Inverter Two-Level PWM Harmonic Enhancement Based on Phase Shift Tuning Technique

Mohammed S. M. A. Khesbak
mohsaheb@yahoo.com
Computer Communications Engineering Dept. - AL- Rafidain University College, Baghdad - Iraq

Abstract: *Frequency harmonic reduction and elimination is a vital field of research due to its importance in minimizing the percentage of total harmonic distortion in power systems. The two-level Pulse Width Modulation (PWM) method of AC generation is with less sophisticated control circuitry requirement compared to higher level PWM techniques. This paper is proposing a new control methodology with a reduced harmonic spectrum. The new trend here is to manipulate the PWM two-level reference waveform by duplicating the generation process with a tuned phase shifting added to the reference waveform. The new technique results in a harmonic reduction of the unfiltered output with about 50% compared to that of the conventional Bipolar SPWM.*

Keywords: Two level PWM, inverter, harmonic reduction

I. Introduction

Conversion of DC voltage supply to AC single or three-phase supply is a major demand in many applications such as renewable energy based applications, Uninterruptable Power Supplies (UPSs) and AC motor drivers. These applications differ in output waveforms harmonic free requirements depending on the type of load and applications.

The PWM technique is considered advanced and useful one in which the width of pulses of the switching devices of an inverter; for an instant; is controlled by various mechanisms and strategies to eliminate low harmonic frequencies and resulting in a high quality spectra [1].

The Pulse Width Modulation PWM results in the generation of fixed amplitude pulse through modulating the width of the pulse by duty cycle modification. Analog type of PWM construction requires two vital signals generation; reference and carrier signals that are fed into a comparator and based on logical output. The resultant output waveform is generated accordingly. The reference waveform is basically the desired signal output waveform which may be sinusoidal or square waveform, while the carrier signal is either a triangular or saw tooth waveform at a frequency significantly larger than the reference one and called the switching frequency. Furthermore, there are three basic PWM techniques as following [2,3]:

Single-PWM; in which there is a unique output pulse per each half-cycle. The output is modified by changing pulse width. The switching waveforms are produced by rectangular reference and triangular reference comparison, where the frequencies of these two waveforms are approximately equal.

Multiple-PWM; where there is multiple number of output pulses per each half-cycle and pulses are with equal width. The switching waveforms are produced by rectangular reference and triangular reference comparison [2, 3].

Sinusoidal-PWM (SPWM); where such technique there is number of output pulses per each half cycle and pulses are recognized with different widths. Each width of a pulse is varying in proportion to the amplitude of a sine waveform evaluated at the centre of the same pulse. The switching waveforms are produced from the comparison of a sinusoidal reference with a high frequency triangular signal [4].

II. Two-Level PWM Technique

The two-level scheme of PWM technique owns a vital importance and applications [5]. In this technique the comparison of the normalized reference sine wave with a triangle wave is shown in Figure 1 for desired reference frequency of 50 Hz. Using these two normalized signals as input to the comparator, the un-filtered normalized output will form a 2-level PWM waveform as depicted in Figure 2. Moreover, signal may then be fed to the control switches connected to the high-voltage bus, which will in turn replicate this signal at suitable voltage. The same may be carried out for the 60Hz desired output frequency as well.

