EXECUTION OF AT89S52 MICROCONTROLLER BASED SINGLE-PHASE SIMPLIFIED NINE-LEVEL INVERTER FED INDUCTION MOTOR

Dr.I.WILLIAM CHRISTOPHER
Professor, Department of Electrical and Electronics Engineering, Tagore Engineering College, Chennai, India, +91-944 529 1948, iwchristop@gmail.com

Dr.R.RAMESH
Associate Professor, Department of Electrical and Electronics Engineering, College of Engineering Guindy, Anna University Chennai, India, rramesh@annauniv.edu

Abstract: *This paper presents the hardware design and implementation of a Microcontroller based single-phase simplified nine- level inverter (SNLI) fed induction motor. Multilevel inverters offer high power capability, associated with lower output harmonics and lower turn-off losses. This work informs a multilevel inverter fed induction motor using an H-bridge output stage with bidirectional auxiliary switches. The inverter is capable of producing nine levels of output-voltage levels (V_{dc}, $3V_{dc}$ /4, $2V_{dc}$ /4, V_{dc} /4,0, - V_{dc} /4, - $2V_{dc}$ /4, -$3V_{dc}$ /4, -V_{dc}) from the DC supply voltage. The control circuit necessary for multilevel inverter operation is implemented using an ATMEL AT89S52 Microcontroller, reducing overall system cost and complexity. Theoretical predictions are validated using simulation in MATLAB SIMULINK, and satisfactory circuit operation is proved with experimental tests performed on an experimental model.*

Key words: *Simplified Nine-Level Inverter (SNLI); H-bridge; Microcontroller; Induction Motor (IM).*

1. Introduction

They are extensively used for electric drive for low power constant speed apparatus such as machine tools, domestic apparatus and agricultural machinery in circumstances where a three-phase supply is not readily available. Advancement in the field of power electronics and microelectronics facilitate the application of induction motors for high-performance drives. The induction motor can be controlled by using an inverter output voltage to the motor stator windings.

The output voltage of the inverters may be a square wave, quasi square wave or six stepped wave. Due to non-sinusoidal nature, the inverter output voltage will have fundamental and the associated harmonics. Filters are used to reduce the harmonics, since it produces additional heating when the inverter output voltage is fed to the induction motor. The recent development in power electronics has initiated to develop the level of inverter instead increasing the size of filter. The total harmonic distortion of the conventional two-level inverter is very high. While multilevel inverter provides better performance compare to the conventional two-level inverters. Multilevel inverters have less total harmonic distortion. The author [1] analyzed the total harmonic distortion between conventional two-level inverters and multilevel inverters. A well-known topology of this inverter is full-bridge three-level. Multilevel inverters are promising; they have nearly sinusoidal output-voltage waveforms, output current with better harmonic profile, less stressing of electronic components due to reduced voltages, switching losses that are lower than those of conventional two-level inverters, a smaller filter size, and lower EMI, all of which make them cheaper, lighter, and more condensed [2], [3].

A variety of topologies for multilevel inverters have been proposed over the years. Familiar ones are diode-clamped [4]–[9], flying capacitor or multicell [10]–[16], cascaded H-bridge [17]–[23], and simplified H-bridge multilevel [24]–[27].This paper describes the development of a simplified H-bridge single-phase multilevel inverter that has three diode embedded bidirectional switches. The proposed microcontroller based single-phase SNLI fed induction motor is shown in figure.1.

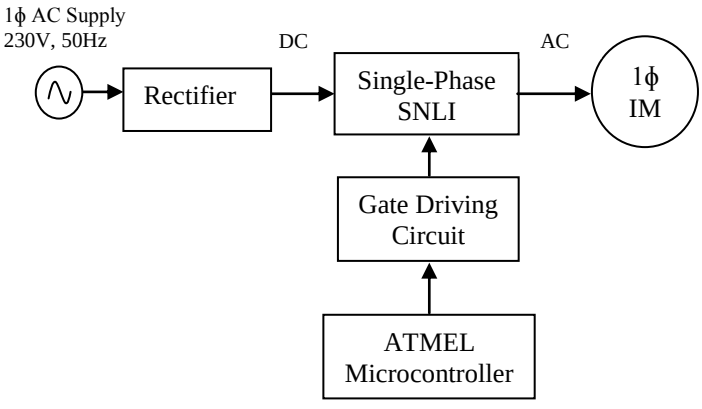

Fig.1. Single-phase SNLI fed IM.

