ISSN (Online) : 2278 - 8875
ISSN (Print) : 2320 - 3765

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering
Vol. 2, Issue 7, July 2013

SIMULATION OF HARMONICS ELIMINATION USING MODULATION INDEX

Sridhar Chakravarthy D [1], Md.Jani Pasha [2], Dr. Himani [3]

PG Student [Power Electronics], Dept. of EEE, Aurora's Engineering College, Bhongir, A.P, India [1]

Assistant professor, Dept. of EEE, Aurora's Engineering College, Bhongir, A.P, India [2]

HOD, Dept. of EEE, Aurora's Engineering College, Bhongir, A.P, India [3]

ABSTRACT: This paper presents a methodology of modulation-based for generating pulse waveforms with selective harmonic elimination technique. In order to deal with harmonic elimination, a sine wave is compared with carrier triangular wave traditionally digital is presented. This approach requires a modified carrier waveform that can be calculated based on concise functions requiring only depth of modulation as input and does not require an initial guess while doing calculations for conventional offline solutions of switching angles and solution of coupled transcendental equations is not required. It also connects modulation to a harmonic elimination process.

Keywords: Pulse width Modulations (PWM), Selective Harmonic Elimination (SHE), Fast Fourier Transform (FFT), Matlab (simulation).

I.INTRODUCTION

Selective Harmonic Elimination (SHE) has been a research topic since the early 1960's, first examined in and developed into a mature form in during the 1970's is a long established method of generating pulse width modulation (PWM) with low baseband distortion [1]–[6]. Originally, it was useful mainly for inverters with naturally low switching frequency due to high power level or slow switching devices. Conventional sine-triangle PWM essentially eliminates baseband harmonics for frequency ratios of about 10:1 or greater [7], so it is arguable that SHE is unnecessary. However, recently Selective Harmonic Elimination (SHE) has received new attention for several reasons. Selective Harmonic Elimination (SHE) offers several advantages compared to traditional modulation methods including acceptable performance with low switching frequency to fundamental frequency ratios, direct control over output waveform harmonics, and the ability to leave triple harmonics uncontrolled to take advantage of circuit topology in three phase systems. First, digital implementation has become common. Second, it has been shown that there are many solutions to the selective harmonic elimination (she) problem that were previously unknown [8]. Each solution has different frequency content above the baseband, which provides options for flattening the high-frequency spectrum for noise suppression or optimizing efficiency. Third, some applications, despite the availability of high-speed switches, have low switching-to-fundamental ratios One ex-ample is high-speed motor drives, useful for reducing mass in applications like electric vehicles [9]. These key advantages make SHE a viable alternative to other methods of modulation in applications such as ground power units, dual-frequency induction heating. Selective harmonic elimination (she) is normally a two-step digital process. First, the switching angles are calculated offline, for several depths of modulation, by solving many nonlinear equations simultaneously. Second, these angles are stored in a look up table to be read in real time. Much prior work has focused on the first step because of its computational difficulty. One possibility is to replace the Fourier series formulation with another orthonormal set based on Walsh functions [10]–[12]. The resulting equations are more tractable due to the similarities between the rectangular Walsh function and the desired wave-form. Another orthonormal set approach based on block-pulse functions is presented in [13]. In [14][20], it is observed that the switching angles obtained traditionally can be represented as regular-sampled PWM where two phase-shifted modulating waves and a "pulse position modulation" technique achieve near-ideal elimination. Another approximate method is posed by [21] where mirror surplus harmonics are used. This involves solving multilevel elimination by considering reduced harmonic elimination waveforms in each switching level. In [22], a general-harmonic-families elimination concept simplifies a transcendental system to an algebraic functional problem by zeroing entire harmonic families. Faster and more complete methods have also been researched. In [23], an optimal PWM problem is solved by converting to a single unvaried polynomial using Newton identities, Padé approximation theory, and symmetric function properties, which can be solved with algorithms that scale as $O(nlog^2n)$. If a few solutions are desired, prediction of initial guess values allows rapid convergence of Newton iteration [24]. Genetic