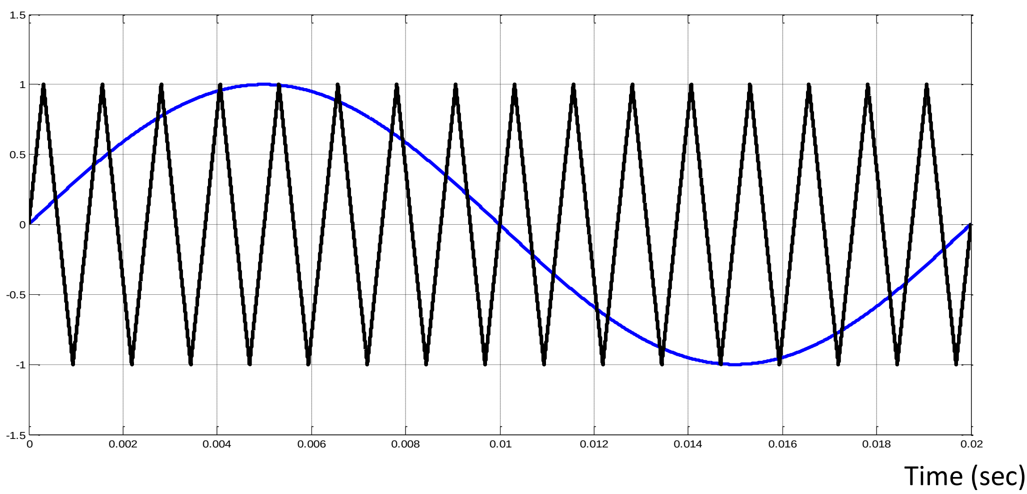


Figure 1 Reference sine waveform (50 Hz) and triangle waveform comparison in 2-level PWM

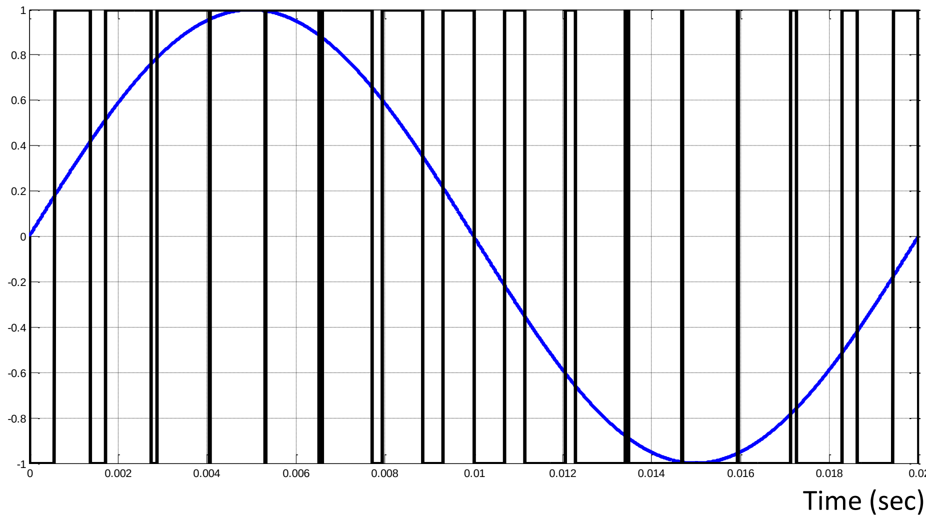


Figure 2 Two-level PWM unfiltered output waveform versus reference sine wave (50 Hz).

To evaluate the frequency spectrum of the two-level PWM in meaning of harmonic content, it is worth to define the percentage Total Harmonic Distortion (THD%) as;

$$THD\% = \sqrt{\frac{\sum_{n=2}^{\infty} C_n^2}{C_1^2}}\ X\,100 \qquad (1)$$

where: the accumulative sum of all squared frequency components (C_n) within the spectrum (all except the fundamental C_1) divided by the square of (C_1) which is in our case the first component in the spectrum. Although the evaluation of the standard IEEE THD% depends on the application type, it is still an issue to decide which harmonic criterion to use. However a more general evaluation equation will be considered in this paper represented by equation (1) and measurement results should be evaluated under the IEEE recommendation and requirements for harmonic content in electric systems [6,7]. Accordingly, the frequency spectrum of the two level PWM output waveform is shown in Figure 3 with 50Hz reference waveform and 4 kHz triangular waveform. The number of harmonics taking in consideration equals to 400 components which is shown in the frequency spectrum and in calculating THD%. Here the frequency spectrum reflects the fundamental desired component together with the repeated banks of switching frequency located at multiples of the 4 kHz used in this demonstration. Accordingly the THD% show a relatively high value (92.35%) caused by the presents of the mentioned repeated banks of switching harmonics.

III. Proposed Technique

The proposed technique is represented in the block diagram shown in Figure 4. The 2-level technique is to be improved from the harmonic content point of view as a result of adjusting reference waveform phase relation.

