Back EMF based Sensorless PMBLDC Motor Control System Simulation Work

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Abstract— This paper deals with the detailed modeling of a speed control of a sensor-less permanent magnet Brushless DC motor (PMBLDC), the MATLAB/ simulation of sensorless PMBLDC is also presented in this work. For this a closed loop control scheme with a Proportional Integral (PI) controller in the speed loop has been designed to for the generation of torque by reference speed and actual speed generated out by the motor. Now this torque is fed to a current hysteresis controller block which generates the pulses for switching on the inverter and also limits the value of current in the desired range. A three phase six pulse full bridge inverter further feds to the Brush less DC motor. The combination of BLDCM block, speed (PI) controller block, current reference block, inverter block and BLDC motor have been incorporated in this simulation model of control system for sensorless operation of BLDCM has been established and modeled in MATLAB/Simulink. The PMBLDC motors are controlled electronically and for the proper commutation of current, rotor position information is required, on the other hand the problems of the cost temperature sensitivity and reliability of position sensors have motivated the research in the area of sensor less PMBLDC motor drives.

Key words: Back Electromotive Force (EMF) Detection, Brushless DC Motor, Filtered Line Voltage Difference, Low Pass Butterworth Filter, Sensorless Control

I. Introduction

Brushless DC (BLDC) are replacing DC motors in a wide range of applications now-a-days such as household goods, automotive and aviation industry. Such applications require a very robust, compactness, reliable, high power density and efficient motors for the operation. These appliances have relied on traditional electric motors such as single phase AC motors including capacitor- start, capacitor- run motors, and universal motors. However, consumers now demand better performance, reduced acoustic noise and higher efficient motor for their appliances. Hence, BLDC have been introduced in order to fulfill these requirements.

BLDCs are commutated electronically unlike the normal DC motors. BLDC's are controlled through a microcontroller which powers a three phase power semiconductor bridge. This three phase semiconductor bridge further provides power to the stator windings of DC motor based on the control algorithm. The motor is commutated electronically, and the control technique/ algorithm required for process of commutation can be achieved either by using a sensor or a sensor-less technique. To achieve the desired level of performance the motor also can be controlled using a feedback loop. There are several Sensor less controlling techniques such as Direct Back Electromotive Force (EMF), Indirect Back EMF Integration and Field Oriented Control (FOC) etc.

To achieve the desired level of performance in the various applications that requires the motor to operate at constant speed over various type of loads, the motor has to be operated using a suitable velocity control loop. These types of controllers are achieved by using a conventional proportional- integral (PI) controller or proportional-integral- derivative (PID) controller. However the application of position sensor makes the motor body heavy, also a lot of wires are used, which in turn encounters the problem of micro-miniaturization and interference-free design of BLDCM. Thus, the position sensor less control technology have attracted the increasing research interests of researchers towards itself and presently becomes one of the most promising trend in BLDCM control system.

The speed v/s torque characteristics of several different sensor less control techniques of BLDCs were studied and compared to the speed v/s. torque curve of a separately excited DC motor. The speed v/s torque characteristic of a BLDC using a PI controller is also discussed here.

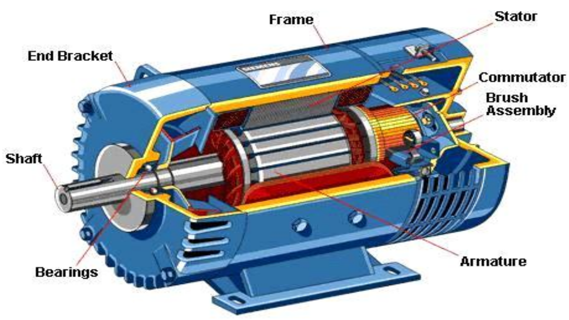

Fig. 1: Cut view of a brushless dc motor

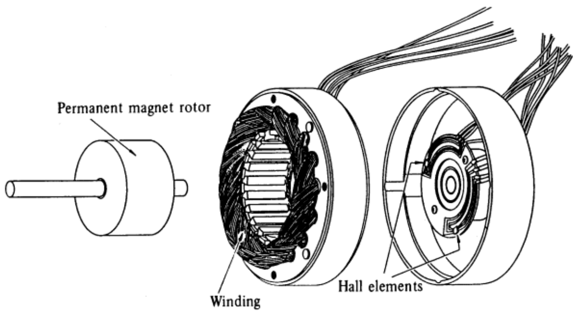

Fig. 2: Disassembled view of a brushless dc motor

A. BLDC Motor Applications:

1) Open Loop Applications

These are the types of applications where variable speed is more important than keeping the accuracy of the speed at a fixed speed. In such type of applications, the load is directly coupled to the shaft of motor. For example, fans, pumps and blowers comes in this types of applications. These applications demands low-cost controllers, mostly operating in open-loop.

