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A Motor Drive Controller for High Voltage Circuit Breakers by using Mechanical Operation of PMSM

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ABSTRACT

In this paper, a new type of motor drive operating mechanism of High Voltage Circuit Breakers (HVCB) based on techniques of power electronics and motor digital control has been studied. In this paper, the structure and the moving principle of operating mechanism for HVCB is analyzed and the control strategy for PMSM drive operating mechanism is described. The simulations, calculations and actual tests all indicate that parameters of the drive-motor such as the rotational inertia, the output torque and the output power will have impact on the performance of the operating mechanism. The research work of this paper has shown that it is advisable to adopt motor for driving operating mechanism of HVCB and such mechanism can meet the requirements for opening and closing operation of HVCBs.

Key Words: *High-voltage circuit breaker, motor drive, operation mechanism, permanent-magnet synchronous motor.*

I. INTRODUCTION

High Voltage Circuit-Breakers (HVCBs) are the very important apparatus responsible for controlling and protection in the electric power systems. The operating mechanism is the basic device which controls the opening and closing operations of HVCB. At present, there are several conventional types of operating mechanisms, such as electromagnetic mechanisms, spring mechanisms, pneumatic mechanisms and hydraulic mechanisms. Even though those conventional mechanisms have many prominent merits, they also have some insurmountable limitations. They usually have complex structures which are difficult to adjust. Therefore periodic check-ups are necessary and costs for operation and maintenance are high. Additionally, with those conventional mechanisms, the process of opening and closing operations could not be controlled [1] [2].

In order to overcome the limitations of conventional operating mechanisms and improve the operation performance of HVCBs, it is necessary to do research on new techniques for operating mechanisms of HVCBs [3-5]. In this paper, a new type of motor drive operating mechanism of HVCB has been studied there is only one rotational part of an electric machine rotor in the motor-drive mechanism, which is compact in structure than conventional mechanisms [6]. In this motor-drive mechanism, capacitor bank is adopted to store the energy for controlling the operating mechanism instead of springs or compressed air [7]. The energy flows out of the capacitor bank, through the converter made up of power electronics device and drives the PMSM Under the control of Digital Signal Processor (DSP), the PMSM directly drives the moving contact of HVCB to conduct opening and closing operations [8]. As no chains, hydraulic fluid or compressed air is needed to transfer the energy, this mechanism has higher efficiency and reliability. A closed-loop control strategy is adopted in the motor drive mechanism and the operation speed of the moving contact could be precisely controlled the change of the ambient temperature and the supply voltage will also have little impact on the motor [9]. Besides, since there are already sensors for velocity, position, current and voltage in the control system of the motor, it is easy to realize continuous self check and monitoring for the operating mechanism and the HVCB.

As a whole, The Motor Drive offers a totally new and versatile way to operate HVCBs. It has the following advantages: I) Fewer moving parts and impacts, low noise level, simple and reliable system; 2) No special power demand, no high short-term loads; 3) Operation curve could be selected due to the practical situation, with closed-loop control; 4) Contact travel is independent of ageing and change in ambient temperature; 5) Condition monitoring is inherent without the need for additional sensors.

The main focus of this paper is the control techniques for thetravel curve of the breaker. The speed, position, current, andvoltage sensors are installed in the control system to obtain continuous self testing and monitoring.

Fig.1 shows a demonstration of a CB operating device. Inthe opening operation driven by the motor-drive mechanism,the crank (8) rotates counterclockwise; pulling the insulatingrod (7) down. This will quickly drive the moving arc contact(3) downwards. At the end of the opening operation, the motorapplies a clockwise torque, as a buffering force, on the drivingshaft (9) todecelerate the crank (8) rotation. The moving arccontact (3) speed will smoothly decrease and the mechanicalimpact will be limited.

During the closing operation, the crank (8) rotates clockwisein the closing operation, pushing the insulation rod (7) upwards.The moving contact (3) accelerates up toward thefixed contact.Using preset calculations and control for speed and position, themotor then applies a reverse counterclockwise torque to decelerate the moving contact, thus toreduce the mechanical impactbetween the breaker contacts.

