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Investigation of Modulation Index, Operational Mode and Load Type on the SHEM Current Source Inverter

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Abstract: This research investigated influence of load type, operational mode and modulation index on the SHEM current source inverter (CSI). For this purpose an inverter designed and constructed which can be operated in single and three phase mode with any number of harmonics elimination capability. In current source inverters with resistive- inductive loads, over voltages in output voltage waveform appears. To remove this over voltage, we used a capacitor. In this study the effect of this capacitor on the output voltage has been investigated. The result of varying of modulation index shows that the amplitude of the system's harmonics varied with their variation, which can cause undesired effects on the supplied devices with inverter. The effect of these parameters on the CSI, simulated with PSPICE. The comparisons have been done on our laboratorial system outputs, with simulated results. Then it has been shown that experimental results verify the simulation results.

Key words: Modulation index, load type, selective harmonic elimination modulation, operational mode

INTRODUCTION

Current source inverters have been used in industry and for using them the effective operational parameters must be investigated carefully. One of the important application of CSI is harmonic studying in a power system which for this purpose, the controllable harmonics are needed. The other application of CSI is speed control of AC machines which in this case the speed control is done with changing of modulation index and frequency. Therefore the changing of these parameters must be studied. An induction motor fed with CSI inverter has investigated by Salo and Tuusa (2005), Espinoza and Joos (1995) and Wiechmann *et al.* (2008) the output load is inductive, so in the output is used a capacitor but haven't been discussed the calculation method and effects of this capacitor.

CSI inverters can be used as AC/AC converter (Kazerani, 2003). In this system, may be the THD of system woken by changing of modulation index which have not been investigated. The other application of CSI inverter is reactive power compensation (Dong and Lehn, 2002; Han *et al.*, 2000, 2001). In this case, also must be considered the load type and modulation index (THD).

Past research has studied and analyzed control strategies as well as pulse width modulation (PWM) schemes for voltage and current-source inverters and rectifiers (VSIs and CSIs) where significant accomplishments have been achieved harmonic distortion minimization, high-input power factor and reduced switching frequencies, among others (Rashid, 2001; Blaabjerg *et al.*, 1995; Kwak and Toliyat, 2006).

There are different methods for elimination of harmonics. Antunes *et al.* (1999), McGrath and Holmes (2008) and Yu *et al.* (2004) are used multilevel structure for this purpose. One of the disadvantages of this method is requiring more devices that are expensive. Selective harmonic elimination modulation (SHEM) is another method for harmonic elimination in which, harmonic of output current can be eliminated by creating appropriate notches.

This study investigated influence of load type, operational mode and modulation index on the SHEM current source inverter. For this purpose an inverter designed and constructed which can be operated in single and three phase mode with any number of harmonics elimination capability. By using of experimental results, variation of modulation index, load type and operational mode are investigated on inverter's operation. Finally, results have been obtained from PSPICE simulation is verified by experimental results.

INTRODUCTION OF SHEM SWITCHING METHOD

SHEM is a PWM switching method for harmonic elimination which harmonic of output current can be eliminated by creating appropriate notches.

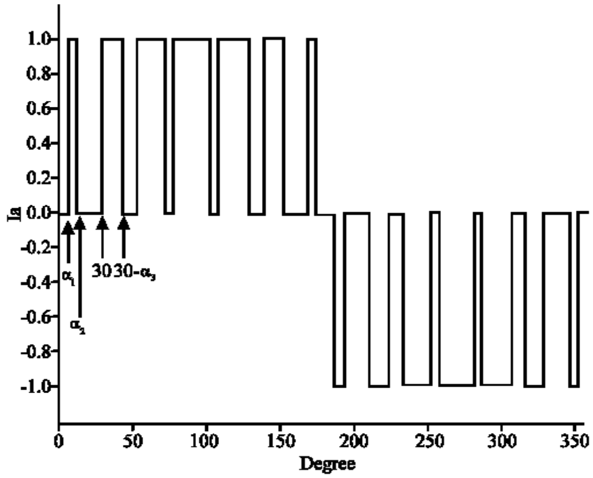


Fig. 1: The waveform of CSI output current without 5 and 7 harmonics and capable of controlling amplitude

In this method, for elimination of N harmonics, N notches must be created in quarter of the waveform and if control of amplitude is necessary, one more notch is needed for this purpose. Hence, for having both amplitude control and harmonic elimination in total N+1 notches are needed.