ISSN (Online) : 2278 - 8875
ISSN (Print) : 2320 - 3765

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering
Vol. 2, Issue 7, July 2013

algorithms can be used to speed the solution [25], [26]. An approach that guarantees all solutions fit narrowly posed selective harmonic elimination (she) problem trans-forms to a multivariate polynomial system [27]–[30] through trigonometric identities [31] and solves with resultant polynomial theory. Another approach [32]–[34] that obtains all solutions to a narrowly-posed problem uses homology and continuation theory. Reference [35] points out the exponentially growing nature of the problem and proposes the "simulated annealing" method as a way to rapidly design the waveform for optimizing distortion and switching loss. Another optimization-based approach is given in [36] and [37], where harmonics are minimized through an objective function to obtain good overall harmonic performance. There have been several multilevel and approximate real-time methods proposed; these are beyond the scope here but discussed briefly in [38]. This manuscript proposes an alternative real-time selective harmonic elimination (SHE) method based on modulation. A modified triangle carrier is identified that is compared to an ordinary sine wave. In place of the conventional offline solution of switching angles, the process simplifies to generation and comparison of the carrier and sine modulation, which can be done in minimal time without convergence or precision concerns. The method does not require an initial guess. In contrast to other selective harmonic elimination (SHE) methods, the method does not restrict the switching frequency to an integer multiple of the fundamental. The underlying idea was proposed in [39] but has been refined here to identify specific carrier requirements that exactly eliminate harmonics and improve performance in deeper modulation. The method involves a function of modulation depth that is derived from simulation and curve fitting. In this respect, it has some similarity to [15] and [16], in which approximate switching angles are calculated and fitted to simple functions for cases of both low-(<0.8 p.u.) and high-modulation depth. It is interesting that the proposed approach connects modulation to a harmonic elimination process. Carrier waveform modulation, the proposed technique is not a variation of random-frequency carriers. Instead, the carrier waveform is modified in a specific and deterministic way to bring about a certain effect. The proposed method is readily implemented in real time. The switching signals themselves can be generated by analog comparison, while the modified carrier is generated with fast digital calculation and digital-to-analog conversion.

II. SIGNAL DEFINITIONS AND SIMULATED RESULTS

Considering a quasi-triangular waveform to be used as the carrier signal in a PWM implementation. In principle, the frequency and phase can be modulated. To represent this, consider a triangular carrier function written as

$$C(t) = 1 - \frac{2}{\pi}\cos^{-1}(\omega_{s\omega} t + \beta(t) + \varphi)) \ldots\ldots\ldots (1)$$

Where $\omega_{s\omega}$ is the base switching frequency, β (t) is a phase-modulation signal, and φ is a static phase shift. For β(t)= 0, (1) reduces to an ordinary triangle wave based on conventional quadrant definitions of the inverse cosine function. The modulating signal will be represented as $m(t) = m_d \sin \omega t$ where m_d is the depth of modulation. The pulse width modulated signal, p (t), is +1 if m(t)>c(t) and -1, otherwise. In [39], a phase modulation function β(t)= $m_d^2 \sin(2\omega t)$ is considered, where ω is the desired output fundamental frequency. This was shown to approach selective harmonic elimination (SHE) at low m_d , but degrades above m_d= 0.8. To determine a better phase modulation function, the pattern of switching angles that occurs was investigated. Fig. 1 shows the phase modulation values needed versus angle (ωt) for various m_d with harmonics 1–109 controlled. Fig. 2 shows the same with harmonics 1–177 controlled. Many other sets of controlled harmonics were tested with similar results. The pattern looks much like a shockwave pattern that can be modelled with the Bessel–Fubini equation from nonlinear acoustics [42]

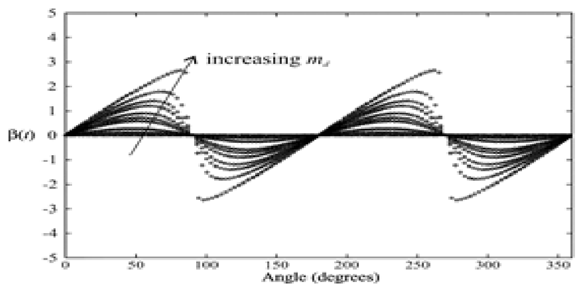


Fig 1

ISSN (Online) : 2278 - 8875
ISSN (Print) : 2320 - 3765

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering
Vol. 2, Issue 7, July 2013