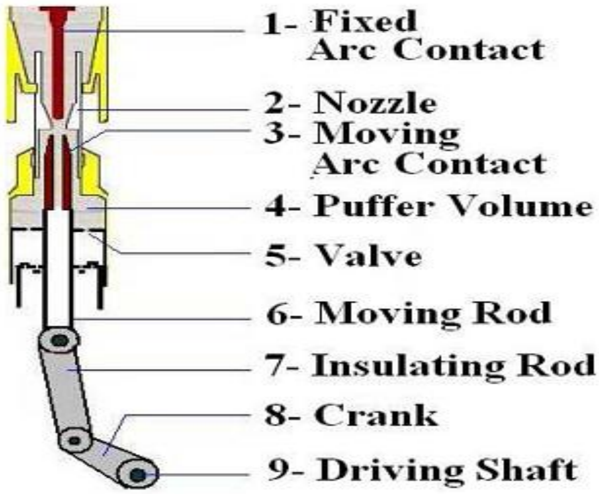

Fig.1. CB actuating device, where: 1:fixed arc contact, 2: -nozzle, 3: movingarc contact, 4: puffer volume, 5: valve, 6: moving rod, 7: insulating rod, 8: crank,9: driving shaft.

II. SYSTEM STRUCTURE AND PRINCIPLE

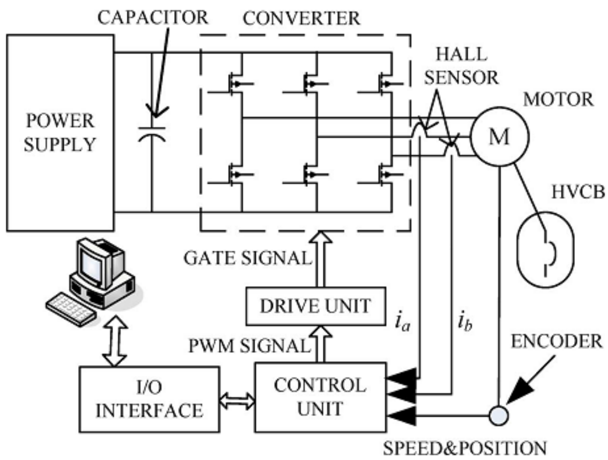

Fig.2. System diagram of the motor-drive mechanism.

The motor-drive mechanism is mainly composed of the ac/dcpower supply, energy buffer capacitors, converter, and control unit and motor, shown in Fig.2.

The capacitors are the energy buffering units. Large transientcurrent is required during the operation of a CB. The energyrequired is provided by the capacitors. Thus, the impact on thepower supply is minimized.

The converter is composed ofintelligent power modules(IPMs). The stator current is measured by hall sensors. Motorspeed and rotor position are measured by the optical encoderinstalled in the shaft. PMSM are used in many applications thatrequire rapid torque response and high-performance operation.The vector control method is used to control the PMSM. Thebasic idea of the vector control algorithm is to decompose astator current into a magnetic field-generating component anda torque generating component. After decomposition, bothcomponents can be separately controlled like a dc machine.The speed and torque of PMSM are separately controlled.

The mathematical model of a PMSM is [9] and [10]

$$\begin{cases} u_d = p\psi_d - \omega\psi_q + Ri_d \\ u_q = p\psi_q + \omega\psi_d + Ri_q \end{cases} \quad (1)$$

Where

$$\begin{cases} \psi_d = L_d i_d + \psi_r \\ \psi_q = L_q i_q. \end{cases} \quad (2)$$

u_d and u_q are the d, q axis voltages, $p$is the differential operator $(d)/(dt)$,i_d and i_q are the d, q axis stator currents, L_d and L_q are the d, q axis inductances, ψ_d and ψ_q are the d, q axis stator flux linkages, while $R$and $\omega$are the stator resistance andinverter frequency, respectively. ψ_r is the flux linkage due tothe rotor magnets linking the stator. The electric torque is

$$T_e = \frac{3}{2} p_m [(L_d - L_q) i_d i_q + \psi_r i_q] \quad (3)$$

And the equation for the motor dynamics is

$$T_e = T_L + Jp\Omega + B\Omega. \quad (4)$$

$p_m$is the number of pole pairs, $T_L$is the load torque, $B$is thedamping coefficient, $\Omega$is the rotor speed, $J$and is the equivalentinertia.

