Development Of Sensor-Less Control Of BLDC Actuator For Agricultural Robotic Arm

Murali muniraj, R, Arulmozhiyal, ilakia T

Abstract: To design and implement the additive controller for permanent magnet brushless dc motor drive in sensor-less control technique for dSPACE controller for Robot movement control. Further the estimation technique for Back-EMF in feedback loop holds better dynamic performance during knee movement in various case loops.In this study algorithm estimates feedback loop valuesto control position and angular speed of the BLDC motor as action part for knee movement. Further this method estimated rotor position and flux information based on initial position of the rotor through Hall feedback signals and encoder pulse. Feedback loop drive eliminated to track the dynamics drive and control logic modeled in MATLAB/SIMULINK and the source code built in MATLAB and loaded onto the dSPACE controller. Proposed control algorithm with improves back-EMF estimation accuracy and rotor position accuracy. Further proposed estimation sensor-less technique enhances capture position parameters at low speed. Additive algorithm and PLL method is simple to implement in MATLAB and configure in dSPACE controller to maintain high stability. An intelligent power module used to drive the BLDC motor through pulse width signals to controller and drive converter for BLDC motor to operate. The proposed algorithm implemented for PMSM motor drive in wind turbine applications due nature of back-EMF estimation. Further this algorithm method can be implemented with high processing controller for low cost drive applications.

Keywords: Sensorless, BLDC, Controller, dspace, robot, knee. Abbreviations:BLDC, Brushless Direct Current Motor;dSPACE, digital signal processing and control engineering; MATLAB, Matrix Laboratory;

1. INTRODUCTION

Control actuation system has been list of topics in area of aerospace, defence and social related applications over in last two decades. Direct Current motors are ideal choice with permanent magnet type carries own attention due additional features of robust, high torque to power ration and delivers better driving efficiency with inverter during the dynamic speed of motor. Major classifications of permanent magnet motors acquire high torque density intended to operate in both sinusoidal back EMF and BLDC motor to operate in with trapezoidal Back EMF. Back EMF play vital role in BLDC motor control strategy many estimation techniques proposed to obtain the stator current values. Due back-EMF the estimation and better construability BLDC used in many applications unit such as conversion systems, HEVs, propulsion drive unit. In 2019 Lei Yang described the control analogy for driving brushless DC motor drive with zero point cross section [1]. A conventional hall sensor and encoder to obtain pulse position through sensors resolvers. Further the complexity of drive and reliability with system parameters increases in many applications. Hall Effect sensors not only increase the drive cost and offers high maintenance cost. Further the drive reduces the reliability of whole system inclined to disturbances [2-5]. The literature reviews suggest the back-EMF estimation offers high accuracy than non-ideal methods and internal power factor angle methods [5-8]. Aged peoples increasing day by day due living style and average life time of person increased from 65 to 75 years. Many aged peoples are suffering from knee pain due weakness, vitamins and proteins deficiency. Many researchers suggest that peoples with less strength mainly facing this knee problems.

- Murali muniraj1,R, Arulmozhiyal2 and ilakia T3,
- Assistant Professor, Department of Electrical and Electronics.Sona College of Tech,Salem, (TamilNadu), INDIA
- Professor, Department of Electrical and Electronics.Sona College of Tech,Salem, (TamilNadu), INDIA
- Assistant Professor, Department of Electrical and Electronics.Sona College of Tech,Salem, (TamilNadu), INDIA

Many knee replacement surgeries are ongoing in medical field due severe pain on knee and related issues are cleared. Effective solution proposed is knee replacement by effective drive unit using BLDC motor [9-12]. Sensor placement in robots is difficult to establish and with high risk. A BLDC motor drive coupled for knee movement obtains self-estimation algorithm to drive parameters of BLDC through sensor-less estimation method. Finally an experimental validation is incorporated with high power density BLDC motor with dSPACE controller.

2. MATERIALS AND METHODS

Internal structure of BLDC motor with permanent magnet type and shaft sensors are shown in Fig. 1. The cross section view of rotor and stator of BLDC motor with Hall sensors mounted on shaft delivers signals to feedback unit.

