CHAPTER 5

COMPARISON AND SIMULATION RESULTS

5.1 Objective

At the same output power, the proposed Optimized Harmonic Stepped-Waveform (OHSW) technique is compared to the Selective Harmonic Eliminated Pulse Width Modulation (SHE PWM) technique.

In this thesis, three-phase system will be focused. A cascaded inverters connected in wye-configuration is shown in Fig. 5.1 There are *s* H-bridge cells per phase, which can generate 2*s*+1 phase voltage levels and up to 4*s*+1 line-to-line voltage levels. Fig. 5.2 shows a three-level inverter connected in wye-configuration. A three level, i.e., positive, negative, and zero level waveform are synthesized using such an inverter.

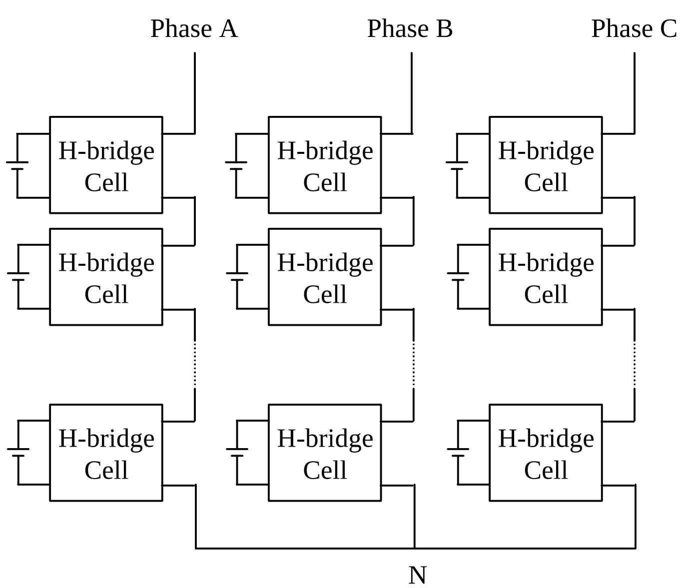


Figure 5.1 A three-phase cascaded inverter connected in Wye configuration.

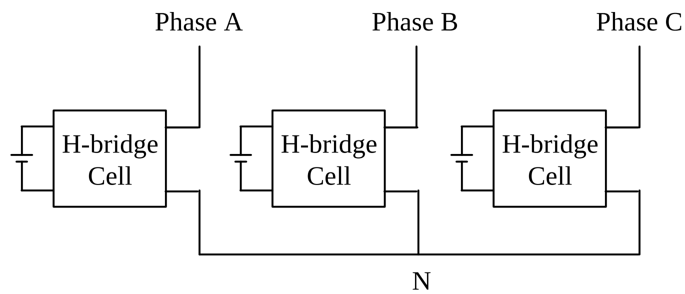


Figure 5.2 A three-phase three-level connected in Wye configuration.

The harmonic contents in line-to-line output voltage, which is synthesized by the multilevel voltage source cascaded inverter with SDCSs and conventional three-level voltage source inverter, will be presented. The OHSW technique will be applied in the multilevel VSI using cascaded-inverter circuit. In the three-level inverter, the SHE PWM is applied.

In the thesis, the total harmonic distortion (THD) methods is used to indicate of the quantity of harmonics contents in the output waveforms. The line-to-line and phase output voltage THD will be calculated and compared between OHSW and SHE PWM in 2 following categories:

1) The relationship between the line voltage THD and the modulation index, M.
2) The relationship between the line voltage THD and the number of switching angle.

To reduce the line voltage THD in OHSW, the lowest *s*-1 non-triplen harmonics in each phase voltage need to be eliminated, where *s* is the number of the full-bridge inverter per phase. Likewise, in SHE PWM, the lowest N-1 non-triplen harmonics in each phase voltage will be removed, where N is the number of switching angles per quarter-cycle. In a three-phase system, each phase voltage is shifted away from each other by 120 electrical degree. Therefore, in both cases, all triplen harmonic, 3^{rd}, 6^{th}, 9^{th}, …, will be theoretically eliminated from their line-to-line voltage. As the result, line-to-line voltage THD can be automatically reduced without increasing the number of levels and the number of switching angles in OHSW and SHE PWM, respectively.

The outline of this chapter is shown as follows:

1) Analysis of the relationship between the voltage THD and the modulation index, M.

For the OHSW technique, to obtain this relationship, a 7-, 9-, and 11-level cascaded inverter will be used as examples. A set of switching angle and line-to-line voltage THD of each inverter will be calculated by MATLAB, which using the Newton-Raphson algorithm in chapter 3.

For the SHE PWM technique, to find the relationship, a 5-, 7-, and 9-switching angles three-level waveform will be used. Sets of switching angle and line-to-line voltage THD of each waveform will be calculated by MATLAB, which using the Newton-Raphson algorithm in chapter 4.

2) Analysis of the relationship between the voltage THD and the number of switching angles.

For the OHSW technique, for given modulation index, a set of switching angles of 7-level to 15-level cascaded inverters will be calculated. The line-to-line voltage THD will then be calculated.

For the SHE PWM technique, for given modulation index, sets of switching angles of 5-, 7-, and 9-switching angles three-level waveform will be calculated. The line-to-line voltage THD will then be calculated.

5.2 Comparison

5.2.1 The relationship between the voltage THD and the modulation index

5.2.1.1 OHSW

In the thesis, the 7-level to 15-level inverter using cascaded-inverter with SDCSs are considered. By using the Newton-Raphson method and MATLAB program, the switching angles of the output voltage waveform are calculated.

For example, the switching angles of 7-level, 9-level, and 11-level with different modulation index, are shown in Table 5.1(a) to 5.1(c), respectively.

Table 5.1(a) The switching angles of 7-level cascaded inverter.

Modulation Index, M	$a_1(°)$	$a_2(°)$	$a_3(°)$
1.00	11.6817	31.1783	58.5774
0.90	17.5104	43.0523	64.1395
0.85	22.7654	49.3798	64.5562
0.80	29.2355	54.4383	64.4844
0.75	34.8935	54.4622	68.5500
0.70	38.3413	53.9297	73.9648
0.65	39.3876	55.5215	78.8979
0.60	39.4298	58.5839	83.1042

Table 5.1(b) The switching angles of 9-level cascaded inverter.

Modulation Index, M	$a_1(°)$	$a_2(°)$	$a_3(°)$	$a_4(°)$
1.00	10.0154	22.1424	40.7521	61.7681
0.95	11.5499	27.3929	46.725	64.4442
0.90	12.4367	34.5875	48.8091	68.8855
0.85	19.0991	39.7221	55.5860	66.9784
0.80	24.6998	45.5307	57.0398	68.8886
0.75	30.0144	49.2484	57.1585	72.8307
0.70	36.1183	47.8768	61.0723	76.2975
0.64	34.4790	51.4007	62.9388	83.8302
0.60	37.0314	51.0230	67.1599	86.0159

Table 5.1(c) The switching angles of 11-level inverter.

Modulation Index, M	$a_1(°)$	$a_2(°)$	$a_3(°)$	$a_4(°)$	$a_5(°)$
1.00	7.8598	19.3725	29.6522	47.68	63.2122
0.95	13.3907	20.9886	36.299	58.915	59.3507
0.90	7.6592	27.5706	40.7891	52.5598	73.0391
0.85	17.7312	32.7053	50.0119	57.8089	68.37
0.80	22.3419	39.2785	52.6866	59.3192	70.9645
0.75	28.4564	45.3922	50.9961	63.5194	73.2291
0.70	34.3709	44.6208	54.1495	65.3723	77.917
0.65	35.7274	44.883	56.8276	68.0465	83.6168
0.60	35.3424	46.9528	58.5799	72.6121	87.8373

The phase and line-to-line voltage THD are calculated by using the following formula:

$$THD = \frac{\sqrt{\sum_{n=2}^{200}\left[\frac{1}{n}\left(\cos(na_1) + \cos(na_2) + \ldots + \cos(na_S)\right)\right]^2}}{\left[\cos(a_1) + \cos(a_2) + \ldots + \cos(a_S)\right]} \quad (5.1)$$

where

s is the number of H-bridge inverters per phase

n is the harmonic order

$a_1, a_2, \ldots, a_S$ are the calculated switching angles

In case of line voltage THD calculation using equation (5.1), all triplen harmonic components are set to zero.

To get a precise result, the harmonic components up to the 200th are used to calculate the voltage THD. The line and phase voltage THD of 7-level, 9-level, and 11-level inverter as function of the modulation index, are shown in Fig. 5.3 to 5.5, respectively.

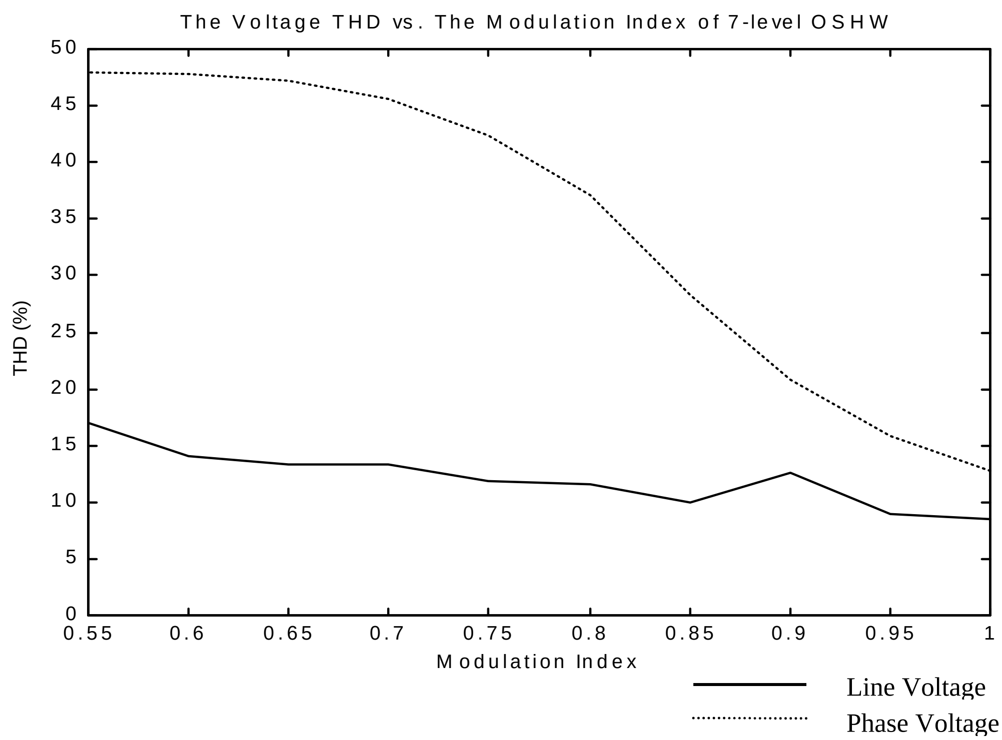


Figure 5.3 The voltage THD as function of the modulation index of 7-level inverter.

By observing Fig. 5.3 to Fig. 5.5, the phase voltage THD increases dramatically, when the modulation index decreases, whereas, the line voltage THD increases slightly, when the modulation index decreases.

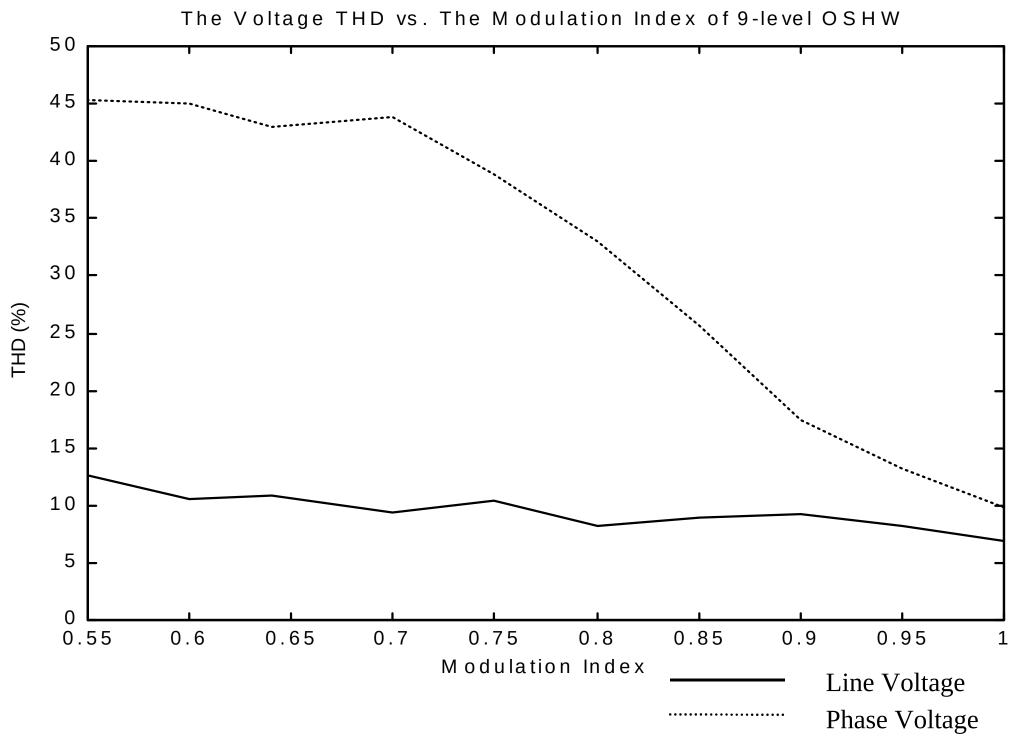


Figure 5.4 The voltage THD as function of the modulation index of 9-level inverter.

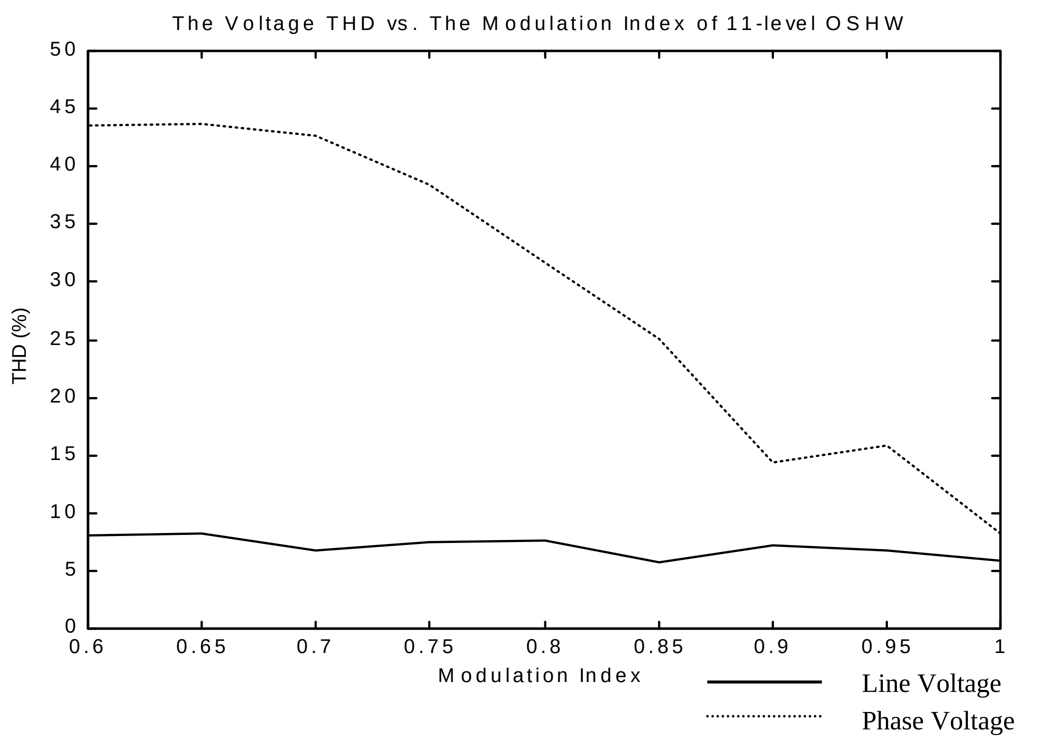


Figure 5.5 The voltage THD as function of the modulation index of 11-level inverter.

At the same modulation index, the line voltage THD is much less than phase voltage THD. At M = 0.7, for example, the THD of 13-level output phase voltage is 41.9%, whereas the THD of its line voltage is 6.39%.

5.2.1.2 SHE PWM

In this section, the 5-switching angle to 9-switching angle SHE PWM waveforms will be used as examples. By using MATLAB and the Newton's method in chapter 4, the switching angle of those waveforms are tabulated in table 5.2(a) to 5.2(c).

Table 5.2(a) The switching angles of 5-switching angle per quarter SHE PWM

Modulation Index, M	a_1(°)	a_2(°)	a_3(°)	a_4(°)	a_5(°)
1.00	10.6166	21.7827	32.8945	67.9288	74.5022
0.95	9.9947	21.1940	33.9964	66.8046	75.0212
0.90	9.3956	20.5319	35.0716	65.7700	75.5984
0.85	8.8180	19.7916	36.1534	64.7860	76.1785
0.80	8.2516	18.9348	37.2921	63.8322	76.7027
0.75	7.6503	17.8211	38.6145	62.8923	77.0402
0.70	6.6629	15.6513	40.7300	61.9245	76.5677
0.68	5.0276	12.8448	42.7964	61.4438	75.0995

Table 5.2(b) The switching angles of 7-switching angle per quarter SHE PWM

Modulation Index, M	a_1(°)	a_2(°)	a_3(°)	a_4(°)	a_5(°)	a_6(°)	a_7(°)
1.00	15.6509	25.7807	30.1194	50.7916	54.8038	78.5096	83.5159
0.95	14.5443	24.6417	32.482	52.4259	56.537	75.1227	80.8694
0.90	13.8891	23.9148	33.4936	53.1586	57.6368	73.4632	80.4884
0.85	13.3551	23.2397	34.3822	53.5379	58.4404	72.21	80.5237
0.80	12.8645	22.5248	35.2694	53.7233	59.049	71.1069	80.6845
0.75	12.3598	21.66	36.2658	53.8054	59.5063	70.035	80.8008
0.70	11.5835	20.0965	37.8407	54.0007	59.8591	68.765	80.3644
0.65	6.0963	14.5083	41.8976	60.9395	75.0241	77.3575	79.2735
0.60	12.0783	22.184	36.1929	52.7058	59.9041	67.6017	84.3863

Table 5.2(c) The switching angles of 9-switching angle per quarter SHE PWM

M	$a_1(°)$	$a_2(°)$	$a_3(°)$	$a_4(°)$	$a_5(°)$	$a_6(°)$	$a_7(°)$	$a_8(°)$	$a_9(°)$
1.00	13.8501	15.7533	20.9972	42.8921	46.3077	53.5155	56.3141	83.4570	87.7603
0.95	17.0393	19.2272	21.3699	44.4445	48.9063	55.2111	57.9796	81.8825	87.6404
0.90	17.0197	25.9556	32.3038	47.2574	52.1768	59.0448	61.2315	77.9781	83.6029
0.85	16.2894	25.1176	33.2974	48.1198	53.3284	60.5536	62.9984	76.3170	83.0024
0.80	15.8346	24.4721	34.0668	48.4506	53.9547	61.0467	63.9270	75.2120	82.9515
0.75	15.4186	23.7699	34.8667	48.6475	54.4149	61.1326	64.4712	74.2198	82.9767
0.70	14.8439	22.6141	36.0608	48.9258	54.8301	60.9919	64.7390	73.0994	82.6570
0.65	10.1150	17.6990	39.9166	54.5859	59.9518	66.8048	78.4339	80.8728	81.8083
0.60	10.0892	17.8952	39.9356	54.1772	59.9589	66.1634	80.1756	87.5438	88.1334

To calculate the phase and line voltage THD, the following formula is applied.

$$THD = \frac{\sqrt{\sum_{n=2}^{200}\left[\frac{1}{n}\sum_{k=1}^{N}(-1)^{k+1}\cos(na_k)\right]^2}}{\sum_{k=1}^{N}(-1)^{k+1}\cos(a_k)} \qquad (5.2)$$

where

N is the number of switching angles per quarter

n is the harmonic order

and a_k is the calculated switching angles

By using equation (5.2), the voltage THD of 5-, 7-, and 9-switching angle SHE PWM as function of the modulation index are shown in Fig. 5.6, 5.7, and 5.8, respectively.