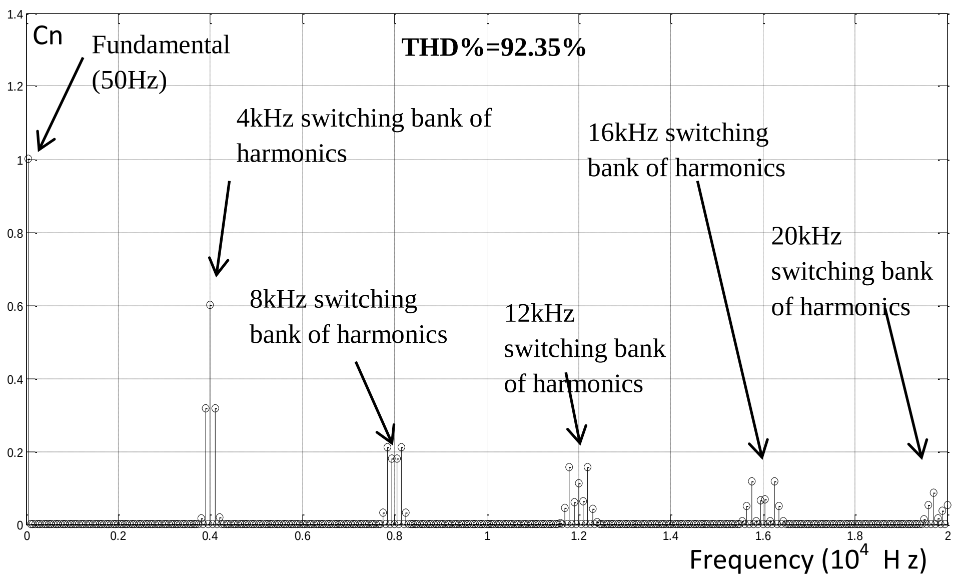


Figure 3 Spectrum of the un-filtered two level PWM output waveform

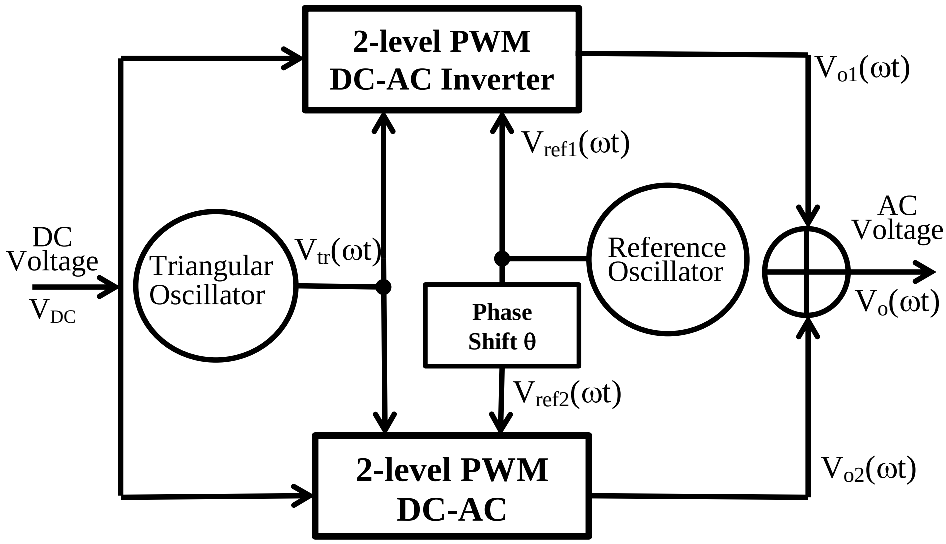


Figure 4 Proposed system technique based on 2-level PWM technique

As it is obvious the technique relies on two independent 2-level PWM Inverter systems. These systems are converting the same input DC voltage using same triangular high frequency carrier waveform. However, the reference waveform of one of the 2-level PWM inverter systems is a sine waveform generated by the reference oscillator while the reference waveform of the other PWM system is a shifted version of the first one. The phase shift value θ is the new technique key factor show previously in system of Figure 4. That is;

$$V_{ref1}(\omega t) = \sin(\omega t) \quad (2)$$

where ω is the desired angular frequency as a design parameter which may be calculated for example for the 50Hz or 60Hz. Moreover;

$$V_{ref2}(\omega t) = V_{ref1}(\omega t \pm \theta) = \sin(\omega t \pm \theta) \quad (3)$$