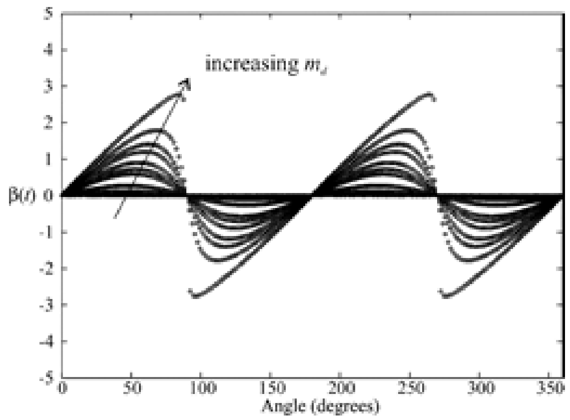


Fig 2

$$\beta(t) = \sum_{n=1}^{M} G(m_d)\frac{J_n(n\sigma(m_d))}{n\sigma(m_d)}\sin(2n(\omega t + \frac{\pi}{2})) \dots (2)$$

Where J_n is a Bessel function of the first kind. The natural number M is infinity in principle, but for calculation purposes $M =$ 15 or higher is usually sufficient, as discussed below. The functions $\sigma(m_d)$ and $G(m_d)$ have been determined by curve fitting as and (4), shown at the bottom of the page, where 0 $\leq m_d \leq$1.

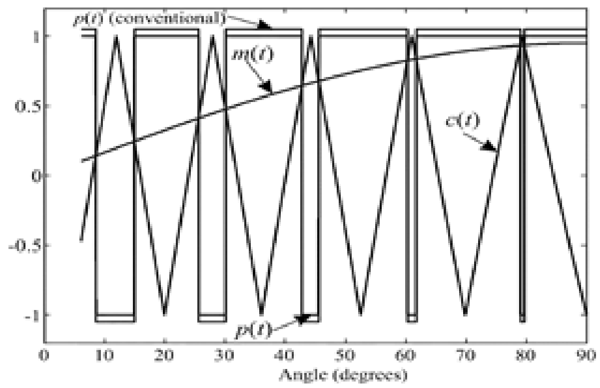


Fig 3

Fig. 3 shows a close up view of a PWM waveform generated with a carrier that uses $\beta(t)$ as in (2). Nineteen harmonics are controlled with a (high) $m_d =$ 0.95. The waveform is compared to one generated with conventional elimination by numerical solution of nonlinear equations. As can be seen, the switching edges match well.

$$\sigma(\omega_d) = \frac{-0.1384m_d^3+0.1527m_d^2-0.01358m_d+0.0003431}{m_d^3-1.948m_d^2+0.7006m_d+0.2491} \dots (3)$$

Fig. 4 shows a full-period time waveform and a magnitude spectrum [fast Fourier transform (FFT)] for $\omega_{sw}/\omega =$ 11. With this switching frequency ratio, the method eliminates harmonics two through ten (even harmonics are zero by

ISSN (Online) : 2278 - 8875
ISSN (Print) : 2320 - 3765

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering
Vol. 2, Issue 7, July 2013

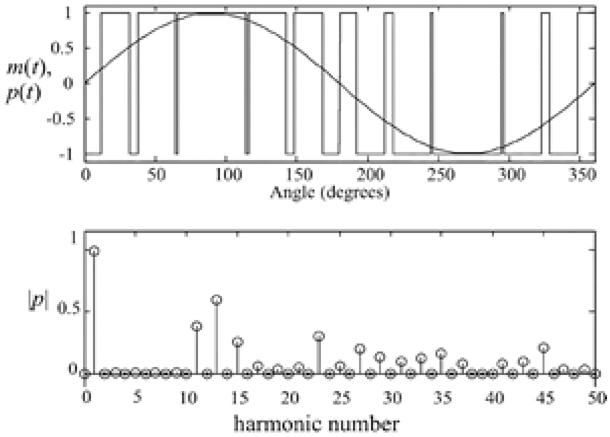


Fig 4

The carrier phase shift is set to $\varphi = \pi/2$ and the modulation depth is $m_d = 1$. The spectrum confirms the desired elimination. Fig. 5 shows the same study except with $\varphi = 0$. This value also achieves satisfactory baseband performance, but with a different pulse pattern. The pattern provides slight differences in higher-order harmonics. For example, the 11th and 13th harmonics vary 2%–3% in magnitude as φ is varied from $-\pi$ to π.