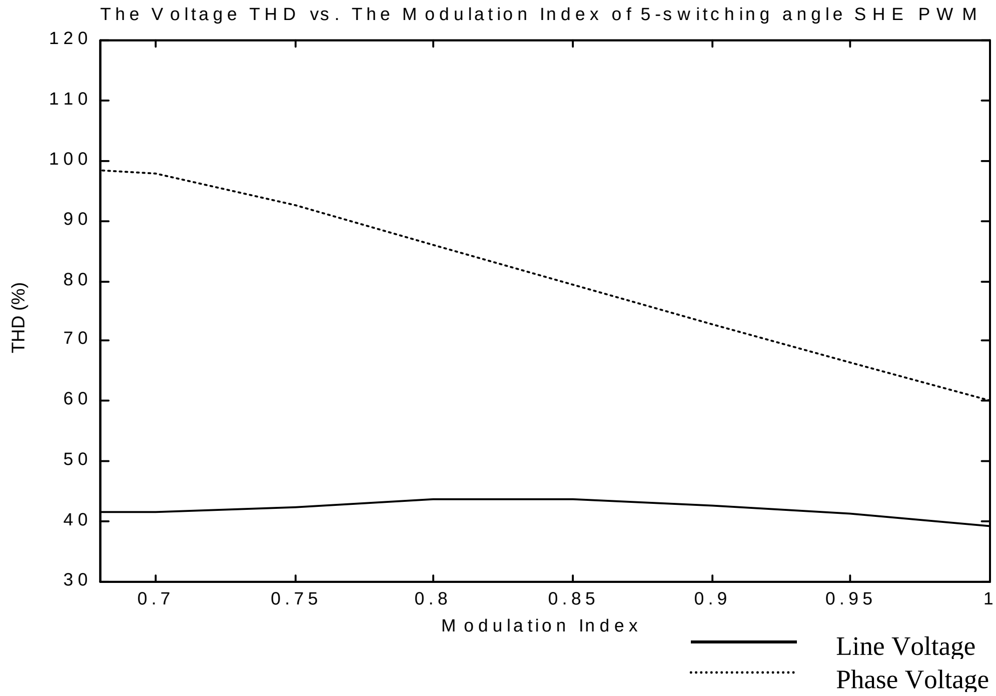


Figure 5.6 The voltage THD as function of the modulation index of 5-switching angle SHE PWM.

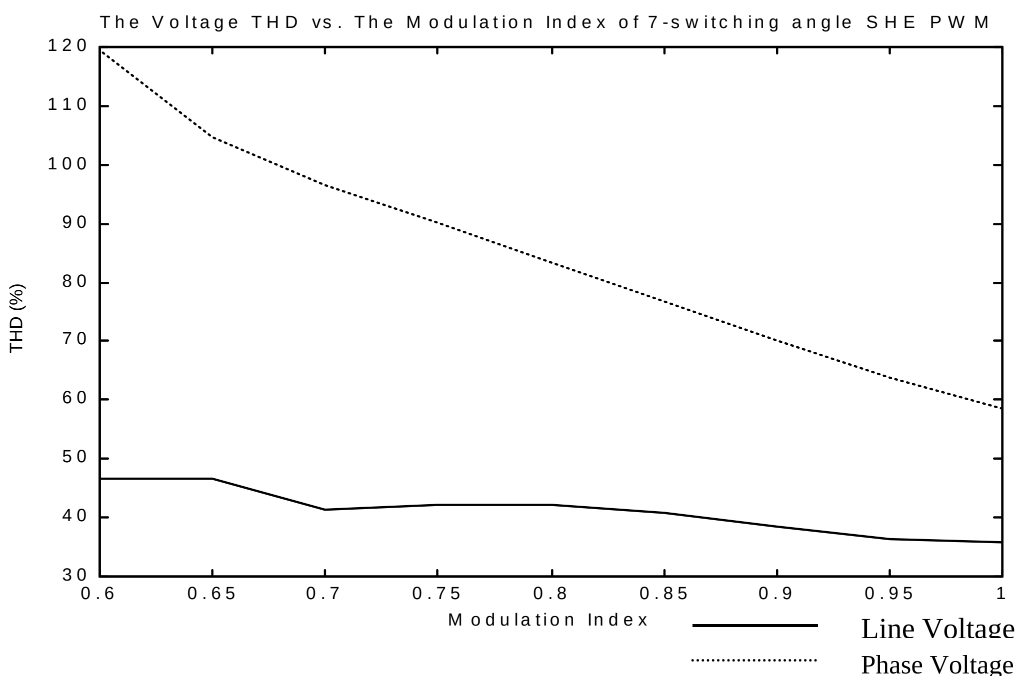


Figure 5.7 The voltage THD as function of the modulation index of 7-switching angle SHE PWM.

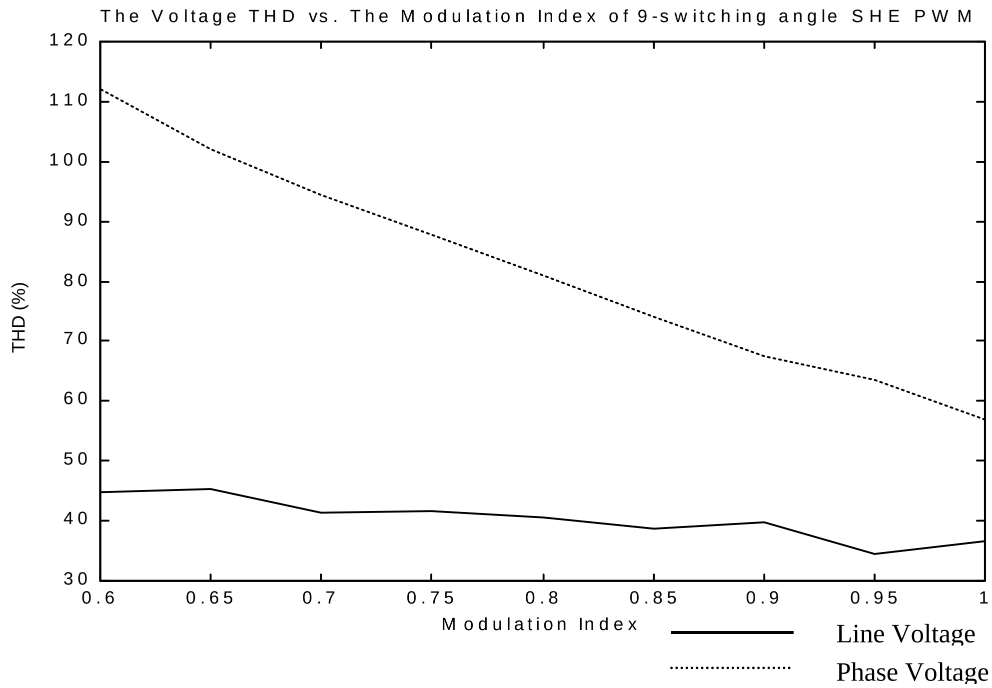


Figure 5.8 The voltage THD as function of the modulation index of 9-switching angle SHE PWM.

Form Fig 5.6 to 5.8, the phase voltage THD significantly increases, when the modulation index decreases. The line voltage THD also increases, when the modulation index decreases.

5.2.1.3 Summary

The results show that the line voltage THD in both cases tend to increase, when the modulation index decreases. However, the THD is minimized with modulation index of approximated 0.80 to 0.90.

5.2.2 The relationship between the voltage THD and the number of switching angles

5.2.2.1 OHSW

From the calculated switching angles in 5.1, each line-to-line voltage THD with given modulation index are calculated and tabulated in table 5.3 as a function of the number of H-bridge inverter per phase, *s*.

Table 5.3 the line voltage THD with given modulation index as a function of the number of H-bridge inverters per phase.

	s =3	s =4	s =5	s =6	s =7
M = 1.00	8.4723	6.9336	5.7959	4.9859	4.0007
M = 0.95	8.9796	8.2324	6.6819	5.5398	4.8179
M = 0.90	12.6407	9.1692	7.2324	4.8794	4.1078
M = 0.80	11.5567	8.1519	7.6398	5.2319	4.6278
M = 0.75	11.8817	10.4339	7.4295	5.6760	4.6640
M = 0.70	13.2744	9.4082	6.8114	6.3877	5.6148

The calculated sets of voltage THD are plotted in Fig. 5.9. At certain modulation index, the line voltage THD decreases, when the number of H-bridge inverter per phase, *s*, increases. Therefore, the line voltage THD can be reduced by increasing the number of full-bridge inverter in the multilevel inverter circuit.

From Table 5.3, without any filter circuit, the line voltage of 13-level OHSW THD is less than 5 percent with modulation index of 0.90. In practice, filter circuits may be applied; therefore, the line voltage THD can meet IEEE standard without any difficulties.

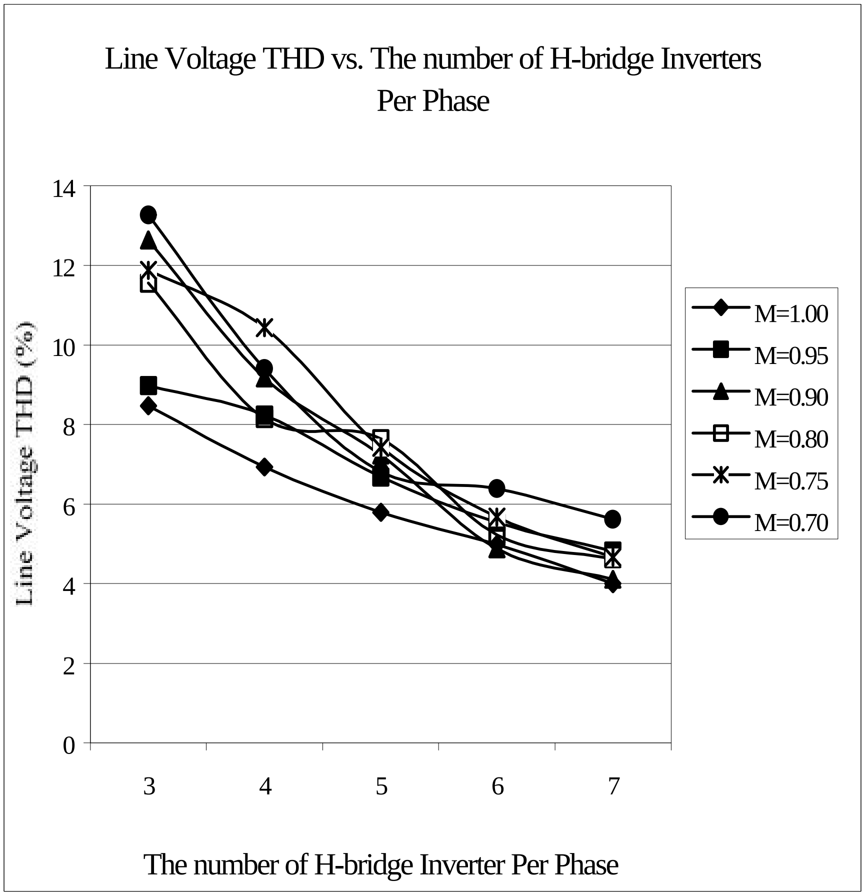


Figure 5.9 The line voltage THD with constant modulation index as function of the number of H-bridge inverters per phase.

5.2.2.2 SHE PWM

Using the switching angles in Table 5.2(a) to 5.2(c), the relationship between the line-to-line voltage THD and the number of switching angle per quarter, N, of SHE PWM waveform is obtained and tabulated in Table 5.4. The calculated sets of line voltage THD are plotted in Fig. 5.10.

Form the plot in Fig. 5.10, the line voltage THD changes slightly, when the number of switching angles per quarter, N, is changed. For example, at M = 1, the line voltage THD decreases, when N is changed from 5 to 7, whereas, the line voltage THD at M = 0.65 increases, when N is changed from 5 to 7.

Table 5.4 The line voltage THD as a function of the number of switching angles per quarter.

	N = 5	N = 7	N = 9
M = 1.00	39.2413	35.8535	36.6751
M = 0.90	42.7595	38.4909	39.8507
M = 0.80	43.6551	42.0817	40.5524
M = 0.75	42.4047	42.1331	41.6168
M = 0.70	41.5758	41.4609	41.2652
M = 0.65	41.6529	46.7129	45.4239

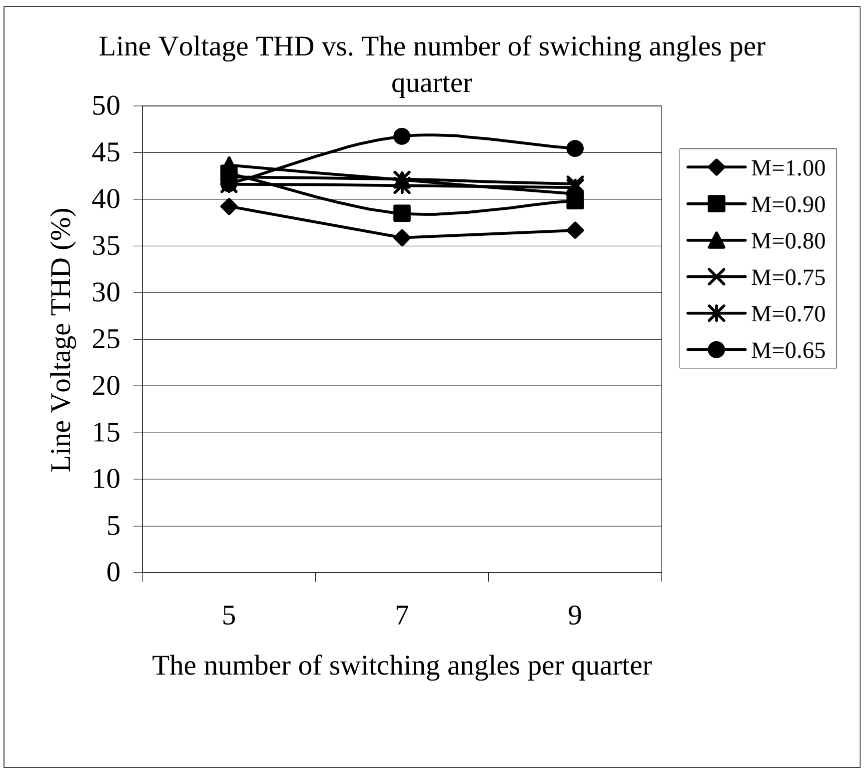


Figure 5.10 The line voltage THD with constant modulation index as a function of the number of switching angles per quarter.

5.2.3 Summary

In both cases, the line and phase voltage THD is inversely proportional to the modulation index less than around 0.80. However, when the modulation index decreases, the line voltage THD increases a little, whereas, the phase voltage THD increases significantly.

In constant voltage source application, a multilevel inverter should be operated with modulation index of 0.80 to 0.90, so that the output voltage THD is minimized.

As the number of switching angles increases, the line voltage THD of the cascaded inverter using OHSW technique decreases, whereas, the line voltage THD of the three-level using SHE PWM tends to be constant. Thus, increasing the number of switching angles in three-level inverter does not reduce the line-to-line voltage THD.

However, the lowest harmonic component in the output waveform in both cases will be shifted to higher frequency, when the number of switching angles is increased. In SHE PWM inverter the output filter circuit size can be reduced, even though, the same voltage THD is obtained. In OHSW multilevel inverter, not only does the line voltage THD decreases, but the lowest harmonic component is shifted to higher frequency as well. Therefore, the output filter circuit can be noticeably reduced with increase the number of switching angles.

All the calculated results will be verified by PSPICE program in the next section.

5.3 Simulation Results

To verify the idea in 5.1, PSPICE is employed as a simulation tool. A piecewise linear (PWL) voltage source is used to represent a full-bridge inverter. For example, a schematic of three-level OHSW inverter is illustrated in Fig. 5.11. A 50Ω resistor and a 10mH inductor, which connected in series, are used as the load per phase in both inverter circuits.

5.3.1 Verify the relationship between the voltage THD and the modulation index

5.3.1.1 OHSW

A seven-level OHSW will be simulated. Three 52V PWL voltage sources are used to generated 110Vrms-400Hz output phase voltage. Thus, the total number of PWL for three-phase system is nine. The simulated modulation indices are 1.00, 0.85, and 0.55.

The simulation results will be shown in Fig. 5.12 to Fig. 5.14.

5.3.1.2 SHE PWM

A 156V PWL source is employed to synthesize 110Vrms-400Hz output phase voltage. In this case, 7-switching angle SHE PWM waveform with three modulation indices such as 1.00, 0.85, and 0.55 will be simulated.

The simulation results will be shown in Fig. 5.15 to Fig. 5.17.

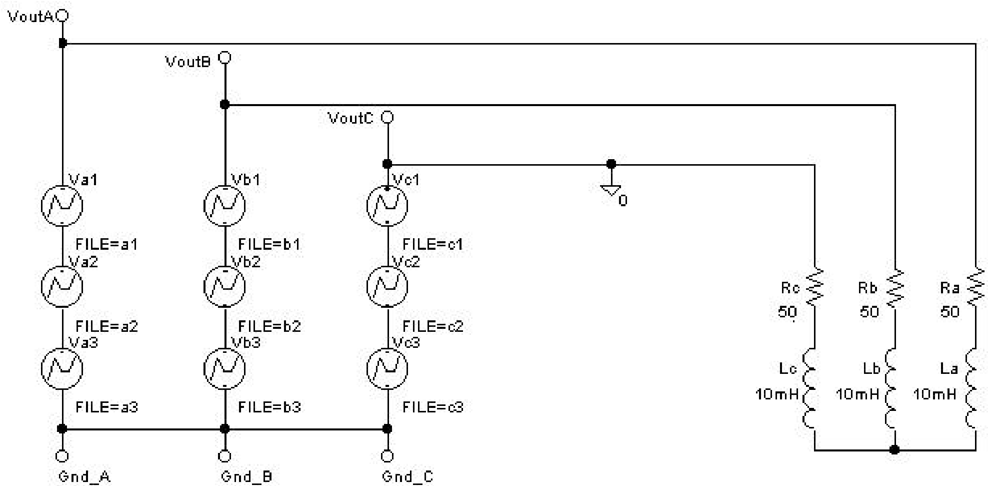


Figure 5.11 A schematic of a three-phase seven-level OHSW inverter.

The 7-level OHSW, M = 1.0, f = 400Hz.

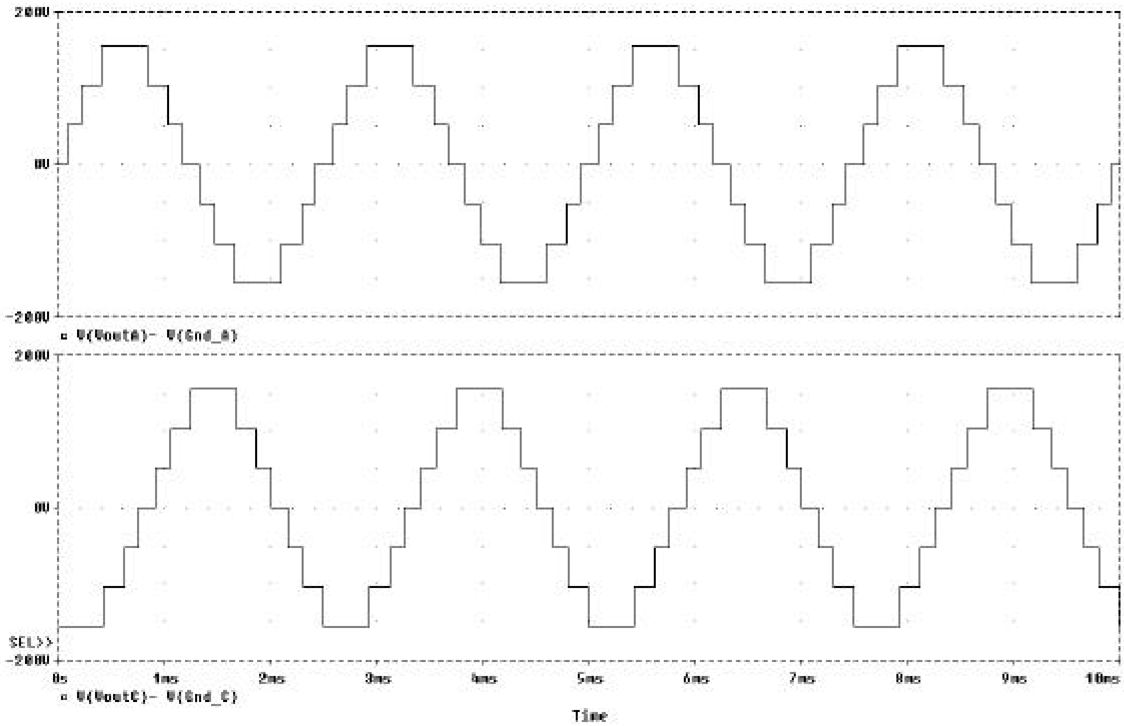


Figure 5.12(a) Phase voltage, A and C.