Using this method, lower order harmonics are cancelled by proper switching and higher order harmonics are filtered by high pass filter. Moreover, elimination of harmonics is optional and possible Current waveform of the output phase is shown in Fig. 1.

According to Fig. 1, the amplitude can be controlled and the harmonics number 5, 7 can be cancelled using α_1-α_3 angles.

INVERTER OPERATION IN DIFFERENT MODES

The constructed inverter can be operated in single and three phase states that each of them included many modes. In this study for each of single or three phase state, the following modes have been investigated:

Mode 1: Without amplitude controlling and any harmonic elimination
Mode 2: Amplitude controlling and without any harmonic elimination
Mode 3: Amplitude controlling and elimination of 5 and 7 harmonics
Mode 4: Amplitude controlling and elimination of 5, 7, 11 and 13 harmonics

Of course, the above modes have been chosen from many different modes and it is depends to the user and application. Figure 2 shows the output current of three phase CSI inverter in mode 2 with resistive load, 50 Hz

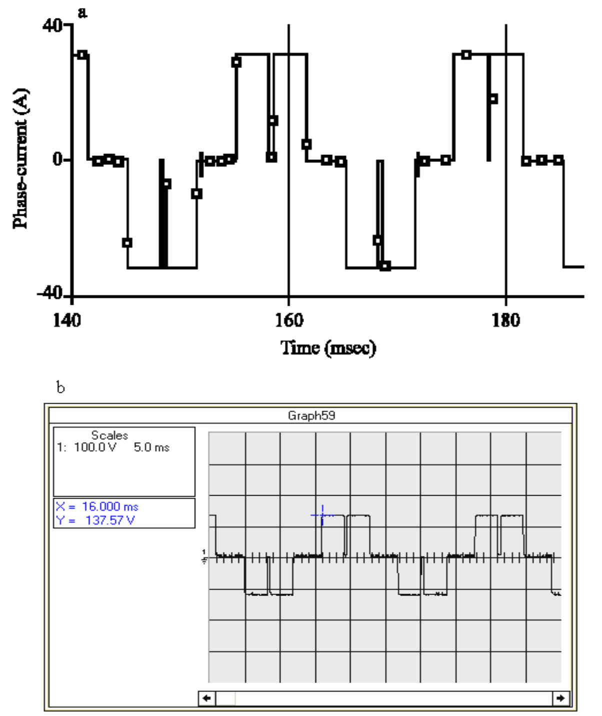


Fig. 2: The output current of CSI in mode 2 of three phase in resistive load, 50 Hz output frequency and MI = 100% (a) PSPICE simulation (b) experimental results

and 100% modulation index. In this waveform by creating a notch can be controlled the amplitude but all of harmonics (6k±1 where k = 1, 2, …, n) remain in the waveform.

One of the other modes is mode 3 in three phase state. For this mode the output current and spectral frequency of it are shown in Fig. 3 and 4, respectively. According to Fig. 4 the harmonics 5 and 7 don't exist in waveform and the frequency of the first presence harmonic is 550 Hz (11th harmonic). In this mode the output line-line voltage has three levels and shown in Fig. 5.

EFFECT OF MODULATION INDEX VARIATION

Figure 6, 7 shows the output current and spectral frequency of it for three phase CSI inverter in mode 3 with resistive load, 50 Hz and 80% modulation index. By comparing (Fig. 6) with (Fig. 3), it is clear that remain harmonics' amplitude has been increased by decreasing of modulation index. For example in 100% modulation index the amplitude of 13th harmonic is 10A and MI = 80% is 15A. Therefore the changing of MI must be considered in CSI applications.

