Random PWM Techniques for Improvement of Torque Ripple, EMC and Acoustic Noise Reduction in Motor Drive Systems.

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Abstract – Random PWM (RPWM) techniques in motor drive systems (LV & MV) are generally used for reducing harmonics, straightening the power density, improving electromagnetic interference, reducing acoustic noise. The basic idea in this structure is to determine the characteristic/behavior of randomly occurring unwanted effects and damping these effects with controlled/systematized randomness. Techniques can be classified in three main captions as Random Switching Frequency, Random Pulse Position with Fixed Switching Frequency and the third one is combining of them (Fig.1).

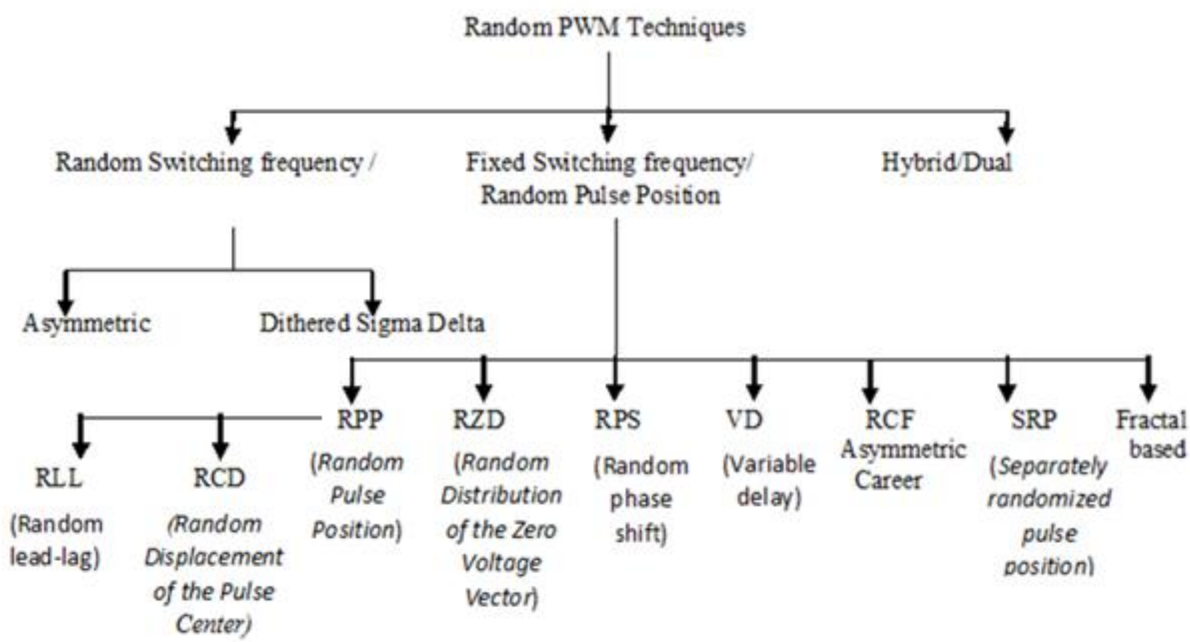


Figure 1: RPWM Techniques Family Tree [1]