2) Applications with speed control

These are such types of applications where the load on the motor varies over a speed range. These applications may demand high-speed control accuracy and good dynamic responses. In home appliances, washers, dryers and compressors are good examples. In Automotive, fuel pump control, electronic steering control, engine control and electric vehicle control are good examples of these. In aerospace, there are a number of applications, like centrifuges, pumps, robotic arm controls, gyroscope controls and many more. These applications may use speed feedback devices and may run either in semi-closed loop or in total closed loop. These applications uses very advanced control algorithms, thus complicating the controller. Also, this increases the price of the entire system.

3) Application with positioning applications

In such applications priority is given to fast dynamic response to speed and torque changes. Many industrial and automation applications appear under this category. Also, some of these applications may have frequent reversal of rotating direction. A typical cycle in these applications will consist of four phases: an accelerating phase, a constant speed phase, a deceleration phase and a positioning phase. The load on the motor can vary in all these phases, causing an increase in the complexity of the controller's algorithm. These systems mostly operate in closed loop with three control loops functioning at the same time: a Torque Control Loop, Speed Control Loop and Position Control Loop. Sometimes sensors are necessary to reduce the time of commutation.

B. BLDC v/s Conventional DC motors:

In a conventional i.e. in a brushed type DC motor, the brushes are responsible for creating the mechanical contacts with a set of electrical contacts on the rotor referred to as the commutator. This forms a electrical circuit between the DC electrical source and the armature winding. As the armature rotates, the stationary brush comes in contact with the different sections of the commutator. The rotating commutator and the brush- system forms a set of electrical switches, which operates in a proper sequence to allow electric current to flow through the armature coils closest to the field which can be either electromagnet or a permanent magnet. In a typical BLDC motor, armature coils do not move, and in its place, the permanent magnets rotate. Therefore the armature remains stationary which avoids the problem of how to transmit current to a moving armature. In a BLDC the commutator assembly is replaced by electronic controller which is programmed to perform switching of coil.

Some major advantages of BLDCs are pointed here:

- Highly efficient.
- Better speed-torque characteristics.
- High dynamic response.
- Low moment of inertia.
- High torque to volume ratio.
- Long operational life
- Low Noise level
- Variable High speed range

The main disadvantage of PMBLDCs is its high cost.

II. PROPOSED METHOD:

With the rapid and increasing advancements in field of semiconductor technology the brushless DC motors are extensively used in the computer peripherals, videos recorders, spindle drives, aerospace industry, military equipments, automated industry, and other household equipments, since practically they need no maintenance, have long life, low inertia and friction. Because of low inertia and friction they can be used in very high speed applications. The PMBLDC motors are controlled electronically and for the proper commutation of current, rotor position information is required, on the other hand the problems of the cost temperature sensitivity and reliability of position sensors have motivated the research in the area of sensor less PMBLDC motor drives.

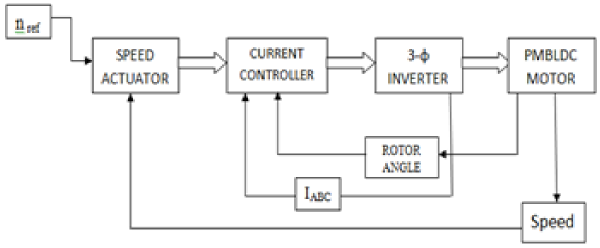

Fig. 3: Block Diagram of closed loop BLDC Control

In this close loop control of sensorless PMBLDC motor rotor angle of motor and the output current of three phase inverter is fed to the Current controller. Measured speed from the motor is applied to the speed actuator which compares the actual speed with reference speed and the resultant output is given to the current controller. Current controller produces required gate pulses for three phase inverter for the desired operation of the motor.

