Random Pulse Width PWM Modulator for Inverter-fed Induction Motor Based on the TMS320F240 DSP Controller

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***Abstract* - A novel random pulse width modulator with varying switching frequency but constant sampling frequency is proposed for application in voltage source inverters for adjustable-speed ac drives. Harmonic Spread Factor is introduced for quality evaluation of voltage spectra of inverters with the random PWM. Realization of the modulator using the Texas Instruments' TMS320F240 DSP controller is described and the results of simulations and experiments are presented.**

I. INTRODUCTION

The random pulse width modulation (RPWM) has become an established means for mitigation of undesirable side effects in PWM converters, the voltage source inverters in adjustable speed ac drives in particular. Significant improvement in the acoustic and electromagnetic noise in RPWM converters has been reported in many publications, for instance [1]-[5].

Randomizing the switching frequency has been found to be the most effective method of RPWM. In converters with fixed switching frequency, the power is concentrated in discreet harmonics of the output voltage. In contrast to that, in converters with randomly varying switching frequency, the harmonic power is transferred to the continuous spectrum [6]. Unfortunately, in the digitally controlled inverter-fed ac drives, switching signals of the inverter are synchronized with the sampling frequency which, therefore, must be varied as well. This is inconvenient, and it muddles the important issue of control bandwidth, which is directly related to the sampling rate.

In the novel random pulse width modulator for voltage source inverters proposed in this paper, the switching and sampling frequencies are decoupled. The sampling rate is maintained at a constant level, required by the desired dynamic characteristics of the drive system incorporating the inverter. The switching frequency is dithered in a random manner to disperse the harmonic power in the voltage spectrum. Realization of the modulator in the TMS320F240 DSP controller from Texas Instruments is described along with the simulation and experimental results.

II. PRINCIPLES OF THE NOVEL RANDOM PWM METHOD

The sampling frequency, f_{samp}, in an ac adjustable-speed drive is mostly determined by the amount of time the digital control system requires for computations associated with the implemented control algorithm. The switching frequency, f_{sw}, is limited by the switching times of inverter switches and the amount of switching losses. Thus, these two frequencies are essentially independent, and set to the same value for convenience only. Therefore, in the proposed method, the sampling and switching frequencies are decoupled, but the average switching frequency is made equal to the fixed sampling frequency.

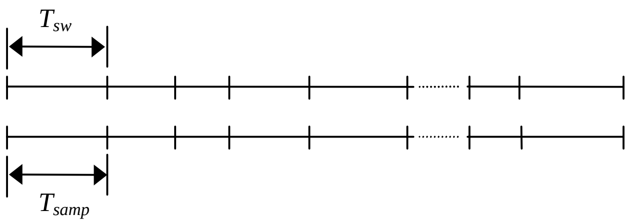
The conventional and proposed random PWM strategies are illustrated in Fig. 1. The whole process of motor control can be divided into two parts: the sampling process denoted as SMP and switching process denoted as SWP. The SMP deals with the necessary data sampling, such as that of motor current, voltage or motor speed, and calculation of the reference voltage vector based on the sampled data and motor control algorithm. The SWP deals with the PWM generation based on the reference voltage vector obtained in the SMP. The basic idea of the proposed random PWM strategy is to make the SMP independent of the SWP, so that the sampling frequency, f_{samp}, can be constant and the switching frequency, f_{sw}, can be modulated randomly.

The instantaneous switching frequency can be expressed as:

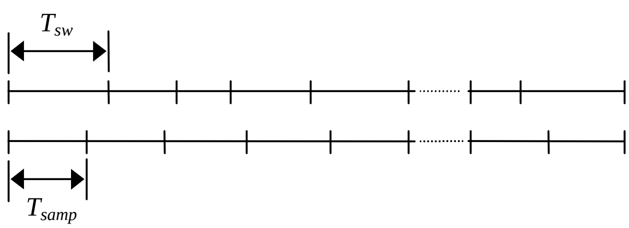
$$f_{sw} = f_{sw0} + \Delta\, f_{sw} \times R \qquad (1)$$

where f_{sw0} is the average switching frequency, Δf_{sw} is switching frequency random modulation range and R is a series of uniformly distributed random numbers in the range [-1, +1], with an average value equal zero. As previously mentioned, $f_{samp} = f_{sw0}$, and the switching period, T_{sw}, will change in the range

$$0.75 \times T_{samp} \leq T_{sw} \leq 1.5 \times T_{asmp} \qquad (2)$$



(a) Conventional random PWM strategy.