A – RANDOM SWITCHING FREQUENCY

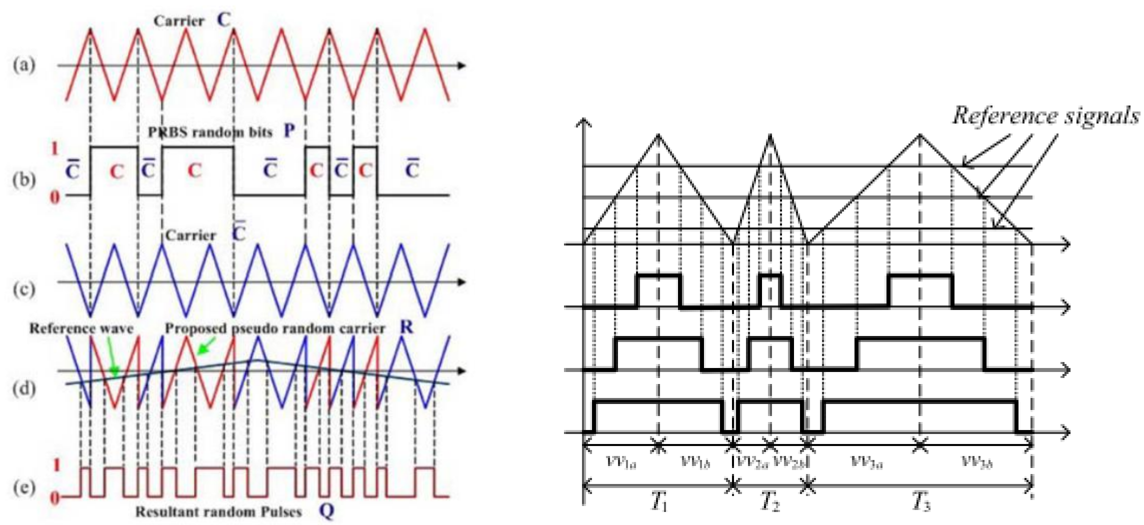
Carrier frequency (Triangular) of control system is changed with random number generator. The purpose is elimination the harmonic effect on the currents. THDs are improved up to ~3-4%.

1. Asymmetric

Two carrier frequency are used as first one original carrier and second one is inverse of it (180' shifted). Also, a random number generator is used (between 1 and 0 : compare two random number and if Rand1>=Rand2, return 1 else 0). Choose original triangular carrier for random ones and choose inverse triangular for random zeros and add them for creating randomized carrier. Random number generator frequency is set to double of the carrier freq. So triangular wave can divide two part from peak points. So some of the parts of randomized carrier look like saw tooth (perpendicular triangle) and some of them look like isosceles triangle. So that is called as asymmetric [2]–[4] (Fig.2a)

Another method is creating triangles of carriers with different slopes but still isosceles triangles. This method uses different duty square wave. Frequency of random square waves must be limited in Nyquist criteria (not bigger than 2fs, no lower than 1/2fs). In this way some of the triangles are narrow and some of them are wide (Asymmetric) (Fig. 2b).

These two methods are significantly used for acoustic noise reduction for BLDCs and Induction Machines.



a) b)

Figure 2: RCF-PWM Methods

2. Dithered Sigma Delta Modulation (DSDM)

This technique works over Nyquist criteria (an over sampling method). Analog signal (Phase current, voltage with harmonics) is taken from hardware and sampled by ADC. Least Significant Bit (LSB) of digitalized data is changed by the 1 bit created by Dithered output. This method is widely used for suppression the harmonics and preferred due to easy implement (Fig. 3).

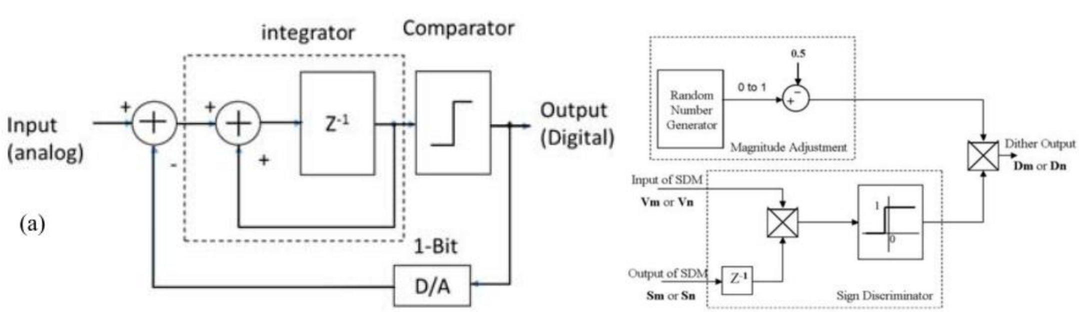


Figure 3: DSDM Method

Space-Dither SDM (SDSDM) scheme employs quantizer being fed from a random dither generator in SDM while in Time-Dither SDM (TDSDM) the quantizer feeds the output to random dither generator [5]–[7].

