Simulation and Implementation of Three-phase Three-level Inverter

M. A. EL-Bakry, S. H. Arafah
Electronics Research Institute, Cairo, Egypt
S. E. E. Abo-Shady, A. A. Mahfouz
Cairo University, Giza, Egypt

Abstract: Three-level inverters have superior characteristics relative to traditional two-level inverters. This paper compares the simulation results, using SIMULINK in conjunction MATLAB software, with the experimental results of a three-phase three-level inverter implemented to control a three-phase induction motor.

Keywords: Power Electronics, Electric Machines and Drives, Modeling and Simulation, Inverters, Microcontroller.

1. Introduction

The multi-level inverter is nowadays increasingly applied in the commercial field [1-5]. Especially, the three-level inverter is already used for controlling AC drive systems to reduce harmonic distortion over wide control range [6-8]. Three-level inverter configured with fast switching devices, such as IGBTs, favor the use of high switching modulation techniques, so the harmonic distortion can be reduced further [9,10].

The design steps for a three-level inverter to control an induction motor include:

i- selecting the type of a three-level inverter,
ii- simulating the performance of the selected inverter and adjusting its for properly operating the induction motor,
iii- implementing the inverter with its associated controls, and
iv- comparing the experimental tests with the simulation results and making the appropriate modifications.

The diode clamped three-level inverter is the inverter type selected for implementation, Fig. 1 [6-8]. The paper summarizes the final results of simulating the system after making suitable component adjustments, then compares them with the experimental tests made on the implemented system.

2. Simulating of the Three-Level Inverter

The MATLAB representation of the inverter with its controls is given in Fig.2. The simulation results shown are for

i- the line voltage, V_{uv}, pole voltage, V_{u0}, and load phase voltage, V_{un}, for six-step waveform, conduction angles = 150°, and with PWM waveform Figs 3,4 and 5 respectively,
ii- the spectral analysis of the line voltage Fig.6, and
iii- the response when the inverter feeds an induction motor. Figure 7 shows the motor speed, torque and stator current as the motor operates from [0.5-1.5-1] full load.

3. Implementing of the Three-Level Inverter

The block diagram of the complete implemented system is shown in Fig.8. It includes:

i- three-phase rectifier and DC-link filter,
ii- three-level diode clamped IGBT inverter with its drive circuits, and
iii-two alternatives for generating the switching signals

a) an analog/ digital switching circuit, based on using an EPROM as a look-up table for the sinusoidal and triangular wave needed for generating PWM signals,
b) a purely digital switching circuit, using a microcontroller board (SAB80C167CRI), [11], which is preprogrammed for either open loop or closed loop control.

In addition an analog simulator circuit is built hat would be fed to the motor according to the generated switching signals. This gives a check before applying the switching signals to the inverter.