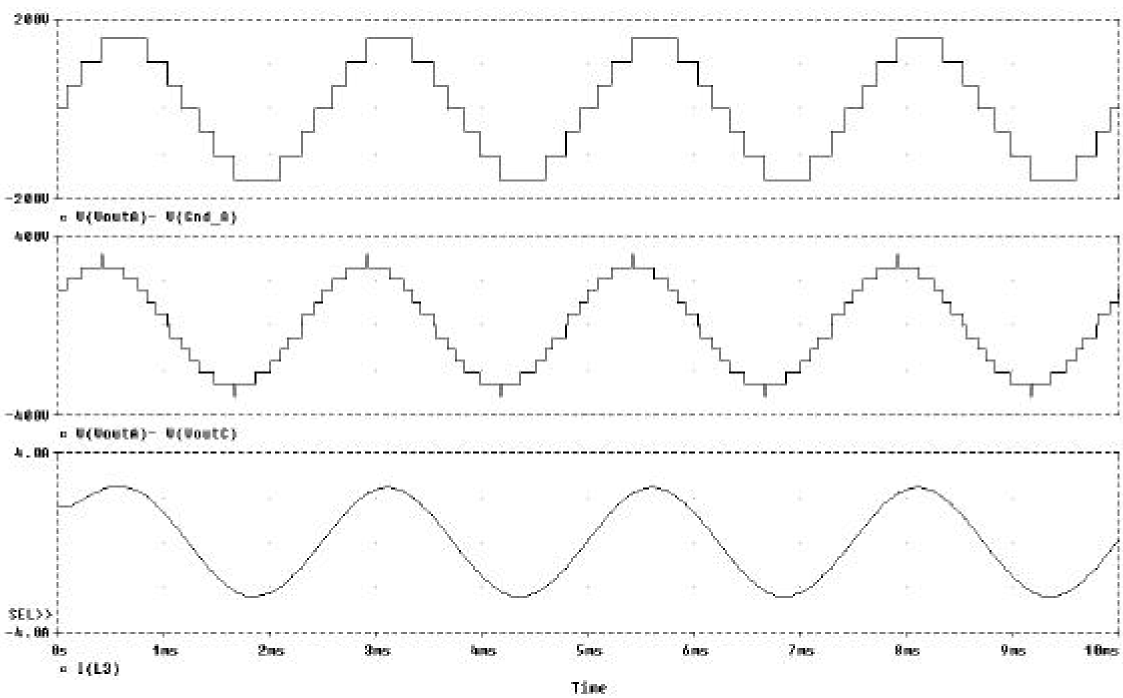


Figure 5.12(b) Phase voltage, line voltage, and load current.

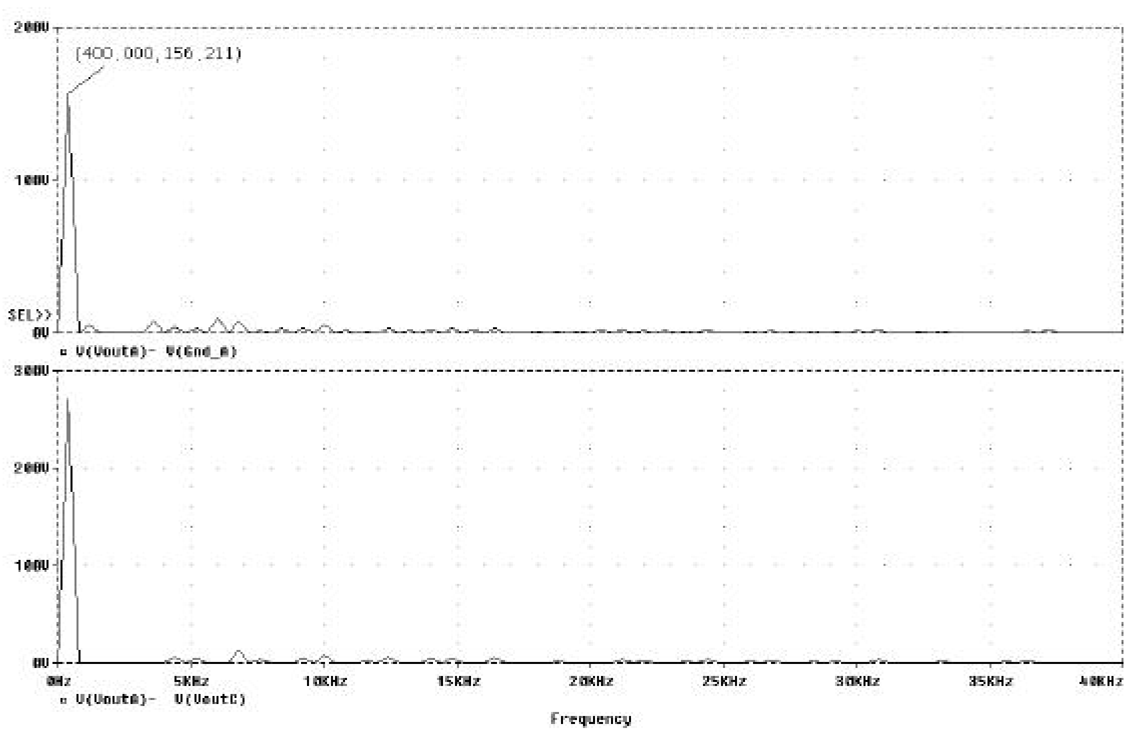
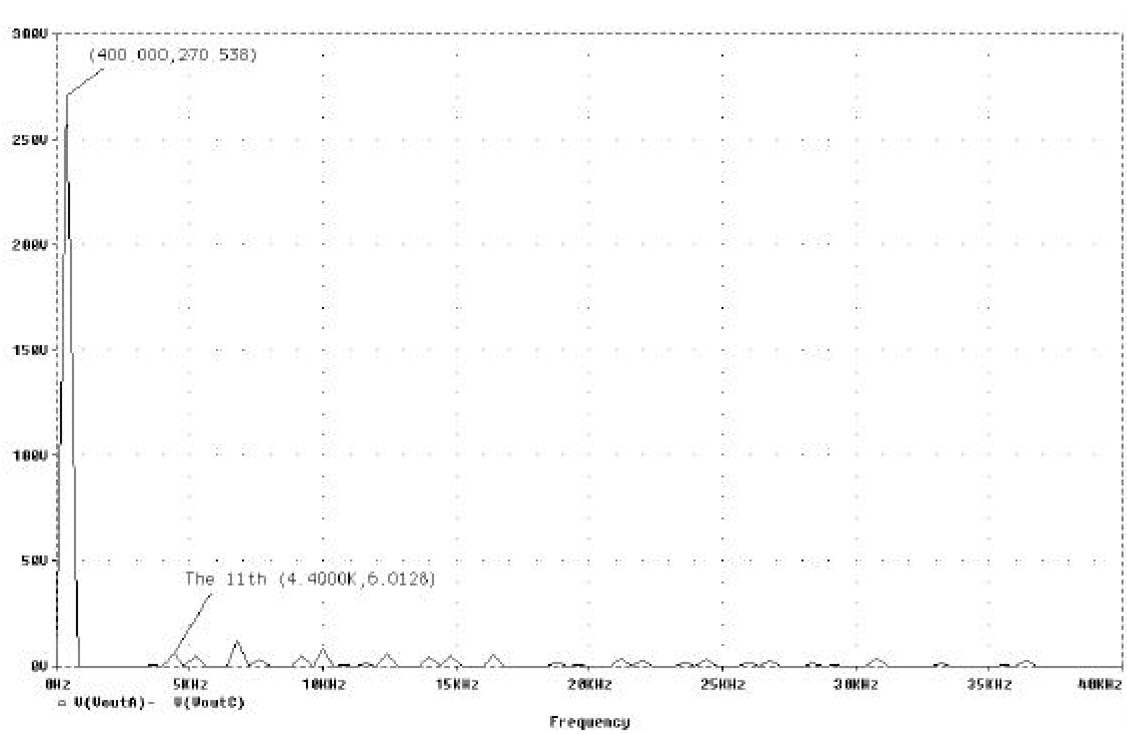


Figure 5.12(c) Frequency spectrum of phase voltage and line voltage.



TOTAL HARMONIC DISTORTION = 8.180942E+00 PERCENT

Figure 5.12(d) Frequency spectrum of line voltage in detail.

The 7-level OHSW, M = 0.85, f = 400Hz.

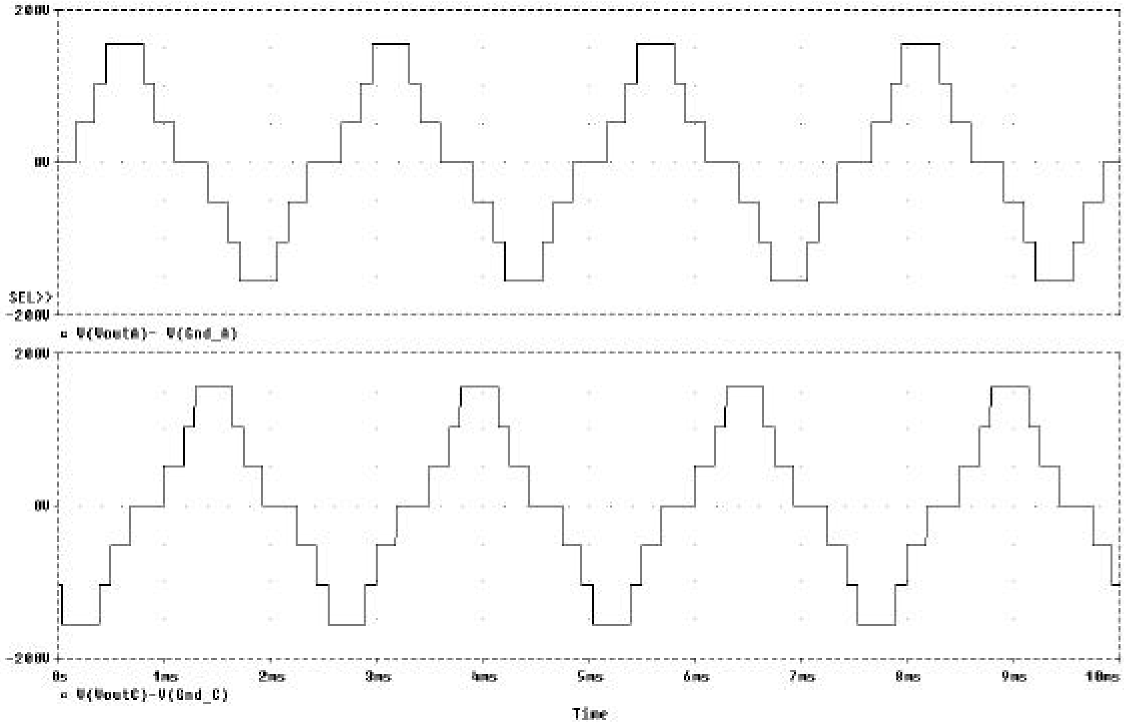


Figure 5.13(a) Phase voltage, A and C.

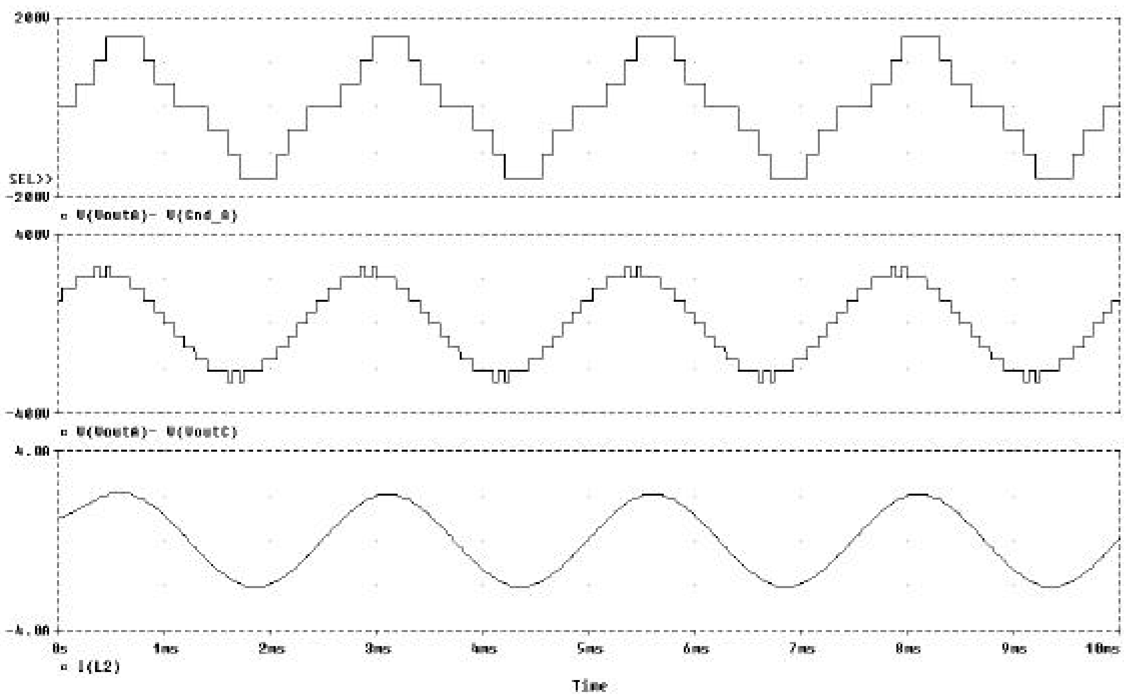


Figure 5.13(b) Phase voltage, line voltage, and load current.

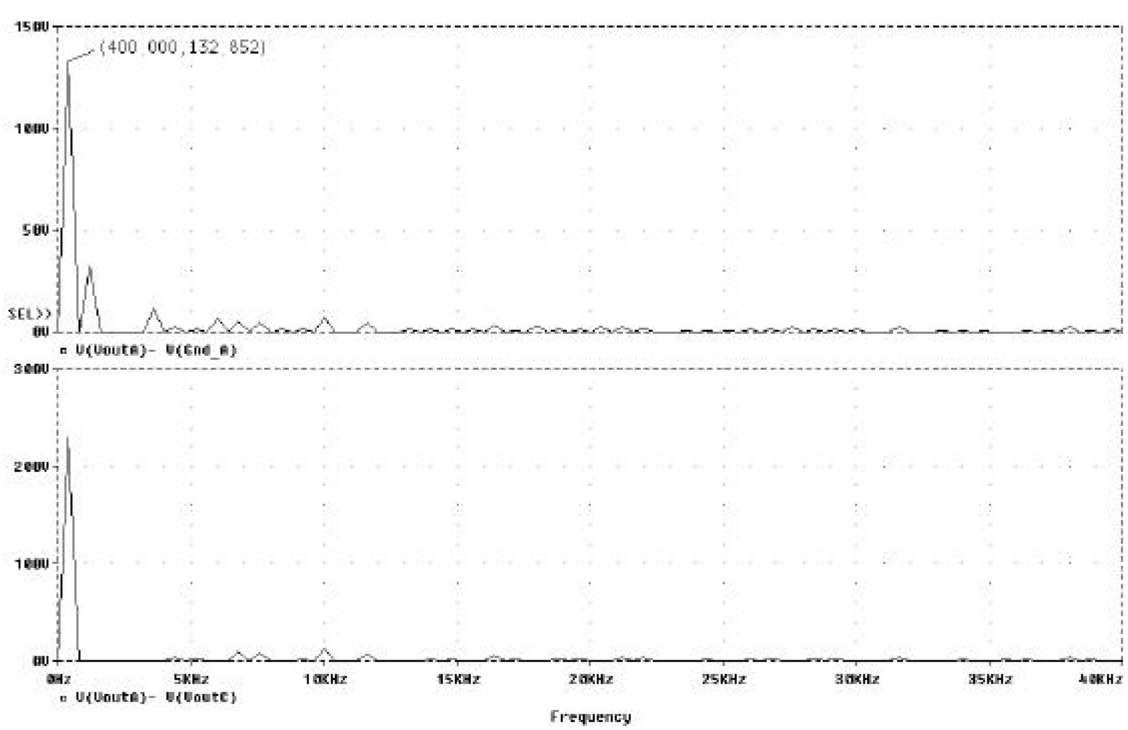
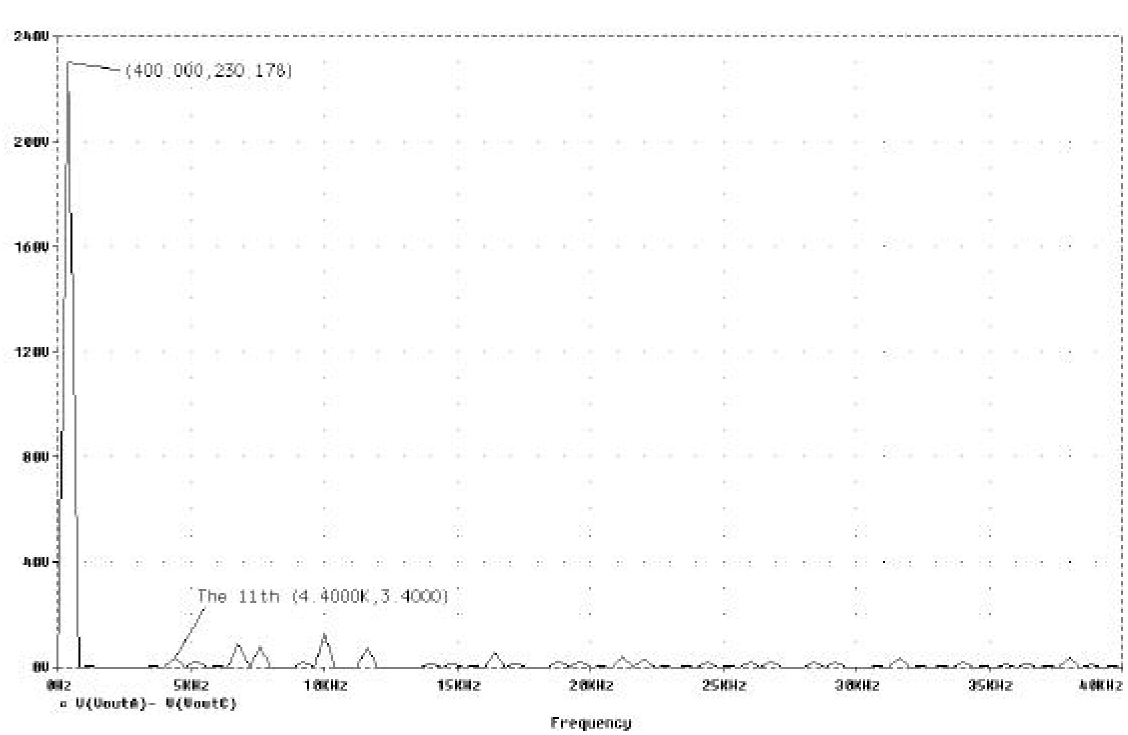


Figure 5.13(c) Frequency spectrum of phase voltage and line voltage.



TOTAL HARMONIC DISTORTION = 9.659834E+00 PERCENT

Figure 5.13(d) Frequency spectrum of line voltage in detail.

The 7-level OHSW, M = 0.55, f = 400Hz.

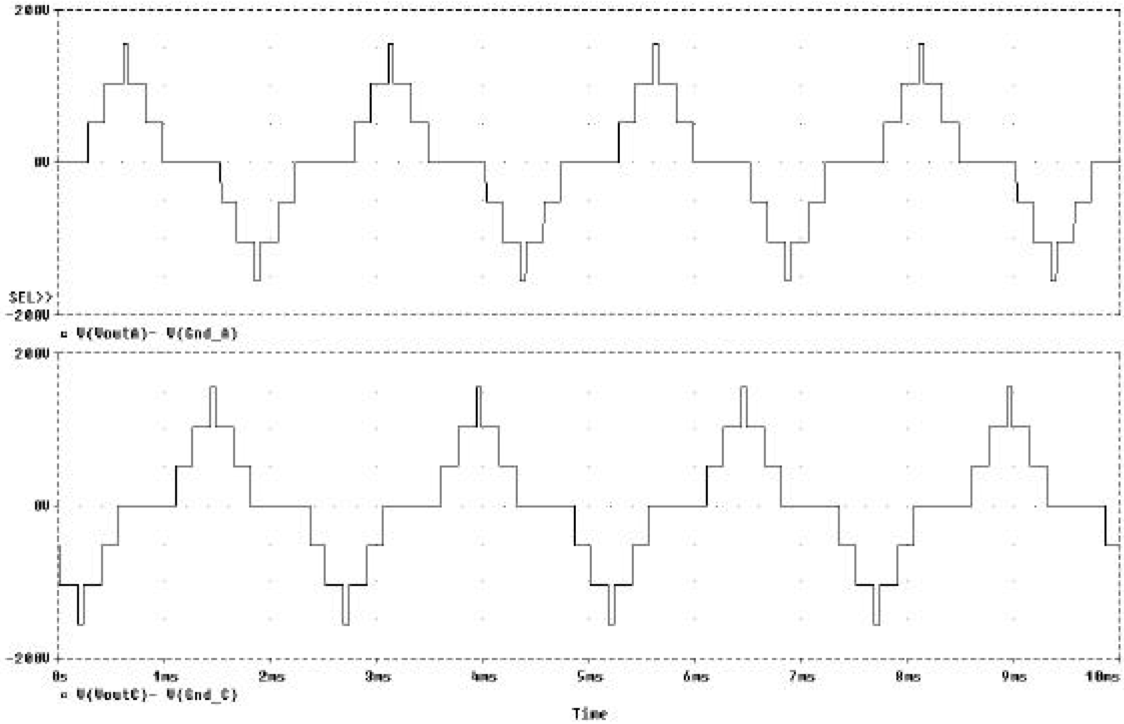


Figure 5.14(a) Phase voltage, A and C.