The triangular waveform against the reference sine waveform together with its shifted version waveform is shown in

Figure 5. The Comparison is made as in the ordinary 2-level technique to generate two different switching waveforms. The first is the comparison of the triangular signal with the sine signal and the other is the comparison made between the triangular and the shifted version of the reference signal. Each switching waveform is to be used for switching one 2-level PWM inverter.

Now, the triangular signal with periodicity period of T time is represented as following;

$$Vtr(t) = \begin{cases} \left(\frac{4}{T}\right)(t-nT) & nT < t < \left(\frac{T}{4}\right) + nT \\ 2-\left(\frac{4}{T}\right)(t-nT) & \left(\frac{T}{4}\right) + nT < t < \left(\frac{3T}{4}\right) + nT \\ \left(\frac{4}{T}\right)(t-nT) - 4 & \left(\frac{3T}{4}\right) + nT < t < T + nT \end{cases} \qquad (4)$$

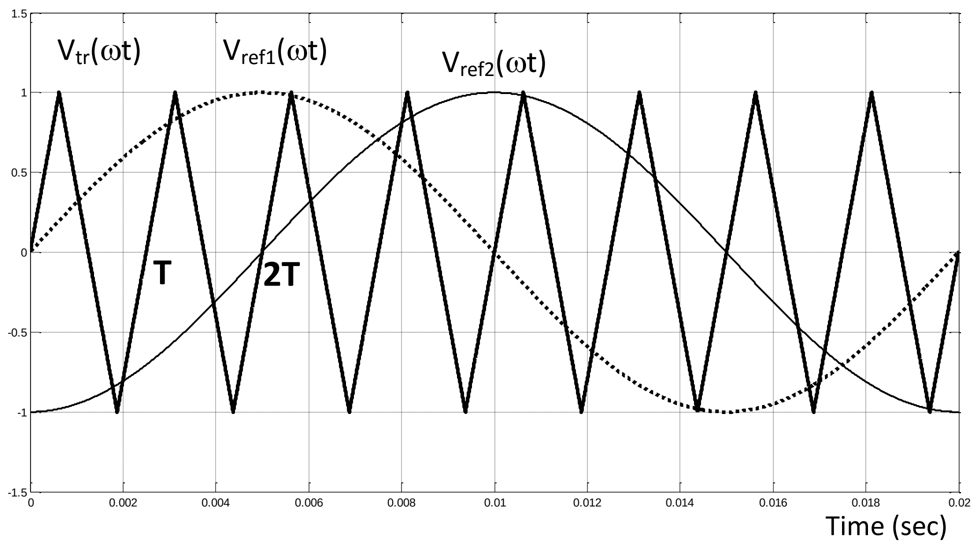


Figure 5 Triangular waveform against the two reference waveforms

IV. Proposed Technique System Simulation And Results

The proposed technique of reducing the THD% of the two-level PWM inverter was simulated according to the system proposed in Figure 4. Two 2-level PWM techniques were simulated as individual inverters with same high frequency triangular waveform and with different reference waveforms. One of the reference waveform is a shifted version of the other one. Accordingly, one of the simulation programs was written to test the effect of the controlled modification of the phase shift between the two PWM inverters reference waveforms. Figure 6 shows the resulting percentage THD of changing the phase shift between the two inverters reference waveforms in degree. The saddle point shown at phase 180 degree is considered as the optimum value at which the THD% is minimized.

