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SVPWM Based Multilevel Inverter for PMSM Drive

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Abstract-*The conventional PWM inverters are able to generate mostly two-level output waveforms. Many improvements have been proposed to classic configuration as regards the circuit structures, the control schemes, but the inverter performance was limited by the available number of levels to build the output voltage. To overcome these difficulties several topologies of multilevel inverter have been recently designed and they are now capturing the attention of many industries, specially for high power converters on account of certain advantages that these inverters have as compared to conventional PWM inverters like less switching losses, reduced harmonic losses, etc. In spite of these advantages some problems are also associated with these inverters. Out of these, capacitor voltage unbalance is prominent one. In this thesis, the Space Vector Pulse Width Modulation (SVPWM) technique has been applied to Permanent Magnet Synchronous Motor (PMSM) to formulate the switching pattern mainly for three-level inverter that minimizes the harmonic distortion at the inverter output.*

PMSM are widely used in low and mid power applications such as computer peripheral equipments, robotics, adjustable speed drives and electric vehicles. The growth in the market of PMSM motor drives has demanded the need of simulation tool capable of handling motor drive simulations. There is a need for controllable AC device which can supply required variable AC voltage to the drives. This controllable AC voltage is obtained from an inverter. The voltage in an inverter is controlled by various controlling techniques. This thesis mainly concerns to a controlling technique known as Space Vector Pulse Width Modulation which is computationally intensive and efficient method and is proved that, SVPWM technique will generate less number of harmonics than the conventional Sinusoidal PWM method. It has been proved that in a three-level inverter, speed remains unchanged irrespective of change in the load and less number of harmonics will be generated compared to a two-level inverter.

I. INTRODUCTION

In this thesis, the principle of Space Vector Pulse Width Modulation (SVPWM) and a method for implementing the SVPWM technique for Permanent Magnet Synchronous Motor (PMSM) based on MATLAB/SIMULINK are discussed. In MATLAB/SIMULINK, the simulation model of the whole system is built with two control loops, which are inner current-loop and the outer speed-loop. By simulating the motor at specific speed and torque, the waveforms are presented, which achieves the expected effect, reasonability and validity [1-3].

Permanent Magnet Synchronous Motors are becoming more popular because of their merits like: high torque/inertia ratio, high power density, high efficiency and small size. PMSM is preferred in industrial servo applications, to the DC motor due to considerations of the cost, size, low maintenance, maximum speed capability, and simplicity of design. Hence they are widely used for electrical appliances such as air conditioners, refrigerators, washing machines and cleaners. PMSM is primarily associated with high performance applications, and is normally fed by a voltage source inverter. A PMSM provides rotation at a fixed speed in synchronization with the frequency of the power source, regardless of the fluctuation of the load or line voltage. PMSMs are therefore ideal for high-accuracy fixed-speed drives [4, 5]. It also has a high overload capability. Precise speed regulation makes PMSM an ideal choice for certain industrial processes.

Digital control techniques of AC motors, such as the Space Vector Pulse Width Modulation (SVPWM), have been developed with wide range industrial applications. The SVPWM was brought forward in the 1980's, specifically for the frequency varying and speed regulation of AC motors. This forms the basis of the magnetic flux linkage tracking pulse width modulation [6]. Compared to other control techniques, SVPWM takes inverter and motor as a whole to realize variable frequency of voltage and speed adjustment. SVPWM can directly transform the stator voltage vectors from α, β-coordinate system to Pulse Width Modulation (PWM) signals (duty cycle values) [7].

This thesis is based on the analysis of mathematical model of PMSM, using the modular thought, with the powerful simulation modeling capabilities of MATLAB/SIMULINK. The entire PMSM control system as a whole will be divided into several independent functional modules: PMSM body module, Inverter module and Coordinate Transformation module and SVPWM production module. Combining these modules organically; we could build the simulation model of PMSM control system [8]. Through the simulation of the motor, a variety of simulation waveforms provide an effective means for the analysis and design of the PMSM control system.