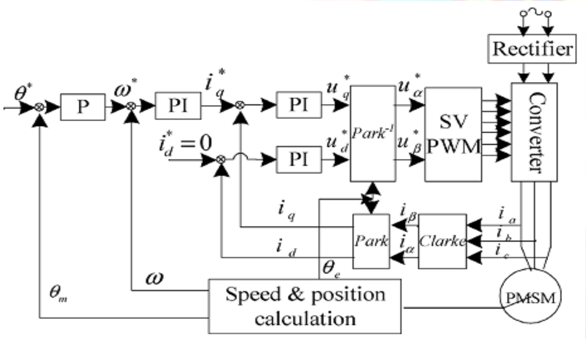

Fig.3. Vector control system diagram of PMSM. P: proportional controller,PI: proportional and integral controller; SVPWM: and space vector pulse widthmodulation.

In MATLAB/Simulink environment, the simulation modelof PMSM control system was created using Power Systemtoolbox. The simulation model is built according to the structure shown in Fig.3 [11]–[14]. Three-loop control strategyis adopted. The current loop uses the most easily achieved$i_d^* = 0$ control strategy. The motor output torque is directlyproportional to the q-axis current. The motor output toquecould be controlled by controlling i_q, and the electromagnetic torque generated by every ampere of current could be maximized. Throughfield orientated control, the PMSMflux andtorque decoupling control is implemented. Thus, good controlperformances similar to dc motors could be obtained [15]–[18].

The currents i_a, i_b, i_c are sampled by Hall current sensors. Through coordinate transformation, i_a, i_b, i_c are transformed tothe dc component i_d and $i_q$in the dq coordinate system. The mechanical angular displacement θ_m is measured by an incremental optical encoder. Through calculation, the electric angle θ_e and ω speed can be obtained. The θ_m is the negative feedback value of the position loop, $\theta^*$is the expected referencecurve, the reference ω^* is obtained by position proportional (P)controller, i_q^* the is obtained by speed Proportional and Integral(PI) controller and the voltage components in dq coordinates are obtained by current PI regulators. Through Park inverse transformation, the voltage components are transformed to the statorvoltage components in $\alpha\beta$ coordinates. Then SVPWM methodis used to generate control signals to control the converter. Thus,the control of motor is achieved [19]–[23].

III. PERMANENT MAGNET SYNCHRONOUS MOTOR (PMSM)

The development of high-quality permanent magnet materials into commercial production hasencouraged severalmanufacturers to launch various permanent magnet synchronous machines (PMSM) into the market. Permanent magnet synchronous machines have been applied to servo drives for a long time already, and nowadays, there are quite large permanent magnet synchronous machines also in industrial use. In wind mill generators, the development has currently been in the direction of permanent magnet machines. In principle, vector control is required for controlling the PMSM. Previously, the poor qualities of the magnetic materials could considerably restrict the implementation of a motor control. For instance, due to the poor demagnetization characteristics of AlNiCo magnets, the so-called id= 0 control was initially adopted inorder to ensure the stability of the polarization. The properties of NdFeB and SmCo magnets instead allow also the use of demagnetizing current. Demagnetizing current is used in particular when aiming at the field weakening of a permanent magnet machine; however, a negative current aligned with the d-axis occurs also in the constant flux range, when aiming at a high power factor for the drive.

The basic differences to the control principlesof other AC motors are due to the magnetic properties of permanent magnets, and particularly tothe fact that the permanent magnet material is a part of the magnetic circuit of the machine, and therefore has a significant influence on its reluctance. The relative permeability of permanent magnet materials μr is close to one, and therefore the effective direct air gap of the PMSM often becomes very large. Thereby also the inductances of the machine – particularly in machines in which the magnets are located on the rotor surface – usually remain rather low. Another difference is that the direct synchronous inductance, when employing embedded magnets, can be less than the quadrature value, while the ratio is the opposite in a separately excited salient-pole synchronous machine.

The field weakening of a PM machine has to be implemented by using a demagnetizing stator current. If the inductances are very low, the field weakening is not a rational option. In the surface magnet type servo motors, the per unit value of the synchronous inductance is typically in the range l_d= 0.2–0.4. An adequate rotation speed range is often achieved by dimensioning the rated frequency of the machine to be sufficientlyhigh. When employing embedded magnets, however, the inductances may be dimensioned so high thatthe rotation speed range can be expanded. Often when staying within the limits of the rated current, the upper limit remains at about double the rated speed at maximum. However, when applying field weakening, it should be borne in mind that the back emf caused by the permanent magnets is directly proportional to the rotation speed of the machine. If the demagnetizing current is lost for some reason, the inverter has to withstand this voltage undamaged; however, the danger of the breakdown of the inverter is obvious. Thewithstanding of DC link capacitors to voltages amounts typically only to 30–50 % above the rated voltage.