The single phase bridge rectifier converts AC power to DC. The DC power is fed to SNLI. The SNLI converts the DC power to controlled AC power. ATMEL *AT89S52* microcontroller is used to generate the gate pulses. These gate pulses of microcontroller are fed to the switches

of SNLI through the driver circuit to drive the induction motor.The inverter used in the power stage offers a significant enhancement in terms of lower component count and condensed design complexity when compared with the other existing nine-level converters. In the control circuit, the ATMEL *AT89S52* microcontroller can provide all essential switching pulses for power switches, results another significant drop in cost and circuit complexity.

This paper is organized as follows. First, the power circuit advantages and its configuration presented in section II. Then, the power circuit operation includes the modes of operation in detail is discussed in section III. Section IV describes the simulation results and functionality verification of the single–phase SNLI fed IM. The experimental validation is described in section V. Then, section VI presents the experimental results validate the theoretical operation of the simplified nine-level inverter fed induction motor. Last section concludes and the scope for further work is presented.

2. Power Circuit

2.1 Power Circuit Advantages

A single-phase simplified multilevel inverter has the following merits over other existing multilevel inverter topologies.

1) It consists of single-phase conventional H-bridge inverter, bidirectional auxiliary switches (number varies depending upon level) and a capacitor voltage divider formed by capacitors.

2) Improved output waveforms.

3) Smaller filter size.

4) Lower electromagnetic interference (EMI) and total harmonic distortion (THD).

5) Reduced number of switches employed.

6) Less complexity of the circuit as the levels increase.

7) Attains minimum 40% drop in the number of main power switches required.

Moreover, since the capacitors are connected in parallel with the main dc power supply, no significant capacitor voltage swing is produced during normal operation, avoiding a problem that can limit operating range in some other multilevel configurations.

2.2 Power Circuit Description

The proposed single-phase simplified nine-level inverter (SNLI) was developed from the five-level inverter in [24]–[28]. It contains a single-phase traditional H-bridge inverter, three auxiliary switches S5, S6, S7 and a capacitor voltage divider formed by four capacitors namely *C*1, *C*2, C3 and *C*4, as illustrated in figureig. 2. The auxiliary switches, formed by the controlled switch S5, S6 and S7 and with twelve diodes, D_1 to D_{12}. The single-phase simplified nine-level inverter (SNLI) power circuit with auxiliary switches is shown in figure.2. Proper switching of the SNLI can produce nine output-voltage levels V_{dc}, $3V_{dc}$ /4, $2V_{dc}$ /4, V_{dc} /4,0, - V_{dc} /4, - $2V_{dc}$ /4, -$3V_{dc}$ /4, -V_{dc} from the dc supply voltage *Vdc.*

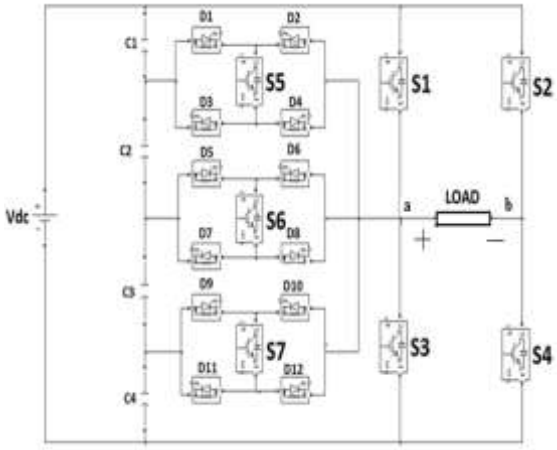

Fig.2. Simplified nine-level inverter (SNLI) power circuit.

The simplified inverter topology is obviously cost-effective compare to other topologies, i.e., it requires less number of power switches, power diodes, and less capacitor for inverters of the same number of levels.