The objectives of the study are:

To simulate PMSM using Space Vector Pulse-width Modulation Technique

To compare the output results and THD for two-level and three-level inverters

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II. PMSM CONTROL

The controller used for PMSM is Field-oriented control or Vector Control. This control method will maintain near-perpendicular stator flux and rotor flux by keeping the sum of stator fluxes constant. When the control axis is coincident with the stator flux, the stator flux in the load angle can be calculated from the stator current and the motor constants. When attempts are made to control this calculated stator flux at the same magnitude as the permanent magnet flux, the error in the flux can be calculated from the stator flux and the load angle. This makes it possible to construct a control system by feeding back the flux phase current calculation to the stator voltages for the various axes of the PMSM, with the control axis coincident with the stator flux producing a control voltage command. This voltage command is applied to the PMSM at the described frequency. On other hand, the field-oriented control method is often applied to PMSM motors with a sinusoidal back-EMF waveform shape to achieve high torque performance and efficiency.

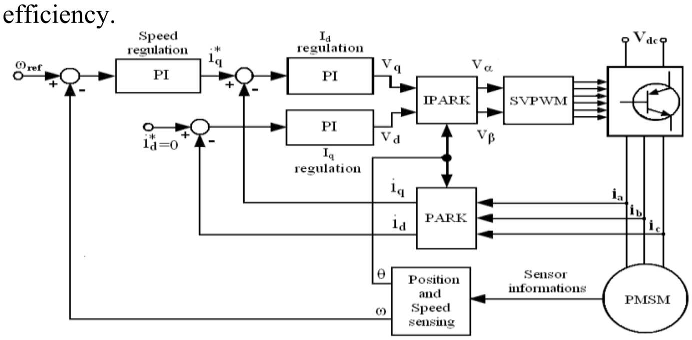

Figure 1: PMSM System Block Diagram Using SVPWM Technique

The controller is based on a current-controlled voltage source inverter structure. The current control loops are arranged in the 2-phase synchronously rotating reference frame d-q aligned with rotor flux, while the rotor position and speed detection operates in the 2-phase stationary reference frame α-β. During normal operations, the output of the speed regulator represents the q axis reference current i_q, while the d axis reference current i_d is set to zero in order to maximize the torque-to-current ratio of the PMSM. The outputs of the current regulators represent the reference voltages in the rotating reference frame. A d-q to α-β transformation then yields the reference voltage values in the stator reference frame, which are the inputs of SVPWM. Current feedback is obtained by measuring the 3-phase currents and the successive transformations to the stator and rotor components, respectively. The stator current components are used inside the observer, while the rotor current components are needed for current regulation.

Standard PI controllers, with limitation, are used for all regulators. PI controller is a generic feedback controller commonly used to implement closed-loop control. A PI controller responds to an error created by subtracting desired value from output quantity. Then it adjusts the controlled quantity to achieve the desired system response. The controlled value can be any measurable system quantity such as speed, torque or flux. The parameters of a PI controller can be adjusted empirically by tuning one or more gain values and observing the change in system response. It is assumed that the controller is executed frequently enough so that the system is under proper control.

III. SIMULATION OF PMSM DRIVE

The PM motor drive simulation was built in several steps like abc phase transformation to dqo variables, calculation torque and speed, and control circuit. The abc phase transformation to dqo variables is built using Parks transformation and for the dqo to abc the reverse transformation is used. For simulation purpose the voltages are the inputs and the current are output. Parks transformation used for converting I_{dqo} to I_{abc} is shown in Fig.2.5

Modeling of SVM Based Vector Controlled PMSM Drive:

The modeling of the SVM Based Vector Controlled PMSM Drive described in the previous chapters has been done in SIMULINK/MATLAB environment. Various system configurations which have been tried are described.

