UNIVERSITI TEKNIKAL MALAYSIA MELAKA

COMPARATIVE EVALUATION OF MODULATION ALGORITHMS FOR THREE-PHASE NEUTRAL POINT CLAMPED (NPC) MULTILEVEL INVERTER

FINAL YEAR PROJECT REPORT

FACULTY OF ELECTRICAL ENGINEERING

NAME : **HO SHUN TEN**

COURSE : **4 BEKP S1**

MATRIC NO. : **B011010008**

YEAR : **2013/2014**

SUPERVISOR : **WAHIDAH BINTI ABDUL HALIM**

"I hereby declare that I have read through this report entitle "Comparative evaluation of modulation algorithms for three-phase neutral point clamped (NPC) multilevel inverter" and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)"

Signature	:	………………………………………
Supervisor's Name	:	………………………………………
Date	:	………………………………………

COMPARATIVE EVALUATION OF MODULATION ALGORITHMS FOR THREE-PHASE NEUTRAL-POINT-CLAMPED (NPC) MULTILEVEL INVERTER

HO SHUN TEN

A report submitted in partial fulfilment of the degree of Electrical Engineer (Industrial Power)

Faculty of Electrical Engineering
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2013/2014

"I declare that this report entitle "Comparative evaluation of modulation algorithms for three-phase neutral point clamped (NPC) multilevel inverter" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ACKNOWLEDGEMENT

First of all, I would like to express my sincere appreciation to Pn. Wahidah Binti Abdul Halim for help and support me. Precious advice from her had greatly enhanced my understanding on the project title.

Furthermore, I would like to Universiti Teknikal Malaysia Melaka for providing friendly atmosphere to finish this project. Next, I would like thank some of the lecturer for being help and support; especially Pn. Maaspaliza Binti Azri and my academic advice, Mr. Azhar Bin Ahmad.

Finally, I would like to thanks for whole family for having strong faith and believe on me; especially to my father and mother.

ABSTRACT

This project gives a comparative evaluation of modulation algorithms for neutral point clamped (NPC), which is a multilevel inverter topology which converted DC sources to AC sources. Neutral point clamped topology is progressively applied in motor drive applications due to their low harmonic output and low switching losses. Nevertheless, higher number levels of NPC multilevel inverter topology and increasing number of semiconductor devices promotes the difficulty to balance capacitors' potential and raise the complexity of switching techniques involved. The important parameters of inverter such as total harmonic distortion (THD) measurements and voltage balancing are controlled by the adopted switching technique. Two switching modulation techniques have been proposed in this study, which are sinusoidal pulse-width modulation (SPWM) and space vector pulse-width modulation (SVPWM), but the selection of switching technique is based on several key properties which are simple, flexible, and produce low harmonic output. Besides that, this project also presents comparisons between two-level conventional inverter, three-level NPC and five-level NPC. The simulation will done using MATLAB/Simulink. Maintaining the THD level as low as possible is very crucial, because it would cost less effort on filtering. The percentages of voltage THD can be lessened by increasing the modulation index. Besides that, the implementation of SPWM is easier but the THD level is higher, than SVPWM.