3. Power Circuit Operation

The single-phase SNLI is capable of producing nine different levels of output-voltage levels (V_{dc}, $3V_{dc}$ /4, $2V_{dc}$ /4, V_{dc} /4, 0, - V_{dc} /4, - $2V_{dc}$ /4, -$3V_{dc}$ /4, -V_{dc}) from the dc supply voltage V_{dc}, shown in figure.3.

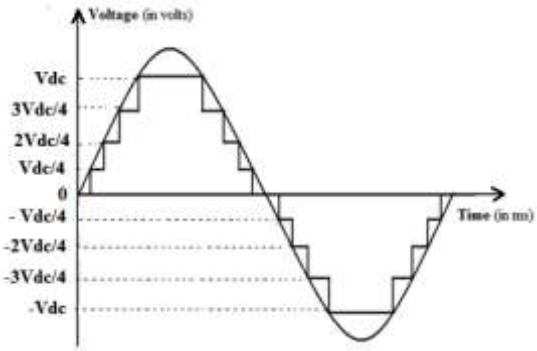

Fig. 3. Single-phase SNLI output voltage waveform

The required nine levels of output voltage were generated as follows and can be easily understand by the table. I.

3.1 Mode I Operation

The switch S1 is ON, connecting the load positive terminal to Vdc, and S4 is ON, connecting the load negative terminal to ground. Remaining switches S2, S3, S5, S6 and S7 are OFF; the voltage across the load terminals ab is Vdc.

3.2 Mode I Operation

The bidirectional switch S5 is ON, connecting the load positive terminal, and S4 is ON, connecting the load negative terminal to ground. Remaining switches S1, S2, S3, S6 and S7 are OFF; the voltage across the load terminals ab is 3Vdc/4.

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3.3 Mode III Operation

The bidirectional switch S6 is ON, connecting the load positive terminal, and S4 is ON, connecting the load negative terminal to ground. Remaining switches S1, S2, S3, S5 and S7 are OFF; the voltage across the load terminals ab is 2Vdc/4.

3.4 Mode IV Operation

The bidirectional switch S7 is ON, connecting the load positive terminal, and S4 is ON, connecting the load negative terminal to ground. Remaining switches S1, S2, S3, S5 and S6 are OFF; the voltage across the load terminals ab is Vdc/4.

3.5 Mode V Operation

This mode of operation has two possible switching combinations. Either switches S3 and S4 are ON, remaining switches S1, S2, S5, S6 and S7 are OFF or S1 and S2 are ON, remaining switches S3, S4, S5, S6 and S7 are OFF. In both switching combinations terminal ab is short circuited, hence the voltage across the load terminals ab is zero.

3.6 Mode VI Operation

The switch S2 is ON, connecting the load negative terminal, and bidirectional switch S5 is ON, connecting the load positive terminal to ground. Remaining switches S1, S3, S4, S6 and S7 are OFF; the voltage across the load terminals ab is –Vdc/4.

Table 1
Switching Combinations required generating the Nine-Level Output Voltage Waveform

Vo	S1	S2	S3	S4	S5	S6	S7
Vdc	1	0	0	1	0	0	0
3Vdc/4	0	0	0	1	1	0	0
2Vdc/4	0	0	0	1	0	1	0
Vdc/4	0	0	0	1	0	0	1
0	1	1	0	0	0	0	0
0*	0	0	1	1	0	0	0
-Vdc/4	0	1	0	0	1	0	0
-2Vdc/4	0	1	0	0	0	1	0
-3Vdc/4	0	1	0	0	0	0	1
-Vdc	0	1	1	0	0	0	0

3.7 Mode VII Operation

The switch S2 is ON, connecting the load negative terminal, and bidirectional switch S6 is ON, connecting the load positive terminal to ground. Remaining switches S1, S3, S4, S5 and S7 are OFF; the voltage across the load terminals ab is −2Vdc/4.

3.8 Mode VIII Operation

The switch S2 is ON, connecting the load negative terminal, and bidirectional switch S7 is ON, connecting the load positive terminal to ground. Remaining switches S1, S3, S4, S5 and S6 are OFF; the voltage across the load terminals ab is −3Vdc/4.