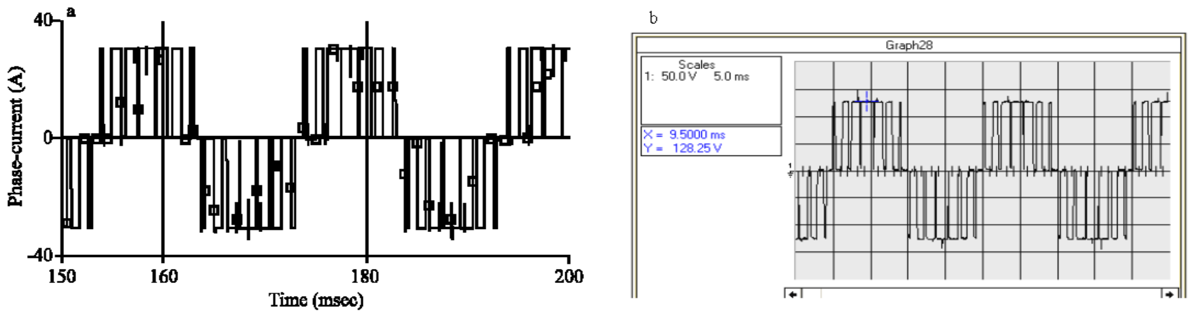


Fig. 3: The output current of CSI in mode 3 of three phase in resistive load, 50 Hz output frequency and MI = 100% (a) PSPICE simulation and (b) experimental results

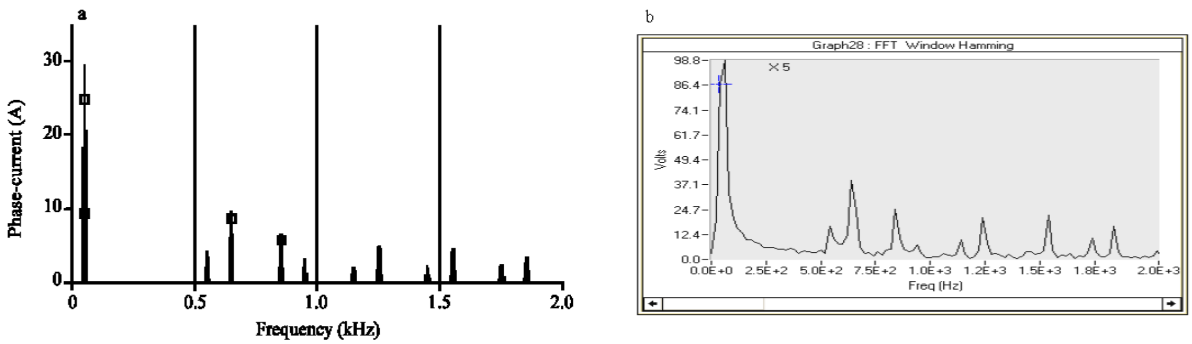


Fig. 4: Output current spectral frequency of CSI in mode 2 of three phase in resistive load, 50 Hz output frequency and MI = 100% (a) PSPICE simulation (b) experimental results

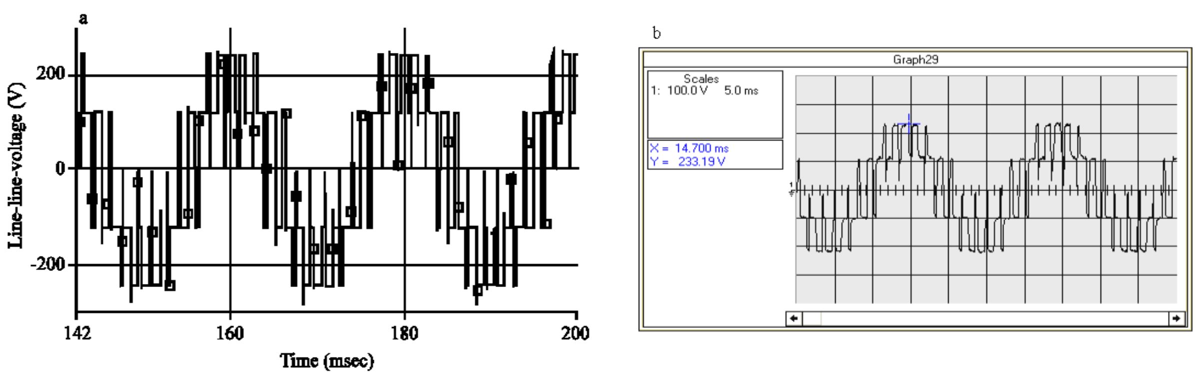


Fig. 5: Line-to-line output voltage of CSI in mode 3 of three phase in resistive load, 50 Hz output frequency and MI = 100% (a) PSPICE simulation and (b) experimental results

EFFECT OF LOAD TYPE ON INVERTER OPERATION

In the resistive-inductive loads, over voltages in output voltage waveform appears which amplitude of this over voltage depends on the amount of resistance and inductance of load. This over voltage can be appeared on the switches and will be caused failing of them.

