A Detailed Model of The Space Vector Modulated Control Of A VVF Controlled Ac Machine Including The Overmodulation Region

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Abstract: This paper proposes a method of speed control of three phase Induction motor which is mainly governed by the Space Vector Modulation technique. The purpose is to show the smooth working of the model in the overmodulation regions of the inverter modulation operation. It is a completely simulated work and the results show that the model can very well be tested in the actual experimental setup. In the scheme, the speed command is compared with the actual speed and the error is processed to generate the gating patterns for the space vector modulated voltage source inverter. The scheme ensures smooth variation and control of the speed and torque in the overmodulation region and even beyond it i.e. in the field weakening region.

Keywords: vvvf method, SVPWM, field weakening region, Overmodulation.

I. INTRODUCTION
The Induction motors need to be fed through three phase inverters to run them at high speeds. Constant switching frequency Field Oriented Control uses either the carrier based sine-triangle methods, [1] or SVM, [2] for switching. Due to simplicity in digital implementation, Direct Torque Controlled SVM schemes use conventional space vector modulation, for switching the inverter, [3]. In [4], the overmodulation range is divided into two sub-regions and the inverter switching is defined based upon the unique characteristics of the two regions. In the first sub-region, a pre-processor modifies the magnitude of the reference voltage vector before it is being processed by the conventional space vector modulator. In the second sub-region, the pre-processor modifies both the angle and magnitude of the reference voltage vector. To avoid the solution of nonlinear equations, two look up tables are used and continuous control of voltage is obtained until six-step region. While the fundamental voltage cannot be obtained in every sampling period, [4] gets it in a fundamental cycle. The other overmodulation schemes like [5], [6], [7], and [8] use the basic geometrical understanding provided in [4].

The normally adopted method of speed control is the variable voltage variable frequency method where the ratio of the applied voltage to the input supply frequency is kept constant in the region of interest. In order to increase the speed of the motor, the frequency is usually increased which results in the increase of the synchronous speed of the rotating magnetic field and if the operating slip is held constant, the speed accordingly increases. The vvvf method necessitates that the applied voltage should also be increased proportionately in order to maintain the magnetic flux in the machine constant. This constant value of the magnetic flux ensures that the capacity torque utilization of the machine is made and also the machine does not go deep into the saturation region.

II. A DETAILED SVM MODEL
The scheme developed in this paper is implemented through a detailed model as shown below in figure (1).

The model starts with three constant blocks representing step inputs for speeds in per unit (pu) which are applied such that they cover all the regions viz. linear, overmodulation and six step. The first step input command is given at t= 0.075 seconds of the value 0.01pu. The second input is applied at t=0.15 seconds of the value 0.8pu thus ensuring the total speed input to be 0.01+0.8=0.81pu. The third input is given at t=0.3 seconds of the value 0.4pu making the total speed command to be 0.81+0.4=1.21pu which is well above the six step operation of 1.0 pu. The sum of these step input speed values in pu is next subtracted from the actual speed to get the speed error which is given as input to a PI controller. The output of this controller is fed to a MATLAB function file which decides the reference value of the torque depending upon the various values of the speed error. The reference torque thus calculated is next subtracted from the actual torque value (estimated) and the error is given to another PI controller whose output is given to a MATLAB function file which gives speed in pu as its output.
The emphasis is that the difference between the reference and actual values of torques decides the value of the slip speed. This slip speed value is next added with the actual speed (which is also derived in pu) to get the value of the synchronous speed in pu. This synchronous speed is multiplied by a gain of 314.159 to get the actual speed value. This actual speed is made to pass through a discrete integrator block in order to get the position (angle) of the reference stator flux vector.