(b) Proposed random PWM strategy.

Fig. 1. Relation between the sampling and switching periods.

to avoid the overlap of multiples of the switching frequencies. When the SWP is invoked, a new reference volatge vector is needed for calculating new parameters for PWM generation. It may happen that the calculation of a new reference voltage vector is not finished by SMP. In this case, the SWP will have to use the last known reference voltage vector. The following experimental results show that such occurences do not affect the effectiveness of PWM modulation.

III. REALIZATION OF THE MODULATOR USING THE TMS320F240 DSP CONTROLLER

Fig. 2 shows the experimental drive system with an IGBT inverter driving an 5.5 kW induction motor. A dc motor was used as the load. The random PWM controller was realized using a TMS320F240 DSP Evaluation Module Board and an IGBT driver circuit. A parallel port for the communication between a PC and control board allows the real-time verification of application software.

For the evaluation of proposed PWM, the following quantities are measured:

(1) Spectrum of motor line-line voltage,
(2) Spectrum of motor line-line current,
(3) Spectrum of dc link current,
(4) Spectrum of acoustic noise,

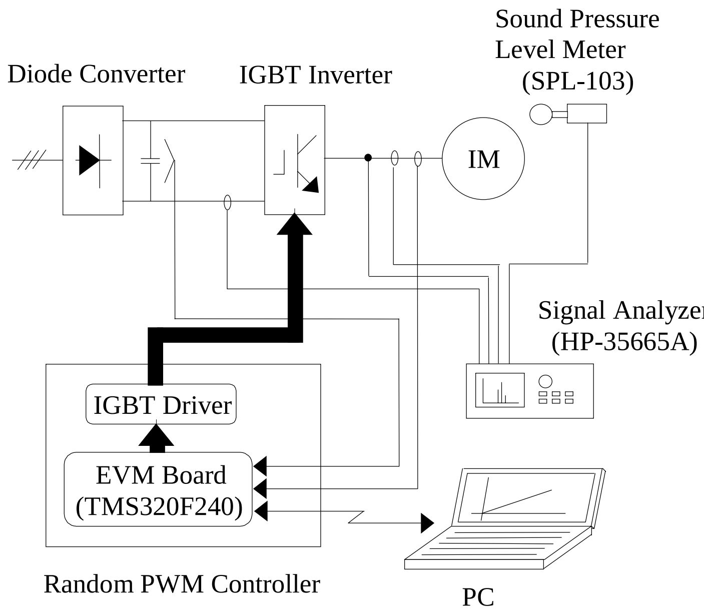


Fig. 2. Experimental system.

The TMS320F240 is a flash-memory device in C24x series of Texas Instrument DSP controllers. It is designed specifically for motor control applications and it has the capability of 20 MIPS. Included in the Event Manager Unit are PWM generation functions, such as the programmable dead time and space vector PWM techniques. Using this DSP controller, the proposed novel PWM technique can easily be realized.

Two application software packages denoted as Ran_gen and PWM_gen, were developed. Ran_gen generates uniformly distributed random numbers. PWM_gen calculates the output voltage vectors based on the space vector PWM method. For running the induction motor, a V/f = constant control algorithm were realized.

The best-known method for generating random numbers, is the linear congruential method [6]. It uses the following formula:

$$R_i = (R_{i-1} \times b + 1) \text{ Mod } M \qquad (3)$$

where b denotes the seed number and M is an arbitrary large number. The seed should be an arbitrary constant with no particular pattern in its digits, except that it ends with x21, where x is an odd digit. Selecting R_0 = 0, b = 121, M = 32768, a series of uniformly distributed random numbers in the range 0 to 32768 can be generated.