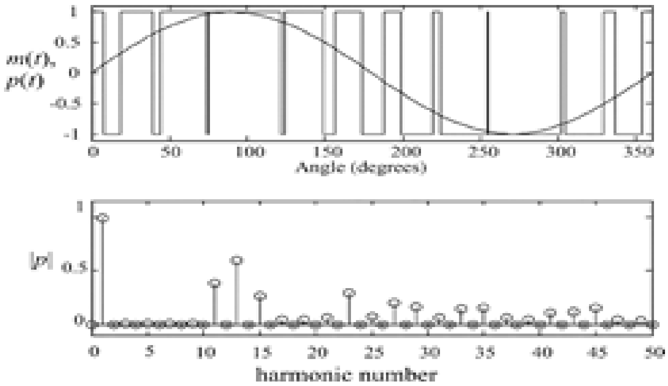


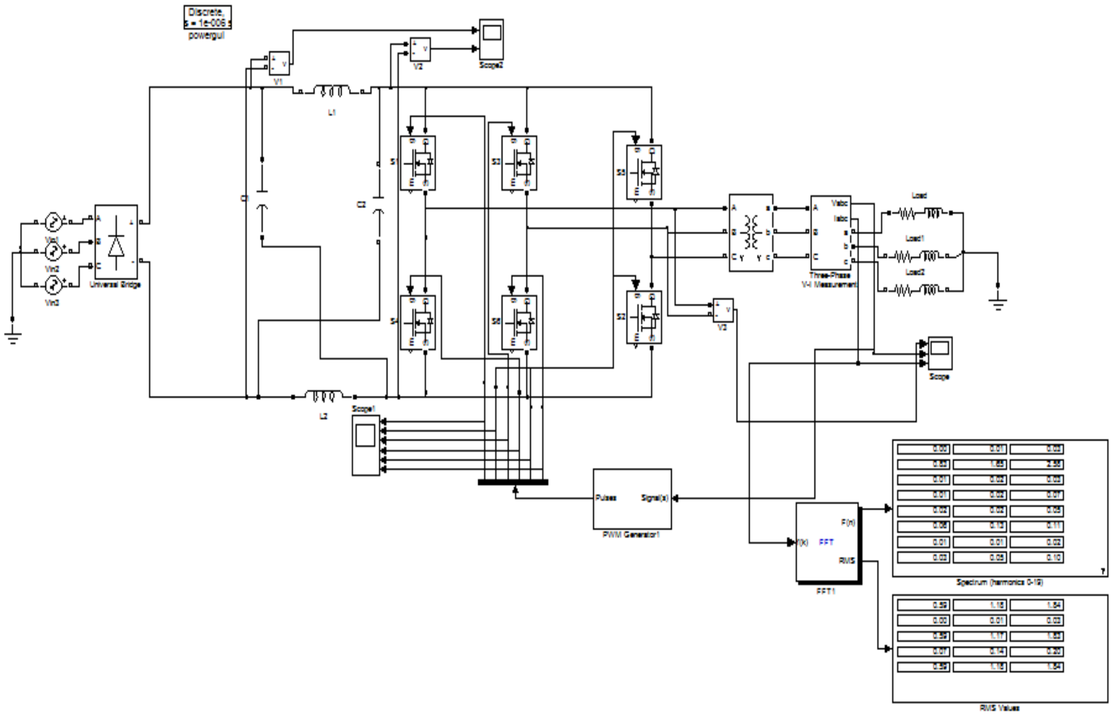
Fig 5

In these cases, all baseband harmonics are eliminated. In three-phase systems, triple harmonics may cancel in the currents automatically if neutral current does not flow. Therefore it is not always necessary to eliminate them by design in the selective harmonic elimination (SHE) process. Modulation-based harmonic elimination excluding triple harmonics is similar in many respects to the case here. However, the phase-modulation functions resemble piecewise polynomials rather than the shockwave form of Figs. 1 and 2., [38].The speed of calculating these waveforms is dictated by$M$, the number of terms to keep in the series (2), and$n$, the number of discrete points used to approximate the waveforms A personal computer (3-GHz AMD Athlon 64 bit Processor with 6-GB RAM) running MATLAB on Windows 7 Ultimate was used to carry out the calculations. First, a modified triangle wave was approximated with $n = 100\ 000$ points per cycle, the modulation depth was set to $m_d = 1$, and a frequency ratio of 19 was used. The number M was varied from five to 35. Over this range, the quality of solution was acceptable and the average calculation time varied from 0.327 to 0.915 s. Next, the same conditions were used with except $M = 35$ and n was varied from 10 000 to 200 000. The average calculation time varied almost linearly from 0.149 to 1.78 s with no significant difference in the resulting spectrum. Finally, with 'n' held constant at 100 000, the frequency ratio was varied from seven to 51. The average calculation time was consistently near 0.92 s. This is expected since the number of harmonics eliminated has no scaling effect in (2). However, for larger frequency ratios, larger n may be needed for precision. In summary, it is recommended that n be set to at least 1,000 $\times$ the frequency ratio and M set to at least 15. In any case, with present-day personal computers the solution can be calculated in less than 1 s (typically) without iteration, divergence, or need for an initial estimate, and reduced versions can be computed in less than 200 ms. Notice that this time interval need not

ISSN (Online) : 2278 - 8875
ISSN (Print) : 2320 - 3765

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering
Vol. 2, Issue 7, July 2013

cause trouble with real-time implementations. The carrier only needs to be recomputed with the modulation signal changes. In applications such as uninterruptible supplies, this is infrequent. In motor-drive applications, a response time of 200 ms to a command change may be acceptable as is. Alternatively, a look-up table can store some of the relevant terms to speed up the process dramatically. Dedicated DSP Please defines DSP algorithms will be much faster than PC computations based on MATLAB.