B – FIXED SWITCHING FREQUENCY / RANDOM PULSE POSITION

In this approach, switching frequency is fixed and position of pulse is varied randomly. Closed loop response of this technique is appropriate. In a conventional closed loop SVM based motor drive operation, SVM block estimates and compare the reference voltage vectors. FF-RPWM block randomizes active vectors and corresponding zero vectors in the modulation process. Duty ratios are converted to comparable values for generating random PWM output (Fig. 4). There are nine types of it.

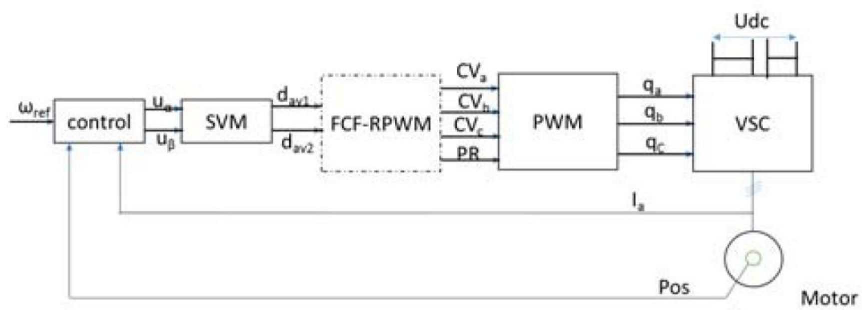


Figure 4: FF-RPWM Application block schematic

1. Random Pulse Position PWM (RPP)

   It covers the Random Lead Lag (RLL) and Random Center Displacement (RCD). Pulses are located randomly in a fixed period (switching interval) [8].

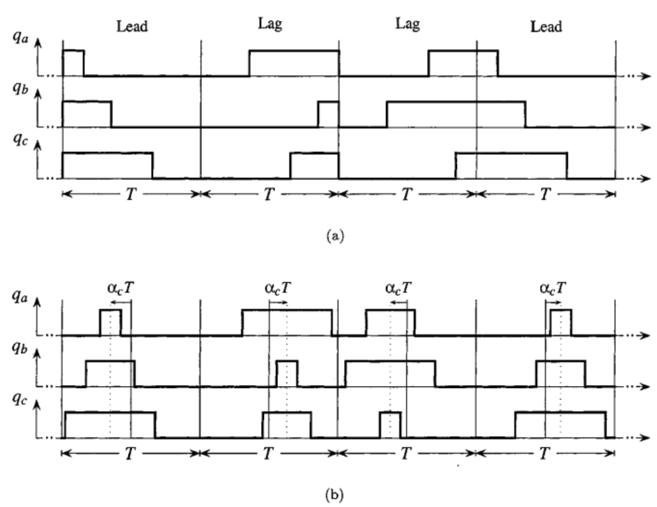


Figure 5: a) RLL, b) RCD

1.1 Random Lead-Lag Modulation (RLL)

A fixed modulation frequency divides the time domain into equal period. Each equal interval has a specific edge. A random number generator determines the leading edge or lagging edge modulation. Average switching frequency interval is determined by situation of quality of output current or voltage (optimized switching losses) [9](Fig.5)

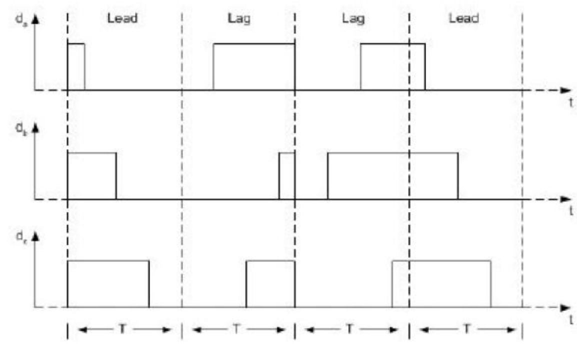


Figure 6: RLL-PWM for 3 phase application.