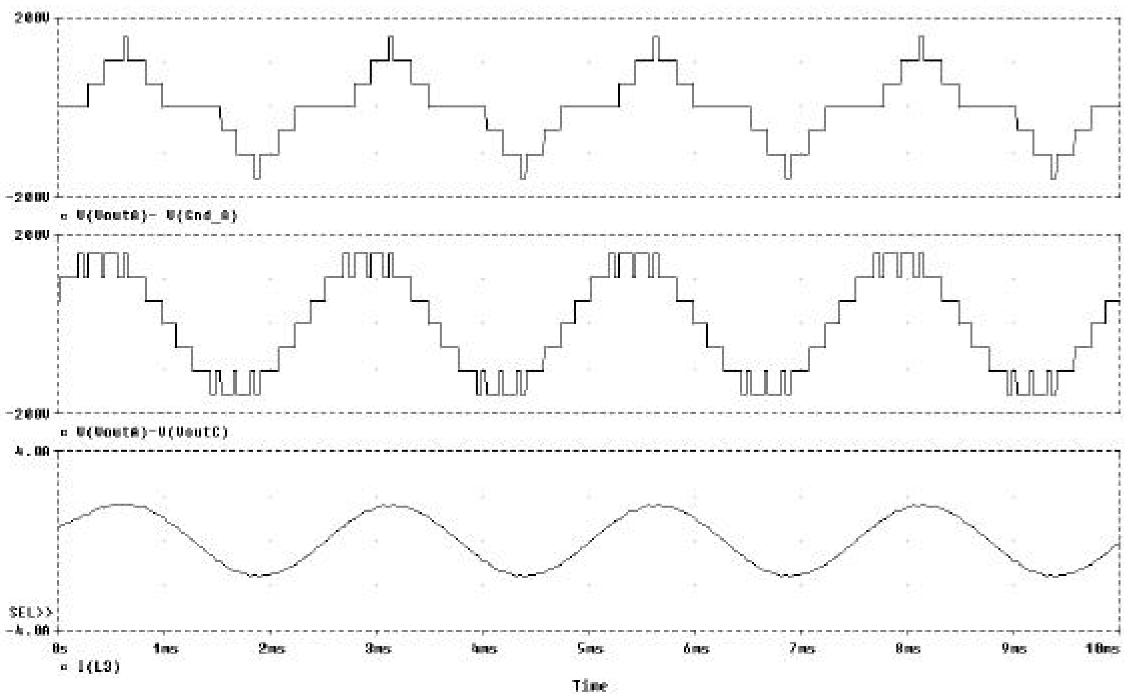


Figure 5.14(b) Phase voltage, line voltage, and load current.

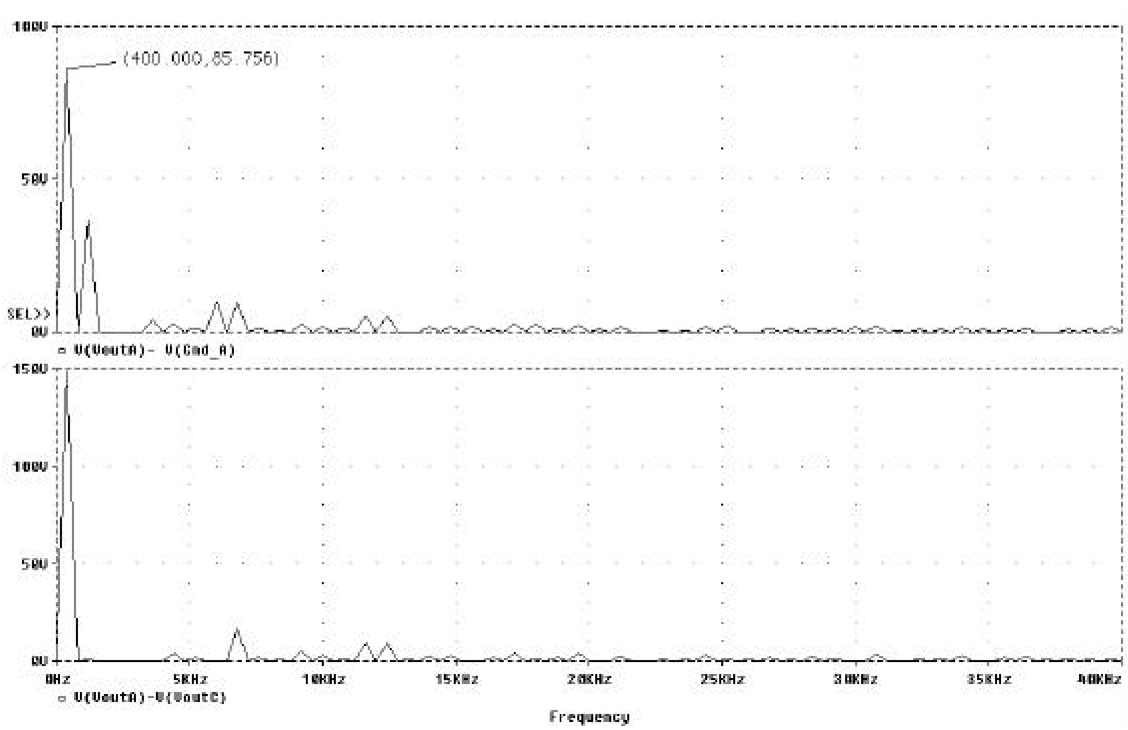
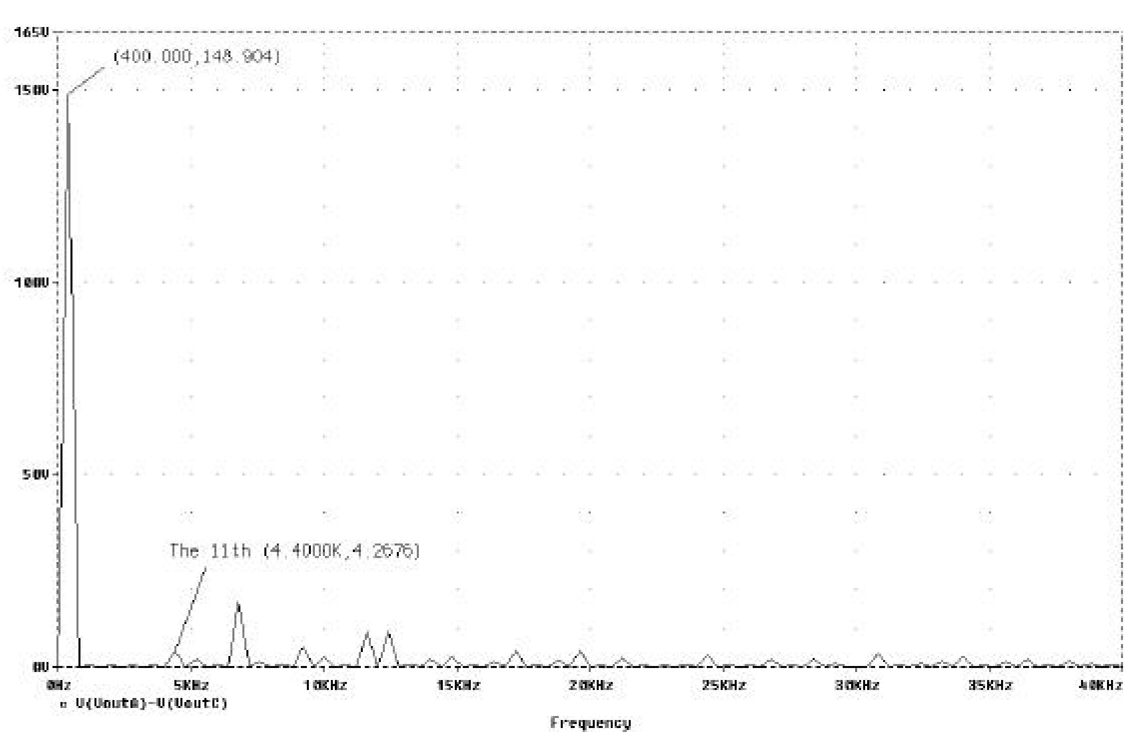


Figure 5.14(c) Frequency spectrum of phase voltage and line voltage.



TOTAL HARMONIC DISTORTION = 1.651415E+01 PERCENT

Figure 5.14(d) Frequency spectrum of line voltage in detail.

The 7-switching angle SHE PWM, M = 1.0, f = 400Hz.

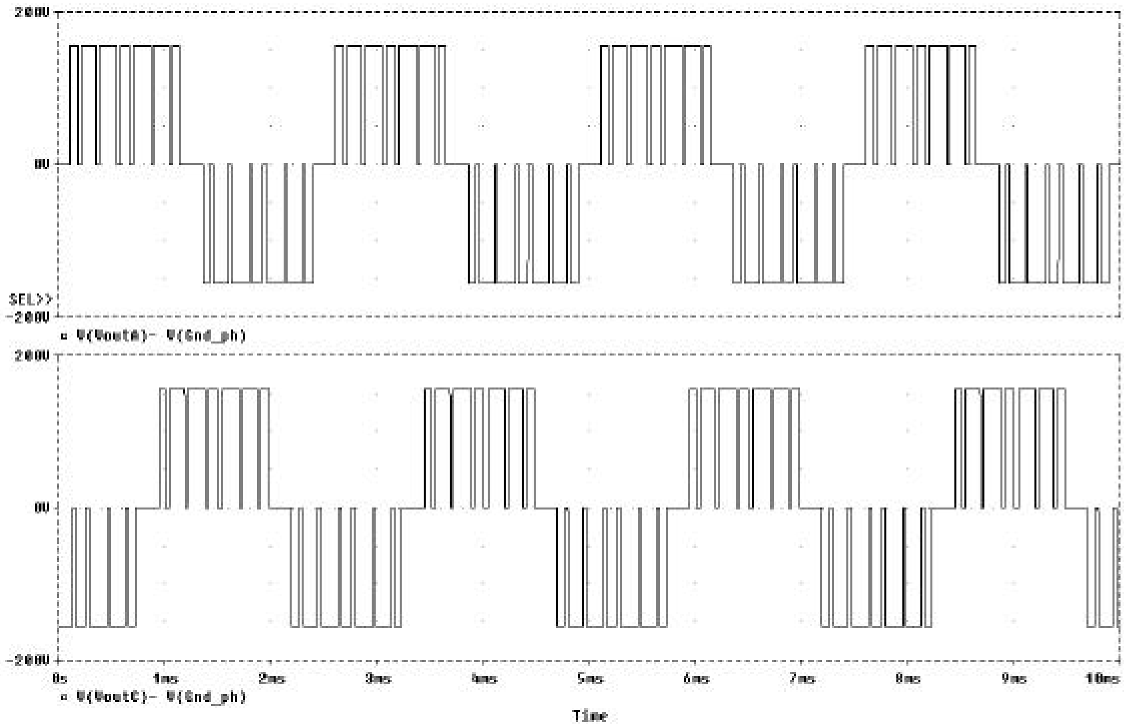


Figure 5.15(a) Phase voltage, A and C.

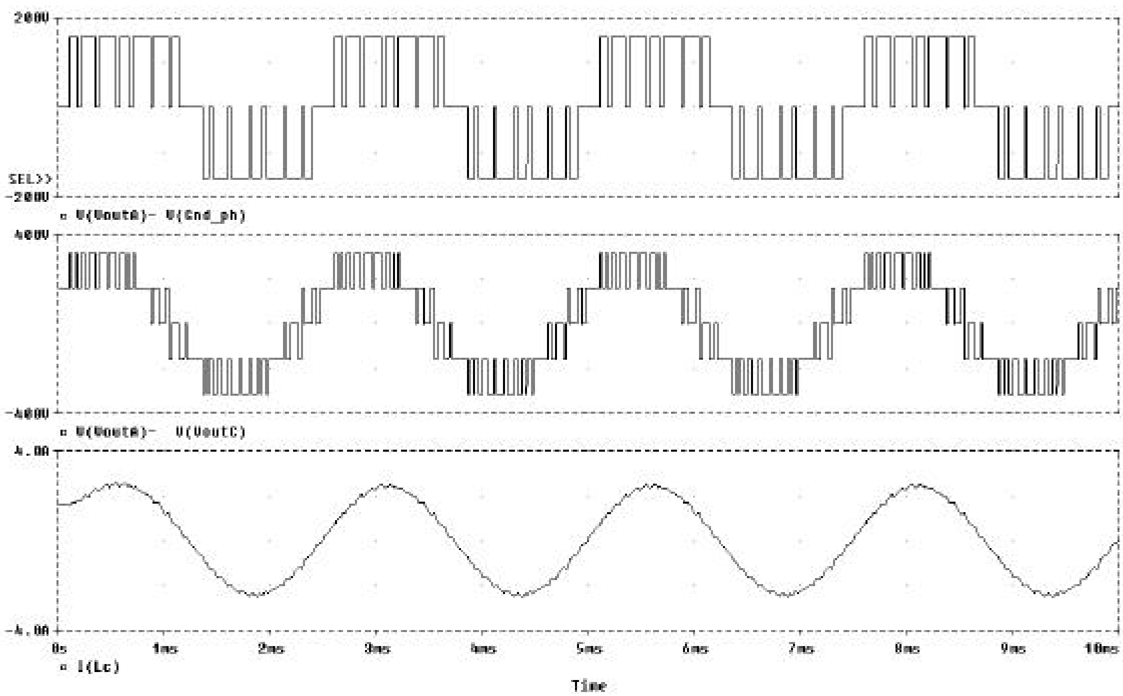


Figure 5.15(b) Phase voltage, line voltage, and load current.

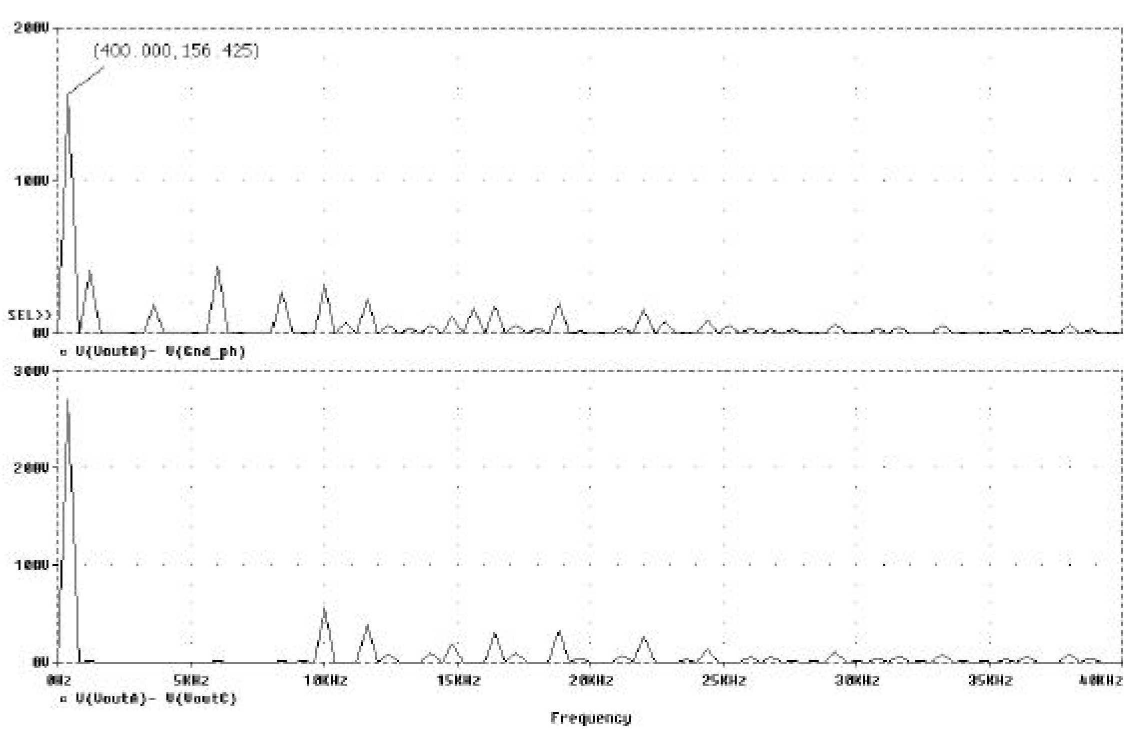
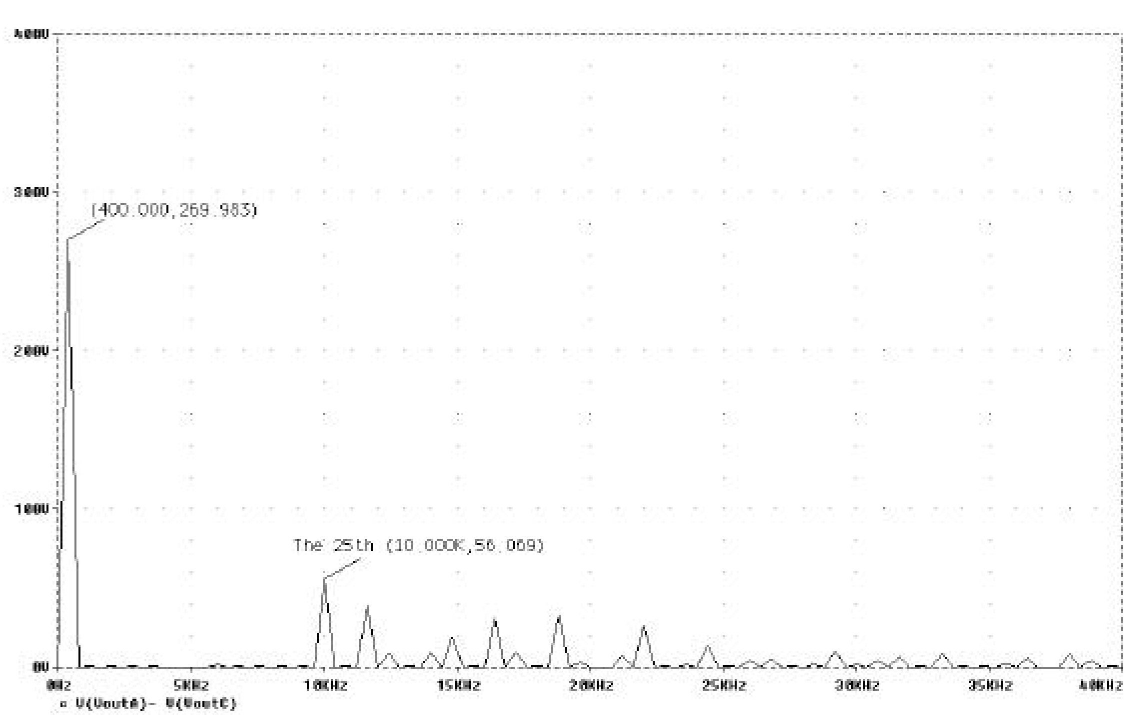


Figure 5.15(c) Frequency spectrum of phase voltage and line voltage.



TOTAL HARMONIC DISTORTION = 3.424862E+01 PERCENT

Figure 5.15(d) Frequency spectrum of line voltage in detail.

The 7-switching angle SHE PWM, M = 0.85, f = 400Hz.

