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Design and Optimization of Battery Voltage Source to Use with PMDC Motor

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Abstract: This project is about the speed control of PMDC motor having high starting torque, supplied with a low voltage lithium-ion battery source. The speed control is implemented by using a boost converter. The main aim of this current work is to control the current consumed by the motor and to achieve the desired speed. Hence a PI controller based closed loop speed control with inner current limit control is implemented. A PMDC motor and a lithium-ion battery are modeled in MATLAB for accuracy in readings. The characteristics of the battery operated motor, under transient conditions are also presented. The open loop and closed loop control systems have been analyzed through MATLAB R2009b package.

Key words: Battery · Boost Converter · Cascaded Control · Lithium-ion model · Optimized · PMDC motor · Speed Control

INTRODUCTION

PERMANENT magnet motors have been useful in a range of applications and widely used in industries nowadays. Due to the development in engineering, material technology and tremendous improvements in solid state devices and circuits, new types of electric motors like stepper motors, switched reluctance motors and permanent magnet motors have emerged [1].

Out of these, the permanent magnet DC motor is the second stage evolution of the conventional DC motor. The main difference in the construction of the PMDC motor from conventional DC motor is the stator poles are replaced by suitable permanent magnets. Because of the presence of permanent neodymium magnets in PMDC motors, there is no need to have field windings.

Also, owing to the technical improvements in motors and closed loop controllers, electronically commutated motors (also known as brushless motors) are replacing brushed motors in many applications. This brushless permanent magnet DC motor is the third stage of evolution of the conventional DC motor.

The conventional DC motors are highly efficient and their superiority makes them suitable for variable speed applications because of lower cost, reliability and simple control. In addition to the adjustable speed applications, the DC drives are widely used in the areas requiring good speed regulation; frequent starting, braking problems and reversing problems.

In this conventional (brushed) DC motors, the brushes make mechanical contact with a set of electrical contacts on the rotor (called the commutator), forming an electronic circuit between the DC electrical source and the armature coil windings. Since the armature rotates on an axis, the stator brushes come into contact with different sections of rotating rotor. The rotor and brush system from a set of six electrical Mosfets, each mosfet is triggered in sequence, so that electrical power always flows through the armature coil closest to the stationary stator. So the drawback of conventional DC motor is that they need a commutator and brushes which are subjected to wear and tear also they require frequent maintenance.

Conventional System: The Conventional system consist of alternating sinusoidal current supply, a controlled rectifier [2, 3], a rated PMDC motor and finally an embedded microcontroller to do computations and to control the speed of the DC motor by controlling the triggering pulse of the controlled rectifier and by sensing the current speed of the PMDC motor and by sensing the input current of the controlled rectifier. The main disadvantage of the conventional controller is that more

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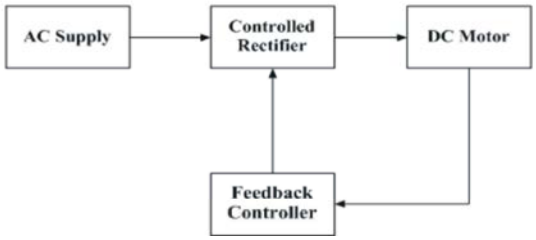

Fig. 1: Block Diagram of conventional system

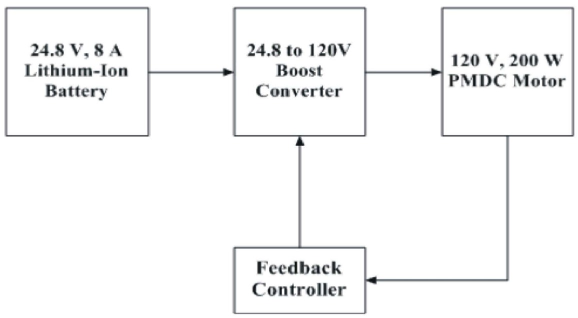

Fig. 2: Block Diagram of Proposed System

Table 1: Individual Ratings of the system

SYSTEM	RATING
Battery	24 V, 8 A
Boost Converter	250 W
PMDC motor	120 V, 2 A

number of ripple count will occur in the input and in the output due to the switching action of the controlled rectifier. Due to this more ripple content the PMDC motor will be affected more and sometimes the permanent magnet will get demagnetized.