ABSTRAK

Projek ini adalah perbandingan penilaian algoritma modulasi untuk titik neutral diapit (NPC), ia merupakan topologi penyonsang bertingkat yang menukar sumber arus terus kepada sumber arus ulang-alik. Kebanyakkan aplikasi topologi titik neutral diapit digunakan dalam aplikasi-aplikasi pemacu motor disebabkan oleh harmonik keluaran yang rendah dan kehilangan pensuisan yang rendah. Walau bagaimanapun, pertambahan tingkat bagi topologi titik neutral diapit dan peningkatan jumlah peranti semikonduktor akan menghadapi masalah keseimbangan potensi kapasitor dan meningkatkan kerumitan teknik pensuisan. Parameter penting dalam penyongsang bertingkat adalah jumlah herotan harmonik (THD) dan keseimbangan voltan adalah dikawal oleh teknik pensuisan yang digunakan. Dua teknik modulasi pensuisan telah dicadangkan dalam kajian ini, iaitu modulasi bentuk lebar denyut sinus (SPWM) dan modulasi lebar denyut vektor ruang (SVPWM). Pemilihan teknik pensuisan adalah berdasarkan beberapa ciri-ciri iaitu kesederhanaan, fleksibiliti, dan menghasilkan keluaran harmonik yang rendah. Selain itu, projek ini juga akan menunjukkan perbandingan antara penyongsang dua tingkat konvensional, tiga tingkat NPC dan lima tingkat NPC. Simulasi tersebut akan dilakukan dengan menggunakan MATLAB/Simulink. Mengekalkan tahap THD yang serendah yang mungkin adalah sangat penting, kerana ia akan mengurangkan kos yang melibatan penapis. Peratusan voltan THD boleh dikurangkan dengan meningkatkan indeks pemodulatan. Di samping itu, pelaksanaan SPWM adalah lebih mudah namun mempunyai tahap THD yang lebih tinggi daripada SVPWM.

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NOMENCLATURE

DC	Direct current
AC	Alternative current
MLI	Multilevel inverter
SPWM	Sinusoidal pulse width modulation
SVPWM	Space vector pulse width modulation
NPC	Neutral point clamped multilevel inverter
FC	Flying capacitor multilevel inverter
CHB	Cascaded H-bridge multilevel inverter

CHAPTER 1

INTRODUCTION

1.1 Motivation

The applications of the inverter have become widely used in all aspects during this modern generation, including home appliances, renewable energy field, and industry field. Due to advance of science and technology, emphasizes on green technology had grown rapidly. Hence, more research has been focused on renewable energy. The renewable energy gained from natural environment is needed to transmit back to national grid; inverter plays a very important role to convert the DC renewable source to AC grid source. Currently, engineers have to work harder on the investment of the high efficiency and low harmonic distortion inverters. The design of inverters involved many circuit theory, switching control theory, control processors, and knowledge on power electronics. Advances in power electronics elements with the suitable switching control method will come out desired outputs that guarantee the efficiency and performance of the inverter. It ensures encourages fast growing on good performance technology.

In this study would mainly concentrate on multilevel inverter neutral point clamped (NPC) topology. Operation and performance of every kind of inverter depend on the switching control modulations that been adopted. The switching control modulation that proposed in this study to control the three-phase NPC multilevel inverter are sinusoidal pulse width modulation (SPWM) and space vector pulse-width modulation (SVPWM).

1.2 Problem Statement

Inverters are electronics device that converts the DC source to AC source. Inverters have proven their great benefits on industrial field such as in power grid system to convert renewable source to power grid AC source. Without a doubt, applications of inverter had experienced rapid growth in the past few decades.

However, due to higher harmonic contents and switching losses of conventional inverter, three main multilevel inverter topologies have been widely reviewed, which are neutral point clamped inverter (NPC), cascaded H-bridge inverter and flying capacitor inverter. Neutral point clamped particularly adopted in motor drive application.

The main advantages of the NPC inverter are improving output voltage waveform quality and less output current ripple, which mean less effort required for filtering. The major drawbacks of NPC are increasing number of switches and semiconductor, and thus increase overall costs and control complexity.

The biggest concern of neutral point clamped inverter is the capacitor voltage imbalance problem, which may cause over-voltages of the switches and increase overall harmonic content and switching losses. Suitable control algorithms have to imply to balance the capacitor DC voltage.

1.3 Objectives

The objectives of this project are:

1) To study modulation methods based on multicarrier pulse-width modulation and space vector pulse-width modulation.
2) To solve the neutral point clamped (NPC) voltage imbalance problem.
3) To compare the adopted performances of inverter (in terms of THD) with two-level conventional inverter.