Two-Level SVM Based Vector Controlled PMSM Drive:

The operation of the controller must be according to the speed range. For operation up to rated speed it will operate in constant torque region and for speeds above rated speed it will operate in flux-weakening region. In this region the d-axis flux and the developed torque are reduced. Speed controller calculates the difference between the reference speed and the actual speed producing an error, which is fed to the PI controller. PI controllers are used widely for motion control systems. They consist of a proportional gain that produces an output proportional to the input error and an integration to make the steady state error zero for a step change in the input. Speed control of motors mainly consist of two loops the inner loop for current and the outer loop for speed. The order of the loops is due to their response, how fast they can be changed. This requires a current loop at least 10 times faster than the speed loop allowing reducing the system block diagram by considering the current loop to be of unity gain. Since the PMSM is operated using field oriented control, it can be modeled like a dc motor. The design begins with the innermost current loop by drawing the block diagram. But in PMSM drive system the motor has current controllers which make the current loop. The current control is performed by the comparison of the reference currents with the actual motor currents.

IV. DISCUSSION OF RESULTS

The phase is switched to the next in every 60 electrical degrees. The operation duration of each power electronic part is 120 electrical degrees. The exciting duration of each winding is 240

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electrical degrees: including 120 degrees for positive direction and 120 degrees for negative direction.

When the sampling period of PWM is $2e^{-6}$sec, the DC bus voltage is 400V for two-level inverter and sampling period is $5e^{-6}$sec, the DC bus voltage is 500V for three-level inverter. The simulation reference speed is set to 400 rad/s and the simulation time is 1sec. At t=0sec, the motor starts up. Then the torque, speed and the 3-phase currents are noted for two-level and three-level inverters. At t=0.5sec, a load torque of 2Nm is applied to the motor and the torque, speed currents are noted as in previous. Finally the harmonics are calculated and are compared for two-level, three-level inverters.

Comparison of Simulation Results for Two-Level and Three-Level Inverters without Load

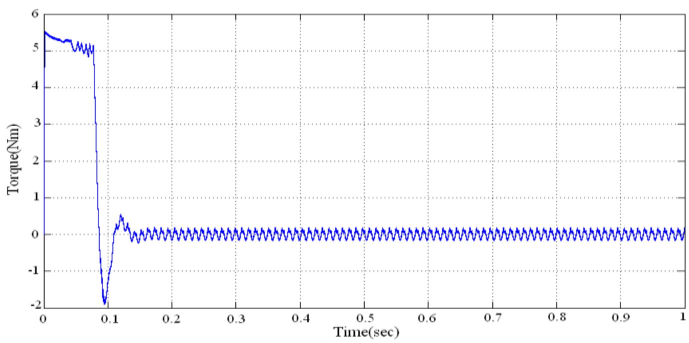

Figure 2: Two-level torque without load

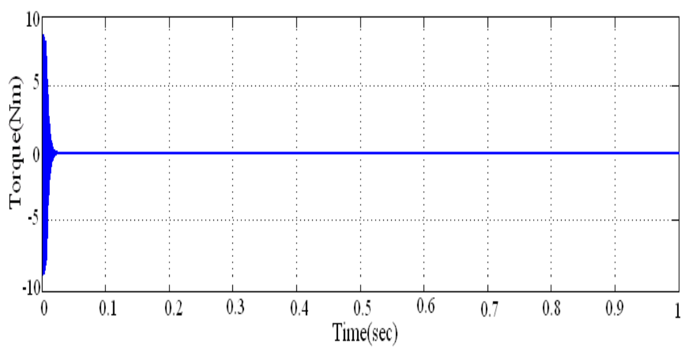

Figure 3: Three-level torque without load

Above figures represent the Two-level and Three-level Torques at no load. We see that there is more distortion in the torque for two-level when compared to three-level.

