in improving the simulation result and with addition MRAC increase its performance. With the overall concern DSP processor associated with hardware components provides improved speed, torque and then the current with the help of MATLAB.

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