The other type of conventional system applications are battery powered electric vehicle wherein the PMDC motor is used as a motor and it is driven by a DC to DC motor drive [3]. In this type application the size of the battery should be similar to the size of the battery and then only the battery can compete with the motor and it can supply the required power to motor. So that that the battery will acquire more space in the electric vehicle and so that the weight of the car will be more and more over it in turns it acts as a additional load to the motor. So that the motor has to work more and it extracts more current from the battery.

In the conventional system.

The basic block diagram of conventional system is shown in Figure 1.

Proposed System: The proposed system is based on logic to reduce the tradeoff between the battery size and motor power. The author has tried to test the efficiency of the motor when it is run by a low voltage battery source.

The proposed system consist of a low voltage DC source, a DC to DC boost converter as a motor drive, a high wattage PMDC motor as a load which will be run by the boost converter and a feedback control block which will consist of a cascaded control loop where in the speed error will acts as a reference current to the feedback system.

For analysis purpose a battery, a PMDC motor, a boost converter has been modeled in MATLAB. The battery model available in the software may be used but we will not acquire the correct output because it is an ideal model.

An attempt has been done to develop a real time model so that we can achieve or predict or will get the correct output as in real time.

The block diagram of the proposed model is shown in Figure 2.

The ratings of the whole system are depicted in the Table 1.

Battery Modeling: In MATLAB many voltage source blocks available, even a lithium ion battery source also available. If we use it we cannot get the exact output. Hence a lithium ion battery is modeled in MATLAB using for taking accurate readings. Among the available choices for portable energy storage devices, batteries have been the most popular choice. The major categories of batteries used or being considered for electric and hybrid vehicle applications are:

- Lead-acid
- Nickel-metal-hydride (NiMH)
- Sodium Sulfur (NaS)
- Lithium-ion (Li-ion)

The batteries for electric vehicle applications such as high specific power, high specific energy and, long calendar and cycle life; Li-ion battery technology is the most promising among the four battery chemistries mentioned above. Table 2 gives a brief display of the different properties of the above mentioned batteries. Li-ion batteries also have good high temperature response, low-self discharge and components of Li-ion batteries are recyclable. All these characteristics make Li-ion batteries highly suitable for all applications.

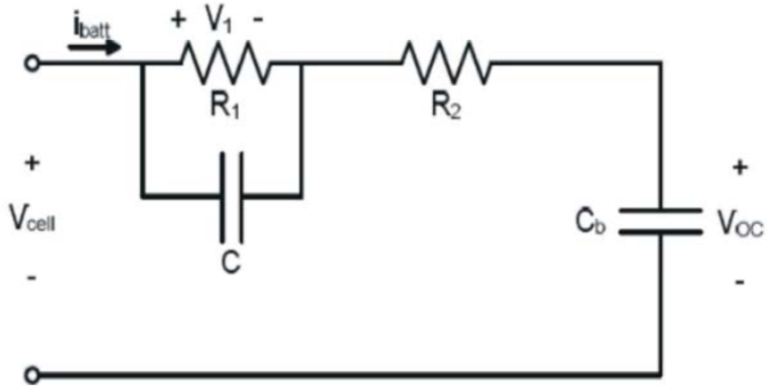

Fig. 3: Equivalent Circuit of Battery

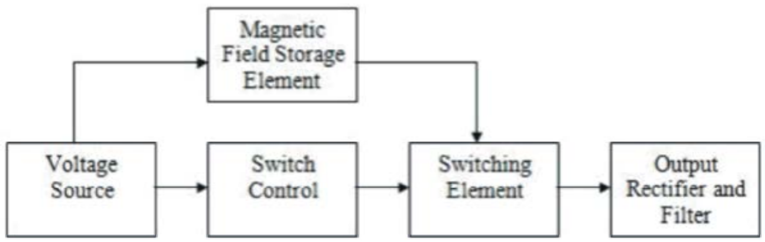

Fig. 4: Block Diagram of Boost Converter

The basic state of charge equation is:

$$SOC = \frac{Q}{Q\max} = \frac{1}{Q\max}\int idt \quad (1)$$

Modeling of Boost Converter: The basic building blocks of a boost converter Circuit are shown.

The boost converter is designed using[4]. The design Equations are shown below.

The boost converter design inputs are: Vs=24.8 V, Va=120 V, fs =20 KHz.