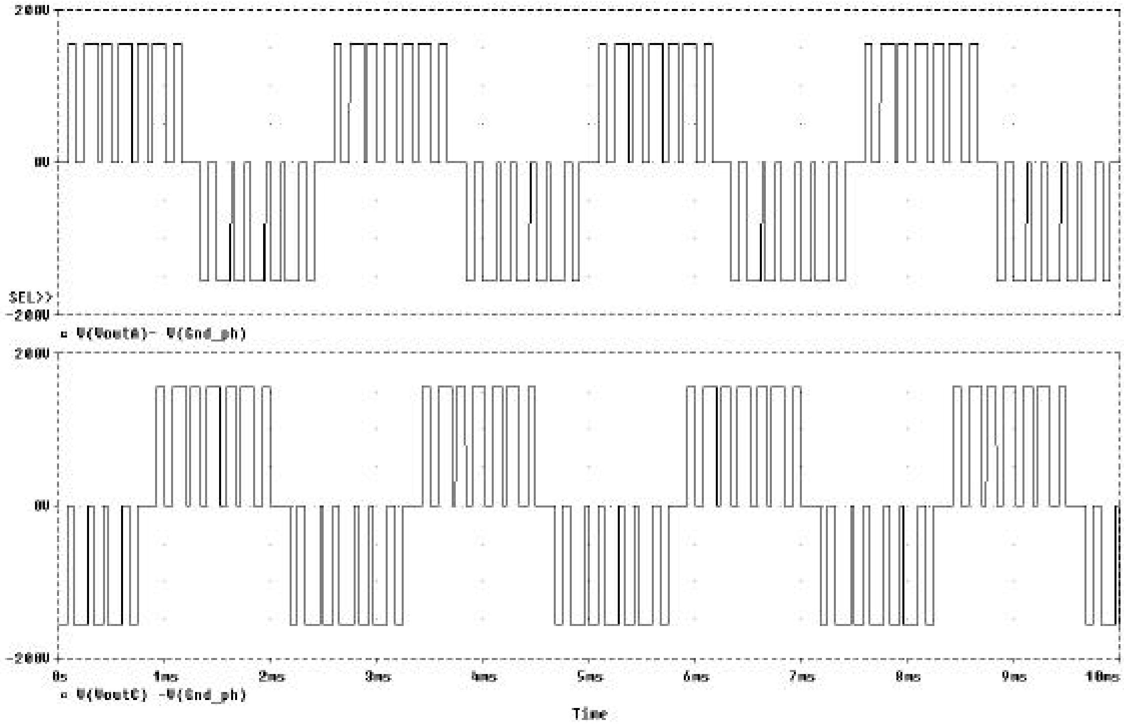


Figure 5.16(a) Phase voltage, A and C.

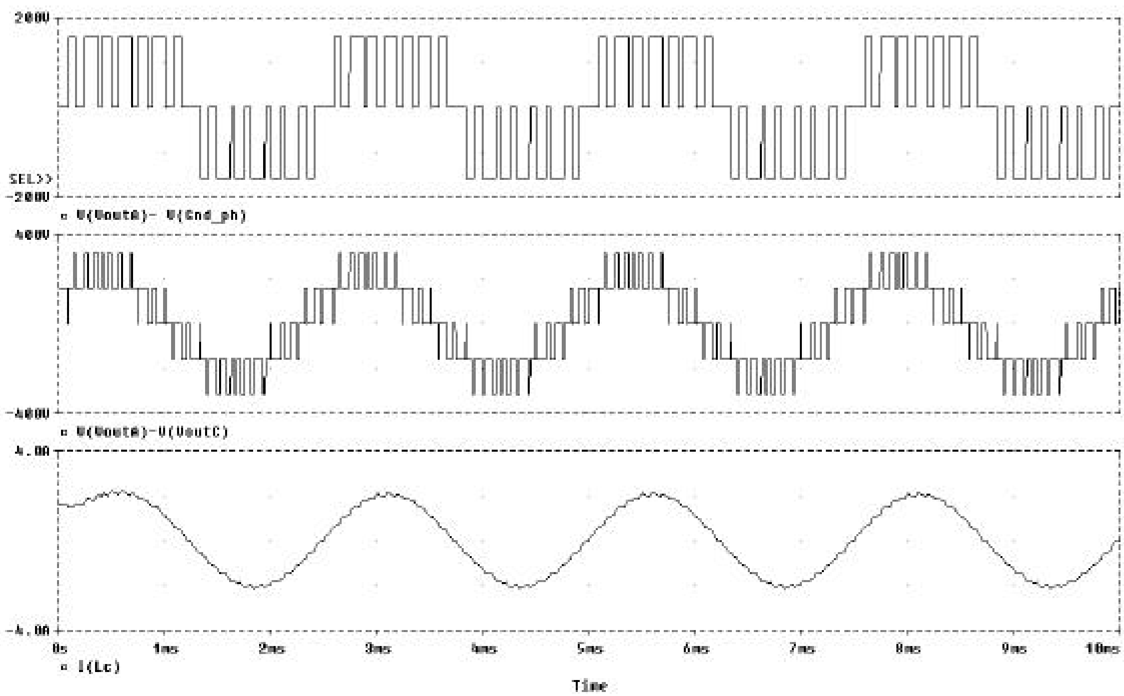


Figure 5.16(b) Phase voltage, line voltage, and load current.

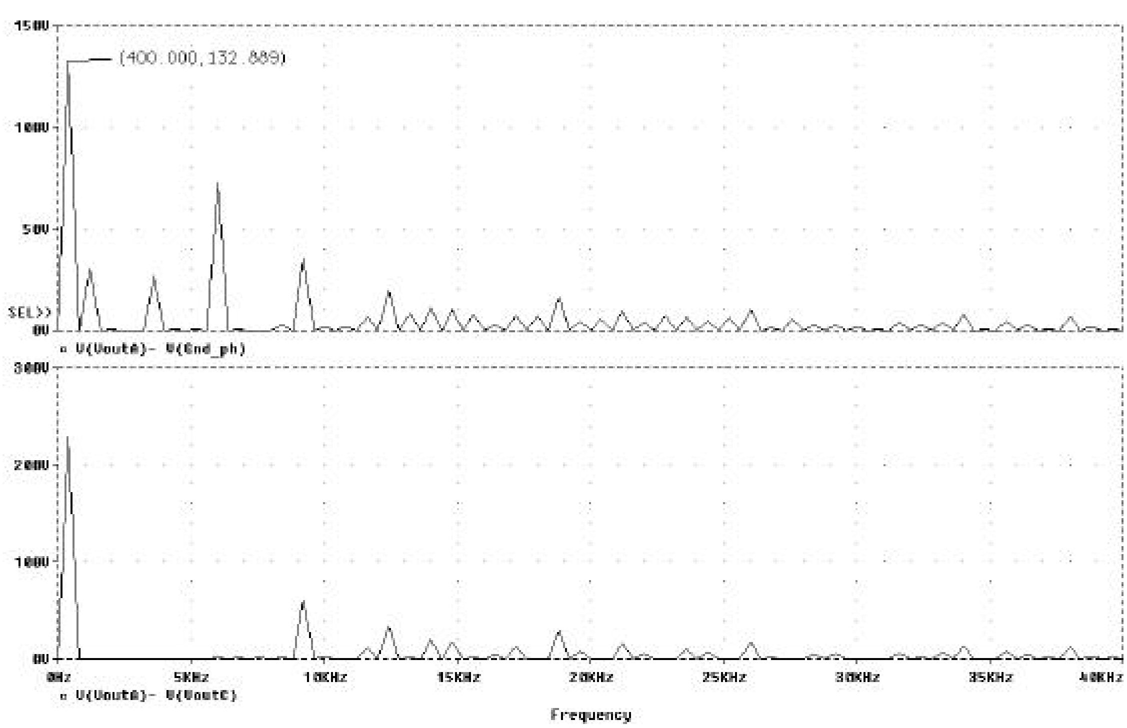
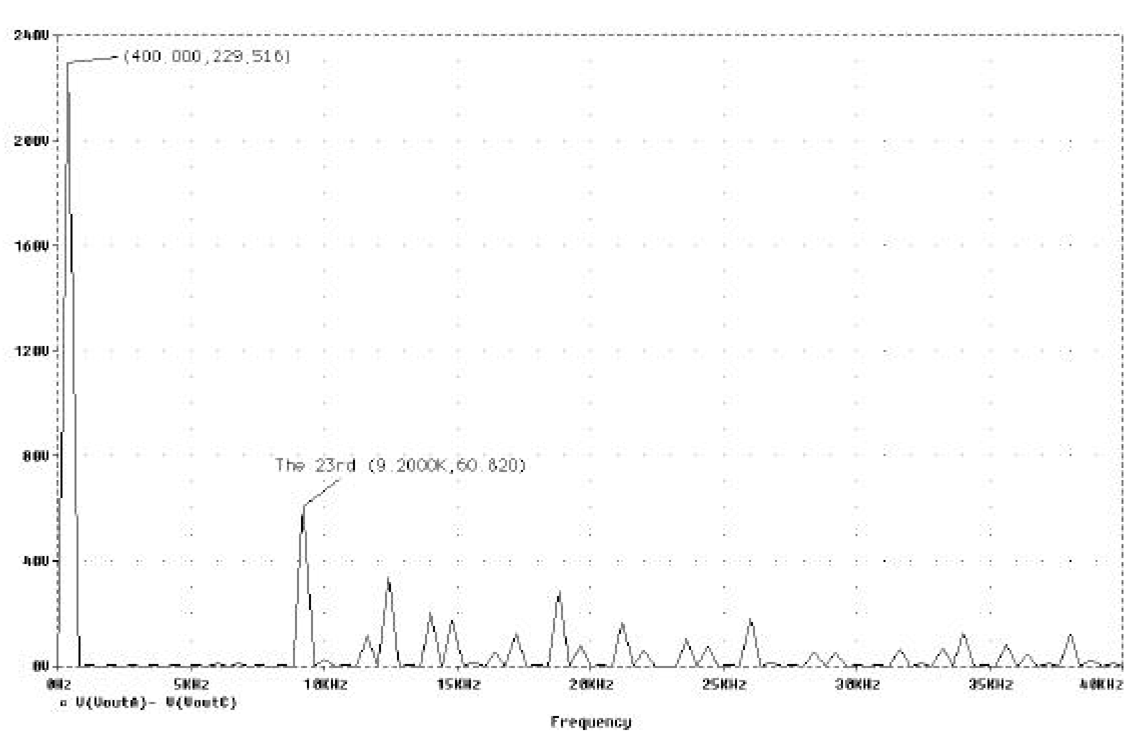


Figure 5.16(c) Frequency spectrum of phase voltage and line voltage.



TOTAL HARMONIC DISTORTION = 3.895322E+01 PERCENT

Figure 5.16(d) Frequency spectrum of line voltage in detail.

The 7-switching angle SHE PWM, M = 0.55, f = 400Hz.

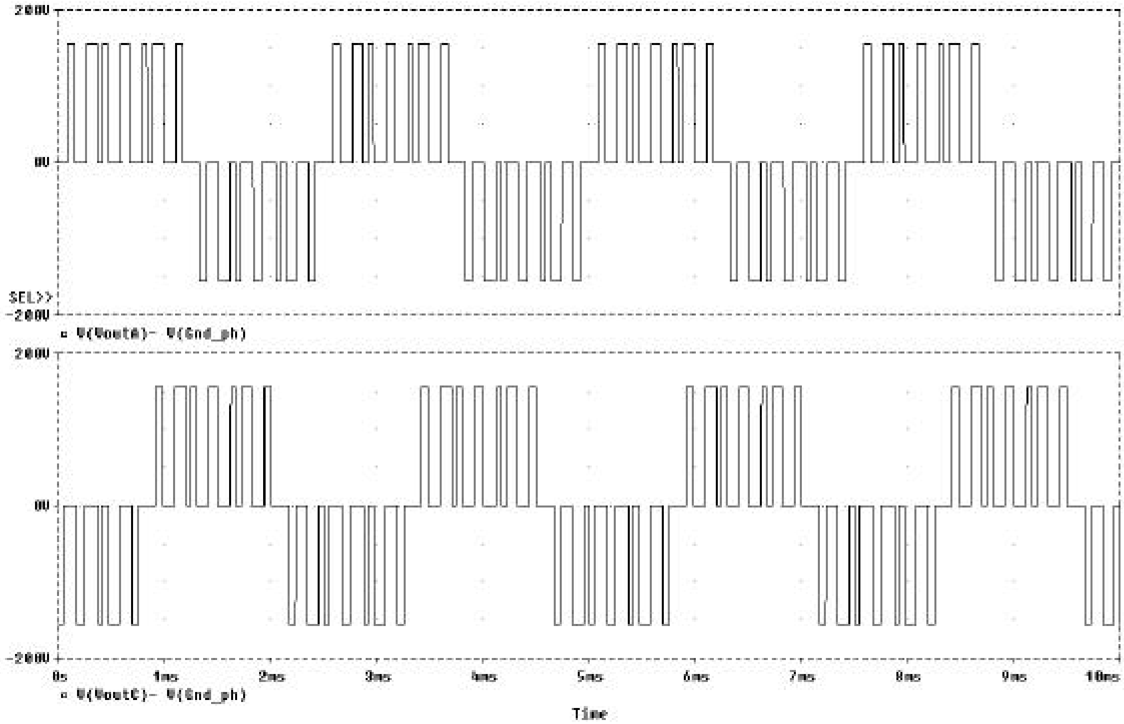


Figure 5.17(a) Phase voltage, A and C.

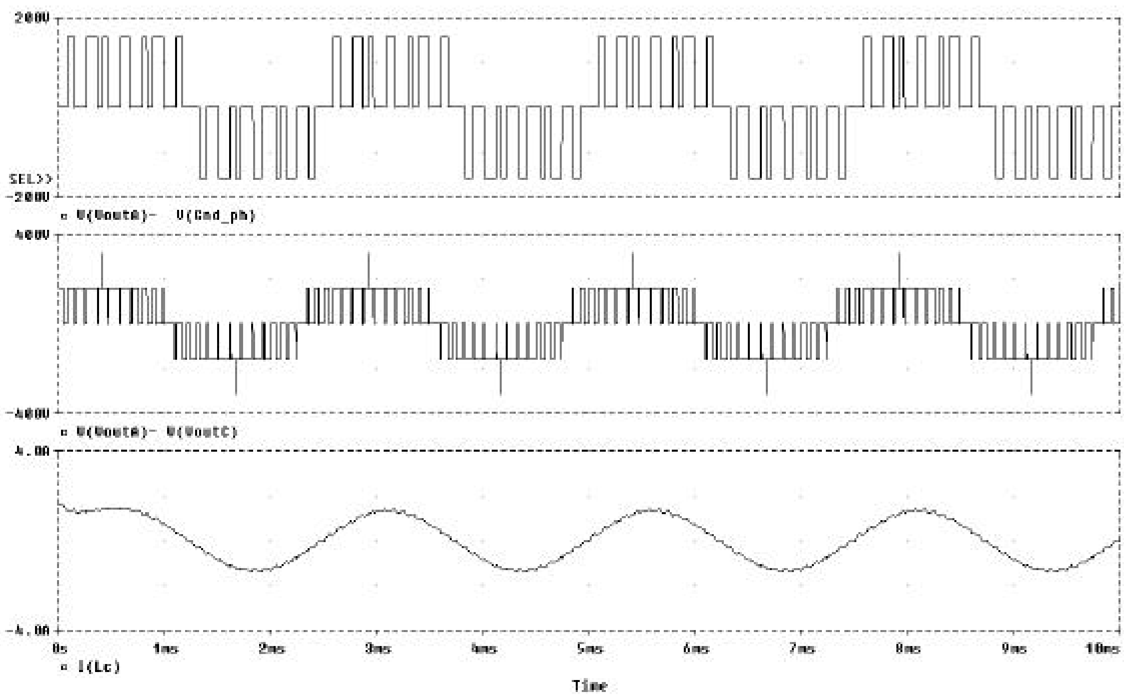


Figure 5.17(b) Phase voltage, line voltage, and load current.

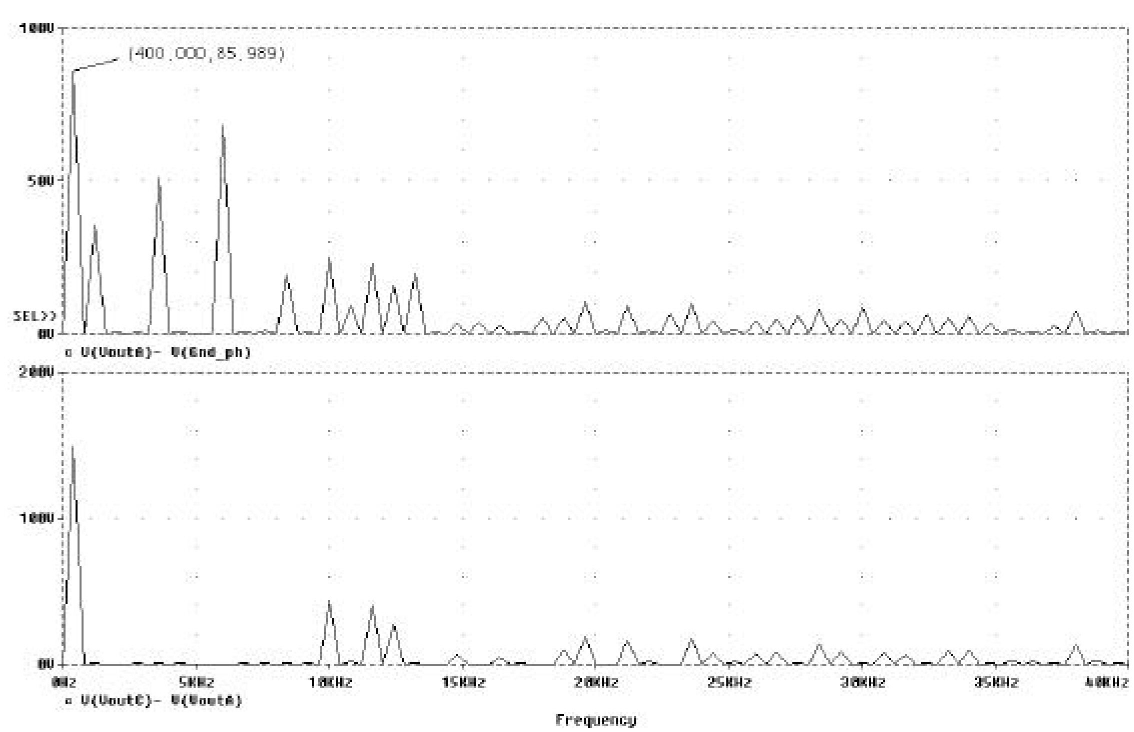
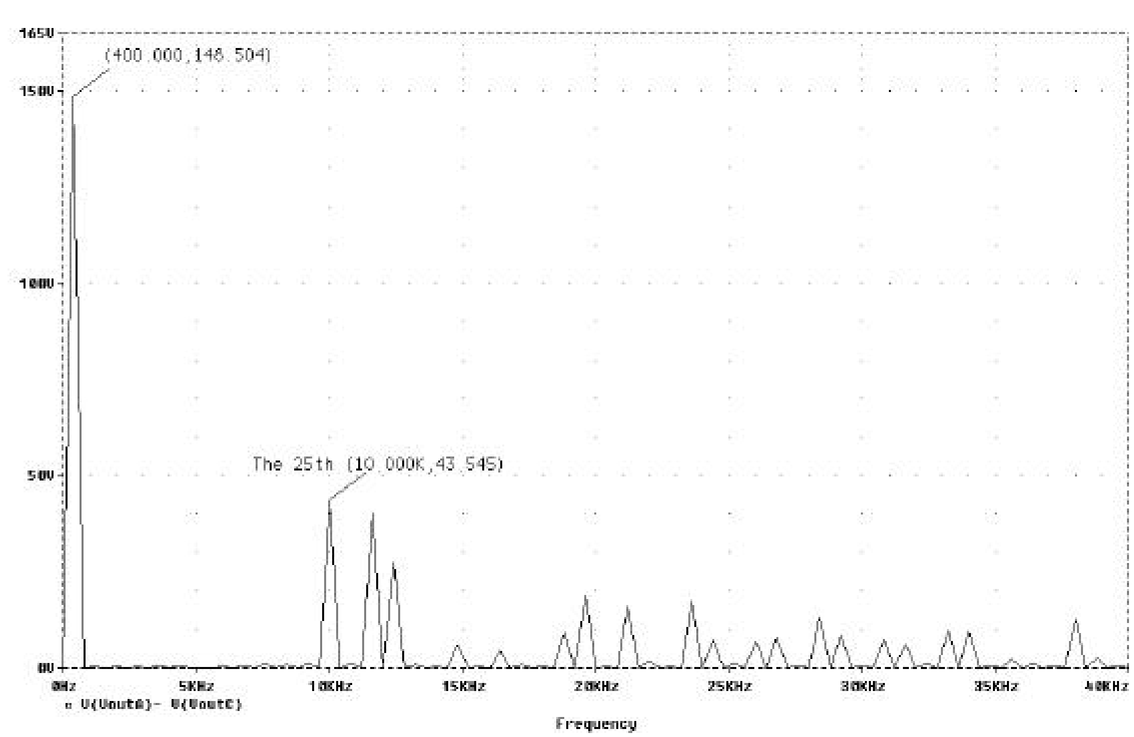


Figure 5.17(c) Frequency spectrum of phase voltage and line voltage.



TOTAL HARMONIC DISTORTION = 5.275046E+01 PERCENT

Figure 5.17(d) Frequency spectrum of line voltage in detail.

5.3.1.3 Summary

From Fig 5.12 to 5.17, the line voltage THDs of the seven-level OHSW and the seven-angle SHE PWM, which are simulated by PSPICE, are plotted as a function of the modulation index in Fig. 5.18.