To remove this over voltage, we used capacitor which parallel with load. The different waveform have been shown for resistive-inductive (R_L = 2.2 Ù, R_L = 0.7 mH) by using of capacitor an without using.

Without using capacitor: Figure 8 shows the switch voltage. In Fig. 8 can be seen the over voltage obviously which amplitude of these over voltages increased with increasing of L/R ratio. This problem leads to failing of switches.

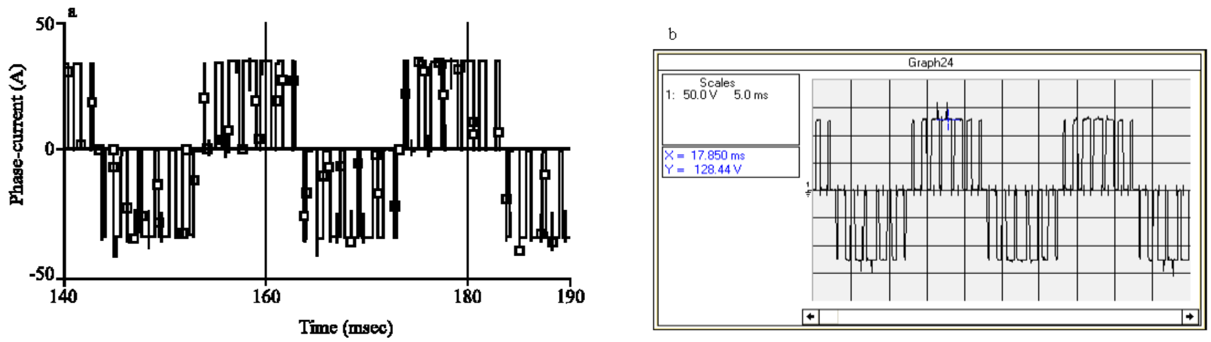


Fig. 6: Output current of CSI in mode 3 of three phase in resistive load, 50 Hz output frequency and MI = 80% (a) PSPICE simulation and (b) experimental results

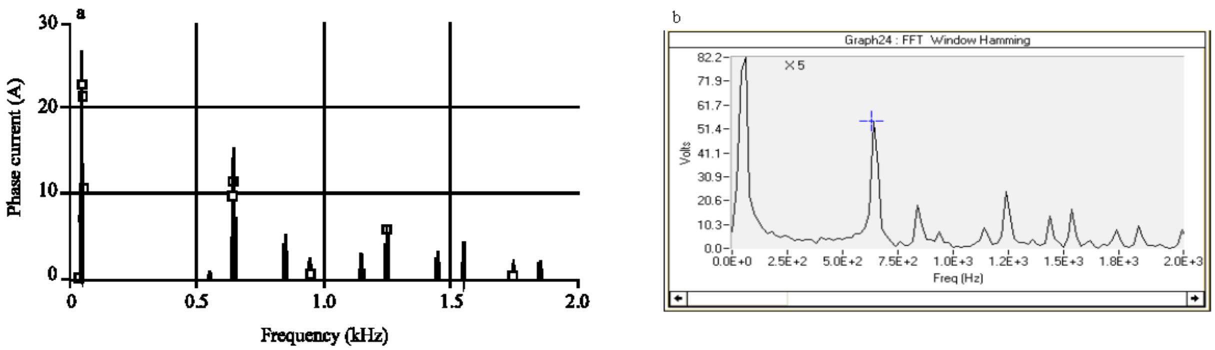


Fig. 7: Output current spectral frequency of CSI in mode 2 of three phase in resistive load, 50 Hz output frequency and MI = 80% (a) PSPICE simulation and (b) experimental results

