A NEW CURRENT CONTROL FOR 3-LEVEL INVERTER

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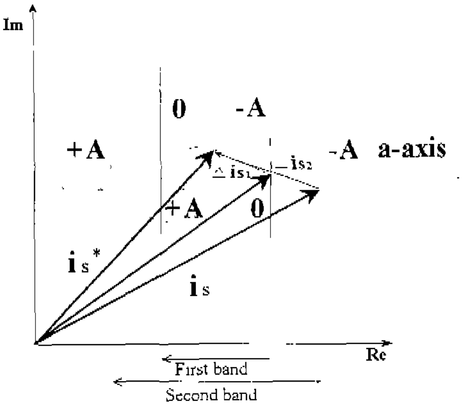
ABSTRACT-A new current controlled PWM technique for a 3-level inverter has been proposed and described in the paper. The proposed current control has the simple structure without needing to calculate the switching angles of the voltage vectors. The output in the proposed inverter contains less harmonic content than that of a conventional current controlled PWM controller, since the current control can be applied to the 3-level inverter. In addition, the proposed current controlled PWM technique has lower switching frequency than that of a conventional current controlled PWM technique at the same current limit. The control method and the performance for a proposed 3-level inverter has been discussed and investigated by the computer simulation.

1.INTRODUCTION

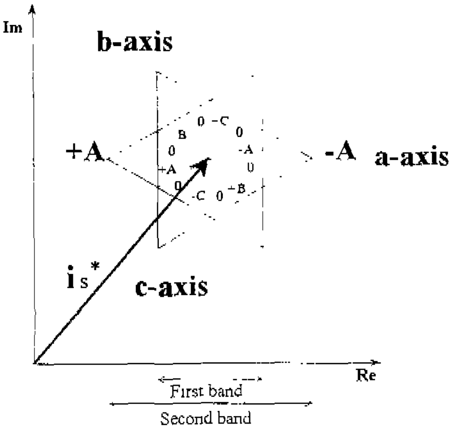
When an inverter is applied to an A.C motor drive system, harmonics cause losses and pulsating torques in the motors. From the energy saving viewpoint, it is necessary to develop a high efficiency motor drive system. Pulse width modulation (PWM) techniques have been developed for inverter circuits to reduce the magnitude of the harmonics and to allow control of the fundamental component of output voltage. So far, several control schemes for 3-level inverters have been proposed. Reported switching patterns are based on the selective harmonic elimination[1][2]. A current controlled PWM with a 3-level inverter is presented in this paper. This inverter output contains less harmonic content than that of a conventional current controlled PWM. Since the imposed voltage across the main switching devices is half the D.C source voltage, the presented current controlled PWM technique has lower switching frequency than that of a conventional current controlled PWM technique at the same current limit. Another important feature of the current controlled PWM is its capability to decrease the switching stress of the switching components. It is particularly attractive in a high power application such as the traction system. In addition, this proposed method has simple control processing without calculating the switching angle in the whole control region. Thus, its implementation is easier than the conventional 3-level PWM method.

2.CHARACTERISTICS OF THE CURRENT CONTROLLER FOR 3-LEVEL INVERTER

The behavior of the proposed current controlled PWM techniques can be explained in terms of a complex plane switching diagram as shown in Fig. 1. Fig. 1(a) shows the reference current vector i_s^*, and the current error vector Δi_s in the complex plane along with the a-axis of a three-phase reference system. The line current error Δi_a is the projection of Δi_s on this axis. The current controller will switch the a-phase inverter leg when Δi_a exceeds the first current band as represented by the two switching lines drawn perpendicular to the a-axis. The switching lines are located distance h apart, equal to the first current band, from the tip of the current reference vector.



(a)Current vectors and switching lines for phase A



(b)Complete switching diagrams

Fig. 1 Current controller switching diagrams for a 3-level inverter.

Similar switching lines can be drawn for phases *b* and *c*, and the resulting complete switching diagram is shown in Fig. 1(b). The entire diagram moves with the current reference vector with its center remaining fixed at the tip of the vector[3][4]. The typical or expected behavior of the controller is such that the operation will be confined to the interior, hexagonal region of the switching diagram. Thus, whenever the current error touches one of the switching lines, that inverter leg is switched to drive the current error in that leg in the opposite direction. It is ,however, noted that the current error can be moved to the region of the tips of the "star". During this period, the motor is in an out of control state since the exact trajectory is determined only by the motor parameters and the internal EMF at this condition, and not by the applied voltages. Hence, an error of $2\Delta i_s$, (twice the expected value equal to the first current band), can occur on an almost random basis, especially when the hysteresis current controlled PWM is applied to the 3-level inverter, the current error periodically exceeds over $2\Delta i_s$ relative to the a-axis, since the imposed voltage across the main switching devices of the 3-level inverter are half the D.C source voltage. This problem can be overcome by incorporating a second current band which is compared to the current error. In comparing the two, the output has a toggle state of positive and negative which is the changing point of the first current band output vector as shown in Fig. 1(a). Fig. 2 shows partial switching modes of the 3-level inverter. Using the space vector representation for output voltages, $\vec{V}$ is defined as :

$$\vec{V} = \sqrt{\frac{2}{3}}(\vec{V_{ab}} + a\cdot\vec{V_{bc}} + a^2\cdot\vec{V_{ca}}) \tag{1}$$