The structure of the application software is shown in Fig.3, and the main features are listed below.

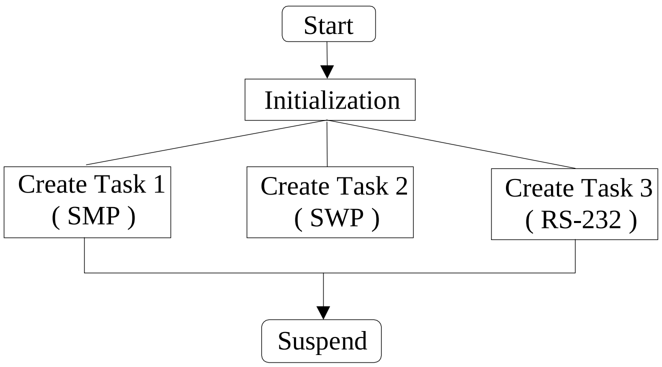


Fig.3. Structure of application software.

(1) The chip built-in space vector PWM function of TMS320F240 is adopted.
(2) Three interrupt service tasks as in Table 1.
(3) The following two universal application software packages are included. They are coded in the assembler language.

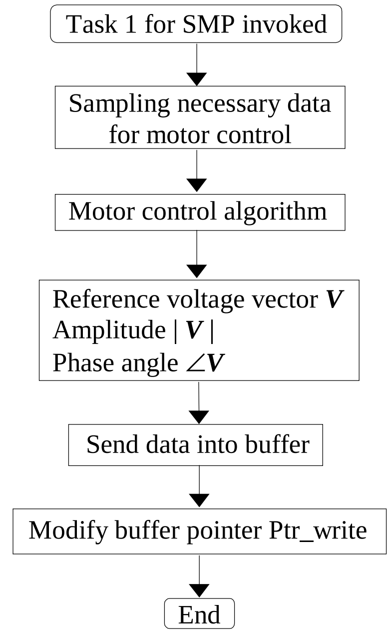
Ran_gen: uniformly distributed random numbers generation.
Input parameter: No.
Output paramter: Random numbers in the range 0 to 32768.
Execution time: 3 µs.

PWM_gen: PWM waveform generation.
Input parameter: Reference voltage vector, including the magnitude and phase angle, the instantaneous switching frequency.
Output parameter: Two timer values and the space vector.
Execution time: 7.5 µs.

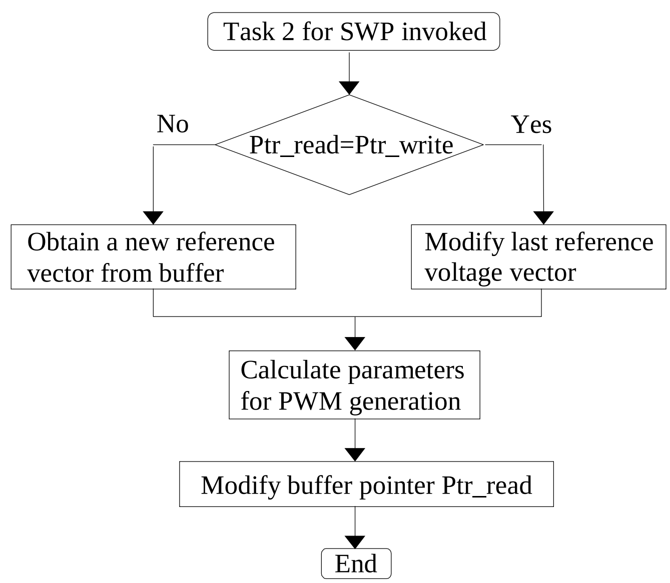
Table1. Description of interrupt service tasks.

Tasks	Description	INT Source	Priority
Task 1	INT service routine for SMP	TPINT 2	6
Task 2	INT service routine for SWP	TPINT 1	5
Task 3	INT service routine for RS232	RXINT	4

The flow chart of Task 1 and Task 2 are illustrated in



(a) Interrupt service routine for SMP



(b) Interrupt service routine for SWP

Fig. 4. Flow chart of interrupt service routines.