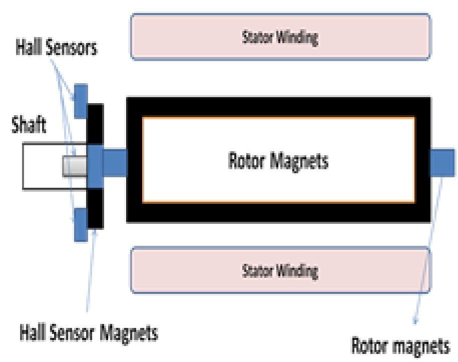

***Fig.** 1.BLDC Motor Frame of Reference.*

BLDC the stator reference model:

$$u_\alpha = Ri_\alpha + L\frac{di_\alpha}{dt} - \omega_r \Psi_r \sin(\theta_r) \quad (1)$$

$$u_\beta = Ri_\beta + L\frac{di_\beta}{dt} + \omega_r \Psi_r \cos(\theta_r) \quad (2)$$

whereu_α,u_βand i_α,i_βvoltage and current in stator side respectively. θ_rand 〖ω〗_rBLDC motor rotor position and speed respectively. Ψ_motor flux. Resistance and Inductance as the stator resistance and inductance respectively with model that the back-EMF. As per model in rotor frame and interior BLDC derived as:

$$e_{s\alpha} = \omega_r \Psi_r \sin(\theta_r) \quad (3)$$
$$e_{s\beta} = \omega_r \Psi_r \cos(\theta_r) \quad (4)$$
$$e_{s\alpha} = -u_\alpha + Ri_\alpha + L\frac{di_\alpha}{dt} \quad (4)$$
$$e_{s\beta} = -\left[-u_\beta + Ri_\beta + L\frac{di_\beta}{dt}\right] \quad (5)$$

With the magnitude of the back-EMF relates to rotor speed angle of rotor that derived from encoder pulse wave. As per Eq. (4) and (5).Further a filter circuits designed to propose the estimation derivative with angle of 90° lead phase shift. Higher band-width in filter design estimated the high accuracy of the fundamental components to magnify the PWM to drive stator current. First-order derivative with high-pass filter gain and time constant τ between T_{PWM} and $2T_{PWM}$ as:

$$\dot{i}_\alpha = \frac{p}{\tau p+1} i_\alpha \quad (6)$$
$$\dot{i}_\beta = \frac{p}{\tau p+1} i_\beta \quad (7)$$

Where $\dot{i}_\alpha$, $\dot{i}_\beta$ are the estimated derivatives of the stator currents and p the differential operator. Then the back-EMF can be estimated as:

$$\hat{e}_{s\alpha} = -u_\alpha + Ri_\alpha + L\dot{i}_\alpha \quad (8)$$
$$\hat{e}_{s\beta} = -\left(-u_\beta + Ri_\beta + L\dot{i}_\beta\right) \quad (9)$$
$$\omega_r^c = \frac{\sqrt{\hat{e}_{s\alpha}{}^2 + \hat{e}_{s\beta}{}^2}}{\Psi_r} \quad (10)$$
$$\theta_r^c = \arctan\left(\frac{\hat{e}_{s\alpha}}{\hat{e}_{s\beta}}\right) \quad (11)$$

where ω_r^c and θ_r^c angle of rotor position with speed as derivative related to BLDC motor.

A. Block Diagram

Sensor-less controller formulated with the position and speed based on back-EMF estimation and stator currents, as potential local feedback loop. An unstable behavior of the control drive simplifies the calculated value of back-EMF and eliminates the algebraic loop with resulted phase delay of the rotor position. Further this position estimation drive seriously deteriorates the control performance in tracking performance and reduces its own performance. An over view sensor-less BLDC motor drive as shown in Fig.2 and output of shaft of BLDC motor connected with robot knee for motion.

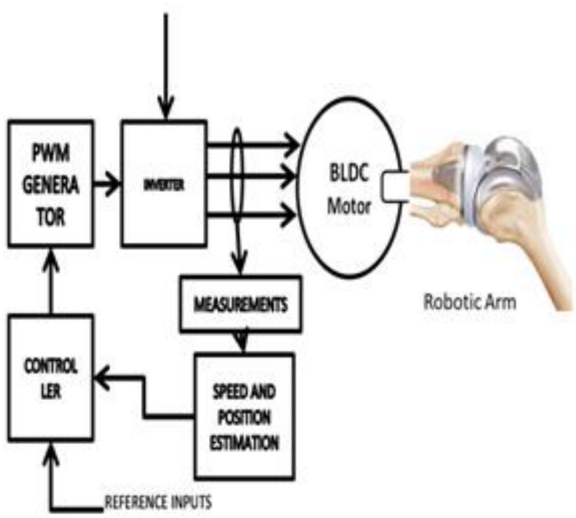

***Fig. 2**. Block Diagram of Sensor-less Control Drive for robot movement.*

$$\hat{\omega}_r = \mathrm{LP}_1(\omega_r^c) \quad (12)$$
$$\hat{\theta}_r = \int_0^t \omega_r^c dt + \hat{\theta}_{r0} \quad (13)$$
$$\hat{\theta}_{r0} = \mathrm{LP}_2(\theta_{r0}^c) = \mathrm{LP}_2\left(\theta_r^c \int_0^t \omega_r^c dt\right) \quad (14)$$

PLL structure algorithms with equation 12-14 implemented. A sensor-less control drive with better dynamic requirement as speed(ω_r) changes slowly and invariably. Hence the rotor angle calculated from the rotor speed to obtain estimated values with respect to EMF model of motor.