1.2 Random Displacement of the Pulse Centre (RCD)

It has the same logic with RLL. In this technique, center axis of each PWM is displaced by a small amount randomly to the + (positive) or – (negative direction). Displacement is limited by modulation index value of PWM [10].

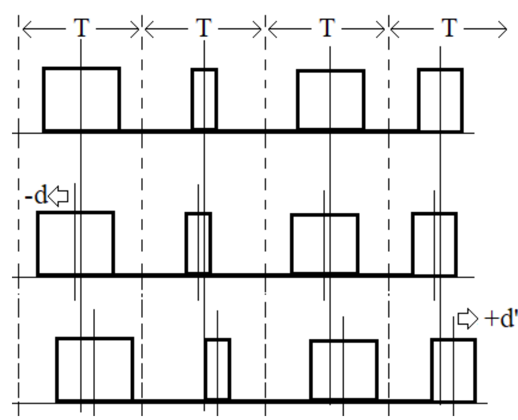


Figure 7: RCD Randomization

2. Random Distribution of the Zero Voltage Vector (RZD)

In a three-phase, three-wire system the duration of the zero voltage vector does not alter the phase voltages. This fact is utilized in the random distribution of the zero voltage vector, where the proportion between the time durations for the two zero-vector states 111 and 000 is randomized in a switching cycle. All pulses are center-aligned as in standard SVM [11] (Fig. 8). It is suggested for Direct Torque Control.

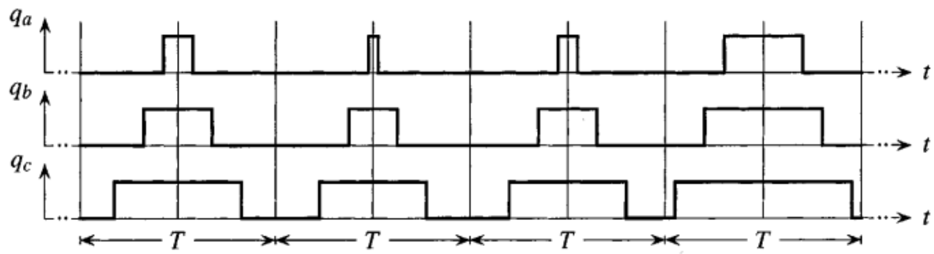


Figure 8: RZD (3 phase)

3. Random Phase Shift PWM (RPS)

In this method, the phase shift is varied randomly, keeping the switching frequency constant. There are two timing which are determined randomly (with keeping the frequency fix) such as for positive cycle (t_{RP}) and for negative cycle (t_{RN}) of PWM. These timing (t_{RP}, t_{RN}) are changed randomly in each halfcycle (Fig. 9) [12].

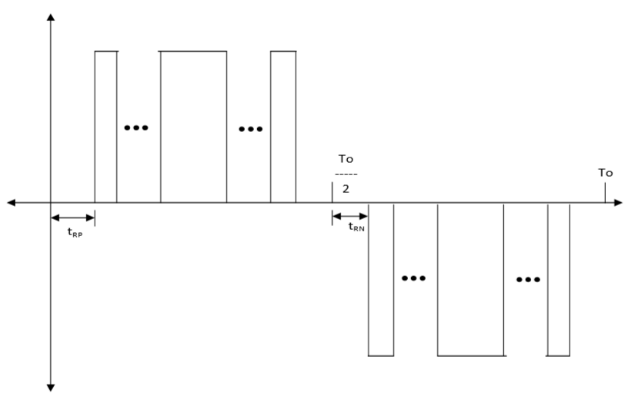


Figure 9: RPS (Output waveform)

4. Variable Delay RPWM (VD-RPWM)

A random delay, which is product of sampling period and random number 0 or 1, is added to end edge of next PWM cycle (Fig. 10). In this method, max. delay time is limited by 1. The switching period can be take variable values between minimum switching period (determined by application specs) and double of sampling period [13], [14].