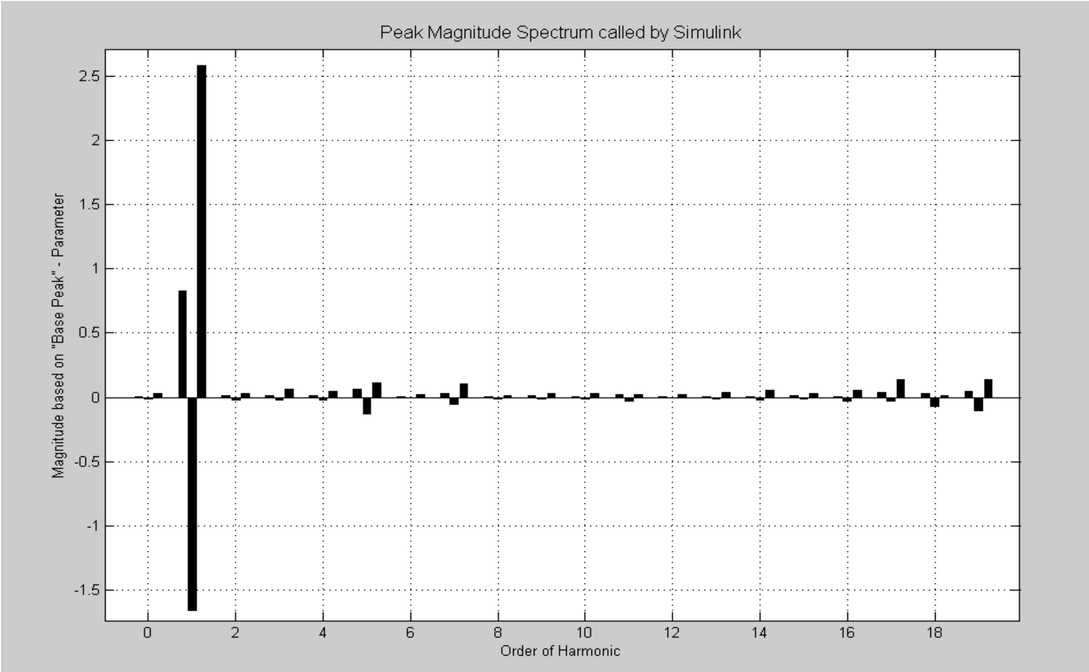
SIMULATION MODEL

III. EXPERIMENTAL EXAMPLES

To show that the proposed technique satisfactorily eliminates harmonics, the modified carrier was programmed into a function generator. The output provided a carrier signal in a conventional sine-triangle eliminated, $\varphi = 0$, and $m_d = 0.95$. The frequency ratio is 21:1 process. High depth case with nineteen harmonics the signals $c(t)$ and $m(t)$ are shown at the top, followed by the PWM waveform and the FFT spectrum. From the spectrum it can be seen that the desired harmonic-free baseband spectrum is achieved. In the next example, the phase shift is $\varphi = \pi/2$. The unexpected result was that the spectrum was insensitive to φ.The desired spectrum occurs despite the difference in carriers. The resulting PWM waveforms at various values of φ may not offer obvious advantages, but it is not worthy that they are not the same as conventionally computed selective harmonic elimination waveforms and would not be achievable with conventional selective harmonic elimination (SHE) solution techniques. As another example, it is that the carrier base frequency,ω_{sw}, need not be an odd multiple ofω. The frequency ratio is adjusted to be 20:1, with $\varphi = 0$, and now $m_d =$ 1.0. The same nineteen harmonics are eliminated, but now the switching frequency is 5% low, Interval during the carrier waveform is non-triangular. The frequency ratio can also be a half integer. In this case, the ratio is 13.5:1, $m_d =$ 0.95 and $\varphi = 0$. a case where a high number of harmonics is eliminated (50 :1 ratio) effectively, which is much higher than typically are reported.

ISSN (Online) : 2278 - 8875
ISSN (Print) : 2320 - 3765

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering
Vol. 2, Issue 7, July 2013



PEAK MAGNITUDE SPECTRUM

0.00	0.01	0.03
0.83	1.65	2.58
0.01	0.02	0.03
0.01	0.02	0.07
0.02	0.02	0.05
0.06	0.13	0.11
0.01	0.01	0.02

Spectrum (harmonics 0-19)

0.59	1.18	1.84
0.00	0.01	0.03
0.59	1.17	1.83
0.07	0.14	0.20
0.59	1.18	1.84

RMS Values

ONLINE CALCULATIONS OF FFT FOR HARMONICS

IV. CONCLUSION

A method for calculating and implementing selective harmonic elimination (SHE) switching angles was proposed and by varying the periodicity of the carrier signal Modulation index improved. This improves THD. The method is based on modulation rather than solution of nonlinear equations. This approach is based on a modified carrier waveform which can be calculated based on concise functions requiring only depth of modulation as input. It rapidly calculates the desired switching waveforms while avoiding iteration and initial estimates. Calculation time is insensitive to the switching frequency ratio so elimination of many harmonics is straightforward. It is conceivable the technique could be realized with low-cost microcontrollers for real-time implementation. Once the carrier is computed, a conventional carrier-modulator comparison process produces switching instants in real time.

ISSN (Online) : 2278 - 8875
ISSN (Print) : 2320 - 3765

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering
Vol. 2, Issue 7, July 2013