3.9 Mode IX Operation

The switch S2 is ON, connecting the load negative terminal to Vdc, and S3 is ON, connecting the load positive terminal to ground. Remaining switches S1, S4, S5, S6 and S7 are OFF; the voltage across the load terminals ab is –Vdc.

In the nine-level inverter circuit three capacitors in the capacitive voltage divider are connected directly across the dc supply voltage V_{dc}, and since all switching combinations are activated in an output cycle, the dynamic voltage balance between the three capacitors is automatically restored.

4. Simulation Results

The MATLAB Simulink model of the single-phase simplified nine-level inverter (SNLI) fed IM circuit is shown in figure.4.

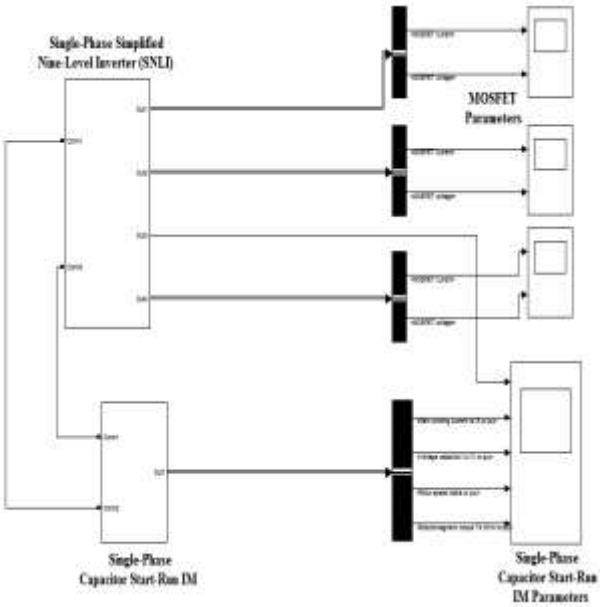

Fig. 4. Single-phase SNLI fed IM simulation circuit

This model, developed using the Simulink power system block set, comprises of components such as power electronic devices (MOSFETs) and elements such as capacitors and resistors.

The PWM signals for each of the switching devices in the power circuit come from the PWM generator block. This block includes all the PWM signals required for switches are multiplexed on a single bus to the nine -level inverter power circuit. The switching sequence required for the simplified nine-level inverter (SNLI) circuit is shown in figure. 5.

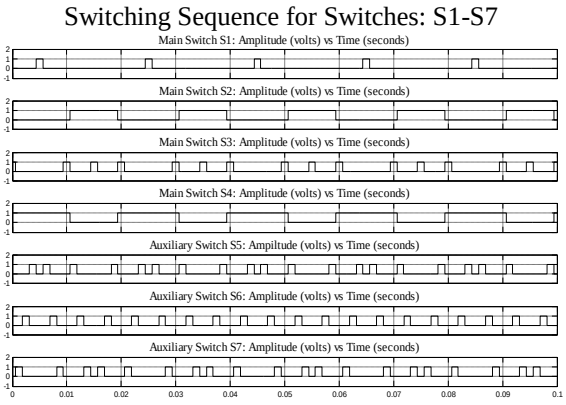

Fig.5. Switching sequence required for SNLI circuit.

Figure 6 shows the simulated nine-level output voltage waveform of the SNLI circuit.

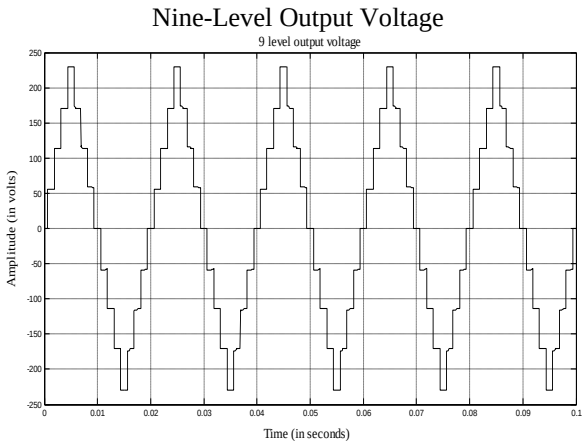

Fig. 6. Simulated output voltage waveform of the simplified nine-level inverter (SNLI) circuit. (V_{dc} bus = 230V; vertical: 50V/d; Horizontal: 10ms/div)