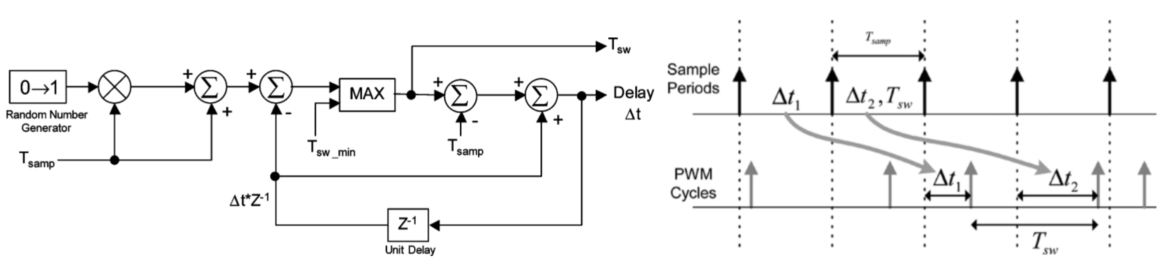


Figure 10: a) VD-RPWM Block schematic b) Resultant RPWM

5. Asymmetric Carrier Random PWM (AC-RPWM)

This is the RCF technique but under the fixed the frequency. The rising and falling edges of carrier waveform is determined randomly for each modulation period. This technique can be applicable for both high or low modulation indexes [15] (Fig. 11).

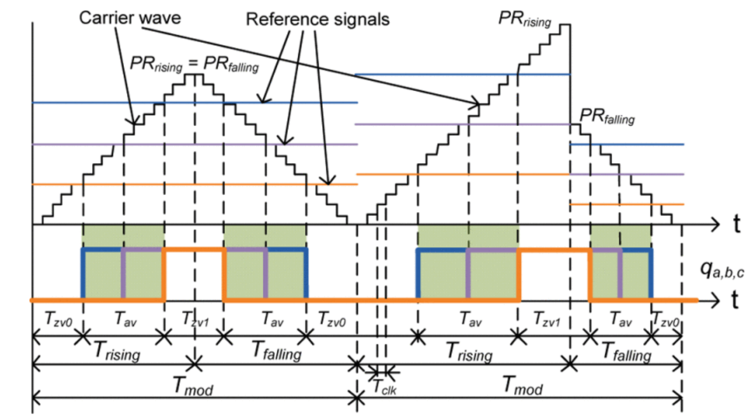


Figure 11: Left side symmetric carrier, Right side AC-RPWM

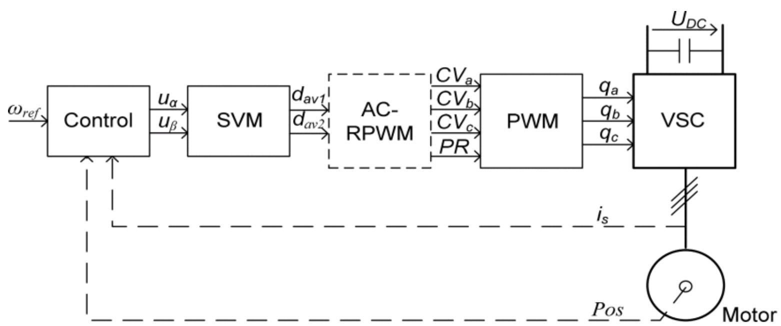


Figure 12: Motor drive application

6. Separately randomized pulse position (SRP)

Same results of RLL and RCD are obtained from this method. But the definition is slightly different from the others. Pulses are located randomly in a fix period. It covers all modulation indexes (0-1). Calculation of duty ratio is done using space vector modulation, with each pulse located randomly. As pulse can be positioned randomly, harmonic spectrum is more flattened as compared to conventional methods.