B. Algorithm

A additive control algorithm proposed based on the dynamic requirement on position of rotor. Further estimation carried with rotor angle θ_r which is radically varying. While motor rotating system parameters fast-changing signal, θ_r, speed, current and gain values. The proposed algorithm with high pass filters obtains the varying signals as initial rotor positionθ_{r0}^c. Due to the impact of the phase delay presented by filtering becomes insignificant. Estimated initial rotor position $\hat{\theta}_{r0}$auxiliary to the calculated rotor position $\int_0^t \omega_r^c dt$to form a balanced estimation of rotor position obtained. The proposed method successfully removes the sum of algebraic loop which more additives in nature supports better dynamic response of the rotor position and estimate values feed to controller drive. The drive unit very sensitive multiple parameters obtained from estimated motor drive units. For tuning controller gain an additive controller with reference parameters of current, speed and rotor angle sum to give signals pulses to controller.

III.RESULTS AND DISCUSSION

In this section a signal flow of the hardware structure setup of BLDC actuator for knee movement based PLL based additive control algorithm setup. Hardware setup robotic movement test setup using BLDC motor divided further as supply unit circuit and control drive unit. The power supply unit consists of the AC power supply, Grid-fed transformer, Power module and Brushless DC motor. The control drive unit consists of PC installed MATLAB with interface software, dSPACE 1104 controller with adapter card. Back EMF estimation performed with encoder unit and hall sensors inbuilt with adapter card interfaced with dSPACE DS1104 controller. Power module has high performed IGBT switches two on each leg drive circuit. The switching pulse provided to IGBT switches from controller through opto-coupler for isolating the controller drive from the power circuit. A master controller incorporated with PC to run the MATLAB software, interface with control desk, DSO and dspace Real Time Interface.

***Fig.3**. Implemented Hardware setup*

Sensorless control designed using MATLAB/SIMULINK with dPACErti1104 blocks as implemented in Fig. 3. From intelligent power module a six IO ADC channels fed to adapter card for isolation and given same signal to dSPACE to provide measured value of current and voltage. Back-EMF estimation algorithm process measured current and voltages to obtain angular velocity and position of shaft of motor drive. Estimated speed and position consider as a vector values and set as reference velocity and position with respect to PWM outputs with the help of control blocks. Further estimated speed compared with reference speed and a error signal generated fed to controller for algorithm is designed and provides desired torque. Stator current estimated from dq axis pf motor is corrected I_q value compared measured actual current fed for pulse generation in controller. Similar process carried another stator current of direct axis and I_d current and reference considered as zero from original poistion. The corrected values of I_q and I_d and estimated with theta angle to convert into a three phase abc current parameters as reference to generate the required duty cycles for the PWM block. The model real time as hardware in co-simulation and algorithm fed to DS1104 board through MATLAB model and control desk. In phase locked loop structure algorithm build in MATLAB model and executed in dSPACE controller to operate as sensor-lessoperation as to estimated values through sub-estimator block. Motor estimate parameters for motor rating as shown in Table.I rotor speed and position angle obtained from encoder pulse through a filter.

TABLE I. MOTOR RATINGS.

Parameters	Values
Rated Load Torque	2.2 Nm
Rated Speed	4600 rpm
Rated Voltage	220Vac

BLDC motor connected with robotic arm movement to drive at no load condition with three phase current waveform described in the section. The current and voltage measured from the stator windings derived from feedback unit to drive controller and based on signals from back-EMF estimated as per algorithm designed for position. Estimated angular and position compared with a reference value of 1250rpm as set speed to drive knee movement with reduced gear. The Algorithm controller used to bring the speed and process the set value and desired with minimum time at 1.5s and rotor position error as minimal.

