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Performance Analysis of Brushless DC Motor under Different Loading Conditions

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ABSTRACT
This paper deal with the speed response characteristics analysis of brushless dc motor under different load variations. BLDC drive are widely used motors now a days due to its good speed control characteristics and high efficiency which improves the performance of motor. PI controller is used in motor operation to maintain the constant speed. The analysis is carried out in three different type of load condition which are given as under-load, rated load and overload conditions. The performance of BLDC motor is observed through speed, current, back emf and torque response. To evaluate the result appropriate value of Kp and Ki of controller has been taken in order to get the better result for characteristics parameter of the speed response of BLDC motor. The result are then calculated mathematically and analysed according to the load variations. The required model has been developed using Simulink/Matlab and speed torque characteristics graph is also analysed using PI controller.

KEYWORDS: *BLDC Motor; PI Controller; MATLAB/SIMLINK*

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I. INTRODUCTION

Brushless DC motors are characterized as permanent magnet synchronous motors. Since it has its own unique characteristics such as long life, good efficiency, remarkable starting torque and low maintenance cost. These motors nowadays greatly used in industrial sectors because their construction that suitable for any safety and critical application. Since they have been used for drives and power generation for a long time i.e. in sub kilowatt range, which has been dominated by BLDC Motors, has always been a grey area. But the modern power electronics and microprocessor technology has allowed the small Brushless DC Motors to thrive, both in terms price and performance. They have several advantages over other motors like DC motor and induction motor. BLDC motor is an electronically commutated DC motor which does not have brushes. BLDC motor does not need any mechanical commutation. This motor basically consists of two main parts: a stator and a rotor. The structure of the stator of a BLDC motor is similar to that of an induction motor. It is made up of stacked steel laminations with axially cut slots for winding.

The rotor part of the motor is made up of permanent magnets. Motor basically comprises of three-phase inverter, a rotor position sensor and a speed controller. A position sensor, which is usually a Hall Sensor (that works on the principle of Hall Effect) is generally used to detect the position of the rotor and converts it into an electrical signal. These types of motors are highly efficient in producing a large amount of torque over a vast speed range.

II. PI CONTROLLER

A PI Controller is a feedback control loop that calculates an error signal by taking the difference between the output of a system, which in this case is the power being drawn from the battery and the set point.

The PI consists of two mode- the proportional mode and integral mode. The P controller utilizes the gain Kp and produces the output which is proportional to the current error value. If the proportional gain is high then the system becomes unstable. In order to make the system performance stable, integral action is to be taken. This integral mode is used to accumulate steady state error which is caused by proportional action and providing slow response.

Proportional Integrative (PI) Controller which is governed by the following equation.

$$P_{out} = K_p e(t) + K_i \int e(t)$$

III. MODELLING OF BRUSHLESS DC MOTOR

A model is developed to study the performance analysis of the motor during different load variation condition (free running condition, half load, rated load, full load). The motor carries of 1KW rated power with 500V dc voltage supply. The reference speed of 3000 rpm is used in the model and is compared with a feedback path and is then connected to a controller i.e. PI controller.

This type of controller can be used to control the linear application motor. The brushless dc motor is fed by a MOSFET bridge inverter. A speed regulator is used to control the DC bus voltage. The inverter gate signal are produced by decoding the hall effect signal of the motor. The outputs of the bridge inverter is applied to the permanent magnet synchronous motor (PMSM). The load torque provided to the machine shaft is step input of 3Nm. The system is first set to zero and then steps to its nominal value of 3Nm at time 0.1sec.

The required values of proportional and integral gain are given as 0.013 and 16.6 respectively. The simulation result of brushless motor are given in the form of time response curve graph.

Table 1: Specification of BLDC Motor

SR. No	Parameter	Specification
1.	No. of poles	4
2.	Rated Speed	3000 rpm
3.	Rated Voltage	500 V
4.	Rated Current	4.52 A
5.	Phase	3

IV. RESULT ANALYSIS

In this paper the analysis of BLDC motor is done through MATLAB software which is used to analyse the speed response of motor under different load variations. A load torque of 3Nm is given to the brushless dc motor at two different step load condition with two different time interval of 0.1 sec and 0.2 sec at the input of unit step. The result analysis is carried out by basically four transient speed response characteristics which are shown in the following table.