A. Simulink Diagram of PMBLDC Motor:

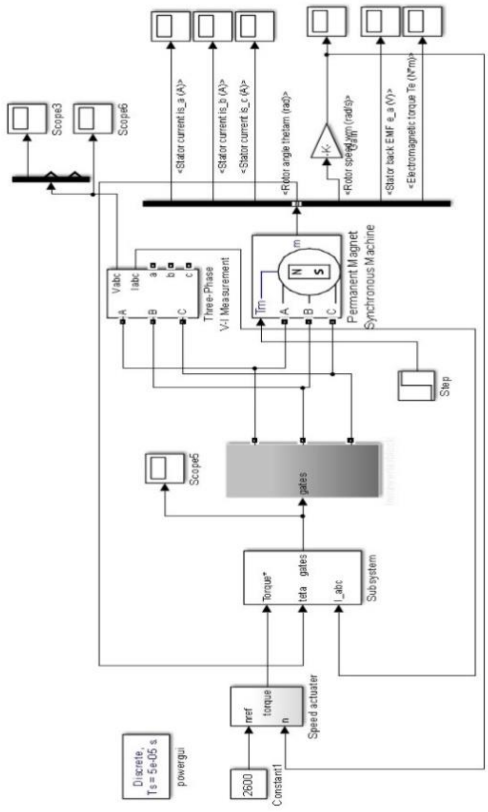

Fig. 4: PMBLDC Motor

In this circuit we have given a costant reference speed (nref) of 2600 RPM which is compared with the actual speed of motor. The PI (proportional-integral) controller generates torque with help of speed nref and n, the values of P, I are 3 and 6.2 chosen resp. Now this torque, theta(Ɵ) i.e. rotor angle and current Iabc combines in current controller to generate gate pulses for turning ON the inverter. The rotor angle theta is obtained through the rotor movement and current Iabc is obtained through the three phase VI measurement, i.e. current Iabc is generated by the combination of Iab I and Ica, which are obtained by the inverter current. The current controller changes torque to current, here two phase to three phase (DQ-ABC) conversion is done by inverse PARK's transformation. The current hystersis contoller employs relays to limit the value of current in a desired range. voltage source inverter consists of six MOSFET's which are turn ON by the six gate pulses, each MOSFET conducts for 60°. The input supply voltage given to the inverter is 450V DC. The inverter runs the three phase permanent magnet synchronous machine and at its output stator currents for phases A, B, C, rotor speed, rotor angle (Ɵ), stator back EMF and electromagnetic torque are obtained.

The above model consist of the following blocks:

– PI controller.
– Speed actuator.
– Current hystersis controller.
– Voltage source inverter.
– Permanent magnet synchronous machine

1) *PI Controller:*

The speed control applies a PI controller, which has been extensively used in numerous fields. And its integral term has the effect of accumulation, memorization and time delay, which enables PI controller to remove the static error. The block diagram of speed PI controller is shown in Fig. The Saturation block restricts the amplitude of outputting three phase reference current to the demanding range. The values of P I are taken as 2 and 6 resp.

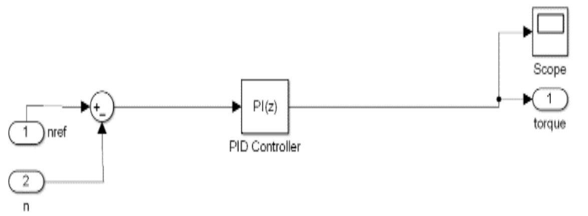

Fig. 5: PI controller

2) *Current Reference Block:*

The function of the current reference block is to generate three-phase reference currents, which depends on the signal of current amplitude *Is*, and the position signal, which is directly inputted into the current hysteresis controller block to carry out the current hysteresis control compared with actual current

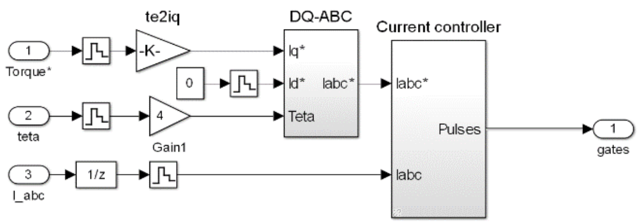

Fig. 6: Current reference block

3) *DQ-ABC Conversion Block:*

This transformation is used to convert the d_q component of rotor flux rotating reference frame into ia, ib, ic current using following equation.