The total number of switching modes is 27(that is 3^3). These modes are represented by voltage vectors. The current control with the 3-level inverter allows a precise regulation of the currents in the current band and automatically compensates for the magnitude of the voltage vectors between low and high reference operating modes. The vectors are classified into four groups; three groups of amplitude vectors (A, B, C) and one group of three zero vectors. For symmetrical reasons, only 60 degree intervals will be considered in the analysis. In the low reference operating mode, the best choice is to select voltage vectors in the circle **A**. Since the voltage vectors of the circle **A** and V(0,0,0) are generally used, three kinds of voltage levels (**Ed/2, 0 ,-Ed/2**) exist in the line-to-line output voltage[5]. Around the circle **A**, there are two voltage vectors in the same vector direction. Using the conventional PWM method, the exchange-points of the voltage vectors should be carefully calculated to avoid waveform distortion. The proposed current controlled PWM technique, however, can automatically decide the voltage vector of the exchanging-points. For higher values in the reference, it is preferable to avoid the use of zero vectors.

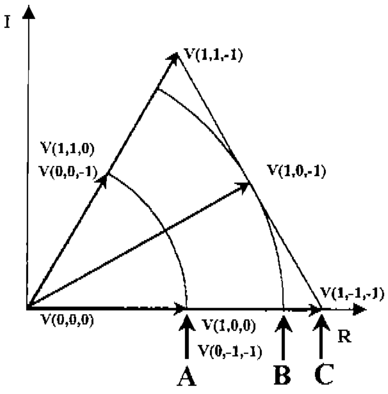


Fig. 2 Partial Switching modes of the 3-level inverter

Thus, the control variables will be regulated by the switching of one of the vector groups **A**, **B** or **C**. The PWM patterns based on the vector approach frequently divide the space plane in triangular areas as shown in Fig. 2. The working area is changed in a certain angle, which relates to the input reference and the D.C source voltage.

3.CONTROL IMPLEMENTATION OF THE CURRENT CONTROLLED PWM

Fig. 3 shows a model of the current controlled 3-level inverter. The line output currents are sensed and compared with those reference currents in the current width comparator. The reference currents are obtained by a system controller. The system controller output with the synchronously rotating reference frame transforms into a stationary reference frame with d-q axis components as follows;

$$\begin{aligned} i_{qs}^{s*} &= i_{qs}^{s}\cos(\theta_e) - i_{ds}^{s}\sin(\theta_e) \\ i_{ds}^{s*} &= i_{qs}^{s}\sin(\theta_e) + i_{ds}^{s}\cos(\theta_e) \end{aligned} \qquad (2)$$

Both the direct and quadrature axis components are transformed to 3-phase stationary reference frames. The 3-phase real currents are compared with the transformed reference current in the hysteresis current band. As a result, the base drive inputs for the main switch of the 3-level inverter are generated. All switching devices are controlled independently by signals from the hysteresis comparators.

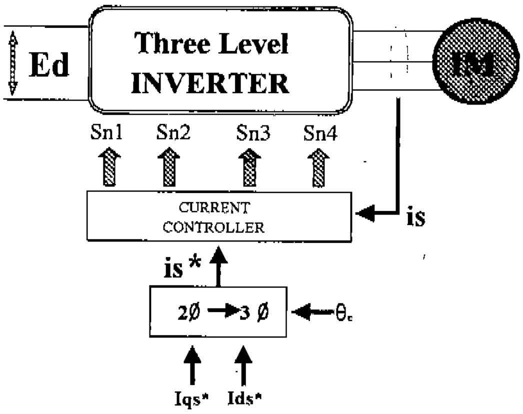


Fig. 3 Model of the current controlled 3-level inverter.

In the case of the 3-level inverter, each arm of the inverter consists of four switching devices and can be clamped to the positive, negative or neutral terminal with switching states such as in Table 1.

Table 1 Switching state of the 3-level inverter

Switching State.	Second band error > 0		Second band error < 0	
Sn1	OFF	ON	OFF	OFF
Sn2	ON	ON	ON	OFF
Sn3	ON	OFF	ON	ON
Sn4	OFF	OFF	OFF	ON

The control method is indicated in Fig. 4. The real output currents are sensed and compared in the first hysteresis band. The results show that three kinds of voltage levels (**Ed/2, 0, -Ed/2**) are generated. The second hysteresis band allows the commutation between positive and negative line voltage output. The hysteresis band widths of the comparators determine the waveform generation and the switching frequency of the inverter switching devices.