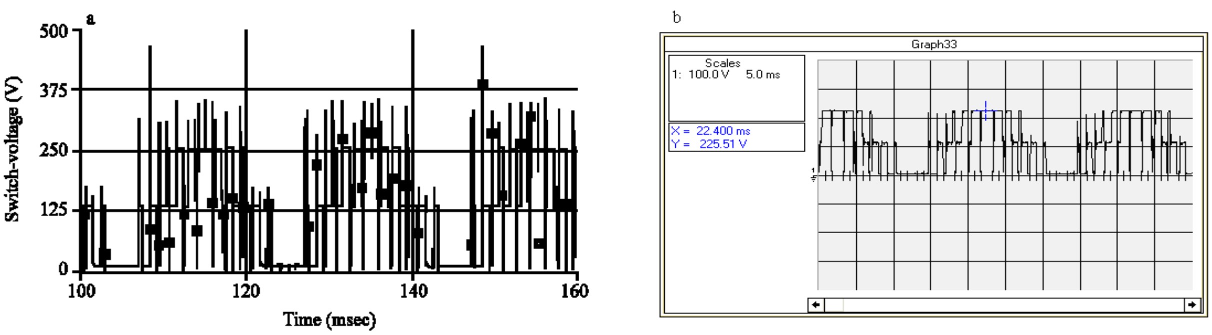


Fig. 8: Switch voltage of CSI in mode 3 of three phase in resistive-inductive load, 50 Hz output frequency and MI = 100% without capacitor (a) PSPICE simulation and (b) experimental results

Figure 9 shows the line to line output voltage. The over voltage is existed. The output current is shown in Fig. 10. According to this, the inductive loads don't have any effect on the output current.

By using capacitor: To remove the over voltage we can use a capacitor in the output. In this study to removing the over voltage has been used the 100 μF capacitors where its advantages are:

- Protects the switches by removing of over voltages
- Act such as low pass filter and remover the high order harmonics

In mode 1, from load view the inverter can be modeled as current source which is shown in Fig. 11b. If don't use from capacitor, the over voltage can be appeared in A point which can be removed these over voltage by using of capacitor. The output transfer function can be written as follow by:

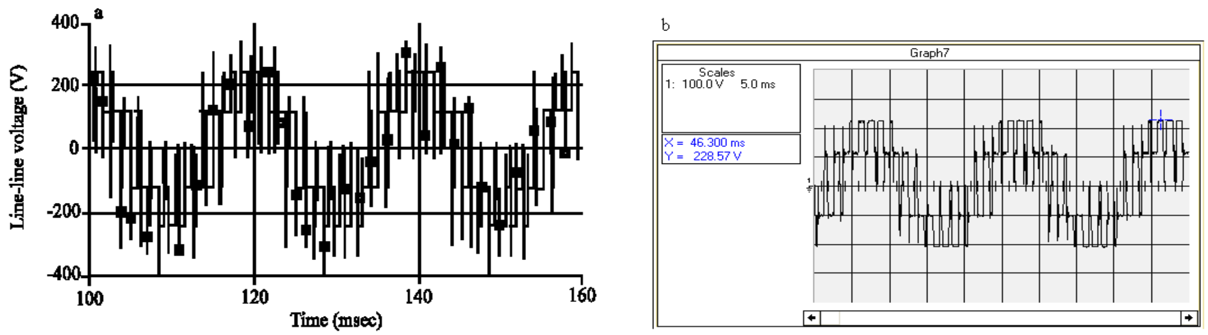


Fig. 9: Line-to-line output voltage of CSI in mode 3 of three phase in resistive-inductive load, 50 Hz output frequency and MI = 100% without capacitor (a) PSPICE simulation and (b) experimental results