***Fig.4Duty** cycles of PWM1, PWM2, PWM5&PWM6.*

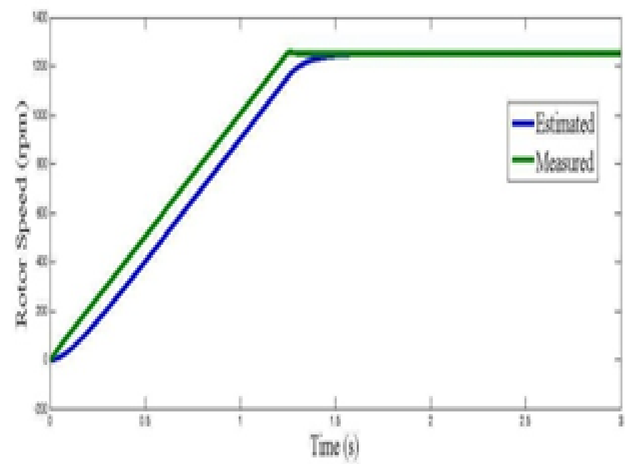

***Fig.5Comparison** of Estimated speed and measure speed.*

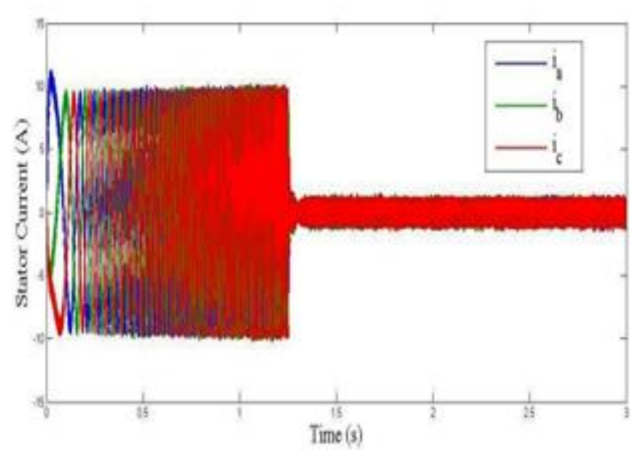

***Fig. 6** Three phase stator currents of BLDC motor drive.*

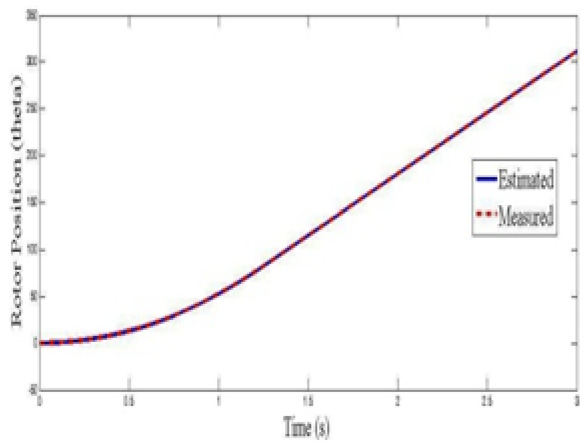

Fig. 7 *Comparison of Estimated theta and measure theta.*

To analysis the proposed estimated algorithm a dynamic pattern of test carried with currents and speed control loops. Use of PI parameters in tuning with additive control and control current drive with three phase values of PWM signals to estimated values fed to converter drive are shown in Fig.4. PWMs generated through adapter card and isolation unit signals from dSPACE controller to drive the IGBT switches PLL locked values tuned with the sensor version of the electrical drive and compared with proposed algorithm drive. A step response test carried as shown in Fig. 5 with sensor-less and sensor based in BLDC motor for knee movement. After proposed gain tuning additive PI parameters tuning and obtain estimated values with controller and three phase currents with Fig. 6. Further the rotor analysis carried with sensor and sensor-less for rotor position and speed while solid line are used for the dashed ones as shown in Fig.7.The switching frequency assigned as 10KHz. Estimated and desired motor speed obtained from algorithm with good accordance and control drive better performance in settling and rise time.

IV. CONCLUSION

The proposed additive control algorithm with PLL structure provides estimated back-EMF values from motor in real time to knee movement controller drive. Further the control drive process through dSPACE control unit and control motor drive parameters to control speed of motor. Proposed method eliminates of necessity of Hall Effect mechanical sensors which reduce sensor drive parameters and deteriorating the performances of drive. Through experimental results that Sensor-less control holds many advantages such as reduced size, high reliability and hardware complexity. Measured back-EMF of the motor connected with artificial robot with gear mechanism to smooth drive of process. Algorithm derives the estimation of the rotor position and speed for sensor-less vector control end and demonstrated to operate in adequate manner with wide speed and position range movement.

V. FUTURE SCOPE

Further the intelligent control algorithms can be proposed for better irrigation in agriculture paddy field for crop production.

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