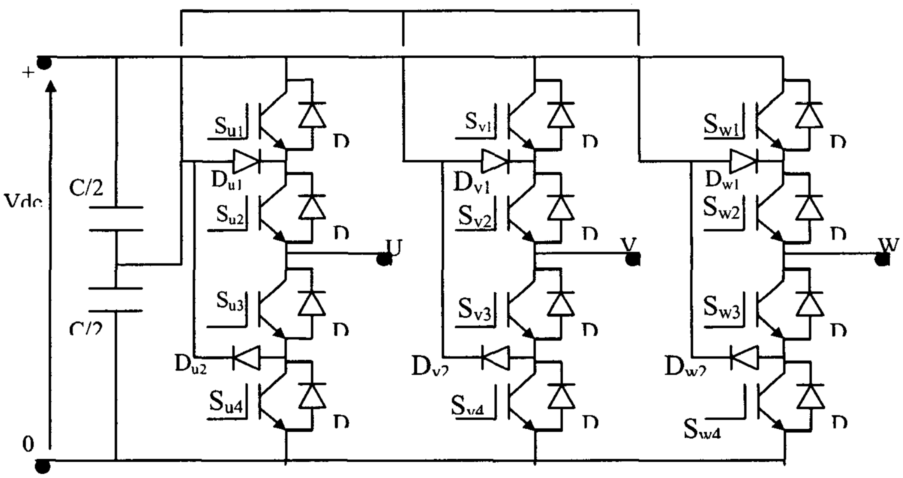


Fig. 1 diode clamped three-level inverter

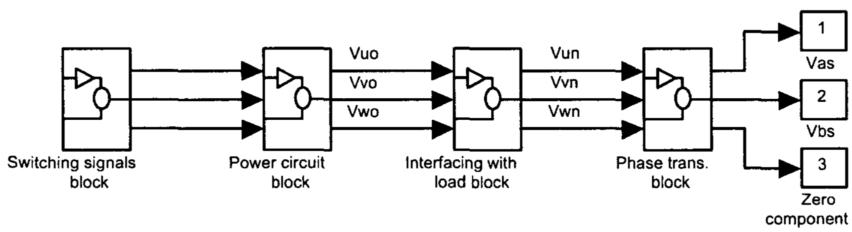


Fig. 2 MATLAB representation of a diode clamped three-level inverter

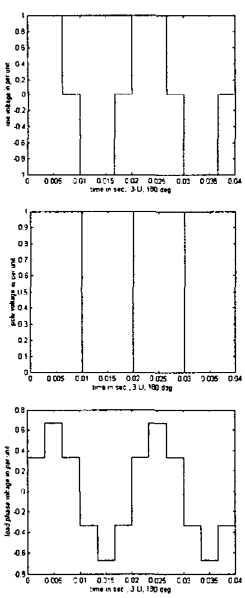


Fig. 3. Six-step three-level inverter

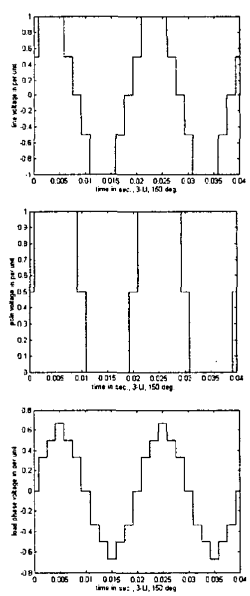
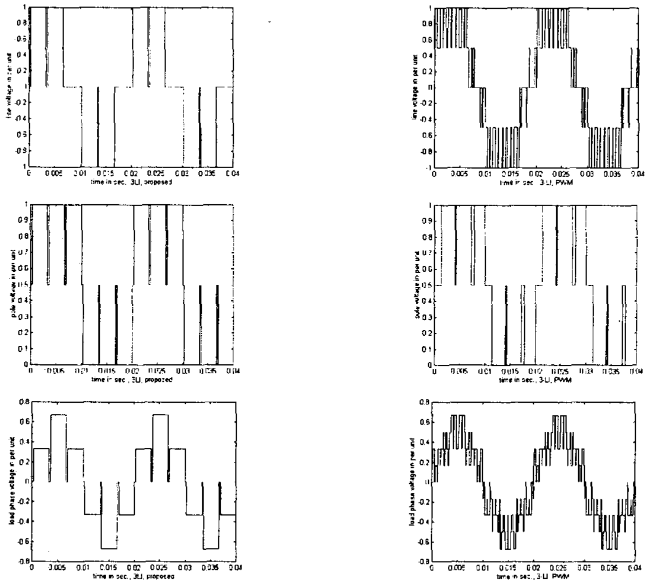
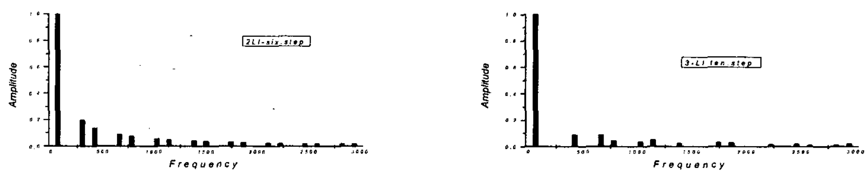


Fig. 4. three-level inverter when the conduction angle=150°



a-regular PWM b- sinusoidal PWM

Fig. 5 Three-level PWM inverter



a- six-step three level inverter b-three level inverter cond. Angle =150 °

Fig. 6 Spectrum analysis of the line to line voltages

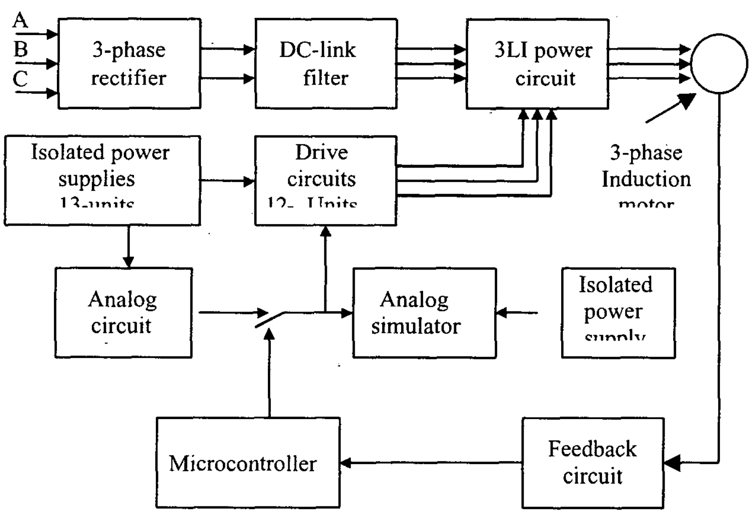


Fig. 8 Block diagram of the complete control system

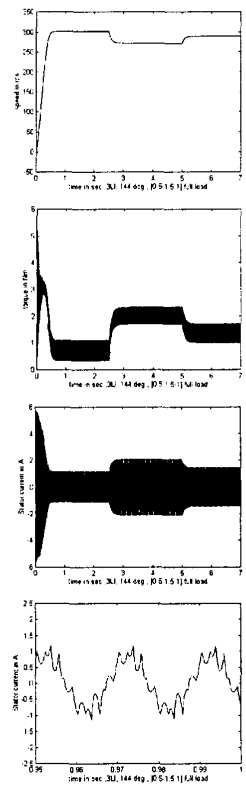


Fig. 7 Simulation results of I.M. with 3-LI (load =(0.5-1.5-1) full load, V_{dc}=513.2V, 150°)

4. Implementation Results and Comparison with Simulation

The simulation results of the output phase voltage of the three-level inverter operated as a six-step inverter, Fig. 3 approximately agree with the experimental results of the designed three-level inverter shown in Fig. 9. Each of them contains six-pulses per cycle.