To calculate the duty cycle;

$$D = 1 - \frac{Vs}{Va} \quad (2)$$

To calculate inductor value;

$$L = \frac{K(1-K)R}{2f} \quad (3)$$

To calculate capacitor value;

$$C = \frac{K}{2fR} \quad (4)$$

The values of boost converter are chosen in such a way that it always works in continuous conduction mode of operation.

Table 2: Boost Converter Values

	D	Vin (V)	V out (V)	R(Ω)	L(H)	C (F)
Calculated Value	0.8	24	120	100	0.4m	0.2µ
Used Value	0.8	24	120	100	9.6m	20µ

Table 3: Summary of motor parameters

Parameter	Value	Unit
Kt	0.7355	N.m/A
Ra	2.83	Ω
La	0.015	H
Tf	0.0007	N.m
Bm	0.0075	N.m.s

Pmdc Motor Modeling: The equivalent circuit of PMDC motor.

The simulation model is developed using resources available from the Simpower systems and Simulink libraries. The model is developed because there is no permanent magnet DC motor function block available in Simpower systems library. The function block is derived from the separately excited DC machine block and in that field winding is removed and instead a constant Kt is given since Kt equals Kv. The model is divided into two parts i.e., mechanical part and electrical part. The mechanical part consists of motor torque equation and the electrical part consists of general motor equation as shown below.