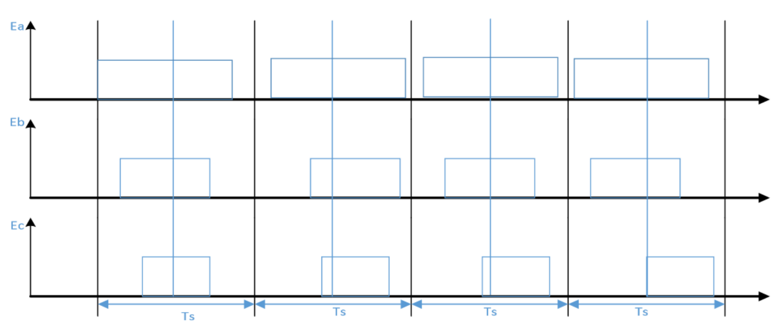


Figure 13: SRP – PWM

7. Fractal Based Space Vector PWM

Fractal approach can reduce the complexity in computation for sector identification and switching vector determination in SVPWM. The position of the reference vector in a given sector can be found by fractal methods. Since in the fractal based algorithm, the levels involved depends on the number of triangularization [16] (Fig. 14).

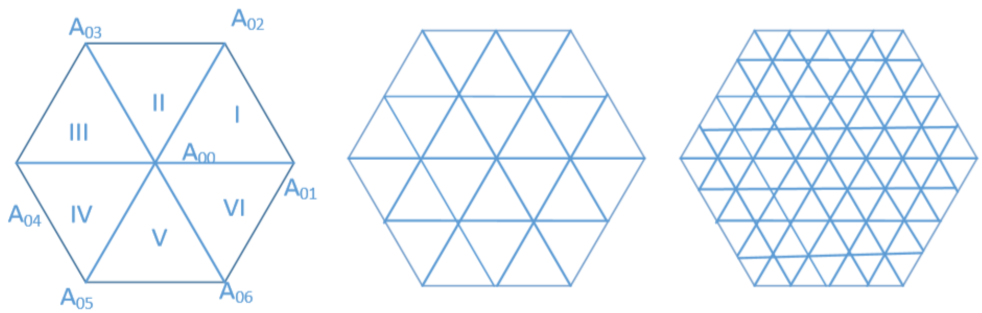


Figure 14: 2-level, 3-level, 5-level SVPWM

C – HYBRID – DUAL

Motivation is better performance for different modulation index values including over modulation region, reducing the complexity of computation.

Some of the examples: Dithered pulse position + zero vector position, Random pulse position + Random carrier frequency PWM, Random Lead-Lag + Random triangular carrier.

COMMENTS (referenced papers are from nearly 2019)

Randomization techniques are applied for damping the random events in motor drive. The main aim is cancellation the unwanted random events such as ripples on the phase currents, voltages or torque of a motor or noise (spikes, inrushes, peaks at load changes) on the converted signal due to switching of a power converter (Especially inverters). Basic techniques as mentioned above provides some improvement for reducing THDs, current ripples, torque ripples and acoustic noise [17][18][19].

The trends of this topics focus on Direct torque, position or speed control applications. Sensorless [20] control techniques also needs or try to randomization process for improvement the system performance. Also, characterization of noise or harmonics and suppressing of them are in trends. Also some new papers introduces as a new switching techniques which is actual randomized based switching [21].

POSSIBLE WORKS ABOUT RANDOMIZATION IN METU EEE

Combining two technique and developing a new Hybrid technique for a special purpose or case (Acoustic noise reduction in train sytem simulator with RPWM) (Train simulation (Laboratory of Prof. Ermiş) in ODTU can be used for this purpose. Simulink based control in this lab. is another advantage for implementation). There is no any literature work such that power level. [22] [23] are small scale applications.

None of these randomization techniques were not applied or tried GaN based switched driver (converter or inverter). IMMD project can be used for this purpose. Only one Random PWM applied SiC inverter in the literature [24].

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