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Performance Analysis of a BLDC Drive under Varying Load

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***Abstract*—Increasingly growing trend towards usage of green and eco friendly electrical devices has lead to research development in Brushless DC (BLDC) motors. The BLDC motors exhibit better performance in terms of higher efficiency, higher torque under low speed range, higher power density, lower maintenance and lesser noise than other motors. BLDC motors can act as acceptable alternatives as against the conventional motors like Induction Motors, Switched Reluctance Motors etc. In this paper, a BLDC motor has been modeled in MATLAB/ SIMULINK environment using appropriate mathematical interventions. The performance of the motor has been analyzed for 120 degree mode of operation. Step and gradual changes in the load have been done to get the response of the motor. A PI controller has been deployed for closed loop speed control of the motor. It is observed that the performance of the motor is much better if the load is applied gradually instead of applying it suddenly.**

Keywords—BLDC Motor; PI Control; Hall Sensors; MATLAB/ SIMULINK

I. INTRODUCTION

A Brushless DC (BLDC) motor is a type of permanent magnet synchronous motor. According to the shape of their induced electromotive force it is further categorized into two types: sinusoidal and trapezoidal [1]. The sinusoidal induced electromotive force waveform is associated with permanent synchronous motor and the trapezoidal electromotive force waveform is associated with brushless DC motor. In a brushless motor, the rotor incorporates the magnets whereas the stator contains the windings. As the name suggests brushes are absent [5], [1] and hence in this case, force of commutation is implemented electronically with a power electronic amplifier that uses semiconductor switches to change current in the windings situated on the rotor. In this respect, the reverse working phenomena of DC motor is being depicted and its equivalent to BLDC motor, in which the magnet rotation is a continuous process while conductor remains stationary. Therefore, BLDC motors often incorporate either internal or external position sensors to sense the actual rotor.

II. BLDC MOTOR

A. Stator

The BLDC motor stator is made out of laminated steel in which winding is stacked similar to as in an Induction AC motor. The stator winding can be fashioned in two connections; i.e. a star connection (Y) or delta connection (Δ). The major difference between the two connections is that the Y connection gives high torque at low RPM and the Δ connection gives low torque at low RPM. A slot less core has lower inductance, thus it can run at very high speeds.

B. Rotor

The rotor of a typical Brushless DC motor is made out of permanent magnets. The poles of rotor may vary according to the application requirements. Ferrite magnets are conventionally used to make permanent magnets. Now a day, rare earth alloy magnets have been used.

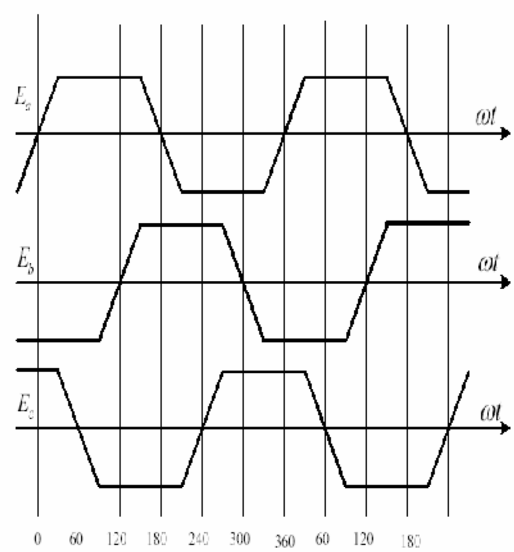

Fig. 1: Trapezoidal Back Emf of Three Phase BLDCM

III. THEORY OF OPERATION

For each of the commutation sequence, one of the winding is fed to positive power (current enters into the winding), the second winding is fed to negative power (current exit the winding) and the third is in a non-energized condition [1]. The interaction of magnetic field generated by the stator coils and the permanent coils produces torque. In order to keep the motor in running condition, the magnetic field produced by the windings should shift position, so that the rotor synchronizes with the stator field.

