Selective Harmonic Elimination PWM Based on Walsh Transform and Its Application in Dynamic Voltage Restorer

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Abstract: - The Selective Harmonic Elimination PWM (SHEPWM) based on Walsh transform converters nonlinear transcendental equations in the Fourier domain to linear algebraic ones. Under appropriate initial condition, the piecewise linear relation between fundamental voltage amplitude and switching angles is obtained, so voltage regulation and harmonic elimination can be realized online. Thus, the technique highly suits to the inverter of dynamic voltage restorer (DVR). In the paper, Walsh transform, construction and solution of SHE equations in Walsh domain are introduced. The sameness and the difference between switch angles distribution of SHEPWM and of Centroid PWM (CPWM) are summarized, and, according to the relationship between both PWM modes, a new method to solve SHE equation in Walsh domain is proposed. In contrast to conventional ones, the new method effectively reduces blindness of searching initial switch angles in the course of SHE equation solution and improves computation efficiency. The experimental result of 200kVA DVR using SHEPWM, which indicates that its inverter can effectively restrain all the harmonics and has good dynamic performance in all the range of output voltage, proves feasibility and validity of the proposed method.

Key-Words: - Dynamic Voltage Restorer, Inverter, PWM, Selective Harmonic Elimination PWM, Centriod PWM, Walsh function

1 Introduction

Dynamic voltage restorer (DVR) is an equipment used to compensate for the dynamic power quality problems such as voltage sag and swell, whose core is a controllable voltage source inverter installed in power system in series[1]. As the executor of compensation command, DVR inverter influences the performance of DVR in great degree and it should fleetly regulate output voltage at any moment and keep enough low total harmonic distortion (THD) in the whole range of output voltage.

Pulse width modulation (PWM) mode directly influences even decides the performance of an inverter. Of various PWM modes, Sine PWM (SPWM) is one most frequently used in constant voltage & constant frequency (CVCF) inverter. However, when an inverter, controlled by SPWM, varies its output voltage amplitude in a wide range, the THD of its output voltage will vary evidently: the lower voltage amplitude is, the higher the THD. While SHEPWM can make the inverter keep a preconcerted THD, no matter how its output voltage varies. In addition, at the same switch frequency, the inverter controlled by SHPWM can raise the frequency of the lowest order of harmonic higher by 33%~35% than the one controlled by SPWM, which can diminish parameters and size of the filter, thereby raising dynamic performance of the inverter. Thus, for DVR inverter, SHEPWM is a better PWM mode than SPWM[2,3].

Now, research on SHEPWM mainly concentrates on SHEPWM based on Fourier transform, whose biggest obstacle lies in that: the relationship between the amplitude of harmonics of output voltage and switch angles is depicted by nonlinear transcendental equations so that it difficult to solve the equations online. As a result, in project practice, the equation is solved off-line and many groups of data are saved to realize voltage regulation, which not only wastes storage space but reduces flexibility of the system[4].

Asumadu and Hoft proposed SHEPWM based on Walsh transform in [6], which converters nonlinear transcendental equations in the Fourier domain to linear algebraic ones so as to obtain piecewise linear relation between fundamental voltage amplitude and switching angles. [7]~[9] improved the computing method of Walsh coefficient on the basis of [6]. But, all literatures above mentioned gave initial switching angles distribution mode relying on experiences and were short of quantitative basis in the course of solving SHE equations.

The paper proposes a new initialization method to solving SHE equation that based on CPWM technique, which evidently improves computation efficiency. The construction and solution of SHE equations are illustrated by an unipolar inverter of 200kVA DVR.

2 Walsh Functions and Walsh series

Walsh functions, one class of piecewise constant basis functions, are introduced by Walsh in 1923[4]. These functions form an ordered set of rectangular waveforms taking only two amplitude values: 1 and -1, over one normalized frequency period. Walsh functions form a complete or orthogonal set, hence, they can be used to represent signals in the same way as the Fourier series. There are three ways of ordering the Walsh functions (natural, dyadic and sequency ordering) depending on the method to generate them. Sequency-ordered Walsh functions, which are chosen in the paper, are arranged in ascending order of zero crossings. Sequency is defined as one half the number of zero crossings over the unit interval [0, 1] and is used as a measure of generalized frequency of waveforms[5].