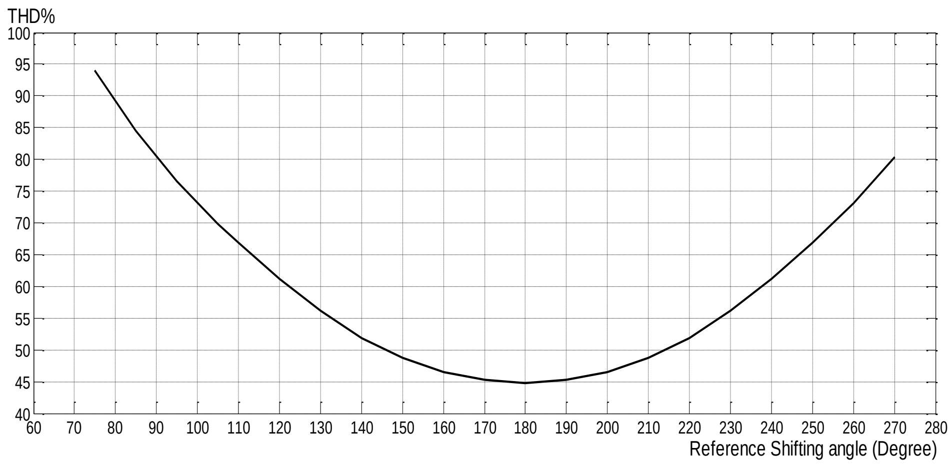
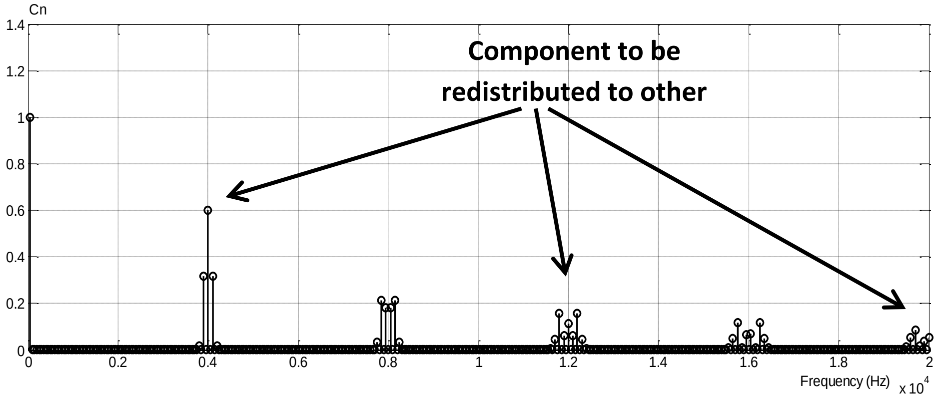


Figure 6 Effect of changing reference waveform phase shift on THD% of the unfiltered voltage output waveform.

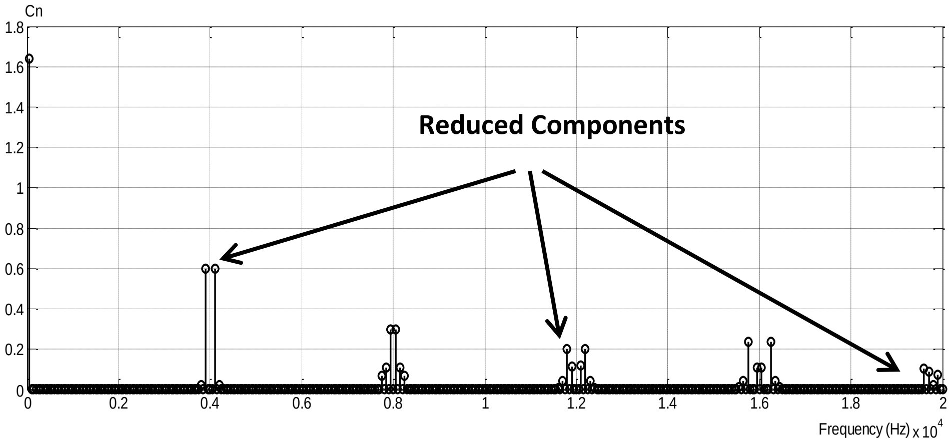
The technique of changing one of the inverter's reference phase angle, results in a considerable redistribution of harmonic components power in a manner of eliminating the odd banks of high frequency components and redistributing these power values to other components. The redistribution process resulted in an increase in the fundamental component power magnitude and disappearance of some major undesirable bank of frequency components as shown in Figure 7. Minimization or elimination is highly desirable for the low order harmonic components near to the fundamental frequency component rather than minimizing the THD% [8].