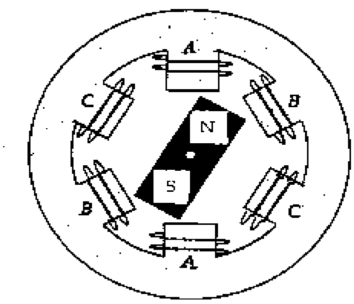

Fig.4 A three-phase synchronous motor with a one permanent magnet pair pole rotor

IV. MATLAB/SIMULINK RESULTS

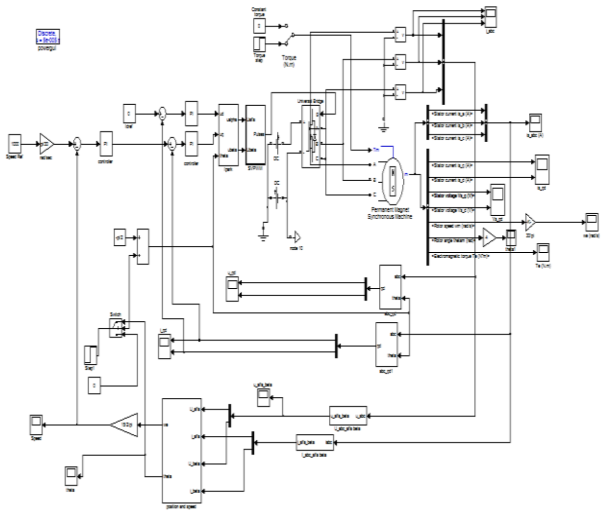

Fig.5 Simulation modeling of motor drive based operating mechanism for high voltage circuit breaker