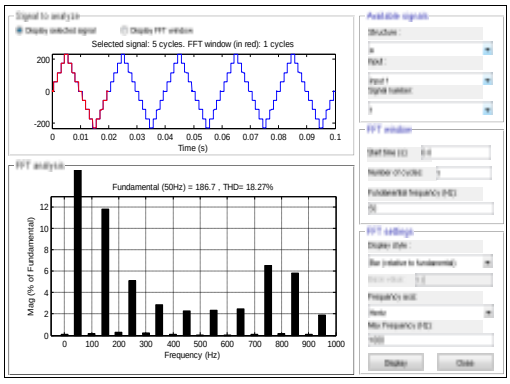

Fig. 7. THD of SNLI.

It is clearly visible that the simulated output waveform is very close to the ideal output defined for a simplified nine-level inverter (SNLI) circuit. The nine-levels of voltages are V_{dc}=230V, $3V_{dc}/4$=172.5V, $2V_{dc}$ /4 = 115V, V_{dc} /4 = 57.5V, 0V, - V_{dc} /4 = -57.5V, $-2V_{dc}$ /4 = -115V, $-3V_{dc}$ /4 = -172.5V, $-V_{dc}$ = -230V for V_{dc} bus voltage of 230V and the resistive load of 10KΩ for the scale of vertical 50V/division and horizontal: 10ms/division. The THD of the single-phase simplified nine-level inverter (SNLI) is 18.27% and fundamental voltage is 186.7V(50Hz) as illustrated in Figure 7. The simulated waveforms for a single-phase SNLI fed capacitor start-run IM parameters are shown in figure 8.

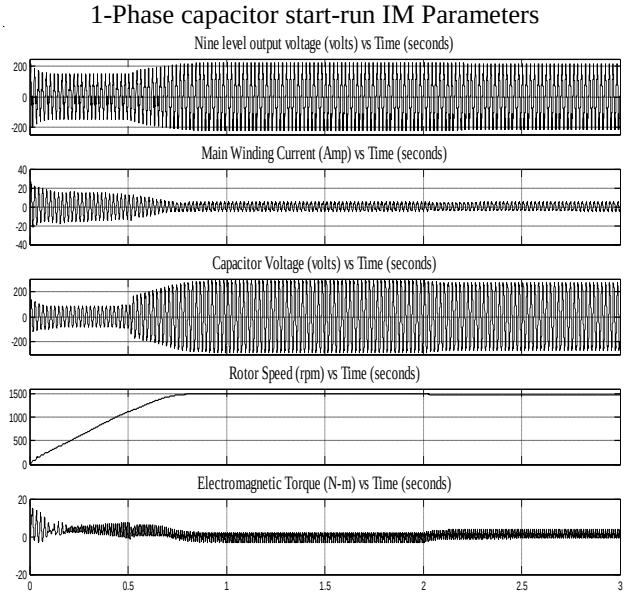

Fig.8. Simulated SNLI fed capacitor start-run IM parameters.

The simulation results shows nine-level output voltage, and 1-phase capacitor start-run IM parameters that includes main winding current, capacitor voltage, rotor speed and electromagnetic torque. The speed of the single-phase IM increases linearly and at steady state it reaches the rated speed of 1500 rpm.

4. Experimental Validation

After the simulation studies, an ATMEL *AT89S52* microcontroller based single-phase simplified nine-level inverter (SNLI) fed IM is fabricated and tested. The experimental validation includes the control circuit, the driver circuit and the power circuit.