Moreover the simulation program was modified using multiple nested loops for each parameter under investigation to show the effect of changing reference waveform phase shift in terms of magnitude spectrum power distribution between components. This is shown by calculating the magnitude of the fundamental frequency component and comparing this with the summation of magnitudes for each higher order harmonic components for each phase shift as shown in Figure 8.

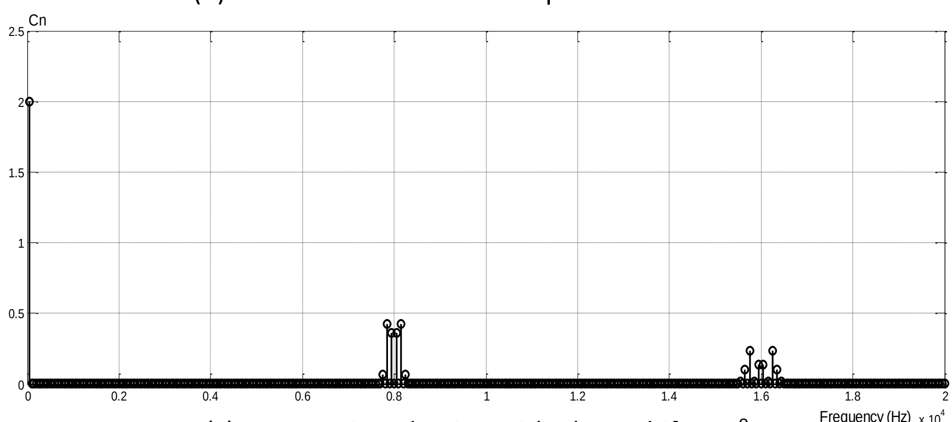
Figure 8 is reflecting a comparison of increase in magnitude of fundamental component magnitude with the decrease in the summation of all other components magnitudes. The optimum change in reference phase shift is shown to be at 180 degree where the normalized magnitude of the fundamental component is maximized while other high frequency components were minimized.



(a) Original 2-level PWM case



(b) Harmonic reduction with phase shift 110^{o}



(c) Harmonic reduction with phase shift 180^{o}

Figure 7 Effect of tuning the reference phase shift on harmonic magnitude distribution of the output unfiltered waveforem.

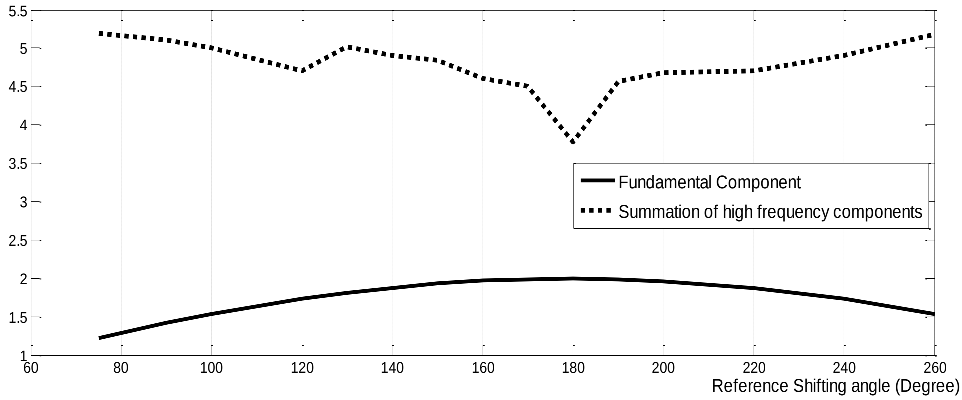


Figure 8 comparison of fundamental component magnitude with summation of other components for each phase change value.