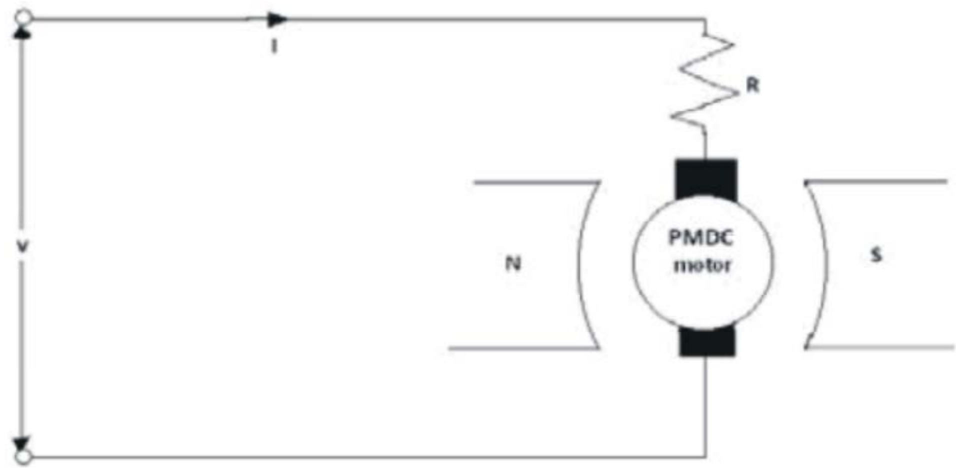

Fig. 5: Equivalent circuit of PMDC motor

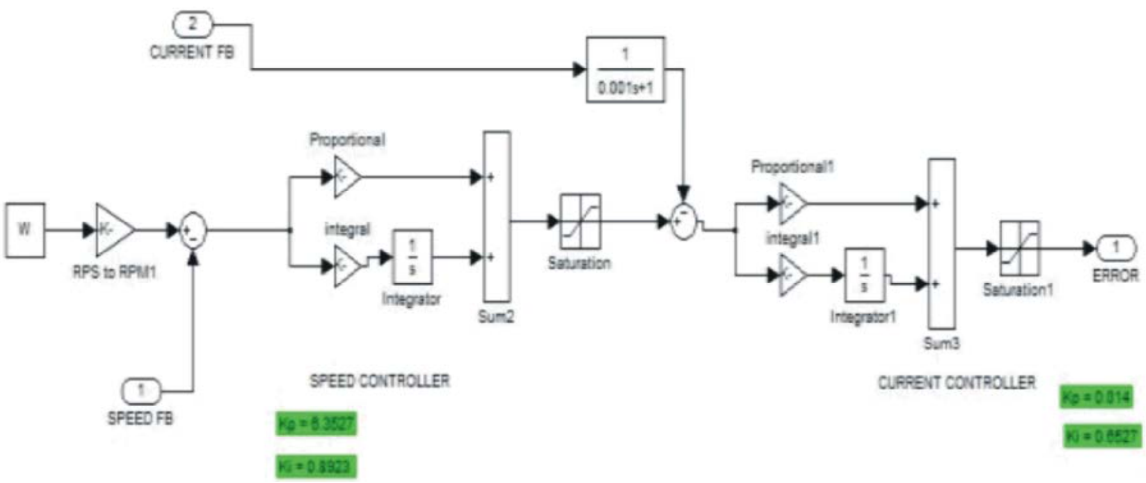

Fig. 6: Controller block

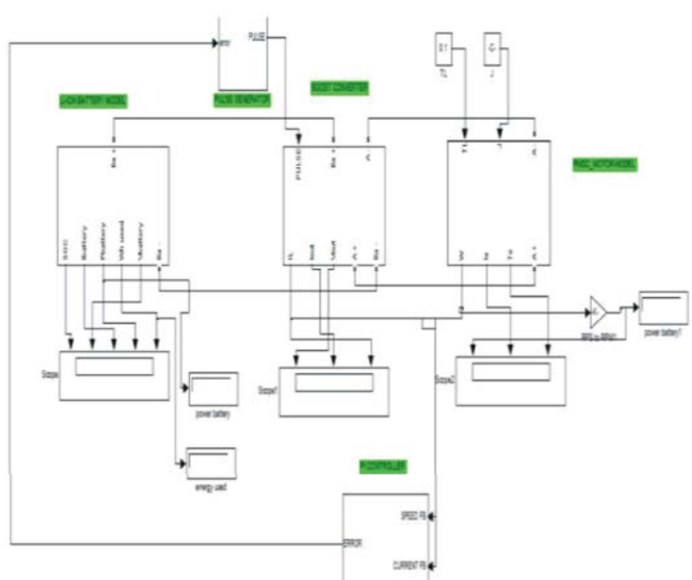

Fig. 7: Overall Circuit of the Proposed Model

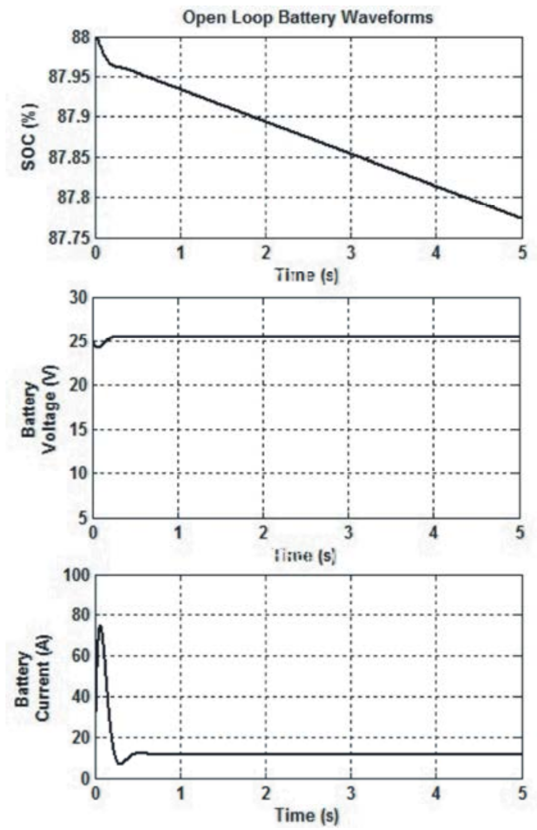

Fig. 8: Open loop battery waveforms

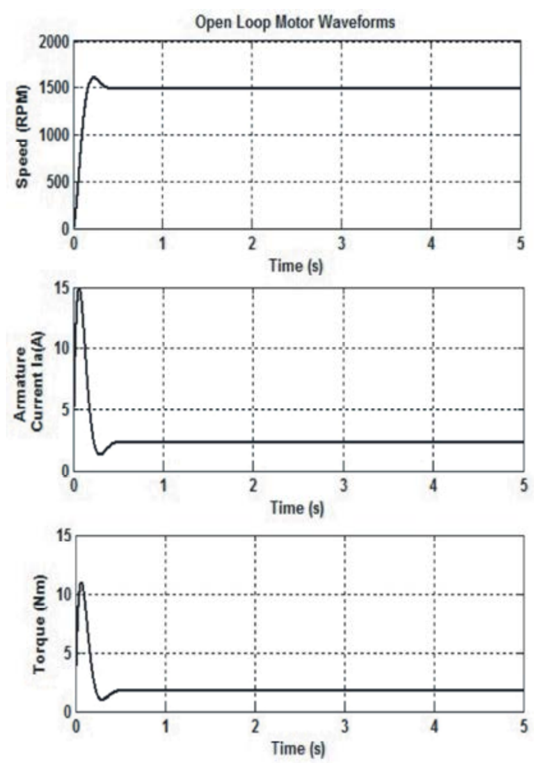

Fig. 9: Open loop Motor Waveforms

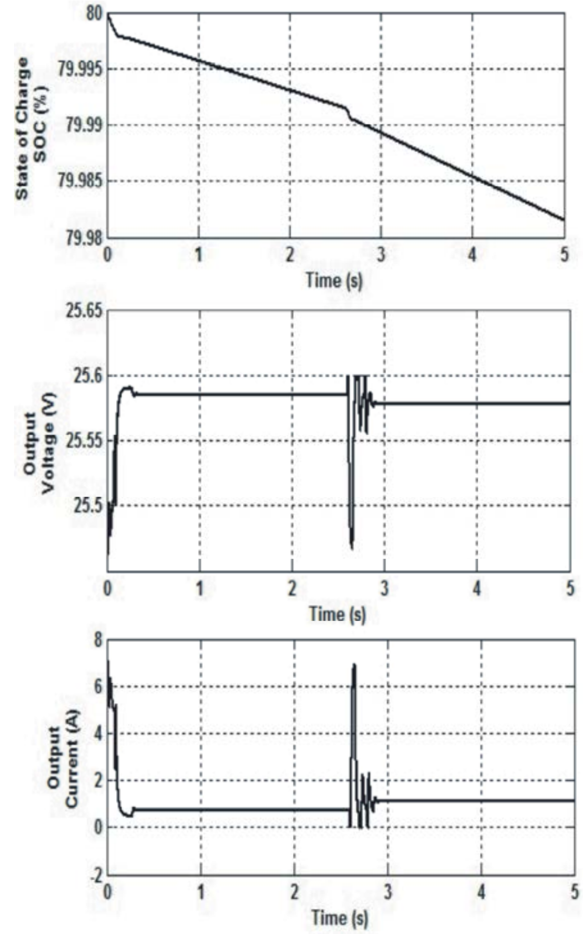

Fig. 10: Closed loop Battery waveforms

Controller Design: A closed loop speed control with inner current limit Control [5] is introduced to control the current used by the motor. In this type of control we have to give only the set speed. The speed error will act as current reference for the next loop. Finally it is compared with the ramp signal and the pulses are generated. The controller part used in the circuit is shown.

The PI values are tuned using Ziegler-Nichols tuning method [6, 7]. The procedure for using Ziegler-Nichols tuning is shown below.

- First set Kp and Ki values to zero.
- Increase the Kp until the output of the loop Oscillates.
- Then increase Ki until any offset is corrected in Sufficient time for the process.
- Too much Ki will cause instability.
- When the required stability is obtained, the value of Kp and Ki obtained is taken as default value.