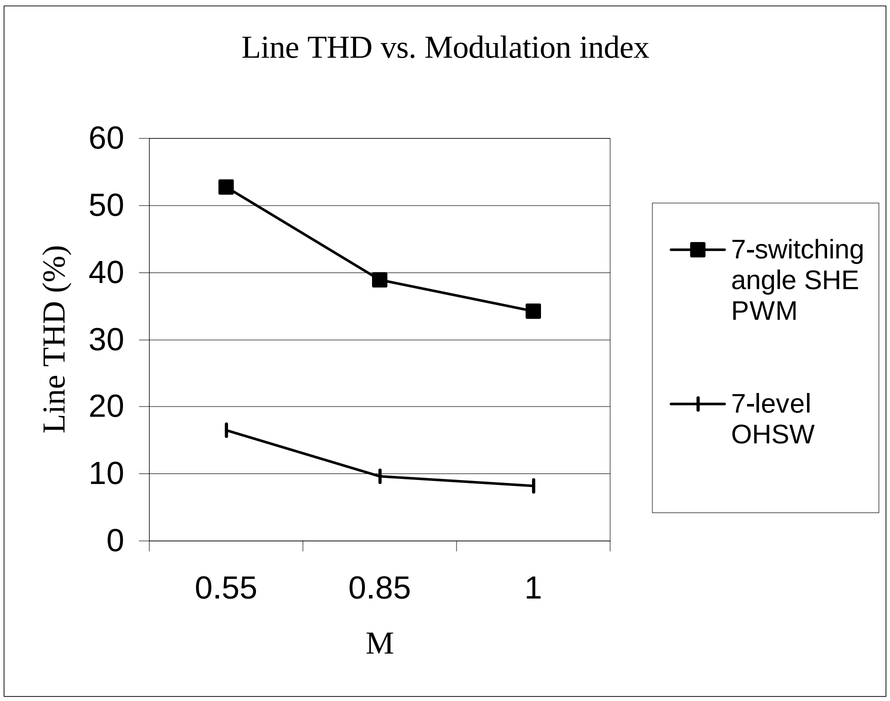


Figure 5.18 Line voltage THD as function of the modulation index.

The plot shown in Fig. 5.18 points out that the simulation results agrees with the MATLAB result very well.

In the next section, the relationship between the voltage THD and the number of switching angles will be verified.

5.3.2 Verify the relationship between the voltage THD and the number of the switching angles

All waveforms will operate at M = 1.00 and 400 Hz. The expected fundamental line voltage is 270 V_{peak}.

5.3.2.1 OHSW

A 9-, 11-, and 13-level OHSW will be simulated by PSPICE. For a 7-level, the simulating results with M = 1.00 will be used again.

By adding extra PWL voltage sources, the schematic shown in Fig. 5.11 can be used in this case. The simulating results will be presented in Fig. 5.19 to 5.21.

5.3.2.2 SHE PWM

To verify the MATLAB results, a 5-switching angle and a 9-switching angle SHE PWM waveform will be simulated here. In case of 7-switching angle, the simulating results in 5.2.1 with M = 1.00 will be considered again.

The simulating results will be presented in Fig. 5.22 and Fig. 5.23.

The 9-level OHSW, M = 1.00, f = 400Hz.

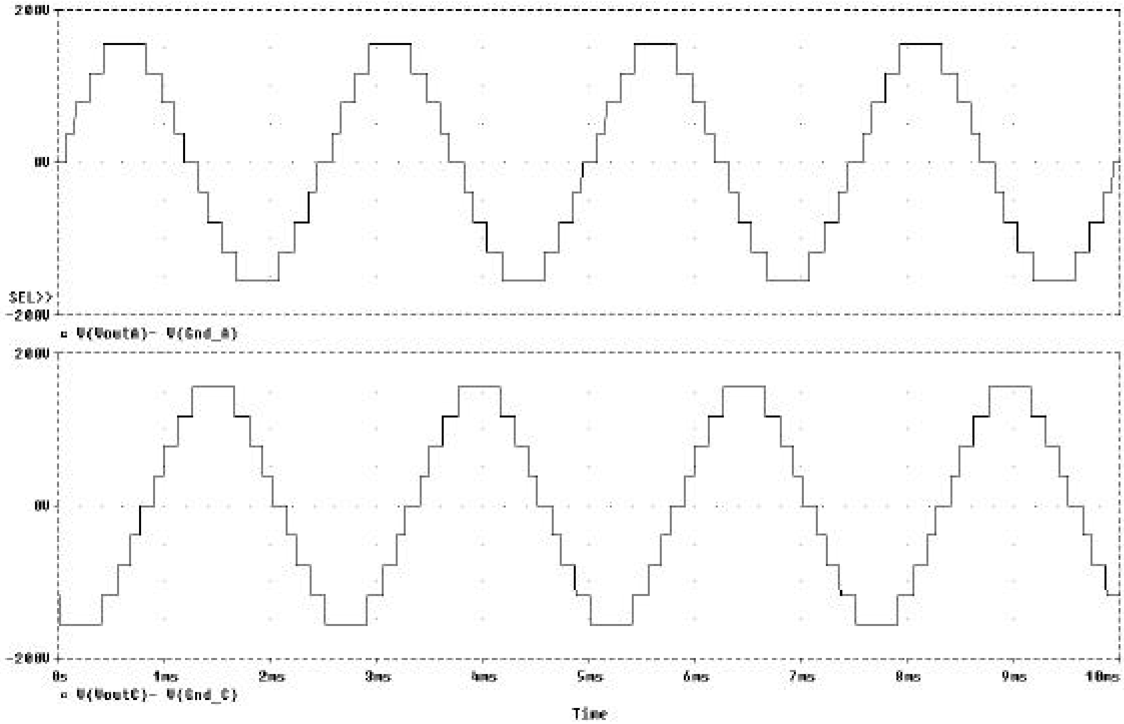


Figure 5.19(a) Phase voltage, A and C.

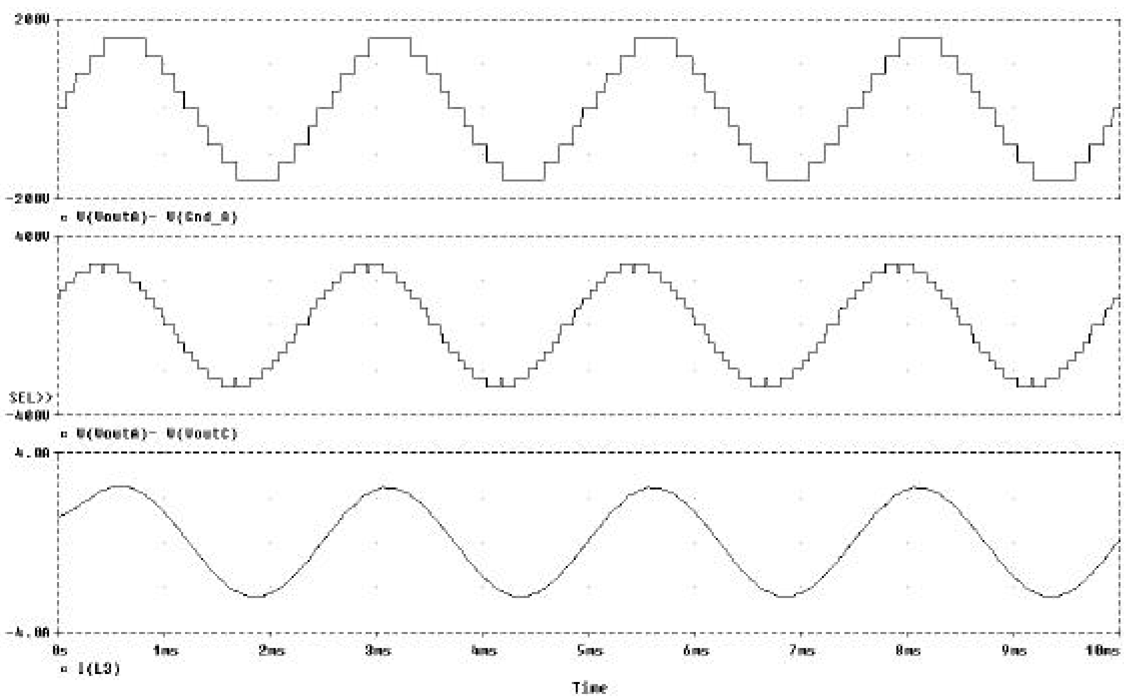


Figure 5.19(b) Phase voltage, line voltage, and load current.

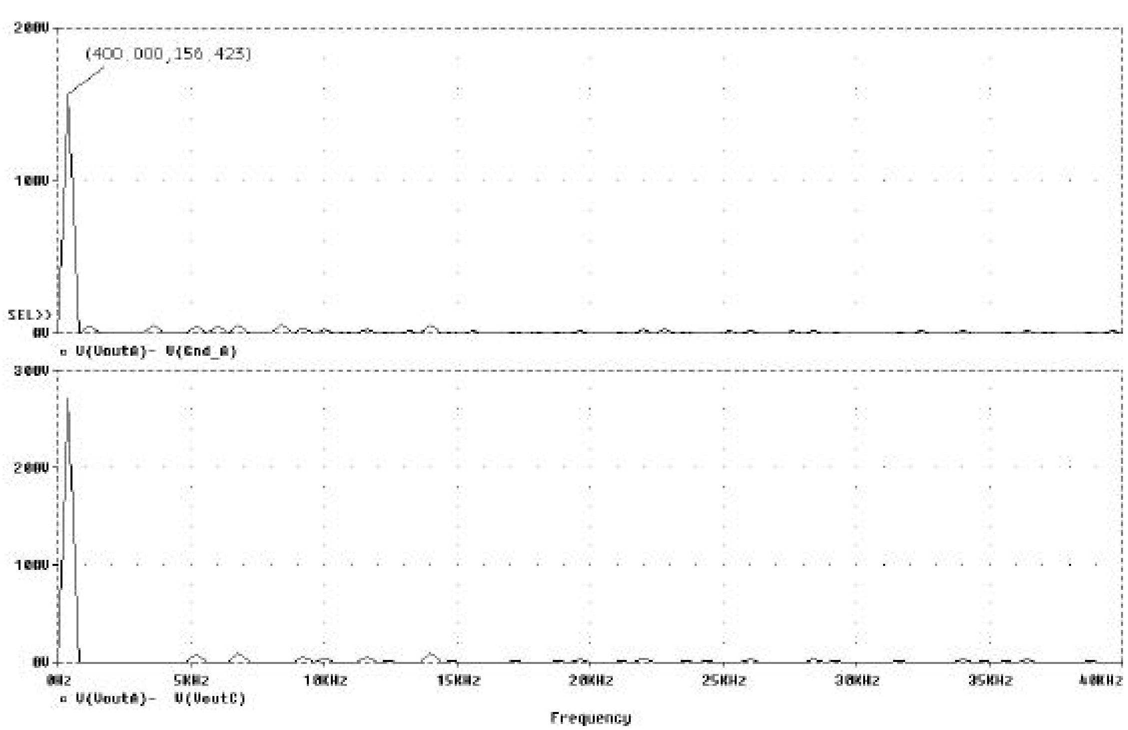
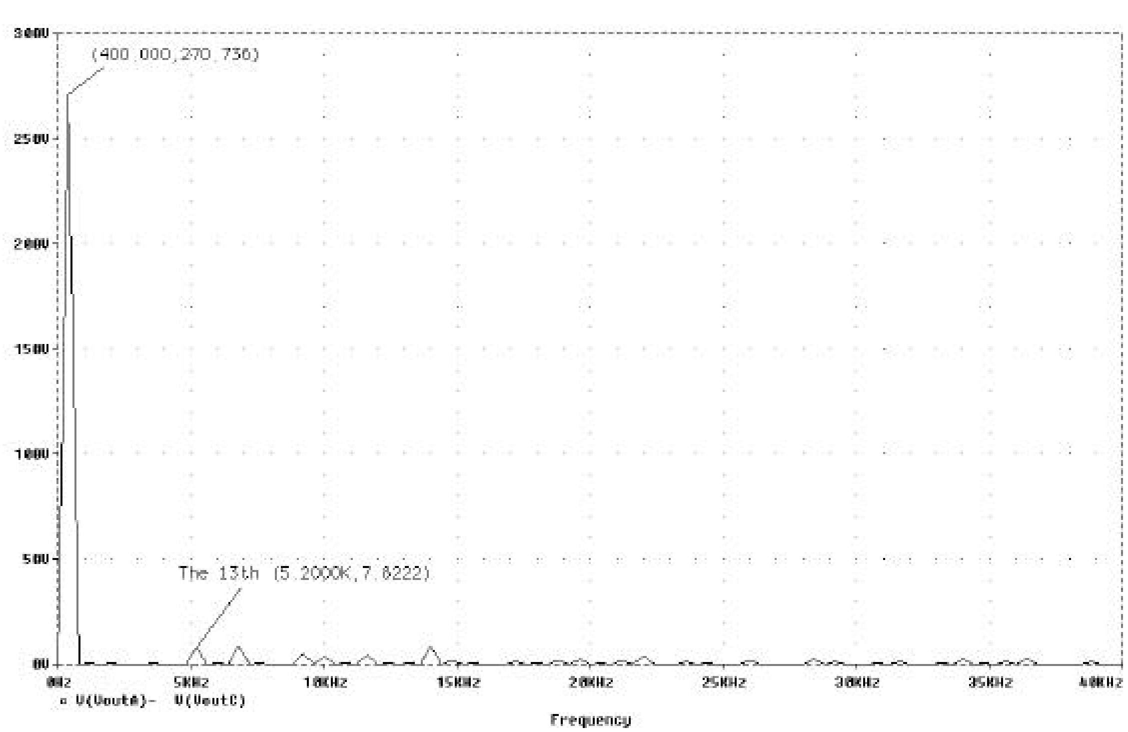


Figure 5.19(c) Frequency spectrum of phase voltage and line voltage.



TOTAL HARMONIC DISTORTION = 6.682816E+00 PERCENT

Figure 5.19(d) Frequency spectrum of line voltage in detail.

The 11-level OHSW, M=1.00, f=400Hz.

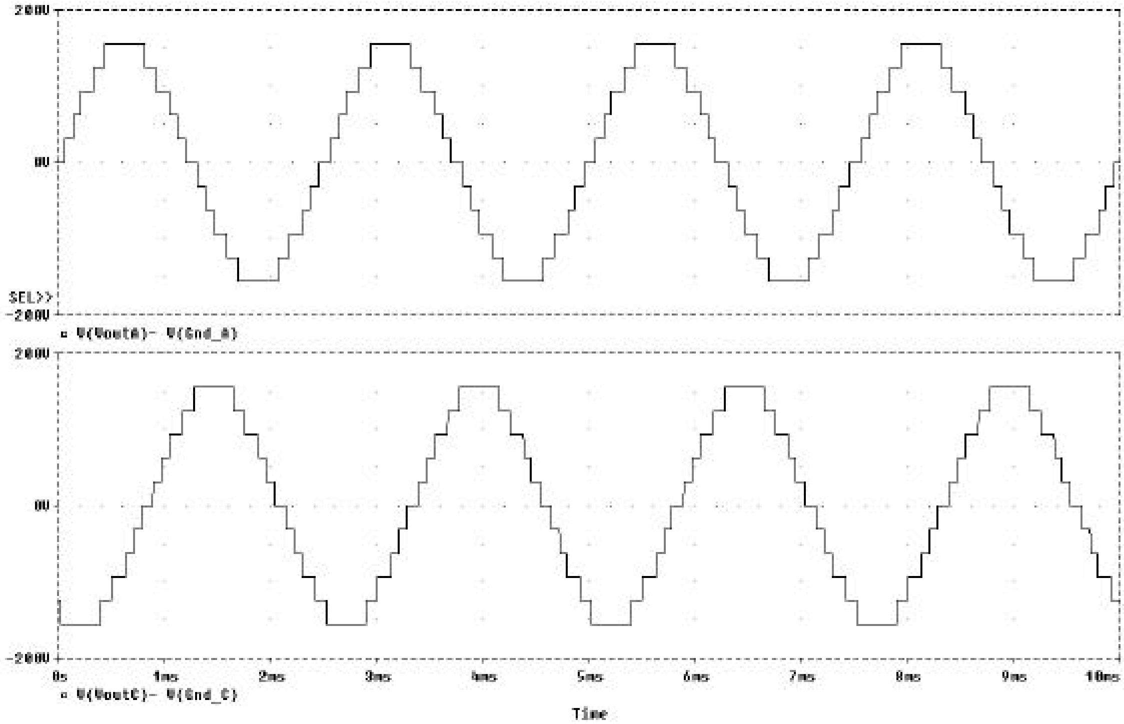


Figure 5.20(a) Phase voltage, A and C.

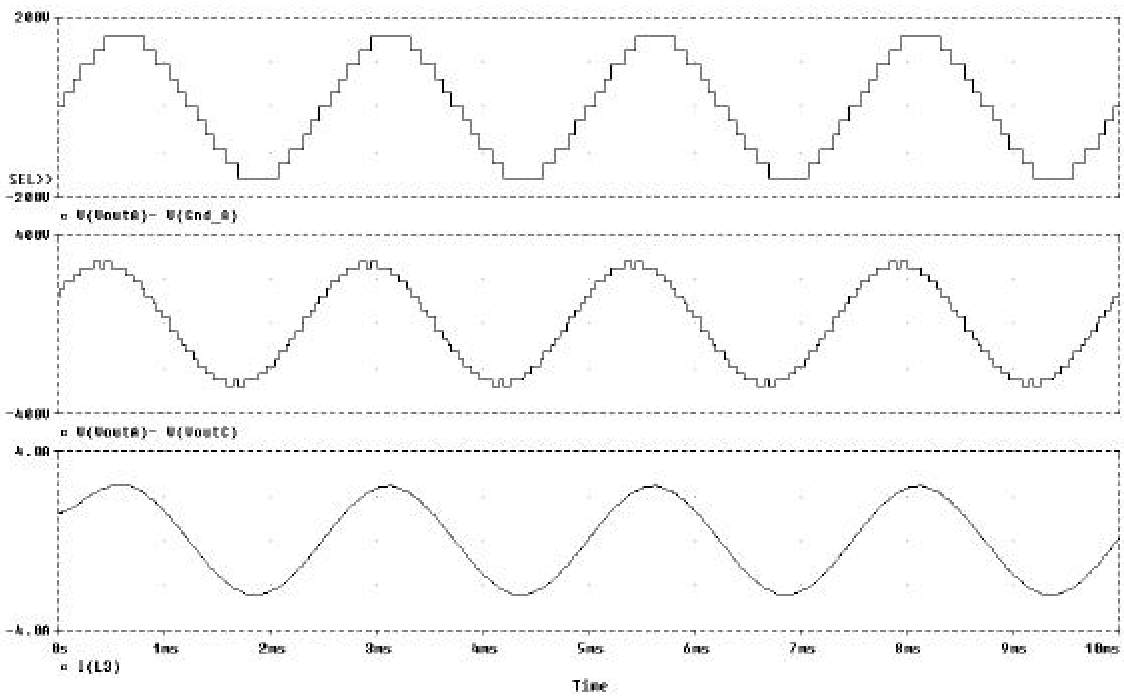


Figure 5.20(b) Phase voltage, line voltage, and load current.