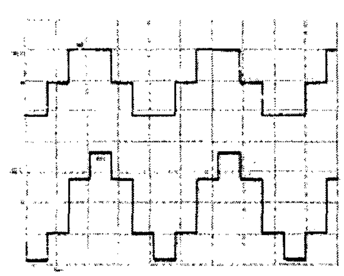


Fig. 9 the output phase and line voltages of the sis-step three level inverter

Also for the simulation results of the phase voltage in Fig. 4 and the corresponding experimental results in Fig. 10, each of them contains twelve-pulses per cycle.The simulation results of the steady state stator current of an induction motor fed from three-level inverter, when the switching angle of the main switches equals 150°, shown in Fig. 7, are different from the experimental results shown in Fig. 11. The difference is small and arises due to the approximation in calculation of the simulation results. As a result, the experimental results approximately agree with the simulation results except for small differences. These differences do not exceed than the allowable error range (5%) and found because the simulation results have approximation in their calculations.

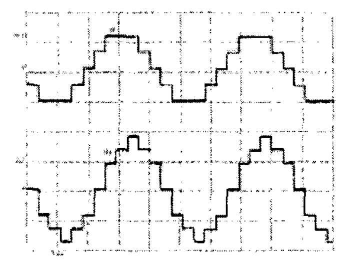


Fig. 10 the output phase and line voltages of the 3-level inverter

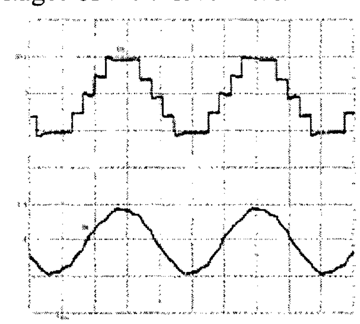


Fig. 11 the steady state stator current of the induction motor

5. Conclusion

The use of three-level inverters reduces the harmonic components of the output voltage compared with the two-level inverter at the same switching frequency.

It needs no additional reactors or transformers to reduce the harmonic components. So it is suitable for high voltage and high power systems. But unbalance between DC link capacitors may occur causing over voltage across the inner switching devices, and this needs careful investigation of their performance. The use of analog simulator of the two-level and three-level inverter shows the correct switching signals before applying them to the basic power circuit of the inverter. The analog switching circuit generates the required switching signals for open loop control systems. The use of SAB80C167

generates the required switching signals for open loop and closed loop control systems according to the software programs down loaded to the board. The designed and implemented diode clamped three-level inverter realized the requirements, did correctly, and fed the induction motor by the required values of voltage and frequency

6. References

1. Jih-Sheng Lai and Fang Zheng Peng, IA, Vol. 32, No. 3, May 1996, pp. 589-517.
2. Sergio Daher and Fernando Antunes, Switching Control Strategy for High Power Society Conference, IECON, Japan, 1996, pp. 1752-1757.
3. Madhav D. Manjrekar and Thomas A. Lipo, on Power Electroncs Drives and Energy Systems for Industrial Growth, PEDES, Australia, 1998, pp. 62-67.
4. Young Seok Kim and Beom-Seok Seo Novel Structure of Multi-Level High Conference on Power Electronics and Applications, EPE, Bringhton, UK, 1993, pp. 132-137.
5. Bum-Seok Suh and Dong-Seok New N-Level High Voltage Inversion Trans. IE, Vol. 44, No. 1, 1997, pp. 107-115.
6. Yoshitaka Iwaji and Toshiaki Okuyama, Factor for Harmonic Evaluation of a Proceedings of International Power Electronics Conference, IPEC, Yokohama, Japan, 1995, pp.476-481.
7. Roberto Rojas and Takayuki Suzuki, Improved Voltage Waveform and Control 42, No.6, December 1995, pp.65-74.
8. Sensorless AC Drive Fed by a 3-Level Inverter with Improved IECON, 1996, pp. 1128-1133.
9. Halasz S. and Hassan Voltage Spectrum and Torque Pulsations of 1994, pp. 1142-1147
10. Bendiabdallah A. and Bellil of a PWM Inverter Fed Induction Motor Using a Proposed Scheme to Improve the Torque Characteristic in the Low Speed Conference on Electrical Machines and Power Electronics, AEGEAN, Turkey, 1995, pp. 321-326.
11. Siemens Aktiengesellschaft, 80C167 Derivatives 1996.