Fig. 4. For the PWM generation, the voltage vector generated in the SMP should be transmitted to the SWP and this is realized by a so-called circular buffer, which is shown in Fig. 5. Two buffer pointers Ptr_write and Ptr_read are used to control the access to the buffer. When the SMP is invoked, a new PWM generation related data is calculated and written into the buffer, then the pointer Ptr_write is modified. When the SWP is

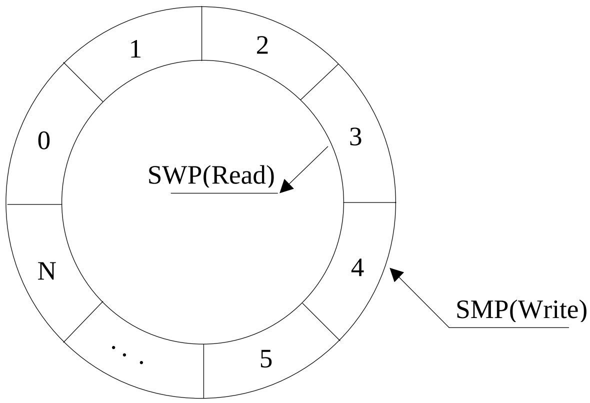


Fig. 5. Circular buffer for data exchange between SWP and SMP.

invoked, the pointer Ptr_read is compared with Ptr_write first. If Ptr_read ≠ Ptr_write, means that there is a new PWM-related data in the buffer, otherwise, it means that no new reference voltage vector is produced. In this case, the last reference voltage vector will be used again to generate the PWM waveform. Considering the time delay, this reference voltage vector should be modified by keeping its amplitude and rotating speed unchanged and adding a corresponding increment to its phase angle. When a new data is read from the buffer, the pointer Ptr_read should be modified. The SMP write data into the buffer with a constant frequency and the SWP read data from the buffer with a random frequency.

IV. Experimental Results

Figs. 6 through 13 show selected experimental results, in which a 3 hp, 230 V induction motor run with the half of its rated load, and with the average switching frequency of 4 kHz, the fundamental frequency of 50 Hz, and PWM modulation index of 0.8. For evaluating the effectiveness of proposed random PWM method, the comparison between random PWM method and deterministic space vector PWM method was performed.

Figs. 6 and 7 show the spectrum of motor line-line voltage with the deterministic PWM and proposed random PWM method, respectively. Figs. 8 and 9 show the respective spectra of motor current. It can be seen that thanks to the random PWM, the peak value of voltage harmonics is reduced by about 8 dB. The motor current spectrum shows very significant reduction of harmonics with the random PWM modulation. Figs. 10 and 11 show the reduction of dc link harmonic current caused by the random PWM. Based on these results, it can be expected that EMI filter can be minimized because of the harmonics power reduction at certain frequency caused by the random PWM method. Figs. 12 and 13 show the spectrum of acoustic noise emitted from induction motor. It can be seen that the acoustic noise related to the switching frequency is also reduced. The experiments have confirmed the effectiveness of the proposed random PWM method.

V. Conclusion

A novel random PWM modulator with a fixed sampling frequency has been developed. The switching frequency is independent of the sampling frequency and randomly modulated. This constitutes a significant improvement over the conventional random PWM, in which the sampling frequency is also randomly modulated. The experimental results have proved the effectiveness of the proposed method.

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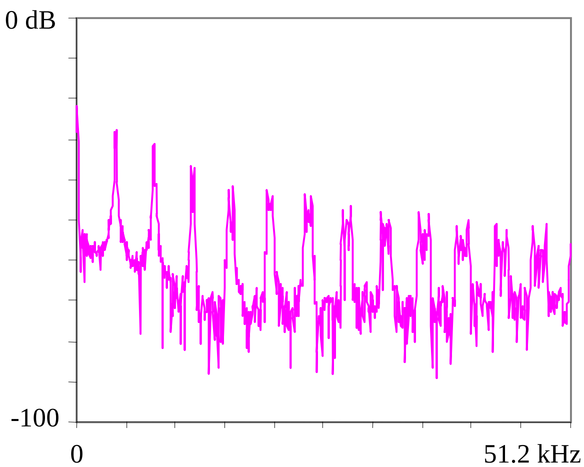

Fig. 6. Power spectrum of line-line voltage with the deterministic PWM.