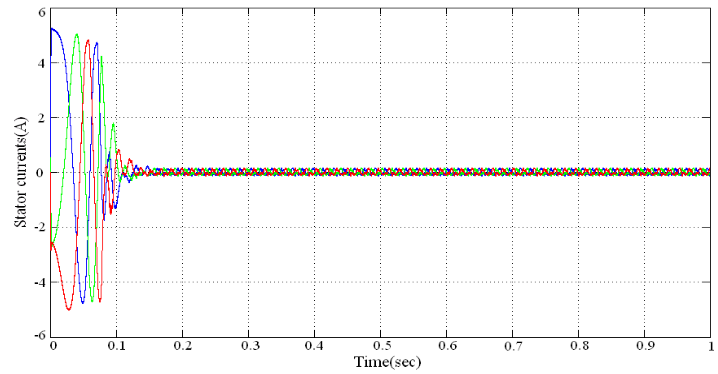

Figure 4: Two-level stator currents without load

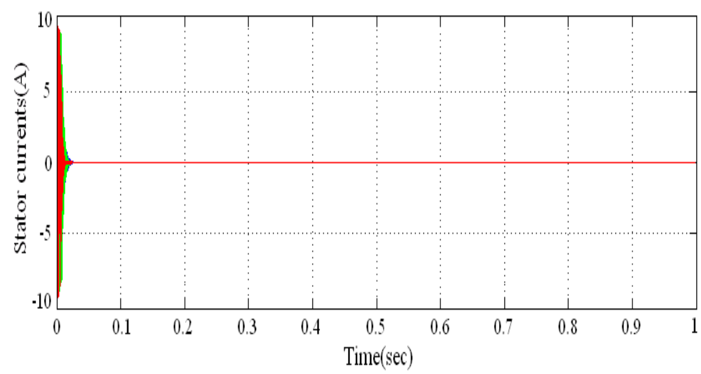

Figure 5: Three-level stator currents without load

Fig 4 and Fig 5 represents the Two-level and Three-level Stator currents. Since no load is applied the currents are at 0. They are not pure sinusoidal for two-level inverter and appears like a single line in three-level inverter.

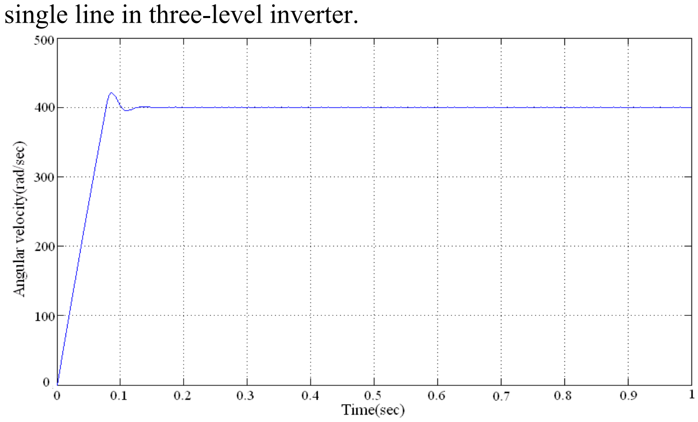

Figure 6: Two-level rotor speed without load

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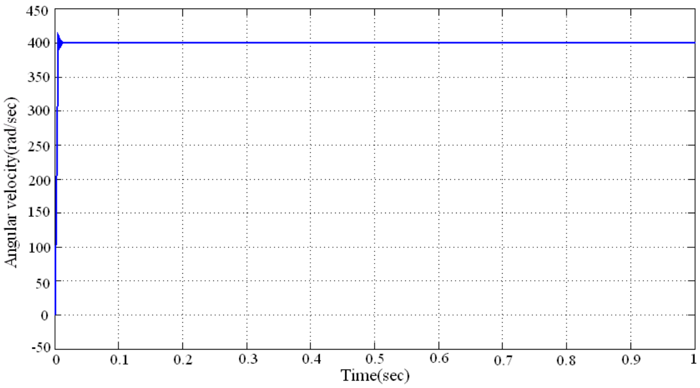

Figure 7: Three-level rotor speed without load

From the above figures we see that the motor settles faster in a Three-level inverter than in a Two-level inverter.