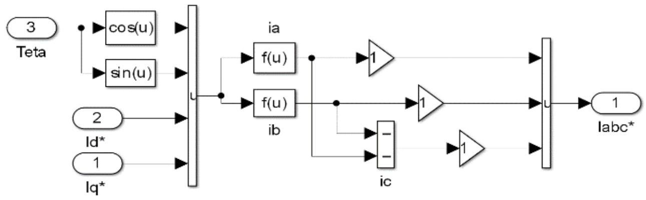

Fig. 7: DQ-ABC conversion block

The important property $T^{-1}(\theta) = \frac{3}{2}T^{T}(\theta)$ can be used to convert dq component into abc, Where

$$T(\theta) = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ -\sin\theta & -\sin(\theta - \frac{2\pi}{3}) & -\sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix}$$

$$T^{T}(\theta) = \frac{3}{2}\begin{bmatrix} \cos\theta & -\sin\theta & \frac{1}{\sqrt{2}} \\ \cos(\theta - \frac{2\pi}{3}) & -\sin(\theta - \frac{2\pi}{3}) & \frac{1}{\sqrt{2}} \\ \cos(\theta + \frac{2\pi}{3}) & -\sin(\theta + \frac{2\pi}{3}) & \frac{1}{\sqrt{2}} \end{bmatrix}$$

$$\begin{bmatrix} fa \\ fb \\ fc \end{bmatrix} = \frac{3}{2}\begin{bmatrix} \cos\theta & -\sin\theta & \frac{1}{\sqrt{2}} \\ \cos(\theta - \frac{2\pi}{3}) & -\sin(\theta - \frac{2\pi}{3}) & \frac{1}{\sqrt{2}} \\ \cos(\theta + \frac{2\pi}{3}) & -\sin(\theta + \frac{2\pi}{3}) & \frac{1}{\sqrt{2}} \end{bmatrix}\begin{bmatrix} fd \\ fq \\ f0 \end{bmatrix}$$

4) *Hysteresis Controller Block:*

The current hysteresis controller block is used here to attain hysteresis current control, in which input signals are three phase reference currents and practical currents, and output signals will act as controlling signals for inverter, as shown in Fig. When the practical current exceeds the reference current, and the error is larger than the ring width of hysteresis comparator, the equivalent phase will be conducted forward and turn OFF reversely, on the contrary, it will be conducted reversely & turns OFF forward. When appropriate hysteresis ring width is chosen, the practical current will trail the reference current continuously. In this manner the closed-loop control of can be achieved. To obtain the out of phase current output current of hysteresis current controller is first converted into digital signals and is fed to NOT gate which is further converted into analog signal. Thus we get six pulse currents for closed loop control.

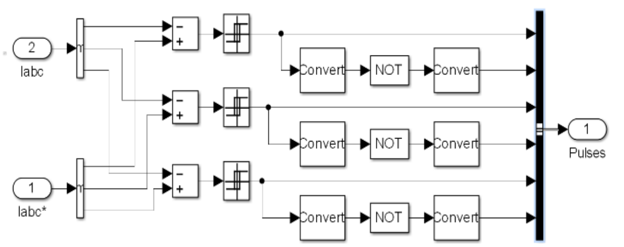

Fig. 8: Current hysteresis controller

5) *Voltage Source Inverter (VSI):*

The function of a voltage source inverter is to convert fixed DC voltage to a variable AC voltage. Depending upon the type of applications one can use single or three phase inverters. The three-phase inverter can be constructed by using three single phase half bridge inverter in parallel. The other way to get three phase output is by using six semiconductor switches such as MOSFET, IGBT, IGCT, etc. The Fig 4.7 shows a simple circuit of the three-phase VSI consisting of six switches and two capacitors.