REFERENCES

[1] F. G. Turnbull, "Selected harmonic reduction in static dc-ac inverters," IEEE Trans. Commun. Electron. vol. CE-83, Jul. 1964.
[2] H. S. Patel and R. G. Hoft, "Generalized techniques of harmonic elimination and voltage control in thyristor inverters: part I-harmonic elimination,"IEEE Trans. Ind. Appl., May/Jun. 1973.
[3] "Generalized techniques of harmonic elimination and voltage control in thyristor inverters: part II-voltage control techniques," IEEE Trans. Ind. Appl., vol. IA-10, Sep./Oct. 1974.
[4] I. J. Pitel, S. N. Talukdar, and P. Wood, "Characterization of programmed waveform pulse width modulation," IEEE Trans. Ind. Appl., Sep./Oct. 1980.
[5] "Characterization of programmed-waveform pulse-width modulation, "in Proc. IEEE Ind. Appl. Soc. Annu.
[6] P. N. Enjeti, P. D. Ziogas, and J. F. Lindsay, "Programmed PWM techniques to eliminate harmonics: a critical evaluation," IEEE Trans. Mar./Apr. 1990.
[7] D. G. Holmes and T. A. Lipo, Pulse Width Modulation for Power Converters Principles and Practice. Hoboken, NJ: IEEE, 2003.
[8] J. R.Wells, B. M. Nee, P. L. Chapman, and P. T. Krein, "Selective harmonic control: a general problem formulation and selected solutions,"IEEE Trans. Power Electron., Nov. 2005.
[9] P. L. Chapman and P. T. Krein, "Motor re-rating for traction applications—field weakening revisited," in Proc. IEEE Int. Elect.
[10] T. J. Liang and R. G. Hoft, "Walsh function method of harmonic elimination, "in Proc. IEEE Appl. Power Electron. Conf., 1993.
[11] T.-J. Liang, R. M. O'Connell, and R. G. Hoft, "Inverter harmonic reduction using Walsh function harmonic elimination method," IEEE Trans. Power Electron, Nov. 1997.
[12] F. Swift and A. Kamberis, "A new Walsh domain technique of harmonic elimination and voltage control in pulse-width modulated inverters,"IEEE Trans. Power Electron., Apr.1993.
[13] J. Nazarzadeh, M. Razzaghi, and K. Y. Nikravesh, "Harmonic elimination in pulse-width modulated inverters using piecewise constant orthogonal functions," Elect. Power Syst. Res., 1997.
[14] S. R. Bowes and P. R. Clark, "Simple microprocessor implementation of new regular-sampled harmonic elimination PWM techniques," in Proc. IEEE Ind. Appl. Soc. Annu. Meeting, 1990.
[15] "Transputer-based harmonic-elimination PWM control of Inverter drives," IEEE Trans. Ind. Appl., Jan./Feb. 1992.
[16] "Simple microprocessor implementation of new regular-sampled harmonic elimination PWM techniques," IEEE Trans. Ind. Appl., vol. 28, no. 1, pp. 89–95, Jan./Feb. 1992.
[17] "Regular-sampled harmonic-elimination PWM control of Inverter drives," IEEE Trans. Power Electron. Sep. 1995.
[18] S. R. Bowes, "Advanced regular-sampled PWM control techniques for drives and static power converters," IEEE Trans. Ind. Electron, Aug. 1995.
[19] S. R. Bowes, S. Grewal, and D. Holliday, "Single-phase harmonic elimination PWM," Electron. Lett, 2000.
[20] S. R. Bowes and S. Grewal, "Novel harmonic elimination PWM control strategies for three-phase PWM inverters using space vector techniques," Proc. Inst. Elect. Eng., 1999.
[21] L. Li, D. Czarkowski, Y. Liu, and P. Pillay, "Multilevel selective Harmonic elimination PWM technique in series-connected voltage inverters,"IEEE Trans. Ind. Appl., Jan./Feb.2000.