Walsh functions are either symmetrical with respect to their point and are called CAL functions, or asymmetrical and are called SAL functions expressed as followed:

$$WAL(2k,t) = CAL(k,t)\,, k = 0,1,2...(\frac{N}{2}-1) \quad (1)$$

$$WAL(2k-1,t) = SAL(k,t)\,, k = 1,2...\frac{N}{2} \quad (2)$$

Similarly to the Fourier series representation, the Walsh series representation of a time function that is absolutely integrable in [0, 1] can be defined as:

$$f(t) = \sum_{m=0}^{\infty} W_m \cdot Wal(m,t) \quad (3)$$

where W_m is the coefficient of the Walsh function $Wal(m,t)$ and is determined by

$$W_m = \int_0^1 f(t)Wal(m,t)dt \quad (4)$$

For the discrete case, the integral of (4) can be approximated by a summation expression as:

$$W_m = \frac{1}{N}\sum_{i=0}^{N-1} f(i)Wal(m,i)\,, m = 0,1,\cdots,N-1 \quad (5)$$

The discrete Walsh series representation of a time function can be easily obtained:

$$f(i) = \sum_{m=0}^{N} W_m \cdot Wal(m,i) \quad (6)$$

In Eq. (5) and (6), $Wal(m,i)$ is the discrete Walsh function corresponding to $Wal(m,t)$, $f(i)$ is the ith sampled value of $f(t)$ obtained by sampling $f(t)$ N times during the interval [0,1], and N is an integer power of 2, the greater the number given, the smaller the mean-square error between the desired waveform and the actual. Chen and Sun[12] proposed "domain-term"[12] to choose the N for synthesizing a waveform if reasonable error is accepted[7,8].

3 Inverter SHEPWM Model Based on Walsh Transform

3.1 SHE Equation in Walsh Domain[6~9]

The paper takes uniploar single phase inverter used in past experiment as research object. A typical output voltage waveform of the inverter is shown in Fig.1 in which one quarter period has M switching angles. These switching angles $\alpha_1, \alpha_2, \cdots, \alpha_M$ are used to eliminate some given lower order harmonics and control the fundamental amplitude of the inverter output voltage.

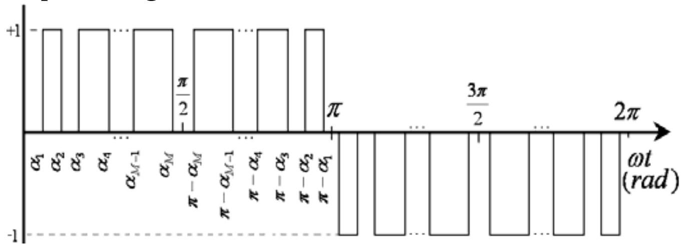


Fig.1 PWM waveform of unipolar inverter

The discrete Walsh series expression of the output voltage waveform function $f(t)$ illustrated by Fig.1 is:

$$f(i) = \sum_{n=1}^{N/4} W_{4n-3} Wal(4n-3,i) \quad (7)$$

where Walsh coefficient W_{4n-3} is determined by

$$W_{4n-3} = \sum_{n=1}^{N/4} f(i) \cdot Wal(4n-3,i) \quad (8)$$

Based on the relationship between the Fourier series and the Walsh series, the fundamental and every order of harmonics of output voltage can be expressed in Walsh domain as follow:

$$\begin{bmatrix} U_{m(1)} \\ U_{m(3)} \\ \cdot \\ U_{m(2K-1)} \end{bmatrix} = \begin{bmatrix} B_{1,1} & B_{1,5} & .. & B_{1,4N1-3} \\ B_{3,1} & B_{3,5} & .. & B_{3,4N1-3} \\ .. & .. & .. & .. \\ B_{2K-1,1} & B_{2K-1,5} & .. & B_{2K-1,4N1-3} \end{bmatrix} \times \begin{bmatrix} W_1 \\ W_5 \\ \cdot \\ W_{4N1-3} \end{bmatrix} \quad (9)$$

where $N1 = N/4$, $U_{m(k)}$ is the amplitude of the k^{th} harmonic, $B_{2K-1,4n-3}$ is Walsh-Fourier transformation coefficient which can be calculated directly from the equation derived by Siemens and Kitai[10] and W_{4n-3} is the Walsh coefficient .