V. Conclusions

The paper introduced a technique that is able to effectively reduce the harmonic content of the output frequency spectrum in such a way that most of the high frequency components are redistributed to other components including the fundamental one. In conclusion, the proposed technique provided a superior performance over that of the ordinary two-level PWM technique represented in eliminating the nearest bank of harmonics to the fundamental component, effectively reducing the THD%, and providing a stepped-up amplitude (as a result of summation process). The results of the minimized THD% of the unfiltered voltage waveform was compared to similar target work with a different method of harmonic reduction called selective harmonic reduction [9]. The achieved results were found to be comparable to previous work results with different approaches but with more simplest and un-sophisticated method.

References

[1] P.N. Enjeti , P.D. Ziogas, and J.F. Lindsay,"Programmed PWM techniques to eliminate harmonics: a critical evaluation”, IEEE Transactions on Industry Applications, Volume: 26, Issue: 2, Mar/Apr 1990.

[2] Sandeep Phogat,” Analysis of Single-Phase SPWM Inverter”, International Journal of Science and Research (IJSR), Volume 3 Issue 8, pp. 1793-1798, August 2014.

[3] Zulkifilie Bin Ibrahim, Md. Liton Hossain, Ismadi Bin Bugis, Nik Munaji Nik Mahadi, Ahmad Shukri Abu Hasim,” Simulation Investigation of SPWM, THIPWM and SVPWMTechniques for Three Phase Voltage Source Inverter”, International Journal of Power Electronics and Drive System (IJPEDS), Vol. 4, No. 2, June 2014, pp. 223-232.

[4] Kalpesh R. Chaudhary, and M J. Mod2,” Switching Control of Inverter Using Spwm Technique”, International Journal of Innovative Research In Technology 2015, Volume 1 Issue 12, pp. 1117-1124.

[5] Abd Almula G. M. Gebreel, “Simulation And Implementation Of Two-Level And Three-Level Inverters By Matlab And Rt-Lab”, MSc thesis, The Ohio State University 2011.

[6] IEEE Power and Energy Society, “IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems”, IEEE Std 519™-2014 (Revision of IEEE Std 519-1992).

[7] Halpin, “Revisions to IEEE Standard 519-1992”, Transmission and Distribution Conference and Exhibition, 2005/2006 IEEE PES.

[8] Surin Khomfoi and Leon M. Tolbert, “Multilevel Power Converters in Power Electronics Handbook”, Editor M. Rashid, 2nd edition, 2007, Academic Press.

[9] V. Surya Manoj, N. Venkata Ramana, And D. Mamatha, “Harmonic Reduction In Two-Level And Three-Level Vsc Usingshe-Pwm And Ripple Repositioning Technique”, International Journal of Signal Processing Systems (IJSPS) Vol. 2, Issue 1, Jun 2016, pp. 1-12.

تحسين تقنية تضمين عرض النبضة للعاكس ذات المستويين أعتمادا على تقنية ضبط فرق الطور

د. محمد صاحب خسباك
mohsaheb@yahoo.com
كلية الرافدين الجامعة – قسم هندسة اتصالات الحاسوب

المستخلص:

أن التقليل أو الغاء توافقيات التردد هو مجال بحثي حيوي وذلك لاهميته في تقليل نسبة تشويه التوافقيات الكلي في أنظمة القدرة. وبما أن طريقة تضمين عرض النبضة ذات المستويين في توليد الأشارة المتناوبة هي الأقل تعقيداً في دوائر سيطرة القدرة مقارنة بتقنيات التضمين ذات المستويات الأعلى لذلك في هذه الورقة البحثية يكون من المجدي التركيز على أقتراح طريقة جديدة تنتج عن طيف توافيات محسن ومطور.

المسار الجديد هنا هو تكييف موجة المصدر الخاصة بعملية تضمين عرض النبضة ذات المستويين وذلك عن طريق استنساخ عملية التضمين وأضافة عملية ضبط فرق طور اشارة المصدر. أظهرت نتائج هذه الطريقة الجديدة أنخفاض في محتوى التوافقيات للأشارة الخارجة الغير مرشحة بنسبة 50% تقريبا.

الكلمات الرئيسية: تضمين عرض النبضة، العاكسات، تقليل التوافقيات