[22] P. Bolognesi and D. Casini, "General harmonic families' elimination methodology for static converters control," in Proc. Int. Conf. Power Electron. Var. Speed Drives, 1998.
[23] D. Czarkowski, D. V. Chudnovsky, G. V. Chudnovsky, and I. W.Selesnick, "Solving the optimal PWM problem for single-phase Inverters," IEEE Trans. Circuits Syst. I, Apr. 2002.
[24] J. Sun and H. Grotstollen, "Solving nonlinear equations for selective harmonic eliminated PWM using predicted initial values," in Proc. Int.Conf. Ind. Electron, Contr., Instrum. Automat, 1992..
[25] A. I. Maswood, S.Wei, and M. A. Rahman, "A flexible way to generate PWM-selective harmonic elimination (SHE) switching patterns using genetic algorithm," in Proc. IEEEAppl. Power Electron..
[26] B. Ozpineci, L. M. Tolbert, and J. N. Chiasson, "Harmonic optimization of multilevel converters is using genetic algorithms," in Proc. IEEE Power Electron. Spec. Conf., 2004.
[27] J. Chiasson, L. Tolbert, K. McKenzie, and D. Zhong, "Eliminating harmonics in a multilevel converter using resultant theory," in Proc. IEEE Power Electron. Spec. Conf., 2002.
[28] J. N. Chiasson, L. M. Tolbert, K. J. McKenzie, and Z. Du, "A complete solution to the harmonic elimination problem," IEEE Trans. Power Electron., Mar. 2004.
[29] J. Chiasson, L. M. Tolbert, K. McKenzie, and Z. Du, "Elimination of harmonics in a multilevel converter using the theory of symmetric polynomials and resultants," in Proc. IEEE Conf. Dec. Contr., 2003.
[30] J. N. Chiasson, L. M. Tolbert, K. J. McKenzie, and Z. Du, "Control of a multilevel converter using resultant theory," IEEE Trans. Contr. Syst.Technol., vol. 11, no. 3, May 2003.
[31] J. Sun and H. Grotstollen, "Pulse width modulation based on real-time solution of algebraic harmonic elimination equations," in Proc. Int.Conf. Ind. Electron., Contr. Instrum., 1994, pp. 79–84.
[32] T. Kato, "Sequential homotopy-based computation of multiple solutions for selected harmonic elimination in PWM inverters," IEEE Trans. Circuits Syst. I, May 1999.
[33] J. Sun, S. Beineke, and H. Grotstollen, "Optimal PWM based on real-time solution of harmonic elimination equations," IEEE Trans. Power Electron., Jul. 1996.
[34] Y.-X. Xie, L. Zhou, and H. Peng, "Homotopy algorithm research of the inverter harmonic elimination PWM model," in Proc. Chin. Soc. Elect. Eng., 2000,
[35] S. R. Shaw, D. K. Jackson, T. A. Denison, and S. B. Leeb, "Computer aided design and application of sinusoidal switching patterns," in Proc.IEEE Workshop Compute. Power Electron. 1998,
[36] V. G. Agelidis, A. Balouktsis, and I. Balouktsis, "On applying a minimization technique to the harmonic elimination PWM control: the bipolar waveform," IEEE Power Electron. Lett.
[37] V. G. Agelidis, A. Balouktsis, and C. Cosar, "Multiple sets of solutions for harmonic elimination PWM bipolar waveforms: analysis and experimental verification," IEEE Trans. Power Electron
[38] J. R. Wells, "Generalized Selective Harmonic Control," Ph.D. dissertation, Univ. Illinois, Urbana, Power Electron. 2004, [38] J. R. Wells, "Generalized Selective Harmonic Control," Ph.D. dissertation, Univ. Illinois, Urbana, 2006.
[39] P. T. Krein, B. M. Nee, and J. R. Wells, "Harmonic elimination switching through modulation," in Proc. IEEE Workshop Computer. Power Electron. 2004, pp. 123–126.