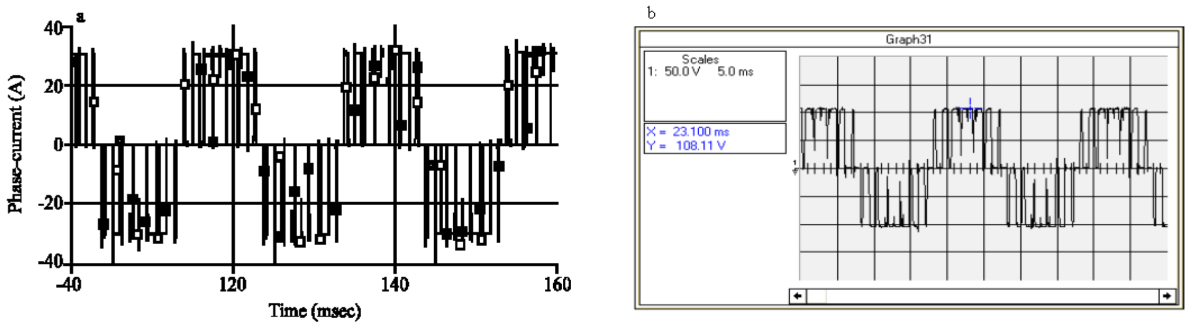


Fig. 10: Output current of CSI in mode3 of three phase in resistive-inductive load, 50 Hz output frequency and MI = 100% without capacitor (a) PSPICE simulation and (b) experimental results

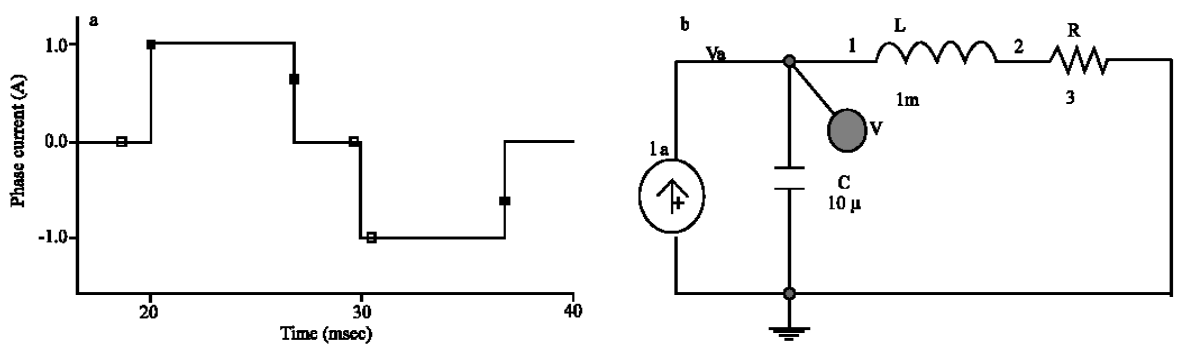


Fig. 11: (a) Equivalent circuit of CSI inverter (b) the output current

$$V_a = \frac{R + LS}{LCS^2 + RCS + 1} \times I_a \quad (1)$$

Where:

$$\Delta = LCS^2 + RCS + 1 \Rightarrow \begin{cases} \omega_n = \dfrac{1}{\sqrt{LC}} \\ \xi = \dfrac{R}{2}\sqrt{\dfrac{C}{L}} \\ \text{overshoot} = e^{\left(-\frac{\xi}{\sqrt{1-\xi^2}} \times \pi\right)} \\ T_s = \dfrac{4}{\xi\omega_n} = \dfrac{2 \times L}{R} \end{cases} \quad (2)$$

According to (2) different parameters have been affected on the over voltage removing. If damping factor less than one, the over voltage will be accorded. Also the changing of capacitor doesn't have any effect on the settling time of output voltage. Figure 12 shows this problem.

The frequency response of the output voltage for Fig. 11 is plotted in Fig. 13 which high cutting frequency is functioned of R, L and C parameters. So, by suitable selecting of capacitor value furthermore over voltage amplitude controlling the high order frequency can be cancelled. Figure 14 shows the effect of capacitor