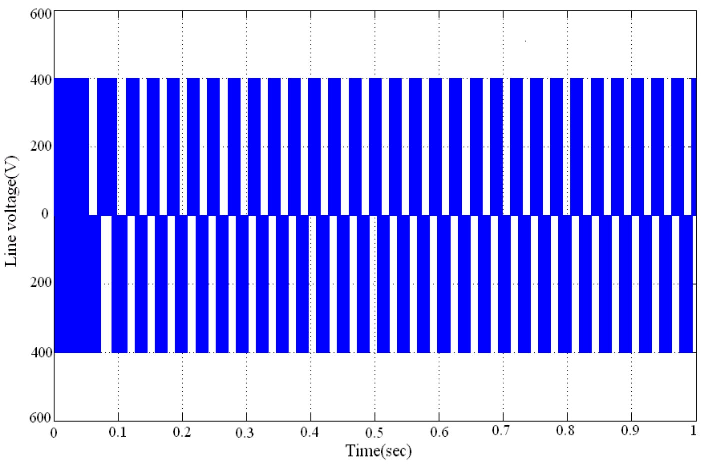

Figure 8: Two-level line voltage without load

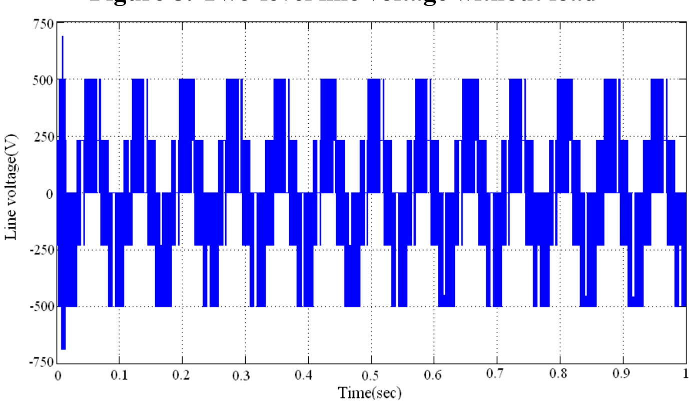

Figure 9: Three-level line voltage without load

Fig 8 and Fig 9 represents the Line voltages of Two-level and Three-level inverters. We see that the number of levels increases for three-level inverter.

Comparison of Simulation Results for Two-Level and Three-Level Inverters with Load:

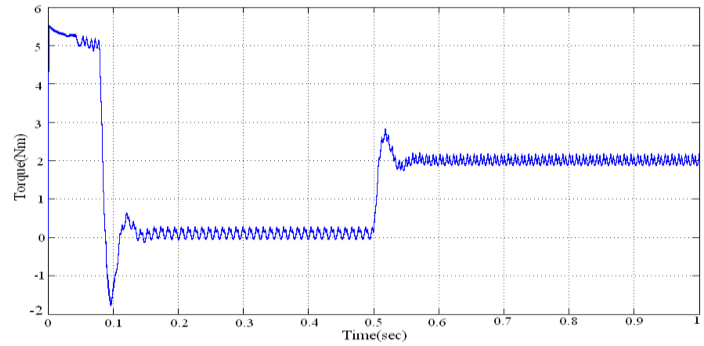

Figure 10: Two-level torque with load

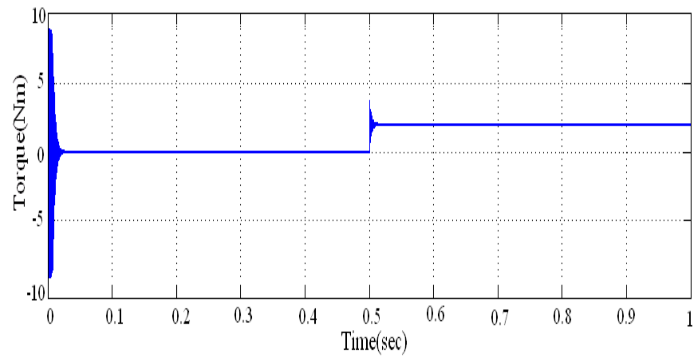

Figure 11: Three-level torque with load

When we apply a load of 2 Nm at 0.5sec the torque increases. When compared to Two-level inverter the distortion is less in a Three-level inverter.