Walsh coefficient W_{4n-3} can be obtained on the grounds of Eq. (8). Assumed that the inverter DC input voltage $U_{dc} = 1$ and there are M switching angles in a quarter of the period of waveform function, each period [0,1] is averagely divided into N sbuintervals and a quarter $N1$ ones. Considering M angles $\alpha_1, \alpha_2, \cdots, \alpha_M$ in the corresponding subintervals $l_1, l_2 ..., l_M$, namely

$$\frac{l_1 - 1}{N} < \alpha_1' < \frac{l_1}{N}, \cdots\cdots, \frac{l_M - 1}{N} < \alpha_M' < \frac{l_M}{N} \tag{10}$$

where $\alpha_i' = \alpha_i / 2\pi$, Walsh coefficent W_m can be derived as[]

$$W_m = \sum_{i=1}^{M} (-1)^{i+1} W(m, l_i) \tag{11}$$

where

$$W(m,l_i) = -4\alpha' Wal(m,l_i) + \frac{4}{N}[\sum_{k=l_i+1}^{N1} Wal(m,k) + l_i Wal(m,l_i)] \tag{12}$$

and $m = 4n - 3; n = 1,2,..., N1$

Note $C_{m,i} = (-1)^{i+1} \cdot Wal(m, l_i)$

$$D_m = \sum_{i=1}^{M} (-1)^{i+1} \cdot S(m, l_i)$$

Then Wash coefficents can be expressed as:

$$\begin{bmatrix} W_1 \\ W_5 \\ .. \\ W_{4N1-3} \end{bmatrix} = \begin{bmatrix} C_{1,1} & C_{1,2} & .. & C_{1,M} \\ C_{5,1} & C_{5,2} & .. & C_{5,M} \\ .. & .. & .. & .. \\ C_{4N1-3,1} & C_{4N1-3,2} & .. & C_{4N1-3,M} \end{bmatrix} \times \begin{bmatrix} \alpha_1' \\ \alpha_2' \\ . \\ \alpha_M' \end{bmatrix} + \begin{bmatrix} D_1 \\ D_5 \\ . \\ D_{4N1-3} \end{bmatrix} \tag{13}$$

Substituting Eq. (13) into Eq. (9), the linear equations between switching angles and every orders of harmonics amplitude can be obtained:

$$[U] = [B][C][\alpha'] + [B][D] = [P][\alpha'] + [Q] \tag{14}$$

Let the amplitudes of harmonics chosen to be eliminated are zero, the linear relation between switching can be obtained:

$$\alpha_i = k_i . U_1 + c_i , \ i = 1,2,..., M \tag{15}$$

Accoring to the angles variations with Eq.(10), the range of fundamental voltage for the i^{th} angle can be gained as $V^i, i = 1,2, \cdots M$, so the range of the fundamental voltage for all the angles must have a common range as followe:

$$V^c = V^1 \cap V^2 \cap ... \cap V^M \tag{16}$$

where $V^i = [\frac{l_i - N \cdot c_i - 1}{N \cdot k_i} \quad \frac{l_i - N \cdot c_i}{N \cdot k_i}]$

3.2 Production of initial switching angles[11]

Before construction and solution of SHE equations, actual distribution mode of M angles in first quarter is unknown. To construct SHE equations, a set of initial swithcing angles must be given in advance. Comparing with tranditional Newtown iteration, SHE equation in Walsh domain is less sensitive to initial condition, but, if the discrepancy between actual swithcing angles and given ones exceeds a certain degree, V^C in Eq.(16) will be an empty set, meaning that the equations have no solution and a new initial condition have to be given.

It is discovered by research that, producing initial switching angles based on Centriod PWM (CPWM) is feasible and efficient.