Figure 1: Model for torque control combining the SVM with DTC
The model proceeds with another MATLAB function file containing nine inputs:
1) 'psi_s_ref_mag' i.e. reference flux magnitude (initial) is taken as unity,
2) 'psi_s_alpha', i.e. the alpha component of the actual flux vector (taken from the motor model),
3) 'psi_s_beta' i.e. the beta component of the actual flux vector (taken from the motor model),
4) 'is_alpha' i.e. the alpha component of the stator current (taken from the motor model),
5) 'is_beta' i.e. the beta component of the stator current (taken from the motor model),
6) \( \Omega_s \) i.e. the synchronous speed which is achieved by the manner as explained above,
7) 'Ts' i.e. the time period of the discrete inverter output,
8) 'ref_angle' is the angle of the stator flux vector obtained by integrating the synchronous speed as explained above and
9) '\( \Omega \)' i.e. the actual motor speed taken from the motor model.

With the help of these nine inputs the main ‘M-file’ is developed. It starts with the calculation of the alpha and beta components of the reference flux vector with the help of the first and the eighth inputs i.e. the starting reference flux vector magnitude and the reference angle which is already calculated. Next step is the calculation of the predicted stator flux vector at the following (i.e. next) sampling interval. The difference of this predicted vector and the actual flux vector is then added to the product of the stator resistance voltage drop and the sampling period \( T_S \) to get the value of the reference flux error vector \( \Delta \Psi_s^r(k) \). The alpha and beta components of this flux error vector give us the expression for delta which is the angular position of \( \Delta \Psi_s^r(k) \). Next the sector number and the angle gamma within a particular sector is calculated and based on the sector number six pairs of active voltage vectors is formulated. This is followed by the algorithms for various regions of modulation i.e. normal, OVM I and OVM II. Finally the outputs of the function file are derived which include the alpha and beta components of the voltage vectors and those of the flux error vectors. These outputs are shown in the figures to follow. The voltage vectors are taken from the MATLAB function file and fed to the three phase induction motor model. The results are displayed and discussed below.

III. RESULTS AND DISCUSSIONS

Figure (2) shows the variation in the stator current values. The d and q components of the stator current vary according to the speed requirements as shown. After the initial starting current values it can be seen that the currents shoot up at t=0.075, t=0.15 and t=0.3 seconds when the speed inputs are applied as discussed before.

Figure 2: Stator currents d and q components

Figure (3) represents the variation of the real component of the stator flux error vector with respect to time. The step demand of speed at t=0.15 and t=0.3 seconds indicates that the rate of change of flux increases at these points thus causing an upward shoot in the value of the flux error vector as can be seen.

Figure 3: Stator flux error vector (real component)

The real and imaginary components of the stator flux vector are shown in figures (4a) and (4b).
It can be observed clearly that as soon as the velocity of the motor increases and crosses the 1.0 pu mark, the field weakening region starts and the magnitude of the flux reduces.

The variations of the actual speed values are shown in figure (6). The figure shows how the speed shoots up at three various points of times i.e. at t=0.075, 0.15 and 0.3. At t=0.3 seconds the speed increases beyond the 1.0 pu value (at 1.21 pu as already discussed), indicating the six-step operation of the three phase inverter. The smooth variation in speed throughout the complete modulation range is the specific advantage of the DTC-SVM scheme used in the model. The speed remains at its demanded value thereafter.

Figure (7) shows the variation in the actual torque value. It can clearly be seen that in the field weakening region (beyond the 1.0 pu speed value after t=0.3 seconds), there is a reduction in the value of the torque. The almost zero response time variation in torque is the advantage this scheme offers.

Figure (8) shows the alpha and beta components of the output voltages of the space vector modulated inverter configuration. These voltages are the inputs to the three phase induction motor.
IV. CONCLUSION

The paper has concentrated mainly on the torque and speed control issues of a three-phase inverter fed induction motor drive. The DTC-SVM is improvised for delivering better performance in the overmodulation region of the three-phase inverter operation. The proposed algorithm enables an easy transition from the linear modulation state (with $\text{MI} \leq 0.907$) to over modulation I and II to six step with the variation only coming in terms of the different expressions of the switching times $\tau_a$, $\tau_b$, and $\tau_0$ which is quite easy to realize in the actual hardware setup. A detailed model has been presented in the paper which encompasses all possible speed ranges including the field weakening region. The algorithm developed emphasizes the geometrical equality of the maximum volt-seconds lost at the centre of the hexagonal side and the maximum compensation that can be provided around the vertex region.

REFERENCES