4.1 Control Circuit

The control circuit was implemented using an ATMEL *AT89S52* 8-bit microcontroller. Reasons for choosing an ATMEL Microcontroller are as follows:

1) Self-sufficient standalone device (IC)
2) Cost- effective & less power consumption
3) Reliability of the system
4) Software protection
5) Wide availability

The gate pulses are produced by the ATMEL *AT89S52* Microcontroller. These pulses are amplified using the seven driver ICs *6N136*

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4.2 Driver Circuit

The driver circuit describes about the isolation between the power circuit and the control circuit and the power supplied to the IGBTs.The circuit operates with the two transistor logic, the supply given to the driver circuit is 12V with the help of a transformer. The 5V supplied by the ATMEL *AT89S52* microcontroller is sensed by the buffer IC and proceeds to the IGBTs through the isolation IC *6N136* which is otherwise known as optocoupler.

4.3 Power Circuit

A single- phase simplified nine-level inverter (SNLI) power circuit was fabricated using seven IGBT ICs *CT60*. The IGBT has advantages of both MOSFET and BJT, lesser power requirement and absence of secondary breakdown phenomenon.

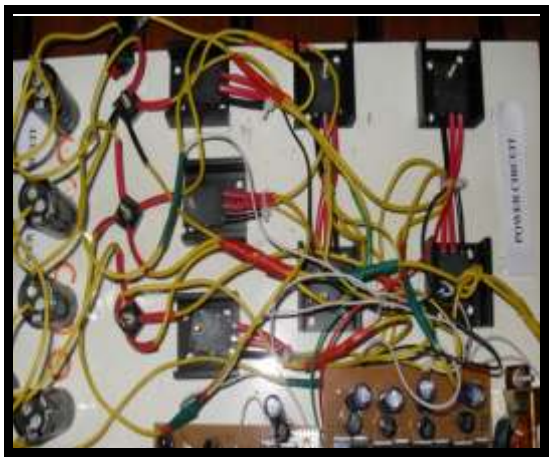

Fig.9. Fabricated single-phase SNLI circuit.

The fabricated single-phase simplified nine-level inverter (SNLI) circuit is illustrated in Figure.9.

5. Experimental results

In the capacitor –start-and –run IM the starting winding and capacitor are permanently connected in the circuit. These motors are also known as permanent-spilt capacitor motors. It has a comparatively low starting torque which is about 50 to 100 percent of the rated torque. The two-value capacitors run IM motor, which start with a high value of capacitance but run with a low value of capacitance. The simulation results are verified experimentally by running a 1-phase capacitor start-run induction motor using SNLI circuit. The motor has the following specification shown in table II.

Table 2
Single-Phase Capacitor Start-Run IM Specifications

S.No	Parameters	Ratings
1.	Power	0.25HP
2.	Voltage	230V
3.	Frequency	50Hz
4.	Speed	1500rpm
5.	Current	2.8A

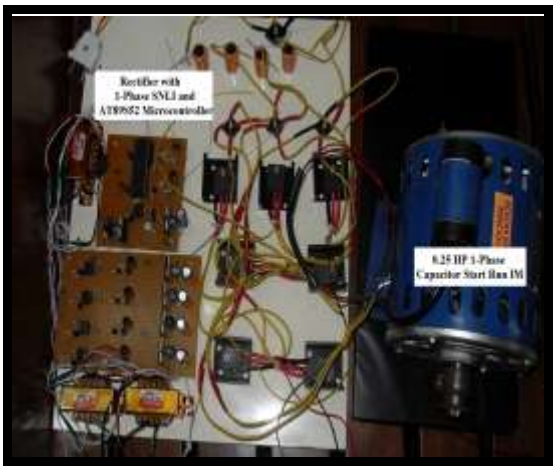

Fig.10. Experimental setup of the 1-phase SNLI fed induction motor.

The whole experimental setup of the single-phase simplified nine- level inverter (SNLI) fed capacitor start run induction motor is shown in figure.10.