CPWM, a new rough selective harmonic elimination PWM mode, is simple and can be realized easily. The procedure to gain the switching angles of CPWM can be summarized as follows:

The first step is to apply the equal areas method which divides the half period of a sinusoidal wave whose peak voltage is V_p into n time sections. The area of the n^{th} sinusoidal section is evaluated by

$$A_n = V_p \cdot (\cos \beta_{n-1} - \cos \beta_n) \tag{17}$$

where β_n and β_{n-1} are the limits of the sinusoidal section. Secondly, the centroid of the n^{th} sinusoidal section is computed, whose horizontal coordinate is expressed as

$$\overline{x_n} = \frac{\sin(\beta_n) - \beta_n \cos(\beta_n) - \sin(\beta_{n-1}) + \beta_{n-1} \cos(\beta_{n-1})}{\cos(\beta_{n-1}) - \cos(\beta_n)} \tag{18}$$

Thridly, a rectangular pulse [$\alpha_{2n-1}, \alpha_{2n}$] is constructed in n^{th} sinusoidal section, whose peak voltage and area are equal to ones of the sinusoidal section and let

$$\overline{x_n} = \frac{\alpha_{2n-1} + \alpha_{2n}}{2} \tag{19}$$

Then, the locations of switching angles, which define the commutation interval [$\alpha_{2n-1}, \alpha_{2n}$], are established by the following equations:

$$\alpha_{2n-1} = \overline{x_n} - m \cdot (\frac{A_n}{2V_p}) \tag{20}$$

$$\alpha_{2n} = \overline{x_n} + m \cdot (\frac{A_n}{2V_p}) \tag{21}$$

where m is the modulation ratio of the inverter.

CPWM and SHEPWM, if the number of their switching angles is equal, can restrian or eliminate the same orders of harmonics despite differnce of restrianing degree, which means their switching angles distribution discrpancy is small. It's discovered by virtue of a great deal of computation and comparison that the bigger the modulation ratio is, the smaller switching angles distribution discrpancy of both PWM modes. Let $\alpha_1^C, \alpha_2^C, ..\alpha_M^C$ and $\alpha_1^S, \alpha_2^S, ..\alpha_M^S$ represent switching angles of the first quarter in the CPWM pulses and SHEPWM pulses, respectively. Note $\Delta\alpha_i = \alpha_i^S - \alpha_i^C$ and $\Delta l_i = \frac{\Delta\alpha_i}{2\pi} \cdot N$, where i is the sequence number of angles, N is the number of subintervals in a period. Under the circumstances that modulation ratio $m \approx 1$, $4 \le M \le 48$ and appropriate computation accuracy is guaranteed, if M is even number, $|\Delta l_i|_{\max} \approx 1$; if M is odd number, $|\Delta l_i|_{\max} \approx 2$. And, change of Δl_i with angle sequence number i is illustrated as Table 1 and 2.

Table 1 Change of Δl_i with angle sequence number (M is odd)

$i \le \frac{M-3}{2}$	$i = \frac{M-1}{2}$	$i \ge \frac{M+1}{2}$
$\Delta l_i > 0$	$\Delta l_i \approx 0$	$\Delta l_i < 0$

Table 2 Change of Δl_i with angle sequence number (M is even)

$i <$	$i = \frac{M}{2}$	$i >$	$i =$
Δl_i	Δl_i or	$\Delta l_i \approx$ $\Delta l_i <$	Δl_i

According to the case above mentioned, the switching angles of CPWM on the condition that $m \approx 1$, after amended referring to the comparison relation between both PWM modes denoted by Table 1 and Table 2, can act as initial switching angles of SHEPWM based on Walsh transform. Generally, efficent solution of SHE equation can be obtained under the initial condition. In case of solving failure, amend the switching angles of CPWM accoring to Table 1 and 2 once more and solve the SHE equation again until that efficient solution is obtained.

4 Application of SHEPWM in 200kVA DVR Inverter

DVR in the paper, used in 220V/380V grid, is composed of three single phase full-bridge inverter. Single line circuit diagram of DVR connected with power system is shown in Fig.2. DC input voltage of each inverter is 330V and rated capacity is 70kVA. Synthetically considering capacity, filter design and other factors, 31 and below orders of harmonics are to be eliminated, thus, the number of switching angles in a quarter $M = 16$.