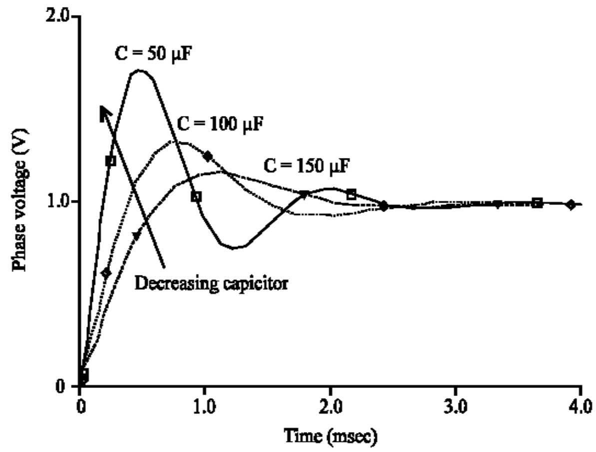


Fig. 12: Capacitor effect on output voltage settling time R = 3 Ω and L = 1 mH

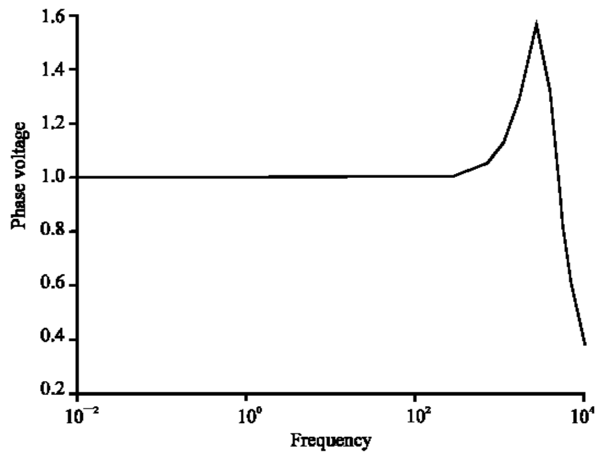


Fig. 13: Frequency response of filter by R = 3 Ω, L = 1 mH and C = 100 μF

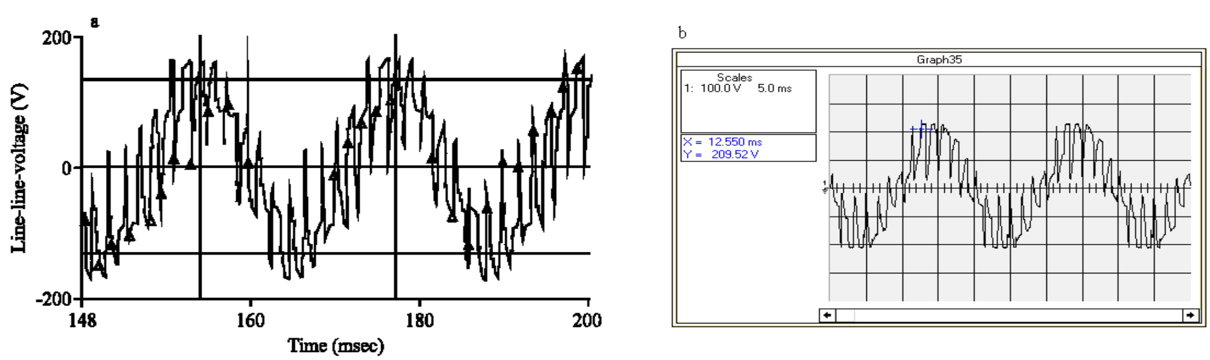
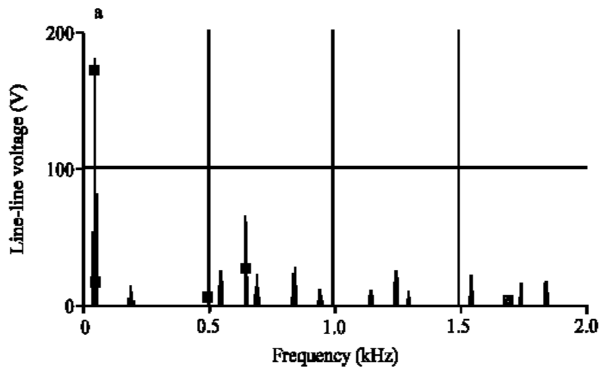


Fig. 14: Line-to-line output voltage of CSI in mode 3 of three phase in resistive-inductive load, 50 Hz output frequency and MI = 100% by using capacitor (a) PSPICE simulation and (b) experimental results

on the output voltage. By comparing Fig. 4 with Fig. 9, can be seen that the waveform is approximately near sinusoidal. According to this fact, by using of capacitor the high order harmonics can be cancelled.

Figure 15 shows the spectral frequency of output line-to-line voltage. The influence of capacitor in removing of over voltages and canceling of high order harmonics.