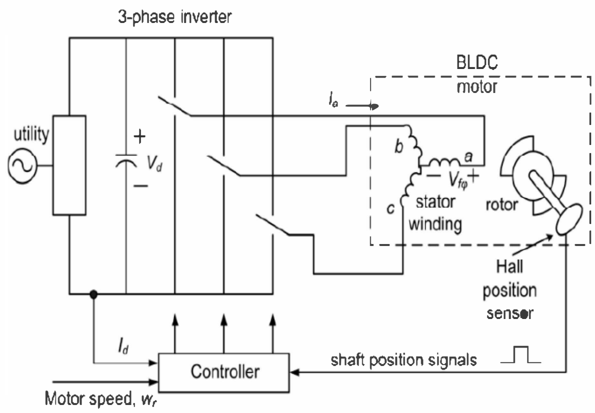

Fig. 2: Electronically Commutated BLDC Motor Drive

To control a BLDC motor the following four assemblies are incorporated.

- Inverter Circuit

The three phase of BLDC motor is fed from the inverter circuit. It consists of two power semiconductor devices (MOSFET) on each phase leg. Appropriate pairs of switch (S1 to S6) are driven according to the principal ability of hall sensors. Three phases are commutated for every 60 DEGREE. Sensors work as a feedback element of the rotor position, so that synchronization is achieved between stator and rotor flux.

- Hall Sensor

The BLDC motor commutation is controlled electronically by the drive amplifier. For the rotation of BLDC motor, the stator windings should be energized in a consecutive manner with the help of power electronic drive circuit. Rotor position is sensed by Hall sensors which are embedded into the stator. The Hall sensors give high or low signal, when the rotor magnetic poles pass from it which indicates that the North or South Pole is passing near the sensors. Based on the combination of these three Hall sensors, the exact sequence of commutation can be determined.

- BLDC Assembly

The output of inverter circuit and reference input fed to BLDC Motor. The output of BLDCM is taken with the help of Bus Selector. The output of bus selector is as Stator Current, Stator back EMF, Rotor Speed and Electromagnetic torque. One of the outputs of PMSM is fed to Decoder/Gate block so that it decides the gate pattern of inverter circuit. The Rotor speed is fed back to the comparator to achieve the desired speed which is required.

- PI Controller

PI controller correct the steady state error by minimizing the difference of measured variable and desired set point accordingly [7]. The PI consists of two mode- the proportional mode and integral mode. The proportional mode determines the reaction to the current error where as integral mode determines the reaction based recent error. The addition of two modes output act as corrective action to the control element [8][9]. The speed of the motor is compared with its set value and the speed error is fed in proportional-integral (PI) controller [10].

IV. MATLAB/ SIMULINK MODELS

The reference value of speed being used in above model is 3000 r.p.m. The simulation is carried out under the different operating conditions such as starting and load application and removal. The Proportional gain K_P=0.013, Integral gain K_I=16.6.

CASE I- Performance with Sudden Application and Removal of Load

The model developed to study the performance of the motor on sudden change in load is as shown in Fig. 3. A load is suddenly increased from 0 Nm to 3 Nm at 0.1 sec. Then it was suddenly removed after 0.4 sec.

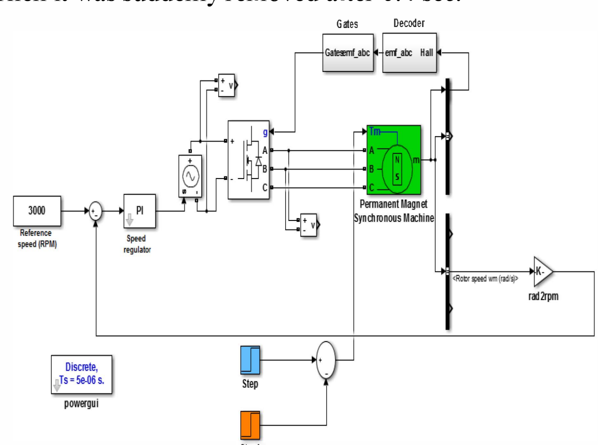

Fig. 3: BLDC SIMULINK Model for Sudden Change in Load

The simulation results for starting the BLDCM at no load from time t=0 sec to the load application at t=0.1 sec and the removal of load at 0.4 sec are shown in Fig. 4. Fig. 4(a) show speed response curve, Fig. 4(b) show current response curve, and Fig. 4(c) show torque response curve. The speed torque characteristics of BLDCM are shown in Fig. 7.