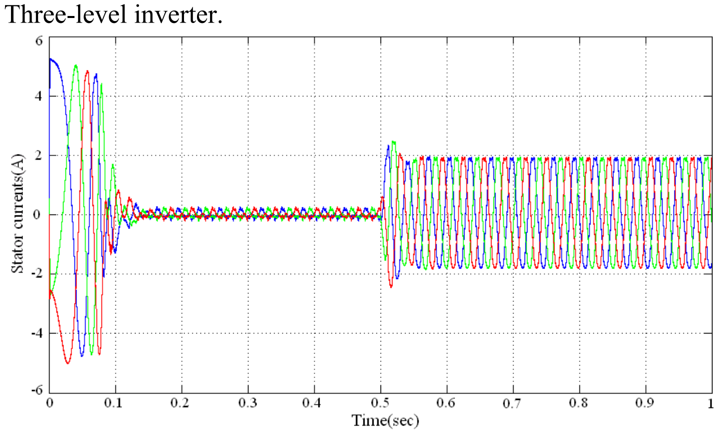

Figure 12: Two-level stator currents with load

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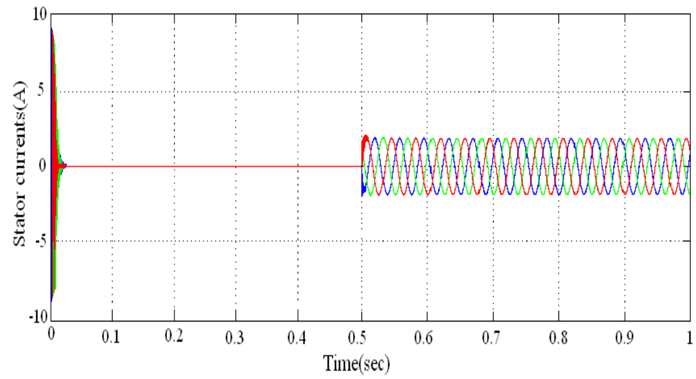

Figure 13: Three-level stator currents with load

From the above figures we see that when we apply load the currents increases. We see that the currents are clear and pure sinusoidal for a three-level inverter than in two-level inverter.

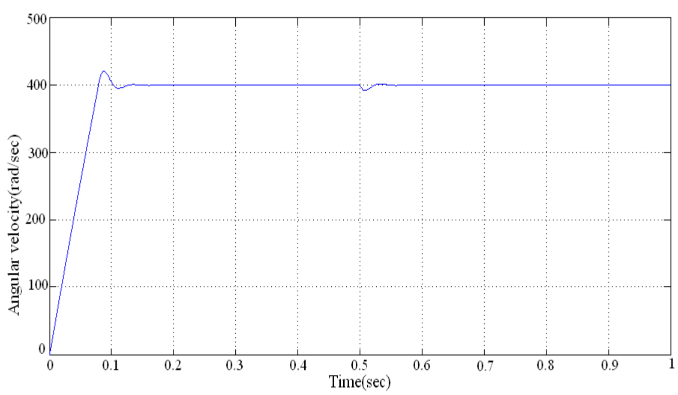

Figure 14: Two-level rotor speed with load

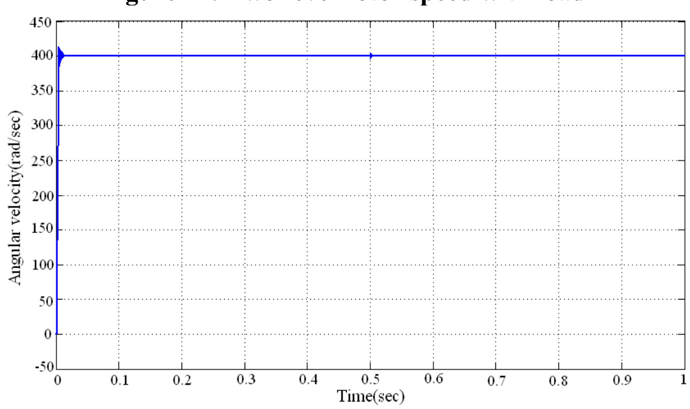

Figure 15: Three-level rotor speed with load

From Fig.14 and 15 we see that when load is applied, in a two-level inverter the speed falls down and then settles at the reference speed after some time. But in a three-level inverter the speed remains constant irrespective of load, which is the main aspect of PMSM.