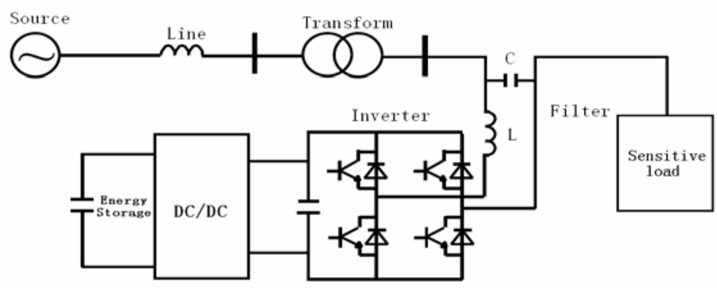


Fig.2. Single line circuit diagram of DVR connected with power system

In order to ensure computing accuracy, according to "domain-term"[12], the period [0, 1] is divided in 256 subintervals. The procedure to obtain the solutions of switching angles is realized as follows:

Firstly, calculate and produce 256×256 dimensions Walsh functions set; secondly, calculate 16×64 dimensions Fourier-Walsh transform matrix [$B_{2K-1,4n-3}$]; thirdly, let modulation ratio $m = 0.95$, produce initial switching angles according the method mentioned in last section, and convert them to the series number of subintervals as follows:

7，8，13，15，19，23，26，31，33，39，40，47，48，55，56，64.

Then, according to Eq.(9)~Eq.(14), switching angles coefficient matrix [P] and constant matrix [Q] can be gained as Table 3. In the end, the piecewise linear relation between switching and fundamental voltage amplitude can be obtained, part of which is illustrated as Table 4, where k is proportion coefficient and c is constant.

Table 3 Switching angles coefficient matrix and constant matrix

P																Q
–1.270 8	1.464 3	–2.416 0	2.787 3	–3.508 8	4.196 6	–4.686 3	5.444 7	–5.725 7	6.483 5	–6.596 5	7.273 2	–7.352 7	7.783 3	–7.826 3	7.999 2	–0.505 4
–3.683 5	4.195 8	–6.365 3	7.007 0	–7.824 8	7.968 7	–7.624 7	6.244 5	–5.443 6	2.415 5	–1.848 0	–2.227 7	2.786 7	–6.120 0	6.482 2	–7.992 8	2.205 6
–5.722 3	6.362 7	–7.989 6	7.821 6	–6.117 5	2.968 7	–0.098 1	–4.523 0	5.989 3	–7.994 4	7.922 2	–4.359 9	3.506 7	3.150 0	–4.025 8	7.979 9	–1.818 7
–7.180 6	7.674 0	–6.6976	4.838 1	0.294 1	–5.292 8	7.555 6	–6.903 3	5.144 3	2.599 3	–3.852 7	7.917 5	–7.617 1	0.490 0	0.880 7	–7.960 7	1.720 2
–7.911 1	7.954 3	–2.964 5	–0.489 6	6.4705	–7.720 1	4.8342	3.501 8	–6.233 2	6.353 8	–5.140 2	–5.980 9	6.994 3	–4.020 1	2.411 1	7.935 1	–1.769 2
–7.841 0	7.167 6	1.842 9	–5.570 1	7.6601	–1.651 9	–4.512 1	7.405 5	–4.829 4	–6.576 7	7.541 9	–0.097 9	–2.032 7	6.685 5	–5.283 2	–7.903 2	1.870 6
–6.978 9	5.421 7	5.9677	–7.936 7	2.958 0	6.219 4	–7.650 9	–2.405 8	6.456 2	–2.218 7	–0.293 2	6.095 4	–4.178 9	–7.917 6	7.242 5	7.865 0	–2.138 7
–5.414 1	2.953 8	7.906 4	–6.447 1	–4.005 6	7.232 3	–0.292 8	–7.739 6	4.500 3	7.949 5	–7.311 5	–7.853 9	7.782 4	7.456 4	–7.954 3	–7.820 5	2.073 0
–3.307 3	0.097 5	6.957 8	–1.835 1	–7.869 8	0.292 3	7.444 4	1.261 7	–6.657 3	–2.767 2	5.546 6	4.166 3	–6.549 0	–5.405 4	7.299 7	7.769 9	–1.997 9
–0.873 8	–2.762 2	3.4772	3.651 0	–5.674 1	–6.945 2	4.953 7	7.898 5	–4.158 8	–6.189 5	3.301 3	2.394 2	1.259 4	2.208 0	–5.395 6	–7.713 2	2.206 8
1.638 6	–5.240 9	–1.256 8	7.346 1	0.872 0	–6.523 9	–4.314 5	–0.097 1	6.835 5	6.631 8	–7.896 9	–7.271 8	4.790 6	1.448 2	2.573 8	7.650 5	–2.277 8
3.975 0	–7.007 2	–5.513 1	7.464 8	6.720 8	1.062 4	–7.633 5	–7.879 3	3.806 5	2.012 0	2.384 1	7.094 3	–7.846 1	–4.780 0	0.677 3	–7.581 8	2.822 4
5.899 5	–7.827 1	–7.742 0	3.965 4	7.3816	7.446 7	–0.482 9	–1.059 8	–6.990 2	–7.860 3	6.148 4	–2.007 1	6.025 8	7.077 1	–3.797 2	7.507 4	–3.000 8
7.219 1	–7.595 0	–7.141 0	–1.437 7	2.3721	5.621 7	7.292 9	7.684 1	–3.445 1	2.916 5	–6.786 0	–4.443 5	–0.481 6	–7.853 8	6.250 8	–7.427 2	2.298 3
7.803 3	–6.347 7	–3.943 8	–6.114 9	–4.430 9	–2.365 4	5.042 6	2.181 4	7.120 8	5.992 9	–1.244 2	7.784 5	–5.330 6	6.952 2	–7.620 3	7.341 4	–3.387 6
7.597 1	–4.258 1	0.669 9	–7.803 1	–7.793 7	–7.709 3	–4.096 2	–7.319 1	3.076 5	–6.647 7	7.639 1	–5.720 9	7.807 8	–4.574 2	7.676 5	–7.250 2	3.109 9