1. At Rated Load Condition

The model has been run at a given step load of 3 Nm. During the time interval of 0 sec to 0.1sec the motor at starting is running at no load condition, the maximum overshoot percentage is 2.83%, peak time is 0.0356 sec, rise time is 0.026 sec and the settling time is given by 0.081sec. During the time of load application between the time interval of 0.1sec-0.2sec maximum overshoot percentage is -5.21%, peak time is 0.1089 sec, rise time is 0.101 sec. At the time of load removal i.e. after 2 sec the peak time is 0.209 sec, rise time is 0.2001 sec and max. overshoot is 5.23% with settling time of 0.5 sec. After 0.2sec there is gradual increase in load and after 0.25sec become constant at 3 Nm.

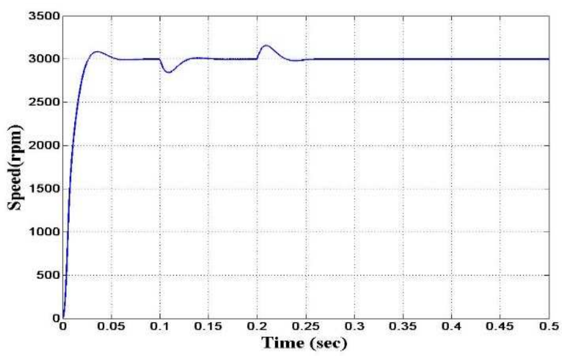

Figure 1: Speed Response Curve

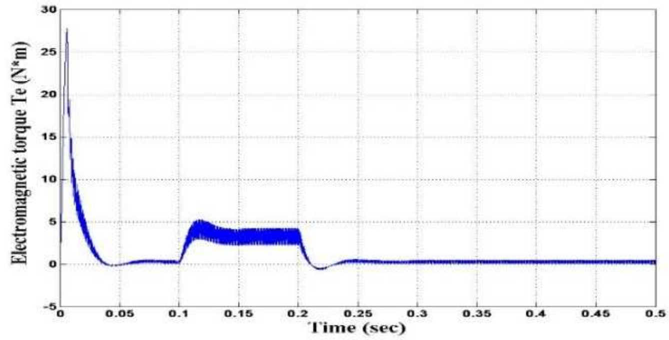

Figure 2: Torque Response Curve

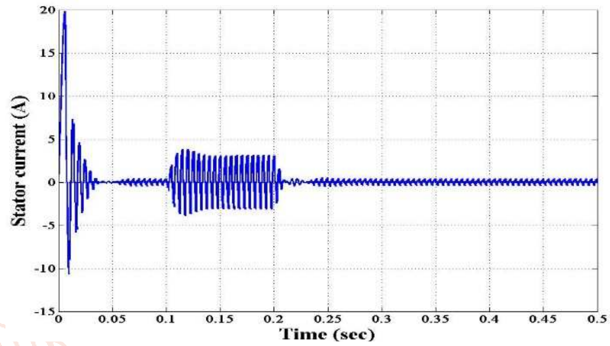

Figure 3: Current Response Curve

2. At Overload Condition

The result at overload condition is analysed with three different increase in load condition at different increase in percentage. The motor has been provided with 150% increase in load variation and result is carried out in form of table.

With the increase of 150% of the load, the load torque of 4.5Nm is applied and at the time of no-load condition the peak time is 0.035sec, rise time is 0.0266sec and maximum overshoot is 2.83% with settling time of 0.086sec. At the time of load application during time interval of 0.1-0.2sec maximum overshoot is -7.7%, peak time is 0.108sec with the rise time of 0.10 sec. At 0.2sec when the load is removed the overshoot become 10.46% with peak time 0.2157sec, rise time of 0.2sec and settling time is 0.396sec.