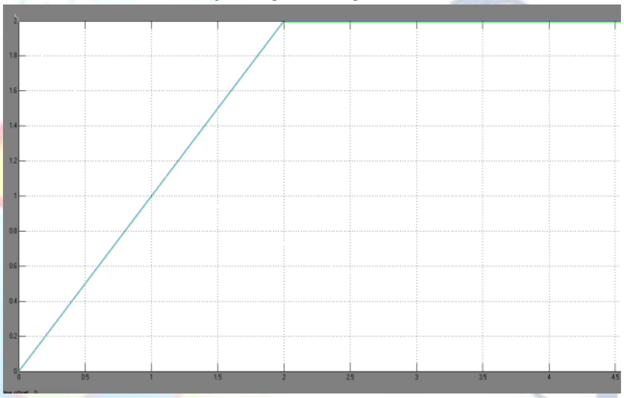

Fig.6 Motor angular speed curve

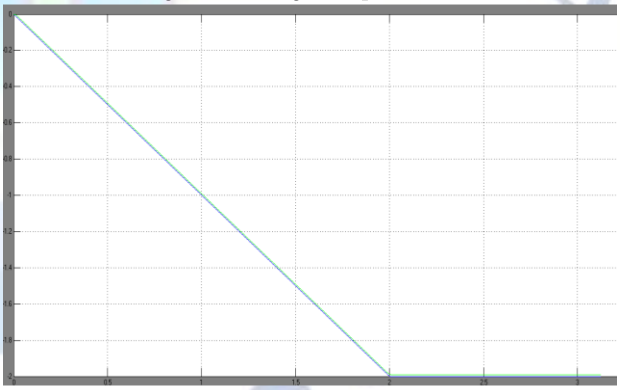

Fig.7 Motor angular displacement curve

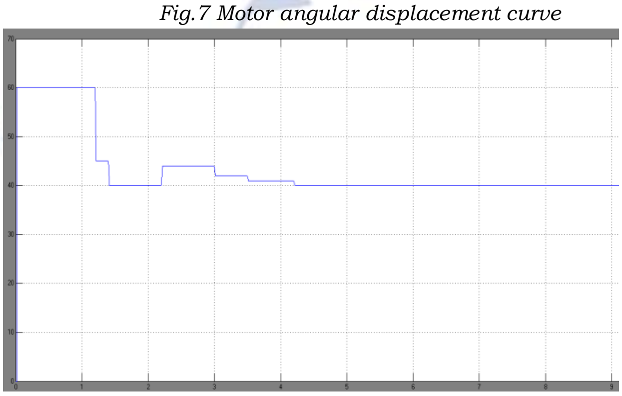

Fig.8 Stator current phase curve

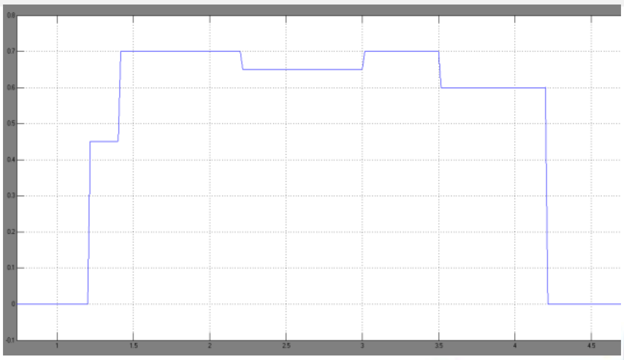

Fig.9 Motor angular displacement

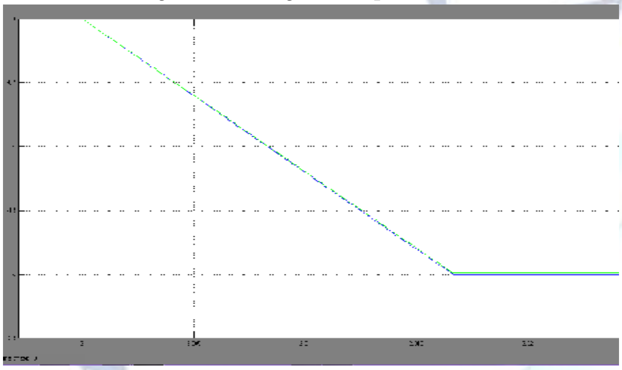

Fig.10 Motor drive mechanism opening test curve

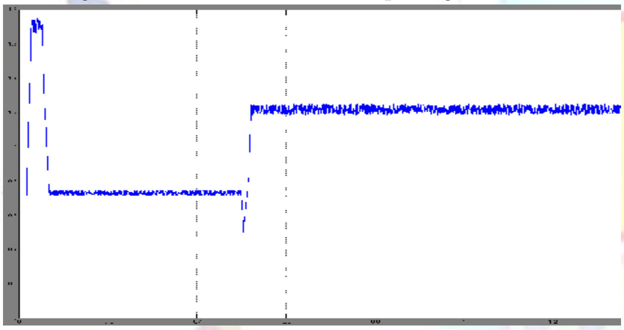

Fig.11 accelerating process in closing operation

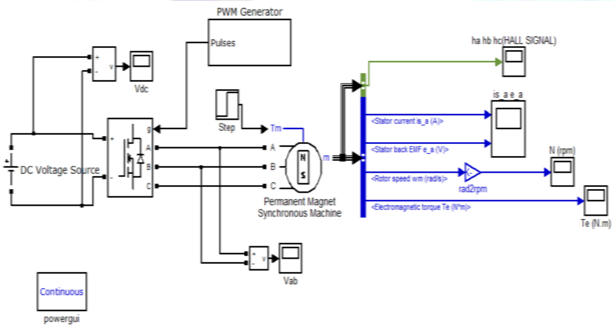

Fig.12 Simulink model of PMSM with PWM Generator

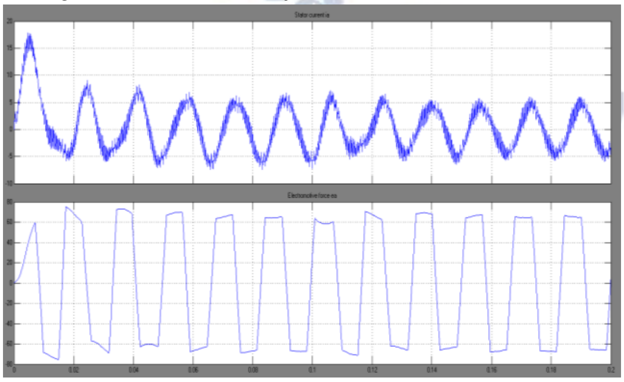

Fig.13 Stator Current and Back EMF

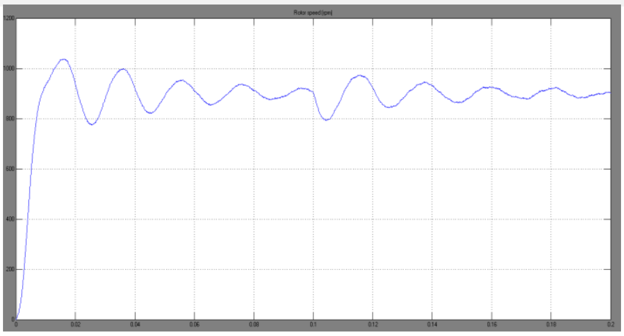

Fig.14 Speed of the motor

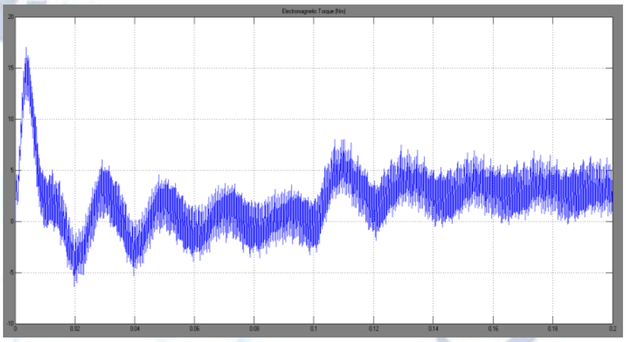

Fig.15 Torque characteristics of the motor

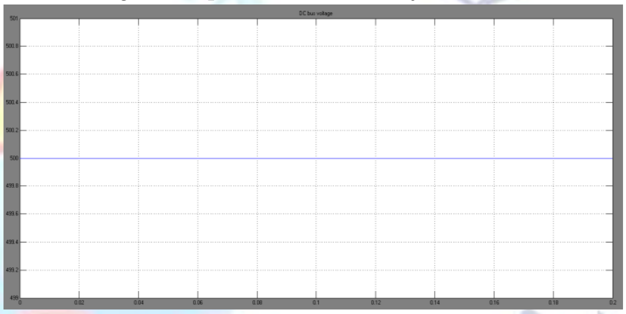