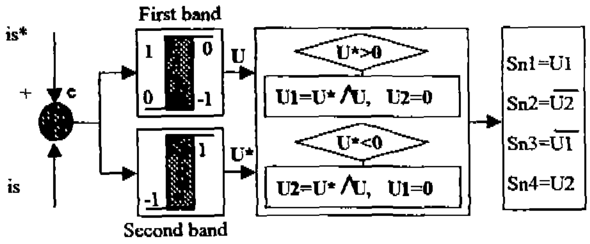


Fig. 4 Switching operation of 3-level inverter.

4.SIMULATION RESULTS

A simulation for a proposed current control 3-level inverter has been carried out with a 10Hp induction machine.

Table 2 Parameter of Induction machine

Rs[Ω]	0.164
Rr[Ω]	0.137
Ls[H]	0.023
Lr[H]	0.0236
Lm[H]	0.0223
P[pole]	4
Jm[Kg.m^2]	0.15

The resulted waveforms of the proposed current controller are shown in this section. Fig. 5 shows the low reference mode which operates on a frequency of 20Hz. The instantaneous vector is chosen by using the switching signal U and the control signal U*. In this low reference mode, the output vectors of the current controller are used by the circle A. Thus, the three kinds of voltage levels (Ed/2, 0 ,-Ed/2) exist in the line-to-line output voltage. At the high reference mode which operates on a frequency of 50Hz, the output vectors of the current controller are used by the circles A, B, and C as shown in Fig. 6. It is defined by U and U* without calculating the exchanging point automatically. The simulation results show that the good quality of the line-to-line voltage and PSD can be obtained. Furthermore, the double error of the current waveforms can be controlled properly, since the current deviation is limited by using the second band.

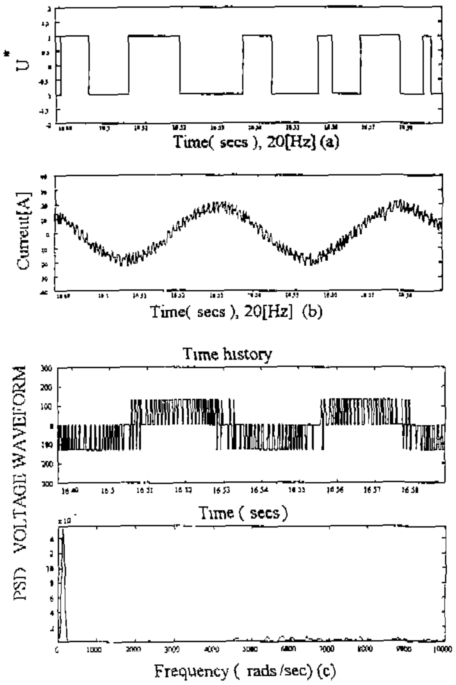


Fig. 5 (a)The U* signal of the current controller.
(b)Current waveform.
(c)Line voltage and PSD.[600rpm]

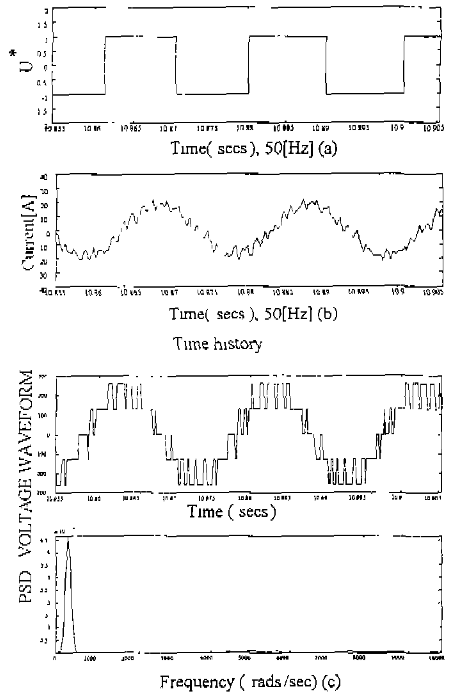


Fig. 6 (a)The U* signal of the current controller.
(b)Current waveform.
(c)Line voltage and PSD.[1500rpm]

5.CONCLUSIONS

A hysteresis current controlled PWM method for a 3-level inverter has been proposed and investigated by the computer simulation. The proposed control technique is simple and compensates the current distortion due to the uncontrollable region of the current controller. Since the imposed voltage across the main switching devices is half the D.C source voltage, the proposed current control technique for the 3-level inverter has a lower switching frequency at the same hysteresis band. Another important feature of this method is its capability to automatically select the switching vector without calculating the switching angle through the whole control range. Thus, its implementation is easier than the conventional PWM method for a 3-level inverter.

6.REFERENCES

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