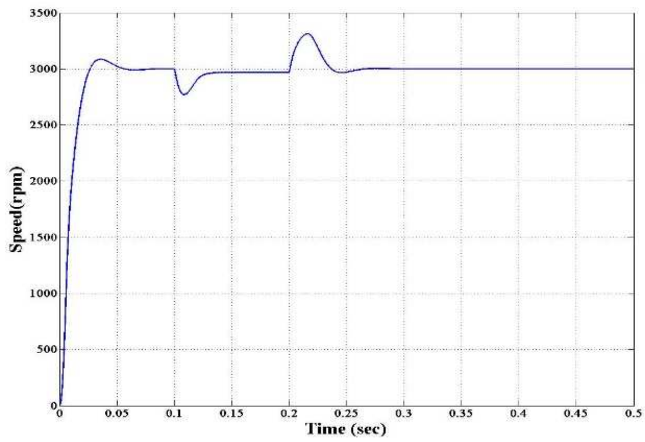

Figure 4: Speed Response Curve

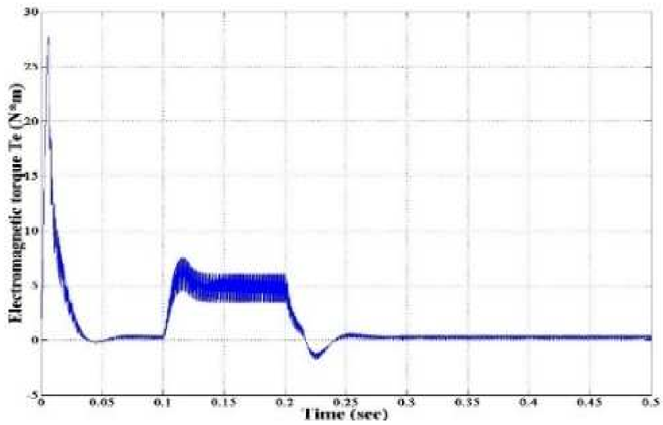

Figure 5: Torque Response Curve

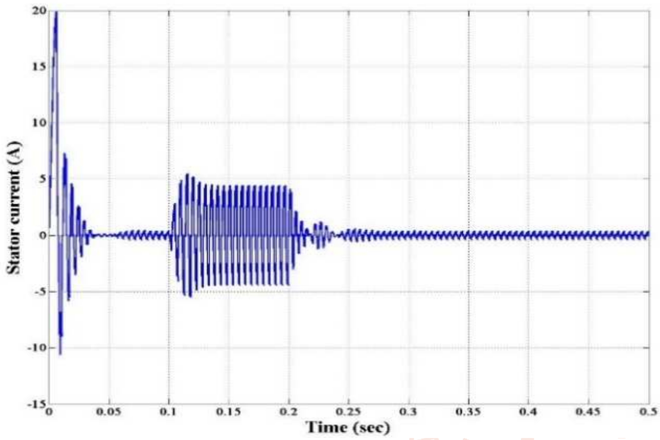

Figure 6: Current Response Curve

3. At Underload Condition

The result has been carried out with the decrease in load variation at different decrease in percentage of 50% and presented in the form of table. At 50% decrease of the underload condition the load torque of 1.5Nm is applied. In this the starting condition at no load between 0-0.1sec is same as the overload condition when the motor is applied at no-load. During the time interval of 0.1-0.2sec when the load is applied the overshoot percentage is -3.94%, rise time is 0.102sec and peak time is 0.1088sec with settling time of 0.155sec. At 0.2sec the overshoot is 3.94% with peak time of 0.2093sec, rise time is 0.201sec and settling time of 0.276sec.