1. Starting Characterstics

During starting the rotor speed attains the reference value and for a moment the torque rises and finally achieves its reference value (zero Nm). At the time of starting, with the motor at no load, the percentage overshoot is 2.83%, peak time is 0.035 sec, rise time is 0.026 sec and the settling time is 0.085 sec.

2. Sudden Application and Removal of Load

The results show that at the time of sudden application of load, the settling time is 0.065 sec having -5.23% overshoot. While at the time of load removal, the overshoot is 5.23% with settling time of 0.088 sec.

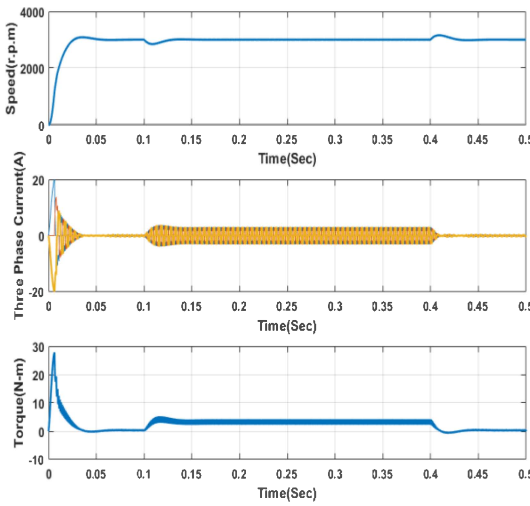

Fig. 4: a) Speed Response Curve b) Current Response Curve c) Torque Response Curve of BLDC under starting and sudden load application and removal

CASE II- Performance with Gradual Application and Removal of Load

The model developed for gradual application and removal of load is shown in Fig. 5. The simulation result for speed, torque and current waveform characteristics of BLDC using PI controller is based on the system configuration as shown in Fig. 6. Fig. 6(a) show speed response curve, Fig. 6(b) show current response curve, and Fig. 6(c) show torque response curve. The speed torque characteristics of BLDCM are shown in Fig. 8.

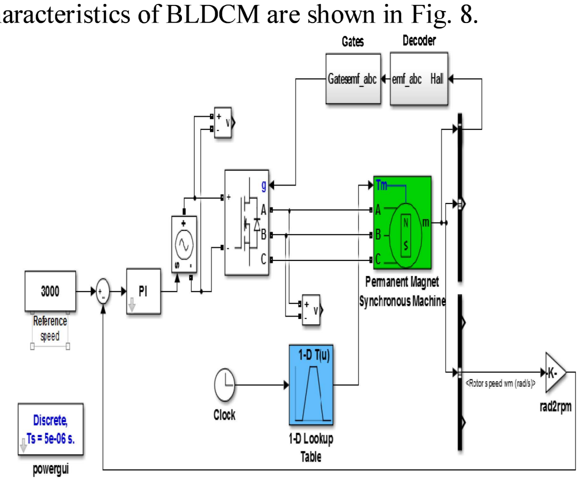

Fig. 5: BLDC SIMULINK Model for Gradual Change in Load

From 0 sec to 0.1 sec, no load is put on the motor. Thereafter, the load is varied in three segments. From 0.1 sec to 0.2 sec, the load is linearly increased from 0 Nm to 3 Nm. Then from 0.2 sec to 0.3 sec, the load is maintained constant at 3 Nm. Further, from 0.3 sec to 0.4 sec the load is linearly decreased from 3 Nm back to 0 Nm.