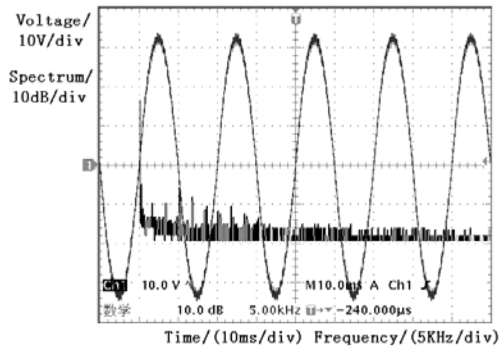
Table 4 First order coefficient and constant of each voltage section

voltage section	0.395~0.467		0.468~0.550		0.551~0.630		0.631~0.698		0.699~0.795		0.796~0.896		0.897~0.945		0.946~1.000	
	k	c	k	c	k	c	k	c	k	c	k	c	k	c	k	c
α_1	-2.216	11.34	-2.312	11.38	-2.417	11.44	-0.8333	10.25	1.174	10.48	-1.311	10.59	-2.151	11.34	-2.722	11.88
α_2	-0.4009	11.37	-0.5342	11.43	-0.6789	11.51	0.8429	10.37	0.4029	10.68	0.2261	10.81	-0.8756	11.80	-1.615	12.50
α_3	-3.203	21.53	-3.666	21.75	-4.168	22.03	-2.335	21.06	-3.019	21.54	-3.282	21.74	-5.365	23.62	-6.583	24.76
α_4	0.4061	21.61	-0.1221	21.85	-0.6944	22.17	1.088	21.25	0.1613	21.89	-0.1860	22.16	-3.511	25.17	-5.267	26.81
α_5	-3.960	32.10	-4.517	32.35	-5.118	32.69	-3.406	31.67	-4.688	32.56	-5.115	32.89	-6.704	34.28	-8.313	35.79
α_6	1.404	32.18	0.6948	32.50	-0.0653	32.93	2.140	31.60	0.0299	33.05	-0.5705	33.52	-2.770	35.41	-5.133	37.62
α_7	-4.321	42.49	-5.215	42.90	-6.141	43.42	-5.389	42.98	-6.137	43.53	-6.844	44.09	-8.791	45.78	-11.40	48.23
α_8	3.261	42.26	1.817	42.93	0.4297	43.70	0.9870	43.39	0.0927	44.10	-1.053	44.99	-4.501	48.03	-9.459	52.67
α_9	-4.667	52.88	-4.647	52.84	-6.832	54.04	-6.616	53.94	-7.104	54.31	-8.498	55.39	-11.82	58.33	-17.57	63.72
α_{10}	3.253	53.10	3.894	52.76	1.440	54.14	1.312	54.25	2.337	53.52	-1.731	56.68	-9.640	63.82	-11.05	65.17
α_{11}	-5.409	63.61	-6.365	64.03	-6.366	64.06	-6.981	64.48	-7.116	64.56	-10.03	66.83	-17.88	73.89	-18.74	74.73
α_{12}	4.525	63.46	2.645	64.30	3.654	63.75	4.164	63.44	1.063	65.55	1.765	65.03	-2.889	68.73	-18.40	83.37
α_{13}	-6.402	74.55	-6.532	74.62	-6.969	74.88	-5.655	74.06	-8.340	75.92	-8.335	75.94	-12.72	79.45	-26.95	92.88
α_{14}	3.824	74.53	4.652	74.19	2.653	75.34	3.263	74.96	4.480	74.17	-1.259	78.77	1.559	76.32	-8.758	85.53
α_{15}	-4.794	84.44	-6.250	85.13	-7.085	85.62	-6.780	85.43	-6.027	84.96	-11.29	89.16	-9.000	87.17	-18.93	96.03
α_{16}	5.899	84.43	4.592	85.04	5.310	84.63	5.368	84.60	4.998	84.88	5.275	84.66	5.396	84.56	5.681	84.29