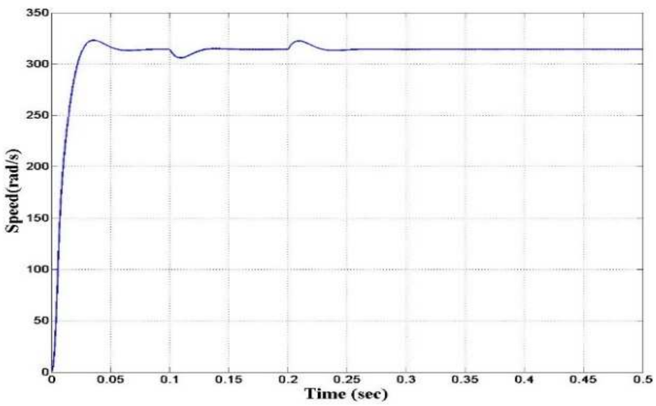

Figure 7: Speed Response Curve

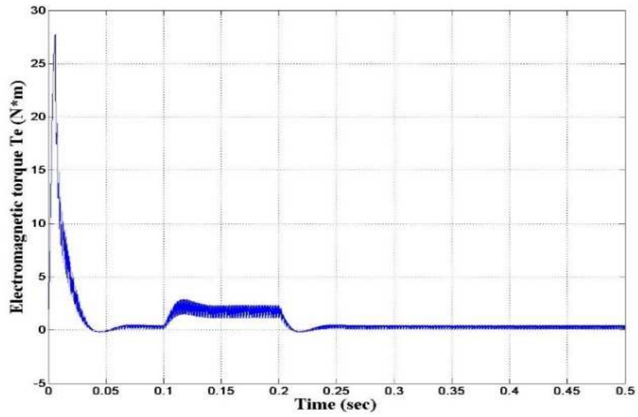

Figure 8: Torque Response Curve

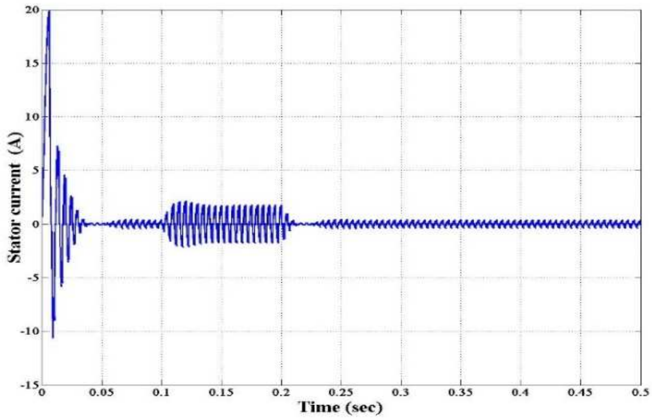

Figure 9: Current Response Curve

Table 2: Time Response Characteristics at Different Load Conditions

SR.No	Load Applied	Characteristics	Time Interval (sec)	Rise Time (sec)	Peak Time (sec)	Settling Time (sec)	Max. Overshoot (%)
1.	Full-Load (At 3 Nm)	No Load	0-0.1sec	0.0266	0.035	0.081	2.83
		Load Application	0.1-0.2sec	0.101	0.1089	0.162	-5.21
		Load Removal	After 0.2sec	0.2001	0.209	0.485	5.21
2.	Half-Load (At 1.5 Nm)	No Load	0-0.1sec	0.0266	0.035	0.067	2.83
		Load Application	0.1-0.2sec	0.102	0.1088	0.155	-3.94
		Load Removal	After 0.2sec	0.201	0.2093	0.276	3.94
3.	Over-Load (At 4.5 Nm)	No Load	0-0.1sec	0.0266	0.035	0.086	2.83
		Load Application	0.1-0.2sec	0.10	0.108	0.16	-7.7
		Load Removal	After 0.2sec	0.2	0.2157	0.396	10.46

V. CONCLUSION

In order to achieve better time response on BLDC motor, a PI controller has been modelled designed and performance analysis is done in this work. The PI controller improves the performance of BLDC motor drive. The simulation results depict that BLDC motor show better performance in the case of underloading condition as compared to rated loading condition or overloading condition in terms of rise time, delay time, settling time, peak time and overshoot.

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