Fig.16 DC bus Voltage

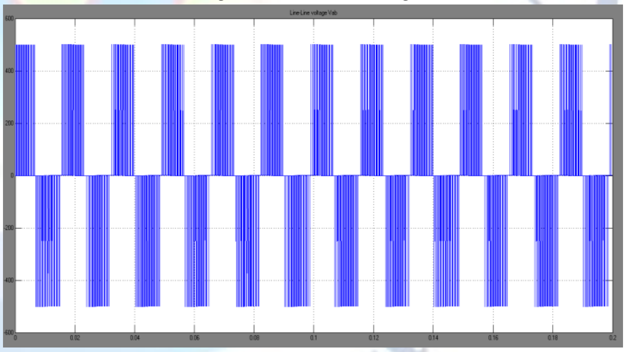

Fig.17 Inverter output Voltage

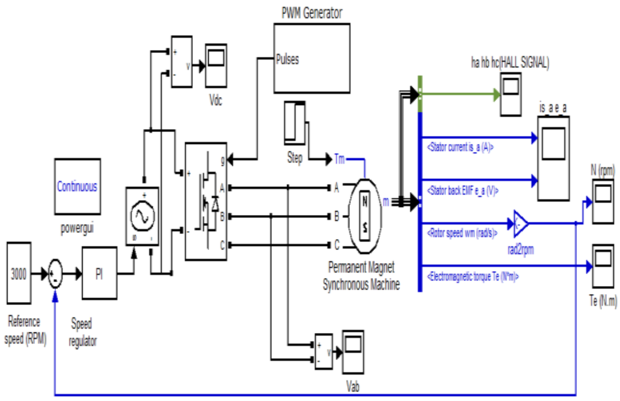

Fig.18 Simulink model of PMSM with PWM Generator with Controller

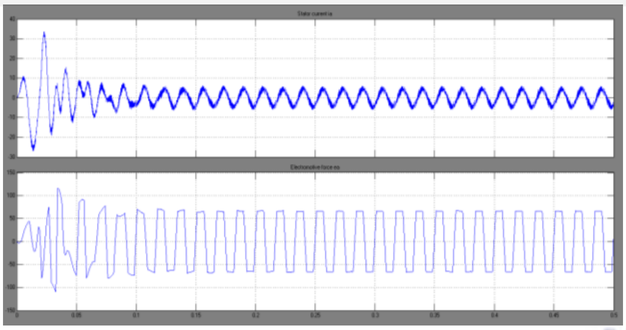

Fig.19 Stator Current and Back EMF

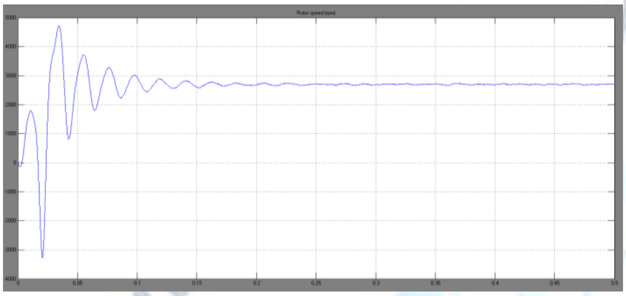

Fig.20 Speed of the motor

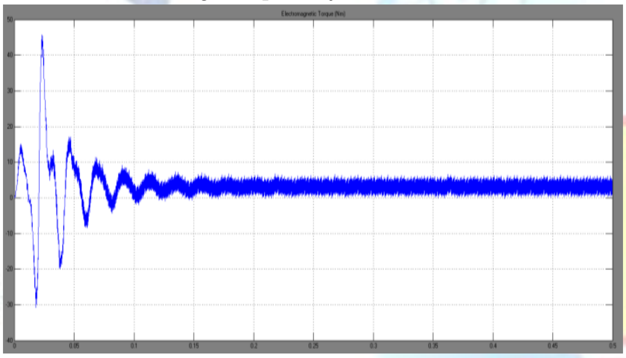

Fig.21 Torque characteristics of the motor

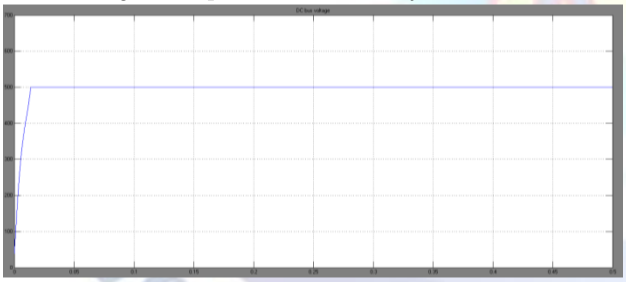

Fig.22 DC bus Voltage

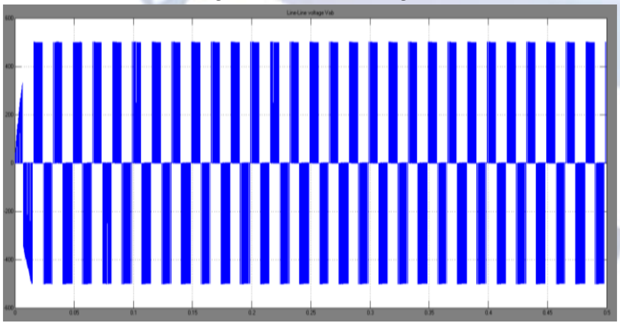

Fig.23 Inverter output Voltage

V. CONCLUSION

Based on the operating requirements of HVCBs, this paper chooses a PMSM as the driving motor. The simulation model is established and the DSP control program is developed according to the angle-speed curve, the angle curve and the torque curve. The test results of the closed-loop control in this paper shows that with the PMSM of specified parameters, the actual opening curves of 4Oms or above and the actual closing curves of 6Oms or above generally go well with those presupposed curves. The results indicate that the motor drive mechanism can operate HVCBs according to the presupposed operating characteristics curves. Therefore using motors to drive the mechanisms of HVCBs is feasible and of favorable control performance. Because of impacts from the gravity and the electrical and mechanical constants of the PMSM, actual operating curves of shorter time, less then 4Oms, do not go well with the presupposed ones. Therefore we should choose the PMSMs with less inertia and greater output torque for the HVCBs with heavier moving contacts and more limited operation time.

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