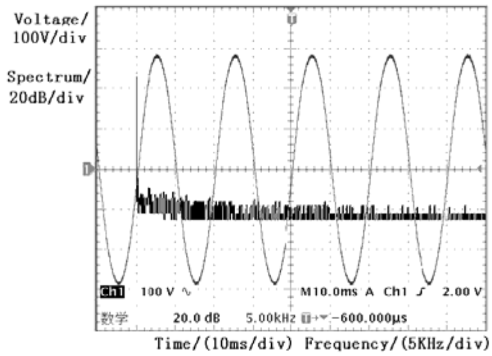
5 Experimental Result

The inverter is controlled by TMS320LF2407A DSP processor. When grid voltage fluctuates in the range of 0.1~1.5 times of rating, after compensated by DVR, the THD of load voltage is below 2.1%. With inductive character load ($\cos\varphi = 0.75$), when modulation ratio $m = 0.1$ and $m = 0.9$, the THD of inverter output voltage is 3.1% and 1.7%, respectively. The waveforms and spectrums are illustrated as Fig.3. Fig.4 denotes two transient cases: modulation ratio change abruptly from 0 to 0.5 and form 0.2 to 0.75.

Experimental results indicate that waveform quality of the output voltage of inverter controlled by SHEPWM is good and THD is low in all the range of output voltage, though the switching frequency is low. In addition, the inverter has comparatively high response speed.

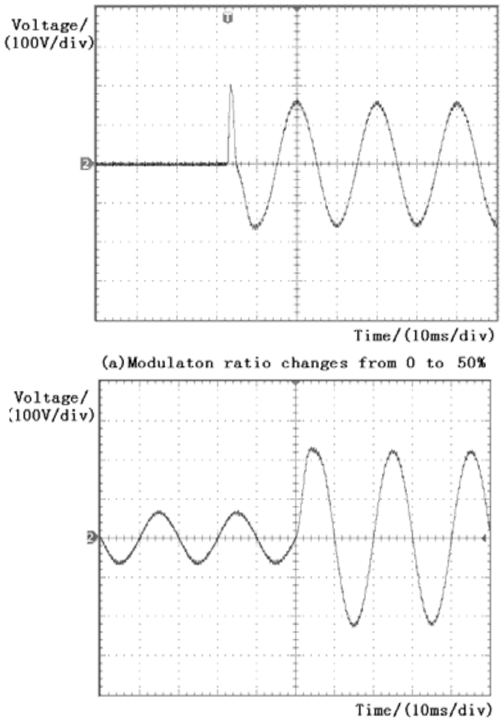


(a) Modulation ratio is 10%



(b) Modulation ratio is 90%

Fig.3. Output voltage waveform and its frequency spectrum



(a) Modulaton ratio changes from 0 to 50%

(b) Modulaton ratio changes from 20% to 75%

Fig.4. Two transient voltage waveform

6 Conclusion

(1) SHEPWM base on Walsh transform avoids solving nonlinear transcendental equations and can obtain piecewise linear relation between fundamental voltage amplitude and switching angles.

(2) The initialization based on CPWM technique effectively reduces blindness of searching initial switch angles in the course of SHE equation solution and improves computation efficiency.

(3) Experimental results indicate that SHEPWM based on Walsh transform has strong ability to eliminate harmonic and good dynamic performance in full range of output voltage.

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