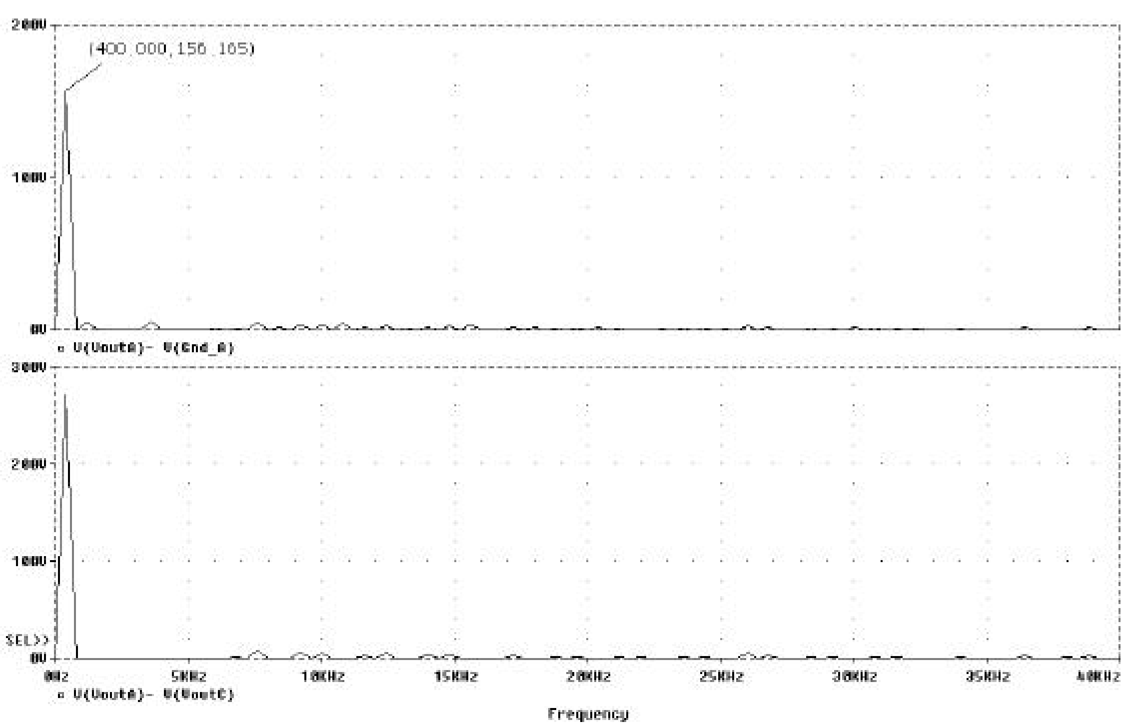
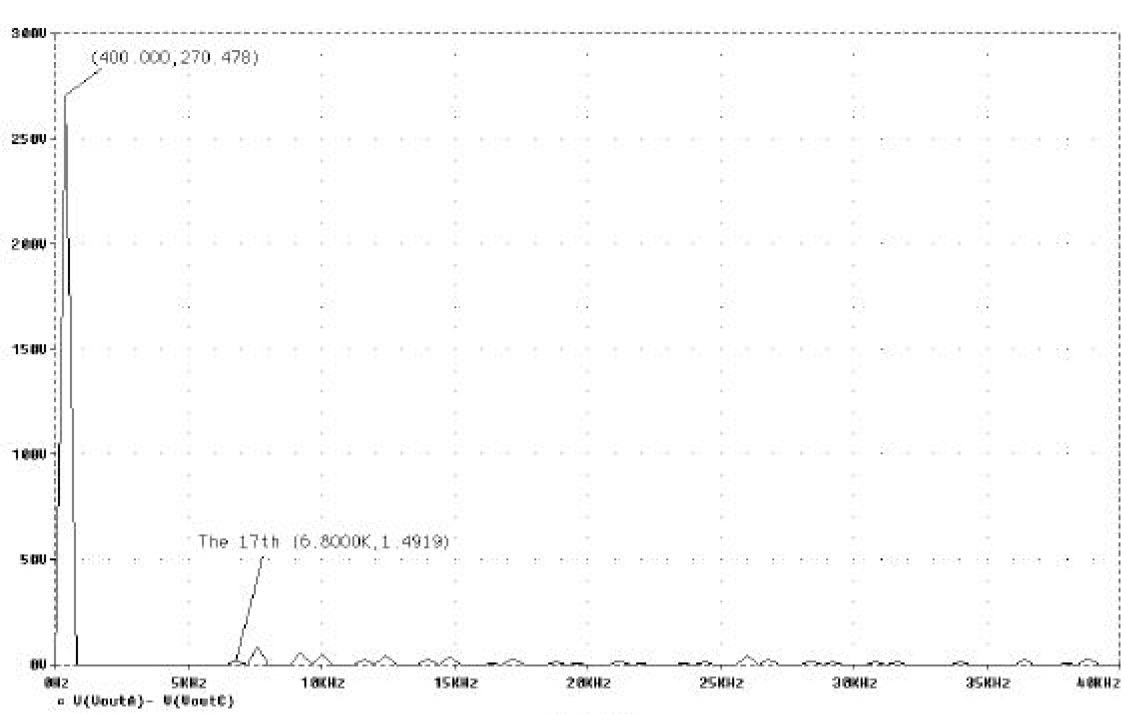


Figure 5.20(c) Frequency spectrum of phase voltage and line voltage.



TOTAL HARMONIC DISTORTION = 5.593177E+00 PERCENT

Figure 5.20(d) Frequency spectrum of line voltage in detail.

The 13-level OHSW, M = 1.00, f = 400Hz

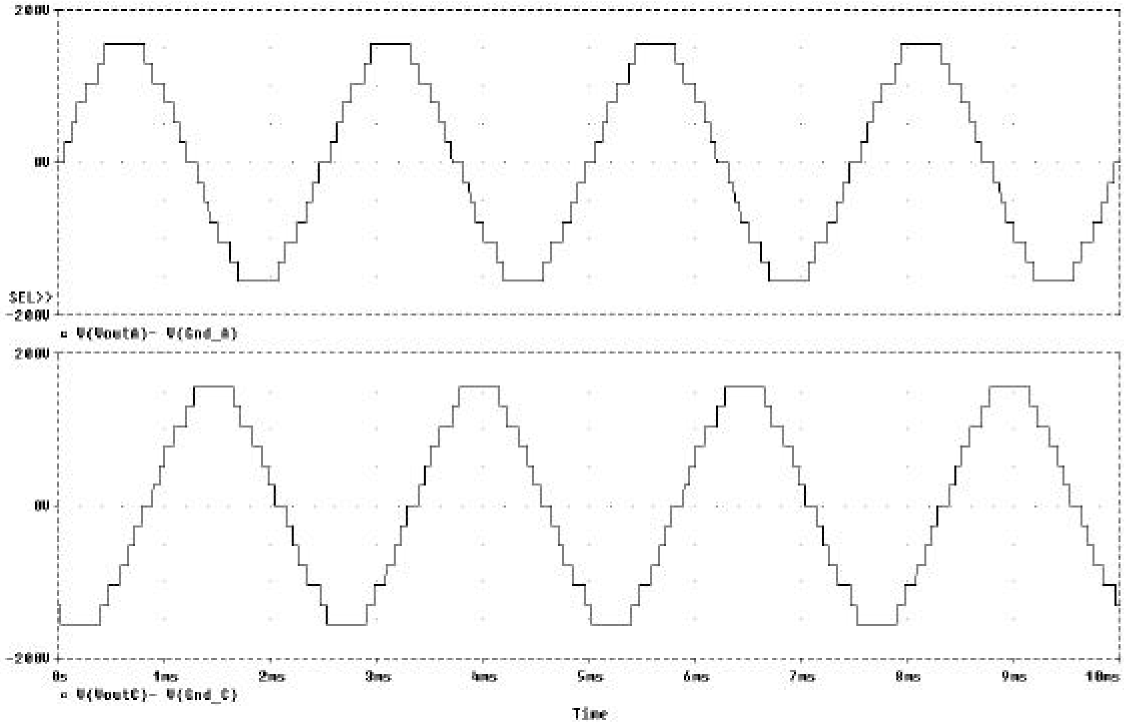


Figure 5.21(a) Phase voltage, A and C.

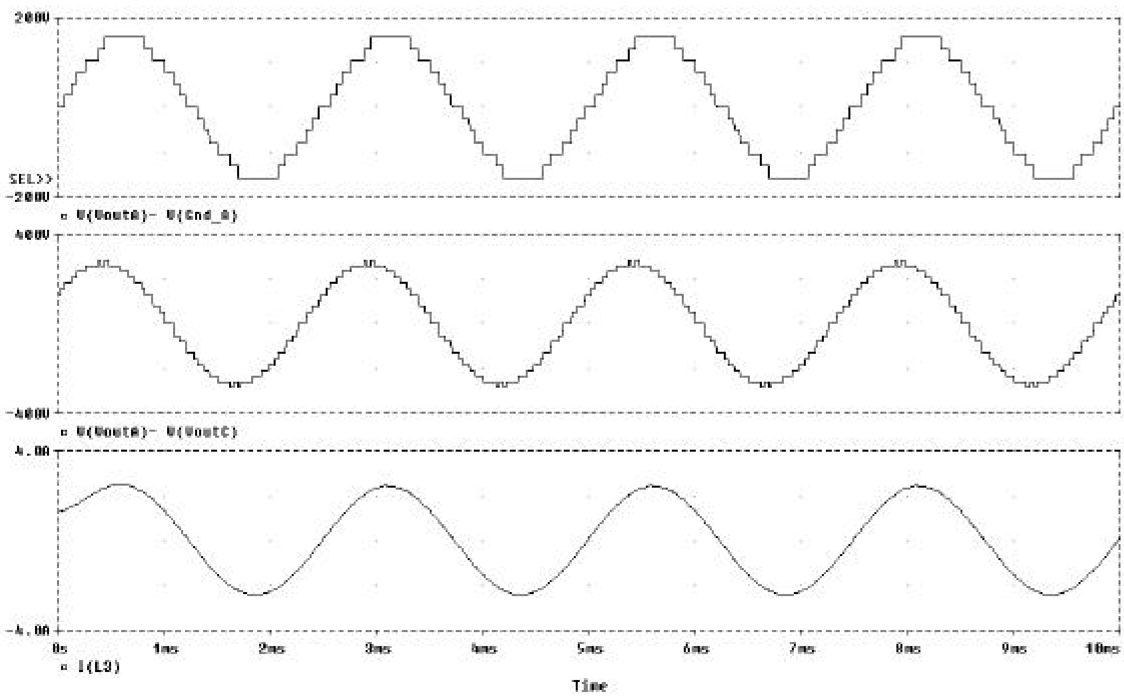


Figure 5.21(b) Phase voltage, line voltage, and load current.

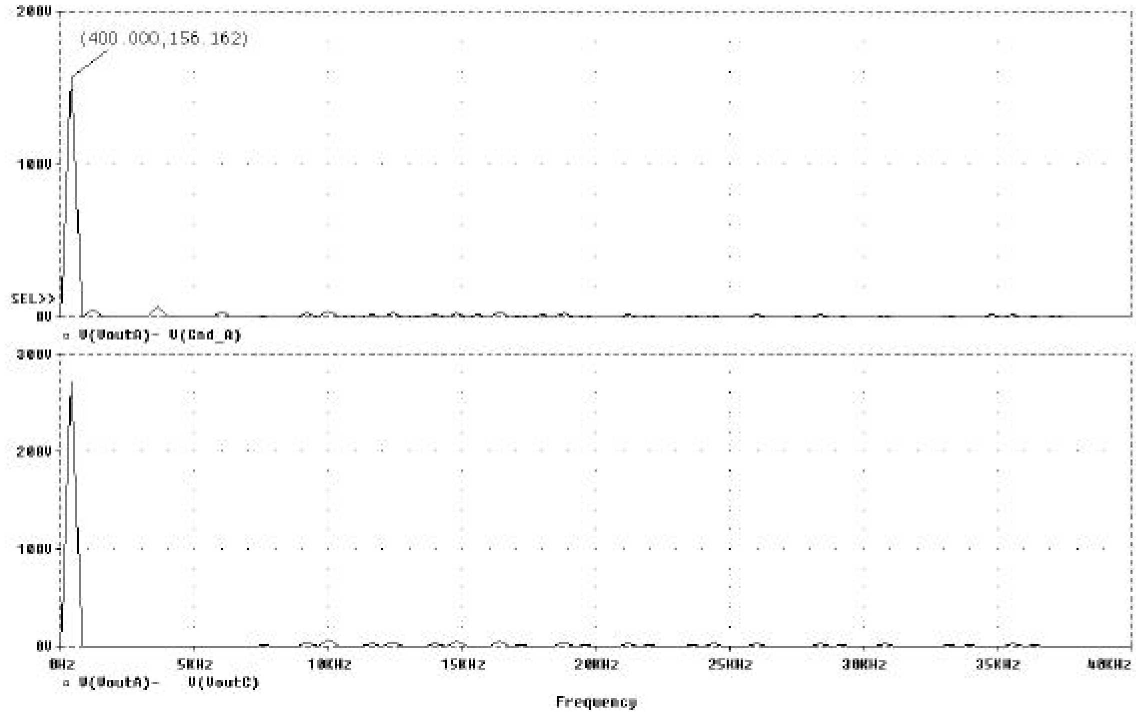
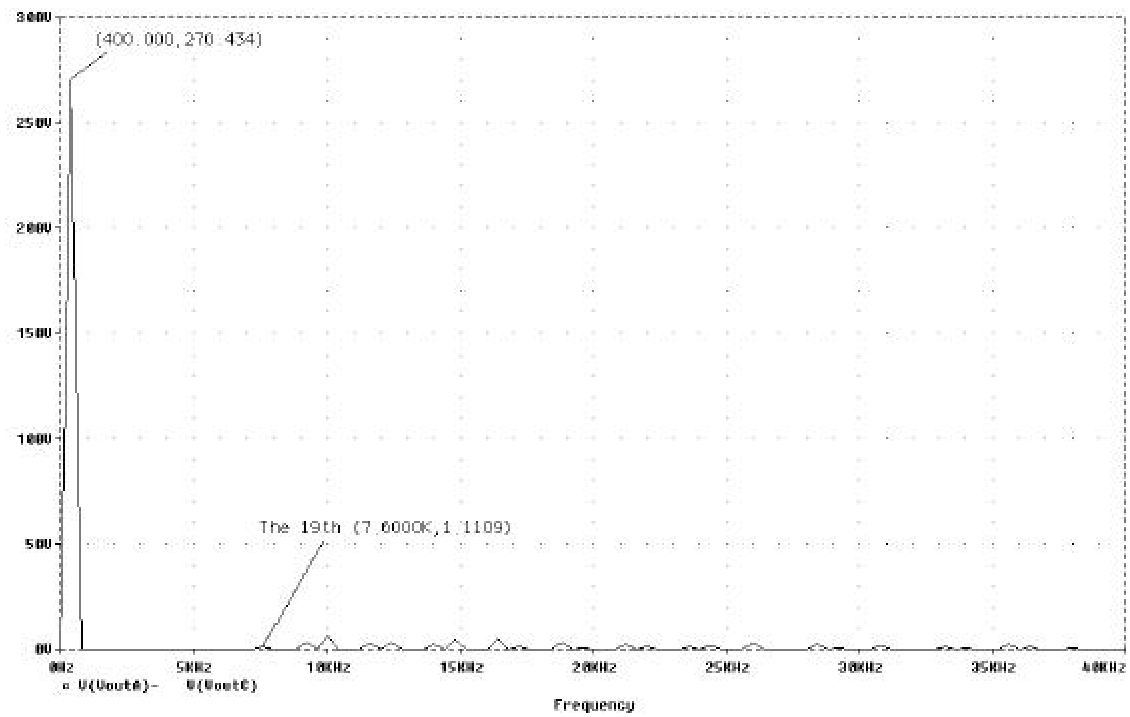


Figure 5.21(c) Frequency spectrum of phase voltage and line voltage.



TOTAL HARMONIC DISTORTION = 4.802129E+00 PERCENT

Figure 5.21(d) Frequency spectrum of line voltage in detail.

The 5-switching angle SHE PWM inverter, M = 1.0, f = 400Hz.

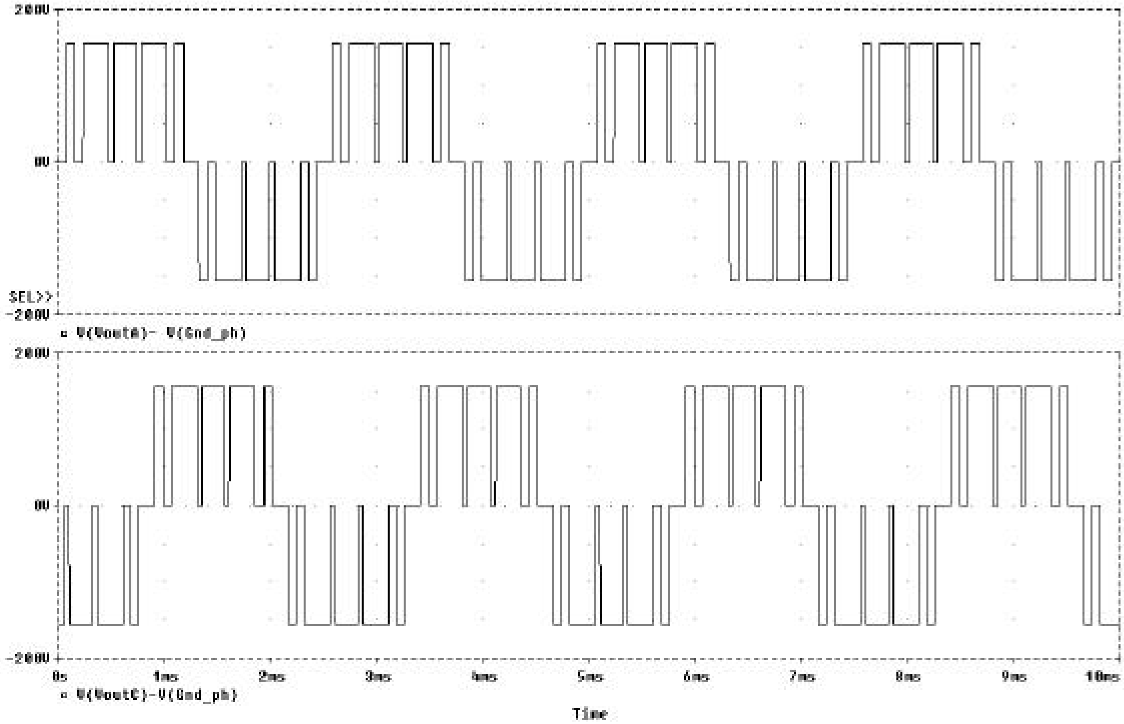


Figure 5.22(a) Phase voltage, A and C.

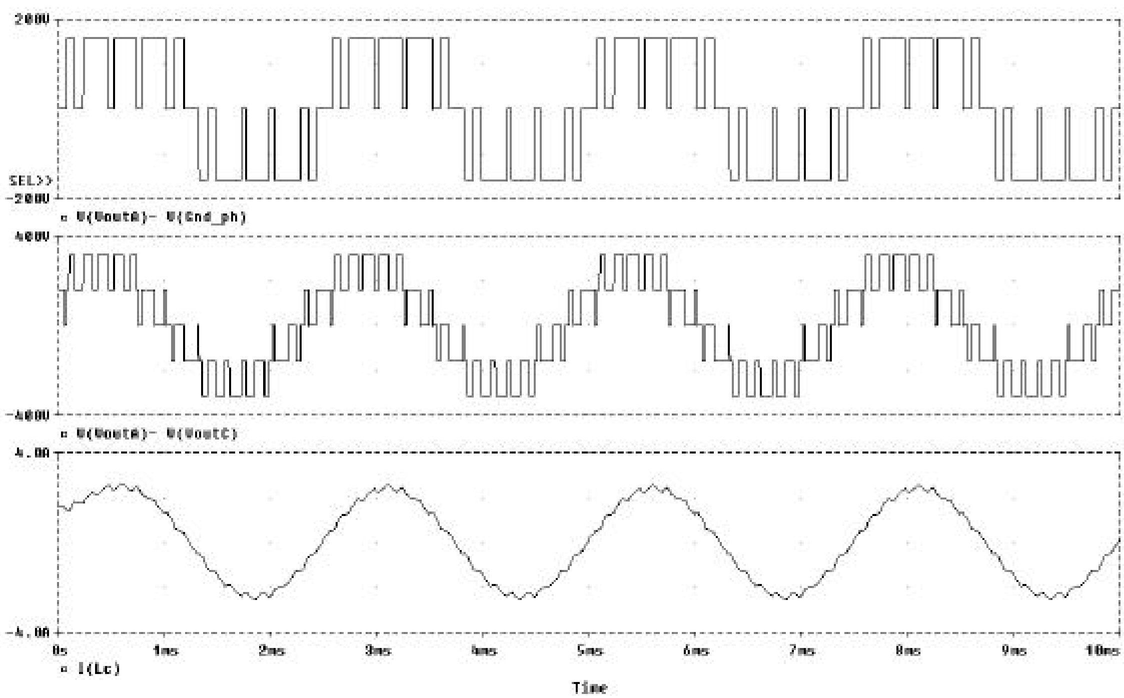


Figure 5.22(b) Phase voltage, line voltage, and load current.