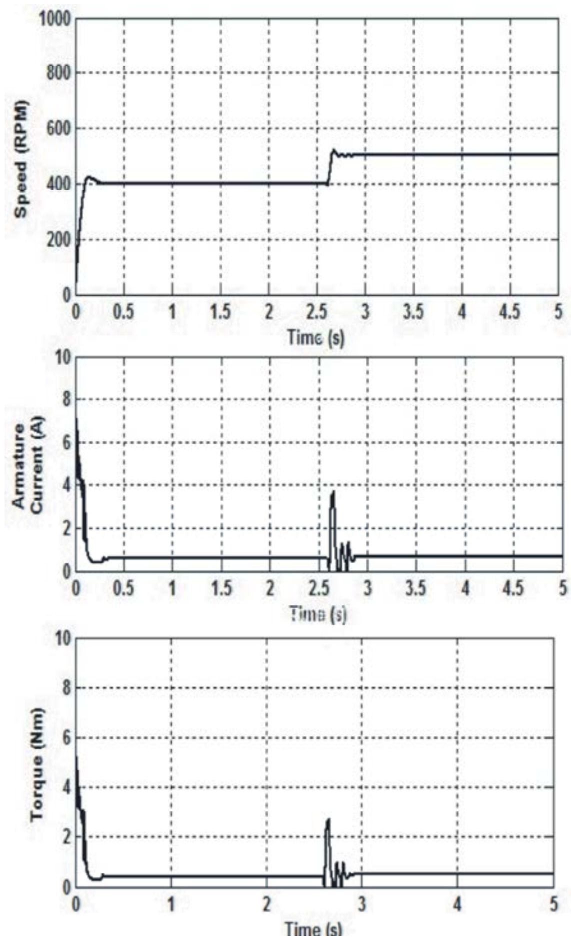

Fig. 11: Closed loop Motor waveforms

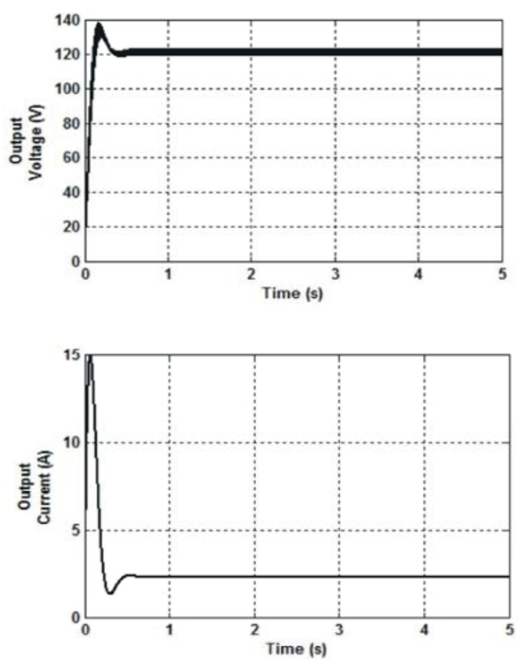

Fig. 12: Open loop Boost converter waveforms

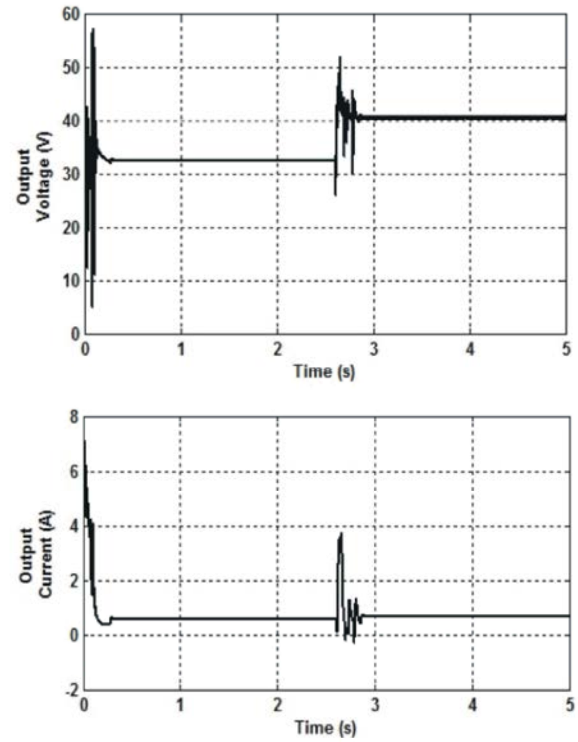

Fig. 13: Closed loop Boost converter

Finally the tuned values obtained are:

Table 4: PI Values of Controller

Speed Controller	Current Countroller
Kp = 6.3527.	Kp = 0.014
Ki= 0.8923	Ki = 0.6527

CONCLUSION

This paper has presented the implementation of boost converter fed PMDC motor drive. The lithium ion battery source is optimized to use with PMDC motor using closed loop. The motor is subjected to varying speed conditions in simulation and the output shows the reduction in peak overshoot, settling time etc. The stability of the controller is analyzed in closed loop condition.

List of Symbols:

D Duty cycle of boost converter.
Va Applied voltage (average output of converter)(V)
Ra Armature resistance.
La Armature inductance (H).
Ke Torque constant (N-m/A)

Kt Voltage constant (V/ rad / sec).
Bm Viscous friction constant (N.m.s).
Tf Coulomb friction torque (N.m).
? Angular velocity (rad/sec).
J Inertia of machine(Kg.m^2).

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