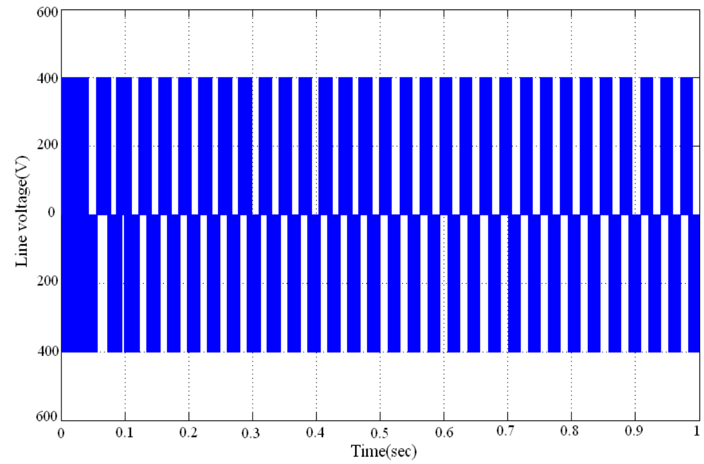

Figure 16: Two-level line voltage with load

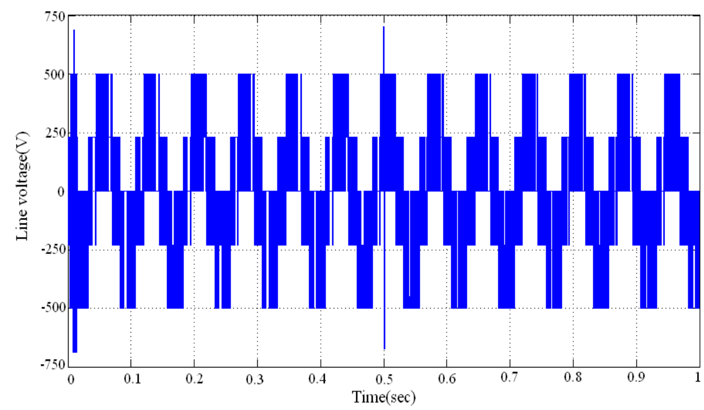

Figure 17: Three-level line voltage with load

Above figures show that there will be no change in the line voltages even after the load is applied.

Comparison of THD for Two-level and Three-level inverters:

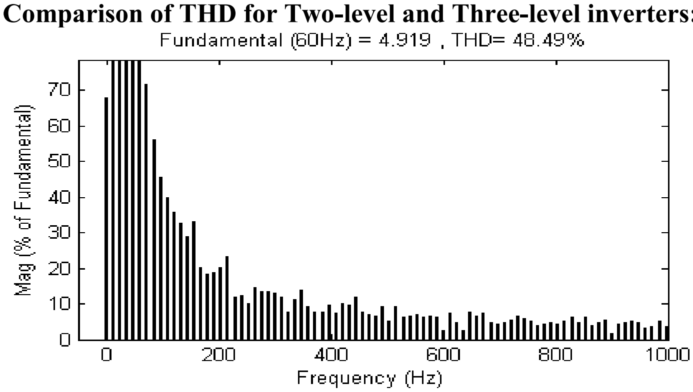

Figure 18: Two-level THD

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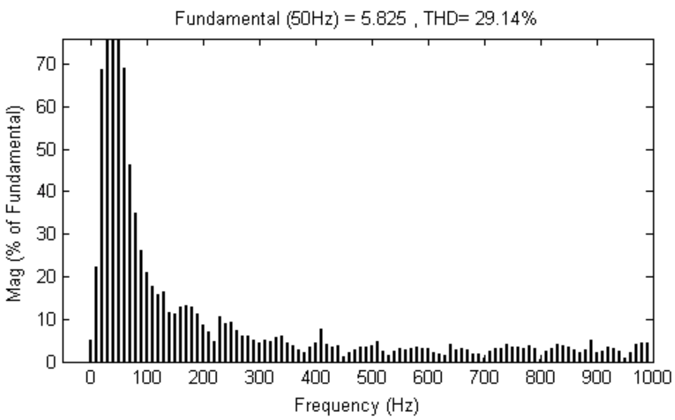

Figure 19: Three-level THD

From the simulations, it can be seen that the startup speed of motor is fast in three-level inverter and is able to follow the reference speed quickly. With load torque, the fluctuation of rotary speed waveform is very small and harmonics are decreased.

CONCLUSION

A complete three-phase PMSM drive simulation with SVPWM technique for the two and three-level inverters is proposed and described in detail. It has been shown by the result that the speed of three-level inverter remains the same even we apply load. Hence it can also be applied for N- levels.

It has been shown that the SVPWM technique utilizes DC bus voltage more efficiently and generates less harmonic distortion in a three-phase voltage-source inverter. In this thesis, a theoretical study concerning the application of the SVPWM control strategy on two-level and three-level voltage inverters were presented. This last aimed on the one hand to prove the effectiveness of the SVPWM in the contribution in the switching power losses reduction, and to show the advantage of multilevel inverters that carry out voltages with less harmonic content's injection than the comparable two-level inverters on the other hand. The obtained simulation results were satisfactory. As prospects, future experimental works will validate the simulation results.

REFERENCES

[1] S. Ogasawara, M. Nishimura, H. Akagi, A. Nabae, and Y. Nakanishi, "A high performance AC servo system with permanent magnet synchronous motors," IEEE Transactions on Industrial Electronics, Vol. 33, No. 1, pp. 87-91, 1986.

[2] Irfan Guney, Yuksetoguz, Fusun Serteller. "Dynamic behavior model of permanent magnet synchronous motor fed by PWM inverter and fuzzy logic controller for stator phase current, flux and torque control of PMSM". IEEE Proceeding from Electric Machines and Drives Conference, Vol.12, No.17, 2001, pp. 479-485.

[3] Changjiang Zhan, Vigna Kumaran Ramachan-daramurthy. "Dynamic Voltage Restorer Based on Voltage-Space-Vector PWM Control". IEEE Transactions on Industry Trans on Industry Applications, Vol.37, No.6, 2001, pp.1885-1863.

[4] B. Vladimir and K. Vikram, "A new mathematical model and control of a three-phase AC–DC Voltage source converter," IEEE Transactions on Power Electronics, Vol. 12, No. 1, pp. 116-123, 1997.

[5] K. Gupta and A. M. Khambadkone, "A Space Vector PWM Scheme for Multilevel Inverters Based on Two-Level Space Vector PWM," IEEE Transactions on Industrial Electronics, Vol. 53, No 5, pp. 1631-1639, Oct. 2006.

[6] R. Wu, S. B. Dewan, and G. R. Slemon, "Analysis of an AC-to-DC Voltage source converter using PWM with phase and amplitude control," IEEE Transactions on Industry Applications, Vol. 27, No. 2, pp. 1156-1163, 1991.

[7] M. Kadjoudj and M. E. H. Benbouzid, "A robust hybrid current control for permanent magnet synchronous motor drive," IEEE Transactions on Energy Conversion, Vol. 19, No. 1, pp. 109-115, Mar. 2004.

[8] Mizutani R, Takeshita T, Mat sui N. "Current Model Based Sensorless Drive of Salient pole PMSM at Low Speed and Standstill". IEEE Trans on Ind Appl, Vol.36, No.6, 2000, pp. 1598-1603.

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