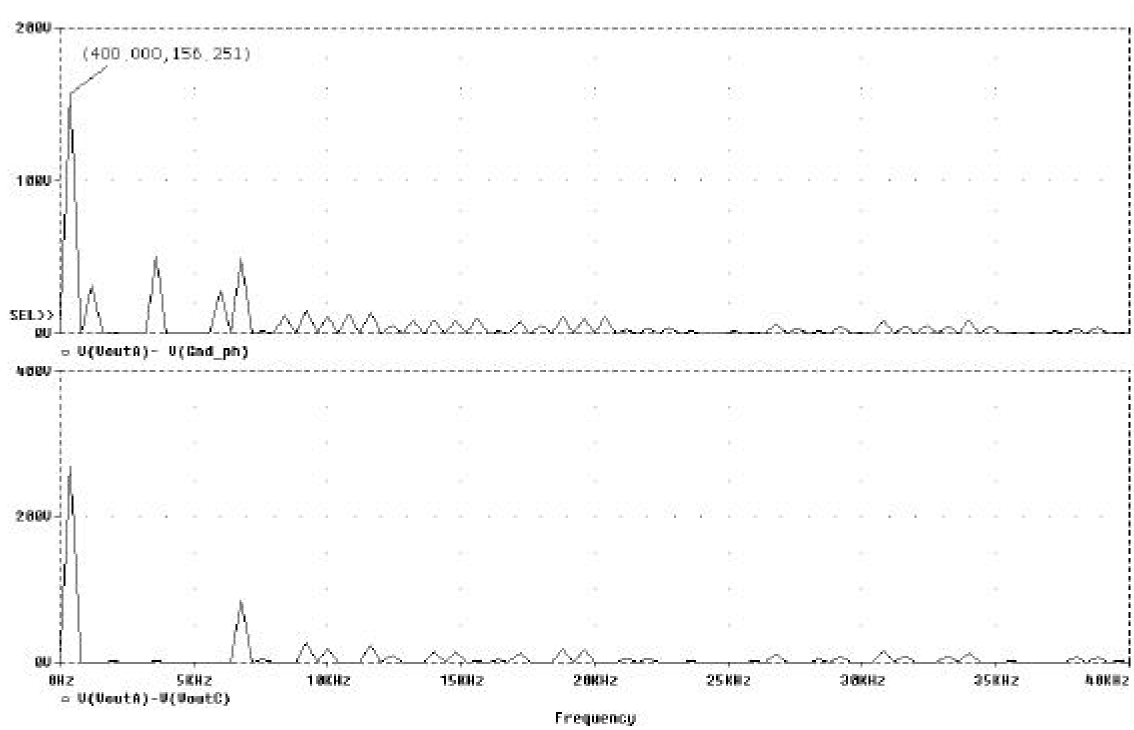
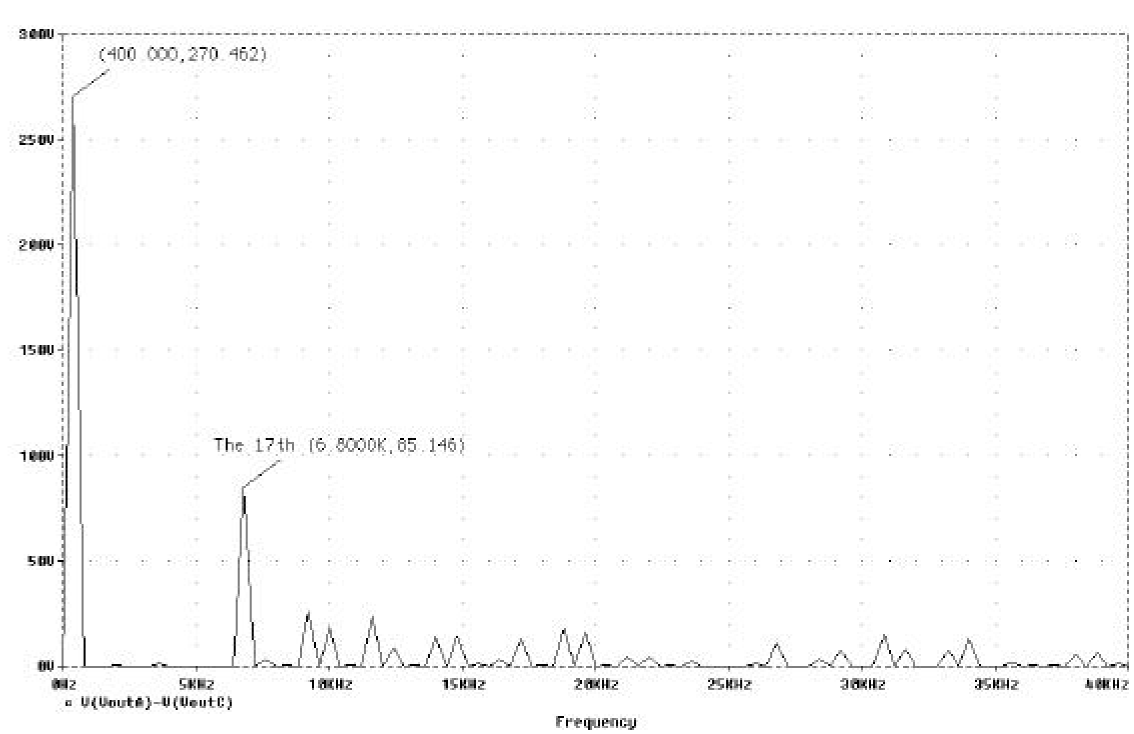


Figure 5.22(c) Frequency spectrum of phase voltage and line voltage.



TOTAL HARMONIC DISTORTION = 3.843884E+01 PERCENT

Figure 5.22(d) Frequency spectrum of line voltage in detail.

The 9-switching angle SHE PWM inverter, M = 1.0, f = 400Hz.

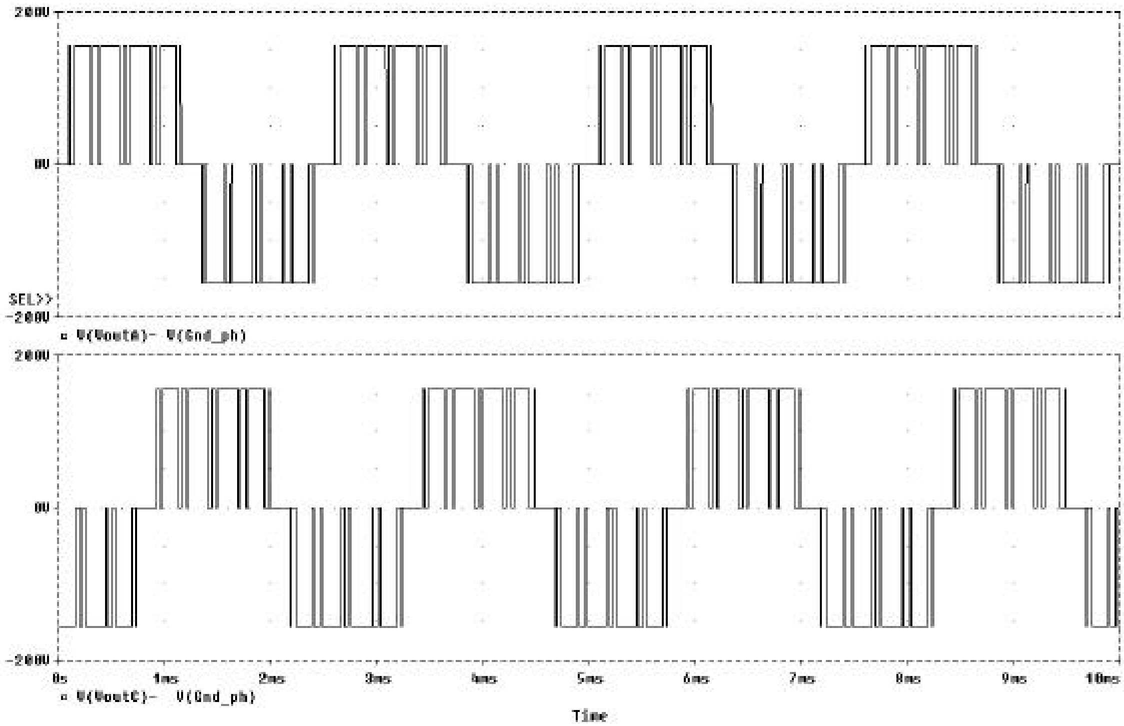


Figure 5.23(a) Phase voltage, A and C.

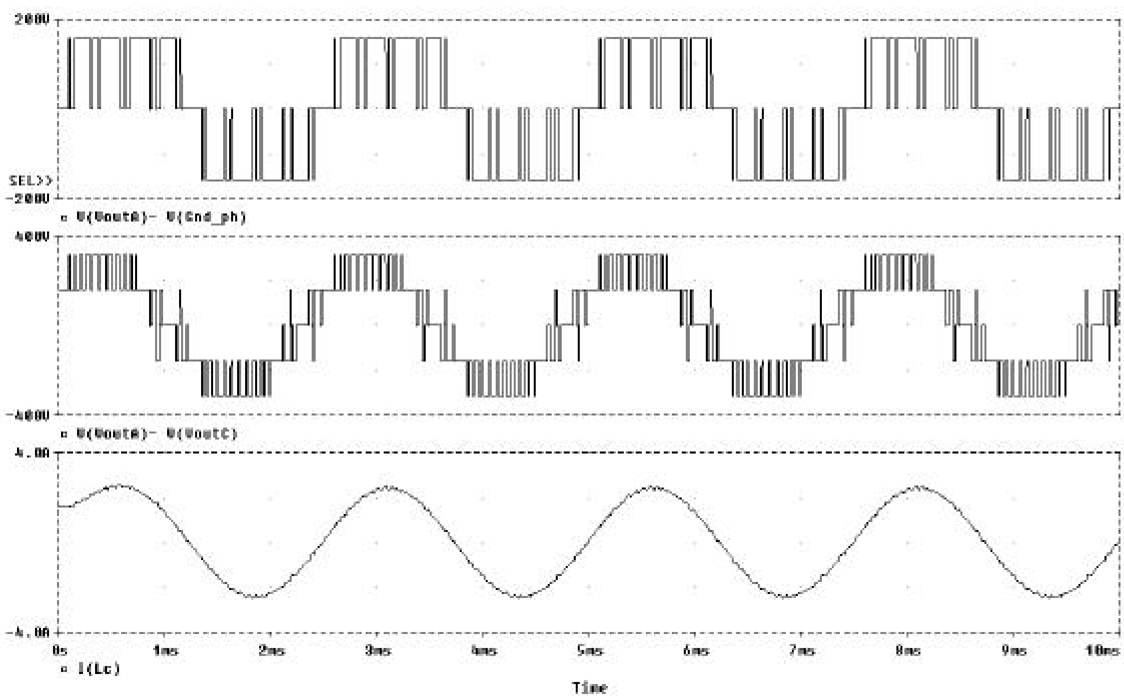


Figure 5.23(b) Phase voltage, line voltage, and load current.

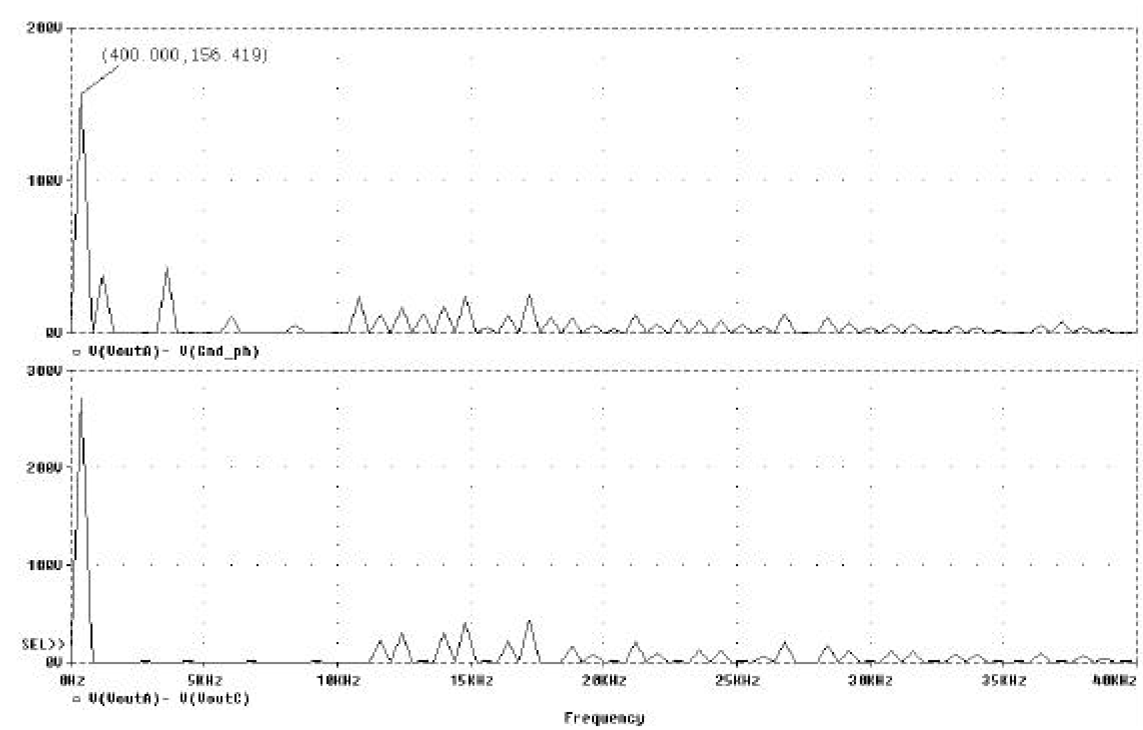
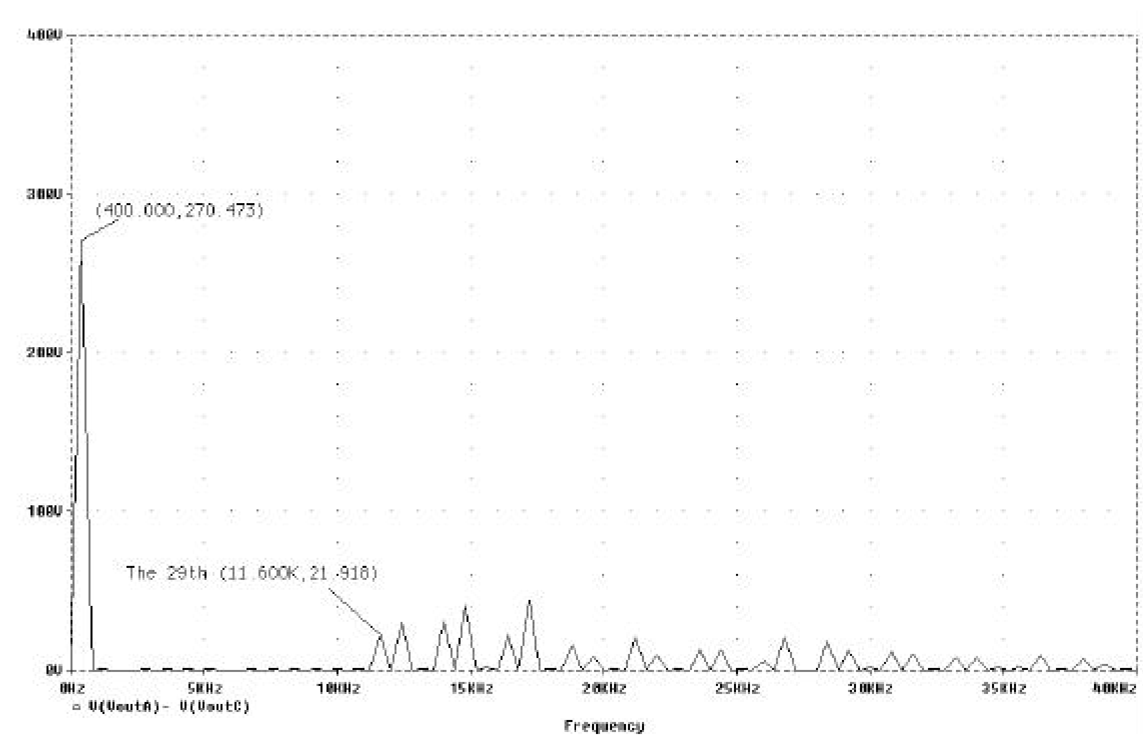


Figure 5.23(c) Frequency spectrum of phase voltage and line voltage.



TOTAL HARMONIC DISTORTION = 3.488980E+01 PERCENT

Figure 5.23(d) Frequency spectrum of line voltage in detail.

5.3.2.3 Summary

From Fig. 5.19 to 5.21, the simulated line voltage THDs of OHSW are plotted in Fig. 5.24 as a function of the number of output voltage. From the plot, the simulating results are very consistent with the MATLAB results. The line voltage THD increases, when the number of output voltage level increases.

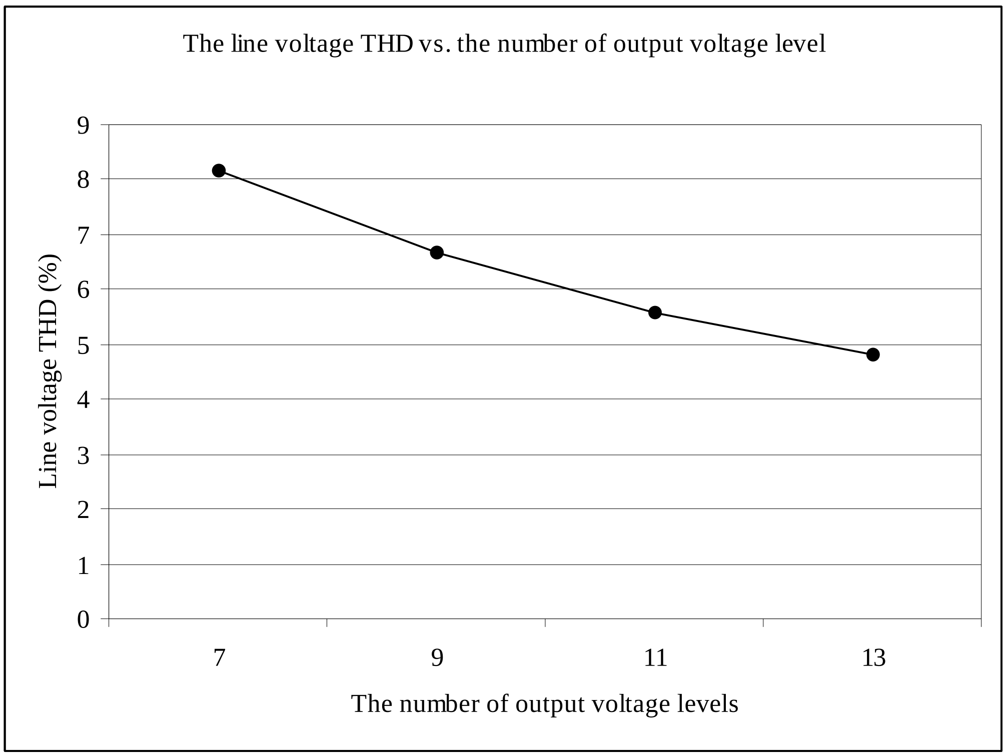


Figure 5.24 The line voltage THD of OHSW as function of the number of output voltage levels.

In case of SHE PWM waveform, the simulated results from Fig. 5.15, 5.22, and 5.23 are plotted in Fig. 5.25 as a function of the number of switching angles per quarter. As shown in the figure, the line voltage THD does not decrease, when the number of switching angles per quarter increases.

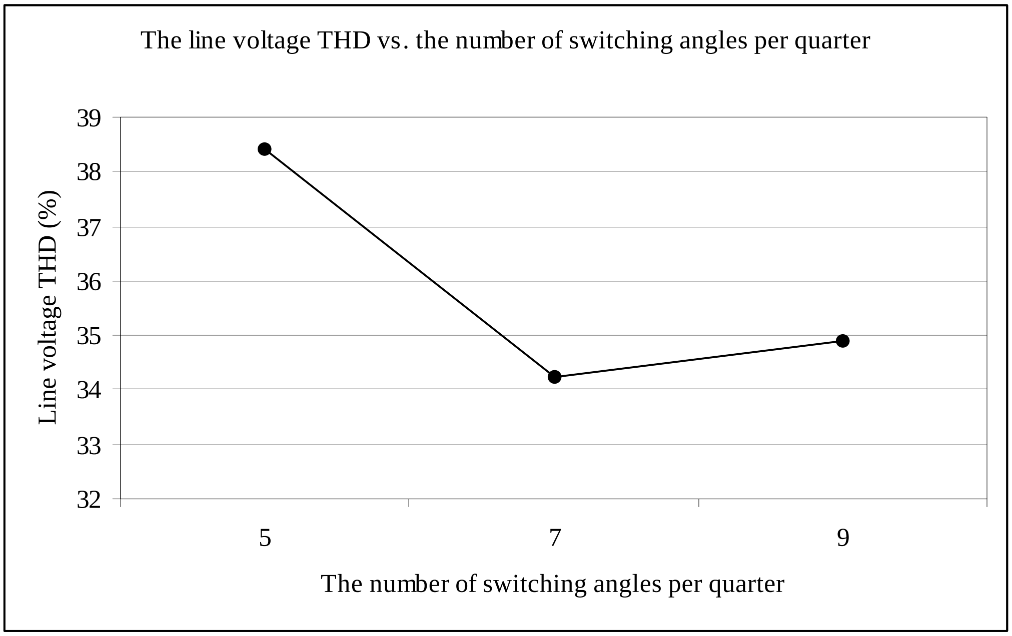


Figure 5.25 The line voltage THD of SHE PWM as function of the number of output voltage levels.

5.3.3 Conclusions

The simulating results of both cases are verified with PSPICE program. The simulating results support the MATLAB results very well.

In the next chapter, the experimental results of the hardware prototype will be presented to verify the calculated results and simulating results.