The simulation results carried out for these different operating conditions are discussed in the text to follow.

3. Starting Characterstics

The simulation result during starting of BLDCM using PI controller at no load (0-0.1sec) is similar to sudden change in load at no load condition. At the time of starting, with the motor at no load, the percentage overshoot is 2.83%, peak time is 0.035 sec, rise time is 0.026 sec and the settling time is 0.085 sec

4. Gradual Load Application and Load Removal

The results show that at 0.1 sec when the linearly increasing load (0-3Nm) is applied, the settling time is 0.05 sec having -0.9% overshoot. At 0.2 sec, when the load reaches its constant value of 3 Nm, it has settling time is 0.05 sec and overshoot is 0.06%. At 0.3 sec, when the load starts decreasing linearly it settles down immediately with an overshoot of 0.83% without the speed settling down to its steady state value. However after 0.4 sec, the overshoot is 0.53% with setting time of 0.0526 sec

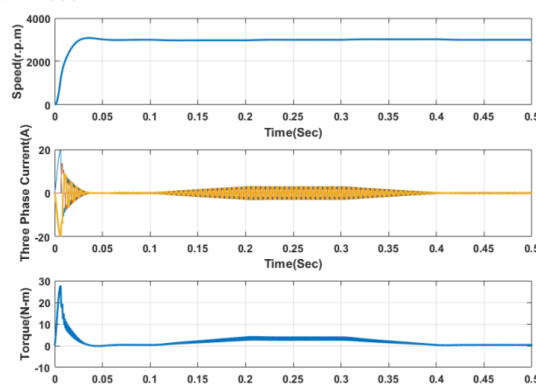

Fig. 6: a) Speed Response Curve b) Current Response Curve, c) Torque Response Curve of BLDC under starting and gradual load application and removal

V. Simulation Results

The comparisons of the responses obtained by running the simulation of the models developed for BLDC motor under sudden change in load and under gradual change in load are summarized in Table 1.

It is found that under sudden application of load, the overshoot is -5.23% and settling time is 0.065 sec. Under the application of gradually increasing load the overshoot is -0.9% having the settling time is 0.05 sec and while gradually decreasing the load the overshoot is 0.83% without the speed settling down to its steady state value.

However after 0.4 sec, the overshoot is 0.53% with setting time of 0.0526sec.

TABLE 1: TIME RESPONSE COMPARSION DURING SUDDEN AND GRADUAL LOAD APPLICATIONS

Load	Characteristics	Time Interval (Sec)	Over Shoot Mp (%)	Peak Time (Sec)	Rise Time (Sec)	Settling Time (Sec)
CASE-I (Sudden Load)	No Load	0-0.1	2.83	0.035	0.026	0.085
	Load Application	0.1-0.4	-5.23	0.088	-	0.065
	Load Removal	After 0.4	5.23	0.087	-	0.088
CASE-II (Gradual Load)	No Load	0-0.1	2.83	0.035	0.026	0.085
	Load Application	0.1-0.2	-0.9	0.025	-	0.05
		0.2-0.3	0.06	0.023	-	0.05
	Load Removal	0.3-0.4	0.83	0.025	-	Not Settled
		After 0.4	0.83	0.004	-	0.0526

VI. SPEED-TORQUE CHARACTERISTICS

Further, a significant observation is made through the speed-torque characteristics of BLDC motor under the two types of load application and removal. It is seen in Fig. 7 and Fig. 8 that the performance of the motor is better when the load is applied and removed gradually instead suddenly.