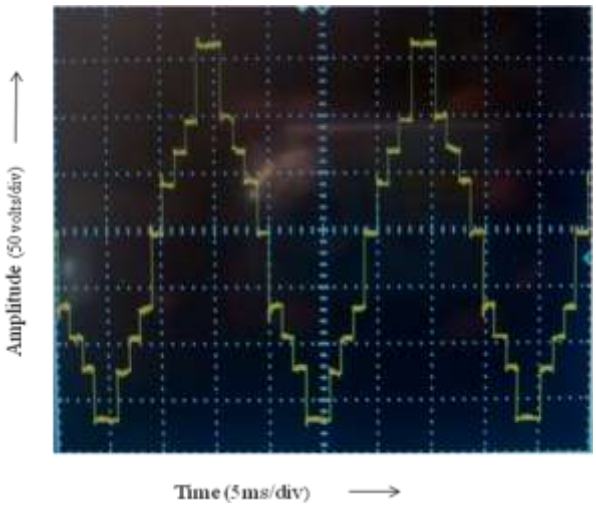

Fig.11. Experimental result of a 1-phase SNLI voltage output.

Figure.11 presents experimental result of a 1-phase SNLI output voltage waveform showing the desired nine voltage levels. The fundamental output frequency is 50Hz. The measured nine different voltage levels are V_{dc} = 168V, $3V_{dc}$ /4 = 126V, $2V_{dc}$ /4 = 84V, V_{dc} /4 = 42V, 0V, - V_{dc} /4 = - 42V, -$2V_{dc}$ /4 = - 84V, -$3V_{dc}$ /4 = -126 V, -V_{dc} = - 168V. The results were taken from the experimental circuit using a two channel, 50 MHz, Digital Storage Oscilloscope (DSO) from GW Instek. The output waveform measured in the experimental setup may be close to the predicted simulation results.

6. Conclusions

The concurrence between the simulated results and the experimental results show clearly that the single-phase SNLI works as expected, generating the required nine-level output voltage for the 1-phase capacitor start-run IM. The 1-phase SNLI can be adapted to any number of voltage levels

for many more applications.

Acknowledgment

The authors wish to thank the Management, Principal and the Department of Electrical and Electronics Engineering of Tagore Engineering College, Chennai for their whole hearted support and providing the laboratory facilities to carry out this work.

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Dr.I.William Christopher received his AMIE degree in Electronics and Communication Engineering from The Institution of Engineers (India), Kolkata in 2001, M.E degree in Power Electronics and Drives from Anna University, Chennai, India in 2005. He received his Ph.D degree in the area of Simulations and Experimental Investigations on Modified H-Bridge Multilevel Inverter from the Department of Electrical and Electronics Engineering, College of Engineering Guindy, Anna University, Chennai, India in 2014. He is currently working as a Professor in the Department of Electrical and Electronics Engineering, Tagore Engineering College, Chennai, India.

His research interests are Power Electronic Converters in Renewable Energy Systems and Embedded control of Electric drives. He has published 27 research papers in reputed Journals, IEEE sponsored International and National Conferences.

He is a Member of Institution of Electronics and Telecommunication Engineers (India), Associate Member of Institution of Engineers (India), Member of Institution of Engineering and Technology (UK) and Member of IAENG, Hong Kong. In 2010, he received the IET YPSC Young Teacher Award from IET (UK) YPS Chennai Network for his contributions to the profession and IET.

Dr.R.Ramesh was received his B.E degree in Electrical and Electronics Engineering from University of Madras, Chennai, India in 1999. He received his M.E degree in Power Systems from Annamalai University, Chidambaram, India in 2002. He received his Ph.D degree in the area of Grid Service Model for Distributed On-Line Load-flow Monitoring from the Department of Electrical and Electronics Engineering, College of Engineering Guindy, Anna University, Chennai, India in 2008. Presently he is working as an Associate Professor in the Department of Electrical and Electronics Engineering, College of Engineering Guindy, Anna University, Chennai, India.

His research areas are Multi-area Power Systems, Solar PV systems, Power Electronic Converters, Web and Embedded based systems. He has published 65 research papers in reputed International Journals and Conferences. He is a Member of Institution of Engineers (India), Member of Indian Society for Technical Education, and Member of IAENG, Hong Kong.

In 2011, he received the IET YPSC Young Teacher Award from IET (UK) YPS Chennai Network for his contributions to the profession and IET. Also he received Young Engineer Award from The Institution of Engineers (India) in 2012.