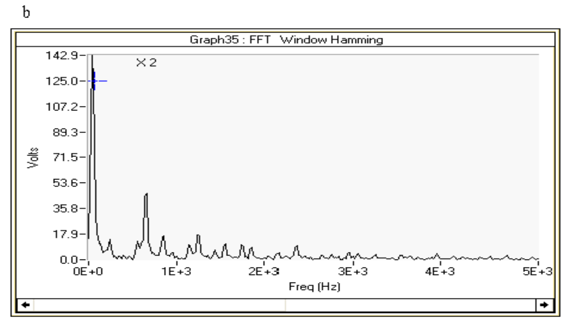


Fig. 15: Output current spectral frequency of CSI in mode 3 of three phase in resistive-inductive load, 50 Hz output frequency and MI = 100% by using (a) PSPICE simulation and (b) experimental results

CONCLUSION

This study investigated influence parameters such as of load type, operational mode and modulation index on the SHEM current source inverter. For this purpose an inverter designed and constructed which can be operated in single and three phase mode with any number of harmonics elimination capability. In current source inverters with resistive- inductive loads, over voltages in output voltage waveform appears. By using of capacitor in the output, these over voltages removed. Variation of modulation index shown that the amplitude of the harmonics can be varied by changing of MI. also shown that by optimal choosing of capacitor value can be cancelled high order harmonics of output voltage. The effect of these parameters on the CSI, simulated with PSPICE. The comparisons have been done on our laboratorial system outputs, with simulated results. Then it has been shown that experimental results verify the simulation results.

REFERENCES

Antunes, F.L.M., H.A.C. Braga and I. Barbi, 1999. Application of a generalized current multilevel cell to current-source inverters. IEEE Trans. Ind. Elect., 46: 31-38.

Blaabjerg, F., U. Jaeger and S. Munk-Nielsen, 1995. Power losses in PWM-VSI inverter using NPT or PT-IGBT devices. IEEE Trans. Power Elect., 10: 358-367.

Dong, S. and P.W. Lehn, 2002. Modeling, analysis and control of a current source inverter-based STATCOM. IEEE Trans. Power Delivery, 17: 248-253.

Espinoza, J.R. and G. Joos, 1995. A current-source inverter fed induction motor drive system with reduced losses. Industry Applications Conference (Thirtieth IAS Annual Meeting, IAS '95), Vol. 1. Oct 8-12 IEEE, pp: 45-52.

Han, B., S. Moon, J. Park and G. Karady, 2000. Static synchronous compensator using thyristor PWM current source inverter. IEEE Trans. Power Delivery, 15: 1285-1290.

Han, B.M., S.T. Baek and H.J. Kim, 2001. Static reactive-power compensator using soft-switching current source inverter. Power Electronics Specialists Conference (PESC 2001 IEEE 32nd Annual, Vol. 4. June 17-21, IEEE Institute of Electrical and Electronics, pp: 1883-1888.

Kazerani, M., 2003. A direct AC/AC converter based on current-source converter modules. IEEE Trans. Power Elect., 18: 1168-1175.

Kwak, S. and H. Toliyat, 2006. Current-source-rectifier topologies for sinusoidal supply current: Theoretical studies and analyses. IEEE Trans. Ind. Elect., 53: 984-987.

McGrath, B.P. and D.G. Holmes, 2008. Natural current balancing of multi cell current source converters. IEEE Trans. Power Elect., pp: 1239-1246 10.1109/TPEL.2008.921166

Rashid, M.R., 2001. Handbook of Power Electronics. 1st Edn., Academic, New York, pp: 599-627.

Salo, M. and H. Tuusa, 2005. Vector-controlled PWM current-source-inverter-fed induction motor drive with a new stator current control method. IEEE Trans. Ind. Elect., 52: 523-531.

Wiechmann, E.P., P. Aqueveque, R. Burgos and J. Rodriguez, 2008. On the efficiency of voltage source and current source inverters for high-power drives. IEEE Trans. Ind. Elect., pp: 1771-1782 10.1109/TIE.2008.918625

Yu, X., C. Danjiang, D. Songquan and Z. Zhongchao, 2004. A new single-phase multilevel current-source inverter. Applied Power Electronics Conference and Exposition (APEC 2004 Nineteenth Annual IEEE), Vol. 3. 2004-09-27 IEEE Institute of Electrical and Electronics, pp: 1682-1685.