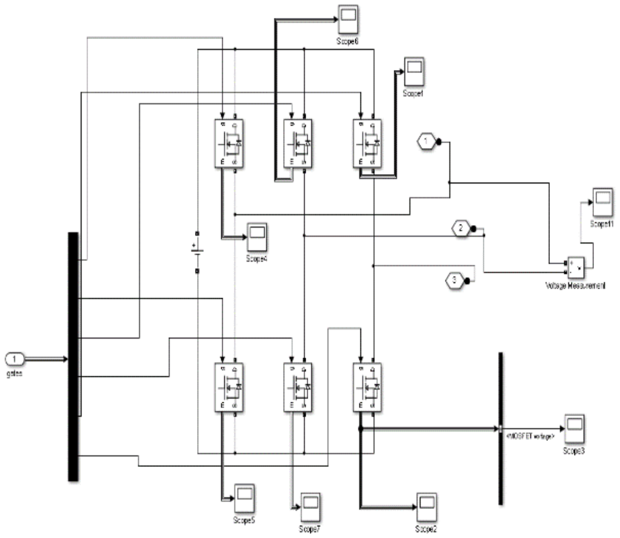

Fig. 9: voltage source inverter block

The voltage source inverter (VSI) uses a three-phase full-bridge inverter. The model of six power tubes can be made by using switching devices like MOSFET's, IGBT, IGCT etc. with shunt-wound diodes reversed in the Simulink/Sims Power systems Toolbox. While modeling, the pulse width modulation system, HPWM-LON, scheme is adopted. The three phase chop signals outputted from the current hysteresis controller and the conducted signals of six power tubes needs to contribute in controlling jointly, so that all the power tubes of inverter will work in a given sequence, and then a three phase adjustable voltages supply for PMBLDC motor will be obtained. Where the PWM signals are added with the conduction signal by using AND Gate and their outputting signals are taken as the inputting ones of the power tubes in upper bridge arm, while the power tubes in down bridge arms are controlled only by the conduction signals.

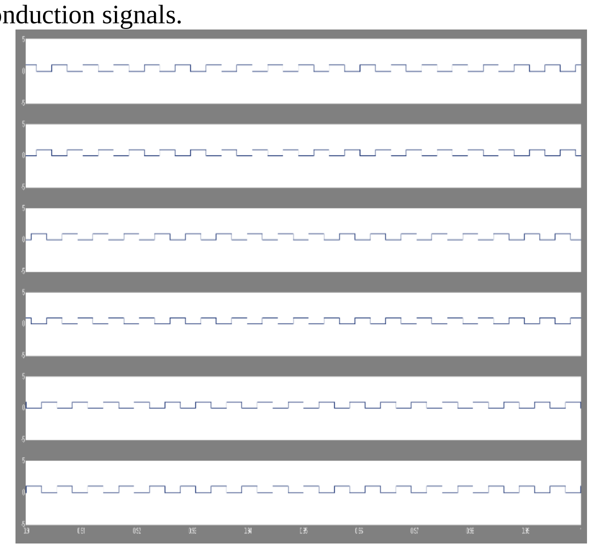

Fig. 10: Graph

III. SIMULATION RESULT

A. *Speed waveform:*

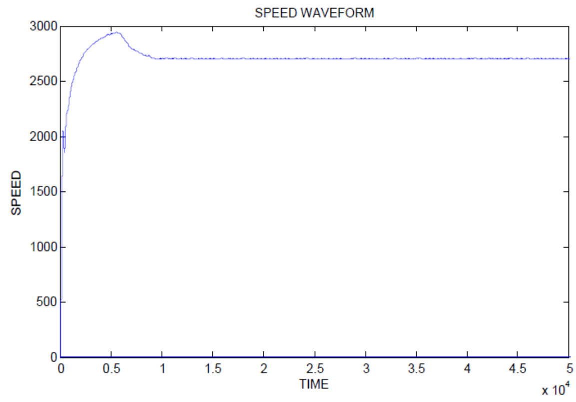

Fig. 11: Rotor Speed Waveform

This above fig depicts that the speed waveform of the rotor of a PMBLDC motor, on the X- axis time and on the Y-axis speed is taken, as the motor just starts speed goes on increasing and continuously rises up to a maximum value of 2900 RPM and then from there it slightly decreases and becomes constant near to a value of 2600 RPM.