ISSN (Online) : 2278 - 8875
ISSN (Print) : 2320 - 3765

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering
Vol. 2, Issue 7, July 2013

[40] A. M. Stankovic, G. C. Verghese, and D. J. Perreault, "Analysis and synthesis of randomized modulation schemes for power converters,"IEEE Trans. Power Electron., vol. 10, no. 6, pp. 680–693, Nov. 1995.
[41] M. J. Meinhart, "Microcontroller Implementation of Modulation-Based Selective Harmonics Elimination," M.S. thesis, Univ-Illinois, Urbana, 2006.
[42] B. Enflo and C. Hedberg, Theory of Nonlinear Acoustics in Fluids. Dordrecht, The Netherlands: Kluwer, 2002.

BIOGRAPHY

SRIDHAR CHAKRAVARTHY D[1] born'85, Graduated in Electrical Engg. (2007) from Vardhaman College Of Engg. JNT.U'ty, (AP), India. He is currently pursuing MTech. (Power Electronics) at Aurora's Engg College. He is interested fields are Power Electronics.

Md.JANI PASHA[2] born'85, graduated in Electrical Engg. From (AP) India. He is currently working as Asst. professor at Aurora's Engg College. He is interested fields are Power Electronics.

Dr.Himani [3], graduated in Electrical Engg. Done PhD from IIT DELHI, She is currently working as HOD at Aurora's Engg College. She is interested fields are Power Electronics.