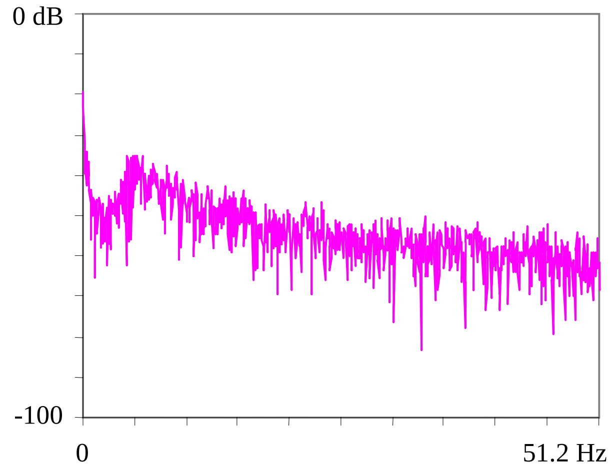

Fig. 7. Power spectrum of line-line voltage with the proposed random PWM.

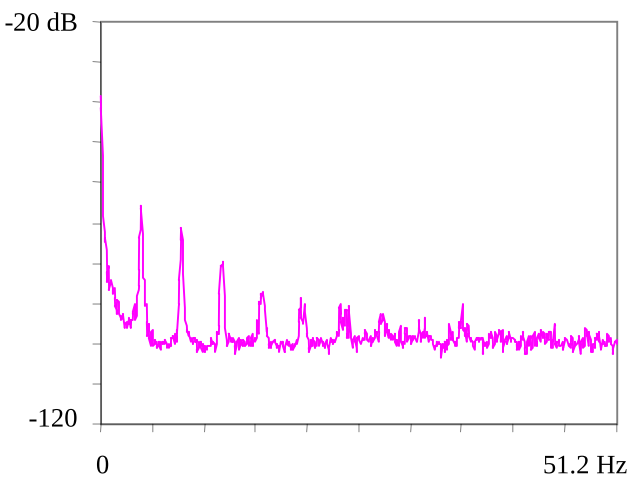

Fig. 8. Power spectrum of line-line current with the deterministic PWM.

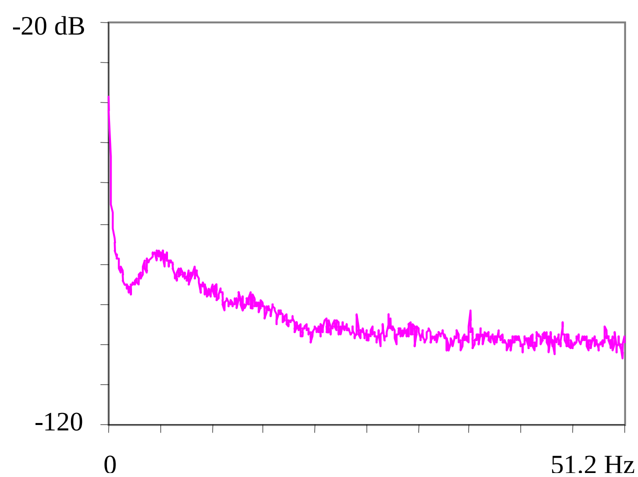

Fig. 9. Power spectrum of line-line current with the proposed random PWM.