B. *Torque Waveform:*

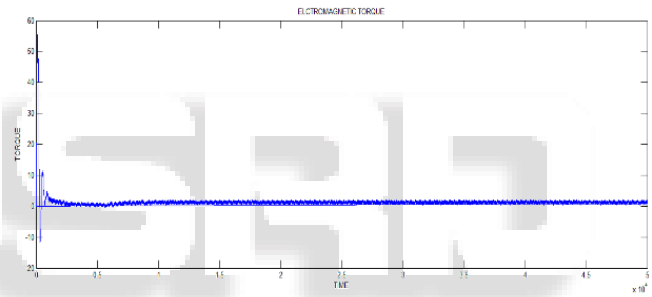

Fig. 12: Electromagnetic Torque (in Nm)

C. *Back EMF waveform:*

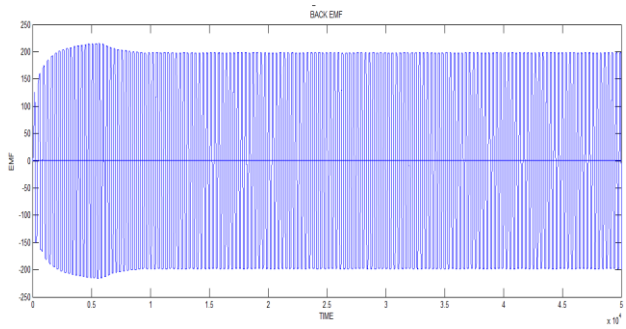

Fig. 13: Back EMF (V/sec) Waveform

D. Stator *Current:*

The below figure clearly shows the stator current waveform for phase A, in which on the X axis we have taken time (in sec) and on the Y axis we have taken current in (A). This figure clearly shows that at first when motor is initially started the stator current rises suddenly to some 40A and then from there it falls down and after 1 sec it becomes almost constant on 8A.

1) Stator current phase A-

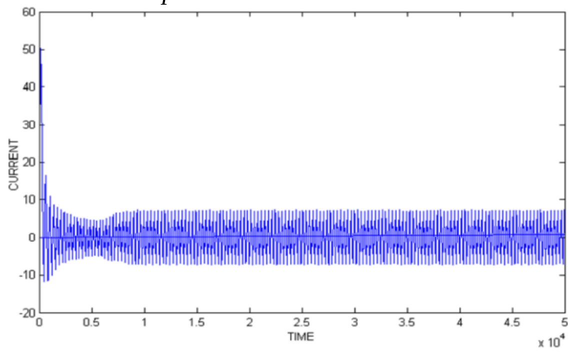

Fig. 14: Stator Current Waveform for Phase A

E. Inverter voltage:

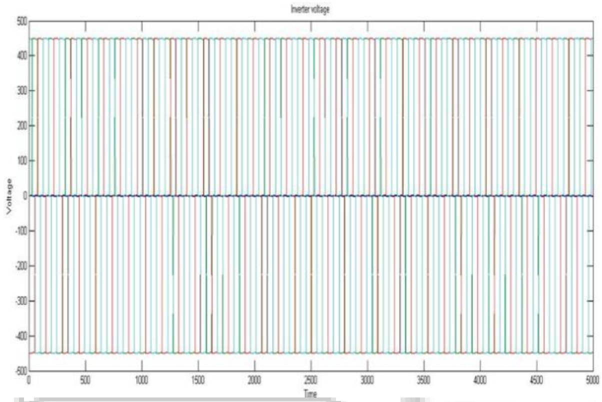

Fig. 15: inverter voltage

IV. CONCLUSION

The speed control of sensorless Permanent Magnet Brushless DC motor by MATLAB simulation is presented in this work. Here we have employed a PI controller for the generation of reference torque by the help of reference speed and actual speed generated by the motor, and this torque is applied to the current hysteresis controller block which generates the required six gate pulses for turning ON the three phase six pulse voltage source inverter. This three phase six pulse voltage source inverter further feds to the permanent magnet synchronous motor. The rotor speed of the permanent magnet brushless DC (PMBLDC) motor is observed 2590 RPM approximately. The back EMF is of Trapezoidal in nature and the voltage of the VSI is stepped type which is fed to the motor. All the simulation work done here is on the MATLAB 2013.

APPENDIX

The Parameters used in MATLAB /Simulation is:

L_S	**8.5e-3**
R_S	2.8750 ohms
P	No. of poles = 4
Flux linkage	0.175
K_P	3
K_i	6.2
V_S	450V

Table 1: Parameters

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