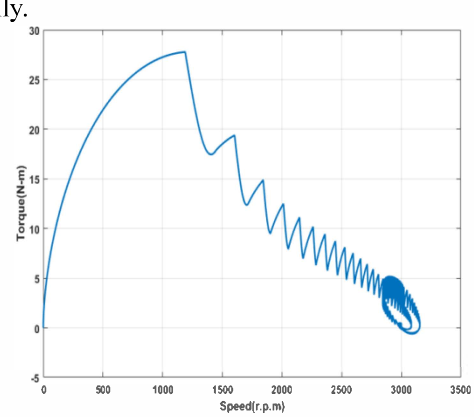

Fig. 7: Speed-Torque Characteristics Under the Effect of Sudden Load Change

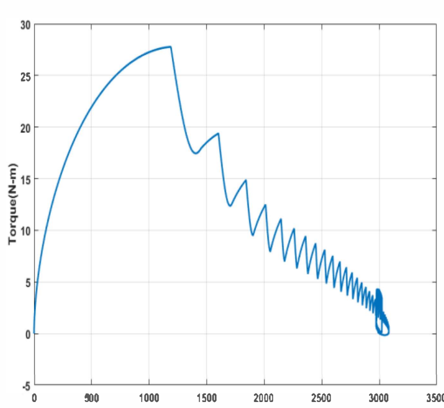

Fig. 8: Speed-Torque Characteristics Under the Effect of Gradual Load Change

VII. CONCLUSION

A model has been developed in this paper using MATLAB/ SIMULINK for BLDCM with PI controller to analyze its performance under discrete and gradual load variations at constant speed. These types of variations in the load have been considered as they are the mostly encountered ones in real life. The performance of the motor has been analyzed on the basis of overshoot, peak time, rise time and settling time for sudden and gradual changes in load. The results obtained demonstrate that the variations in rotor speed and the torque follow the load variations satisfactorily while the PI controller maintains the speed nearly constant. The performance however, is better if the load is applied and removed gradually as against sudden load variations.

REFERENCES

[1] P. Pillay and R. Krishnan, "Modeling, Simulation and Analysis of Permanent-Magnet Motor Drives, Part-I: The Brushless Dc Motor Drives," IEEE Trans. on Industry Applications, vol. 25, pp.274-279, March/April 1989.

[2] P.C. Sen "Principles of Electric Machines and Power Electronics", John Wiley And Sons, 1997.

[3] R. Krishnan and A. J. Beutler, "Performance and design of an axial field permanentmagnet synchronous motor servo drive," in Proc. IEEEI AS Annu. Meeting, pp. 634-640, 1985..

[4] C.S. Joice And Dr. S. R. Paranjothi, "Simulation of Closed Loop Control of Four Quadrant Operation In Three Phase Brushless DC Motor using MATLAB/SIMULINK," in proc. ICPCES, 2010, pp. 259–263.

[5] Gopal K Dubey "Fundamentals of Electrical Drives", Narosa Publishing House, New Delhi, Second Edition, 2001, Chapter 7, pp. 271-277.

[6] S. Baldursson, ―BLDC Motor Modelling and Control – A MATLAB / Simulink Implementation‖, Master Thesis, May, 2005.

[7] Dorf, C. Richard and H. Robert Bishop, "Modern control systems", 9th ed., Prentice Hall Inc., New Jersey-07458, USA, Chapters 1, 5, pp. 1- 23, pp. 173-206, 2001.

[8] Pooja Agarwal, Arpita Bose, " Brushless Dc Motor Speed Control Using Proportional-Integral And Fuzzy Controller", IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE), ISSN: 2320-3331,Volume 5, Issue 5, pp. 68-78,May. - Jun. 2013.

[9] Ravikiran H. Rushiya, Renish M. George, Prateek R. Dongre, Swapnil B. Borkar, Shankar S. Soneker and S. W. Khubalkar, "International Journal of Application or Innovation in Engineering & Management (IJAIEM)" ISSN 2319 – 4847.

[10] Ahmed M. Ahmed, Mohamed S. Elksasy, Amr Ali-Eldin, Faiz F. Areed, "Brushless DC Motor Speed Control using both PI Controller and Fuzzy PI Controller", International Journal of Computer Applications (0975 – 8887),Volume 109 – No. 10, January 2015.