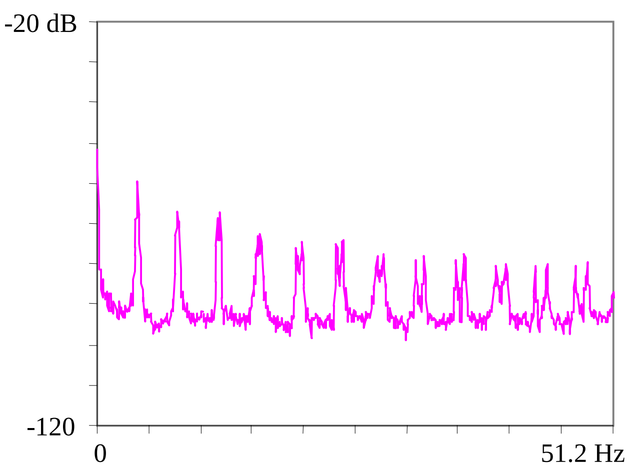

Fig. 10. Power spectrum of dc link current with the deterministic PWM.

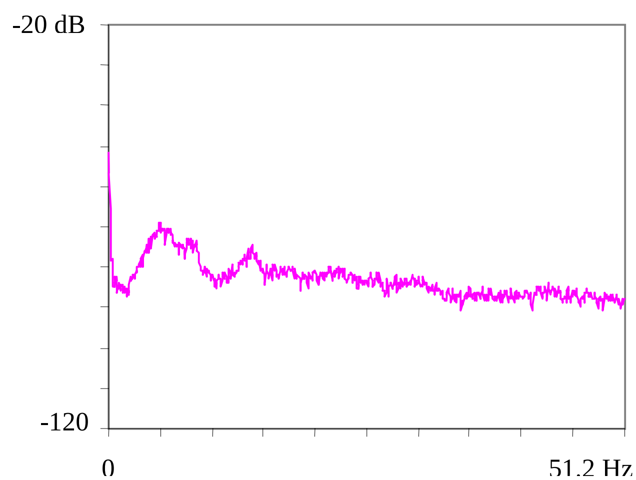

Fig. 11. Power spectrum of dc link current with proposed random PWM.

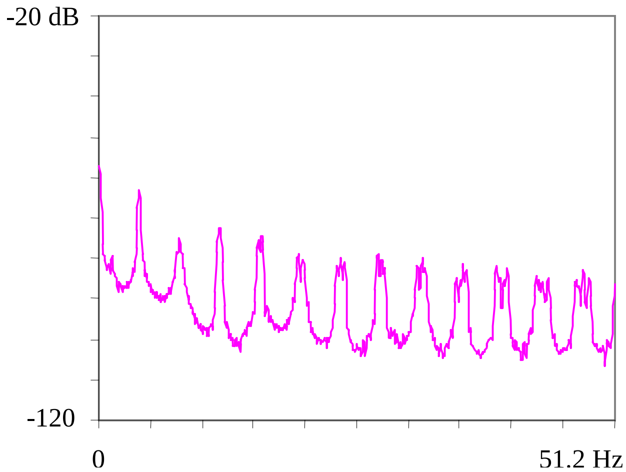

Fig. 12. Power spectrum of acoustic noise with the deterministic PWM.

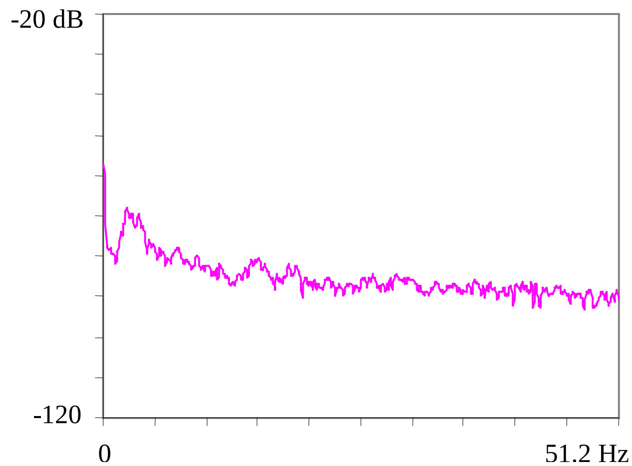

Fig. 13. Power spectrum of acoustic noise with the proposed random PWM.