1.4 Scope

- Analysis performance of conventional inverter and neutral point clamped inverter in term of their voltage imbalance problem, and THD by using MATLAB/Simulink.
- Simulation and modelling process by using MATLAB/Simulink with using different switching techniques to obtain inverters output waveforms
- Performance of inverters with different switching techniques will be analyses and compared with varied switching frequency from 1 kHz to 5 kHz and modulation index from 0.5 to 1.0

CHAPTER 2

LITERATURE REVIEWS

2.1 Introduction

Multilevel inverters having an unshakable position in this industrial field and become an inevitable equipment in most of the applications. This chapter would discussed about the general inverter topologies, such as two-level conventional inverter, neutral point clamped (NPC) multilevel inverter, flying capacitor (FC) multilevel inverter, cascaded H-bridge (CHB) multilevel inverter and asymmetric hybrid multilevel inverter. Asymmetric hybrid multilevel inverter having unique characteristics, as it will combine the advantages of each combine topologies. Besides that, this chapter would also discussed relevant control switching modulation for these inverter topologies; sinusoidal pulse-width modulation (SPWM), space vector pulse-width modulation (SVPWM), and selective harmonic elimination (SHE). Different control switching modulation with different topologies would produce different output power quality. Finally, in this chapter extra attention would pay on the latest application of the multilevel inverters technologies, such as application of inverter in renewable energy field, and adjustable speed device.

2.2 Inverters

Nowadays, multilevel inverters are gained intense attention in the electrical field due to its advantages of lower power dissipation in power switches, low harmonic and low electromagnetic interference outputs [3]. Inverters are the devices used to generate AC voltage from constant DC voltage. Multilevel inverter is the circuit can produce more output voltage level compare with the conventional inverter. An additional voltage levels is to smoother the output waveform, thus lower the total harmonic distortions [4]. In other words, multilevel inverters are categories as the output levels that are more than two. There are several famous multilevel inverters topologies that are used in industry, which are neutral point diode clamped multilevel inverter (NPC-MLI), flying capacitor multilevel inverter (FC-MLI), cascaded H-bridge multilevel inverter (CHB-MLI) and asymmetric hybrid multilevel inverter. The first three types are the most common inverter; meanwhile the asymmetric hybrid multilevel inverter is the combination of various types of inverter. The applications of the inverters have enhanced tremendously especially in the field of renewable energy sources and motor drives applications. For example, the original energy that being collected from PV solar cells is in the DC sources form, but the energy feed into national grid must in AC sources form [1].

2.2.1 Two-Level Conventional Inverter

Nowadays, due rapid develop in power electronics field, multilevel inverters which being led to higher-level are available in market. The origin design of these multilevel inverters is based on two-level conventional inverter as shown in Figure 2.1. This topology has two advantages compared to multilevel inverter. The first advantage that is very obvious and can be easily observed in two-level conventional inverter is less switching devices needed, thus easier control the switching modulation. The second advantage is conventional inverter does not facing any DC-link voltage imbalance problem as faced by multilevel inverter [5]. However, this topology has a defeat which is higher harmonic content and makes it less suitable to sensitive devices. Two-level conventional inverter can only generate two output stages, ½ V_{dc} and – ½ V_{dc} as can be seen in Figure 2.2 [6]. With multilevel inverter, the output can be three level, five level or other higher levels. The phase output of three levels is + ½ V_{dc}, 0, - ½ V_{dc}, meanwhile the output of the five levels is + ½ V_{dc}, + ¼ V_{dc}, 0, - ¼ V_{dc}, and – ½ V_{dc} as illustrated in Figure 2.3. The upper switch and lower switch in one leg are work in complementary manner, which is when the lower switch is turned on and the upper switch must in turned off modes. There are no a single moment for both of switches in one leg are turned on or turned off, or else the DC supply would be shorted [7].

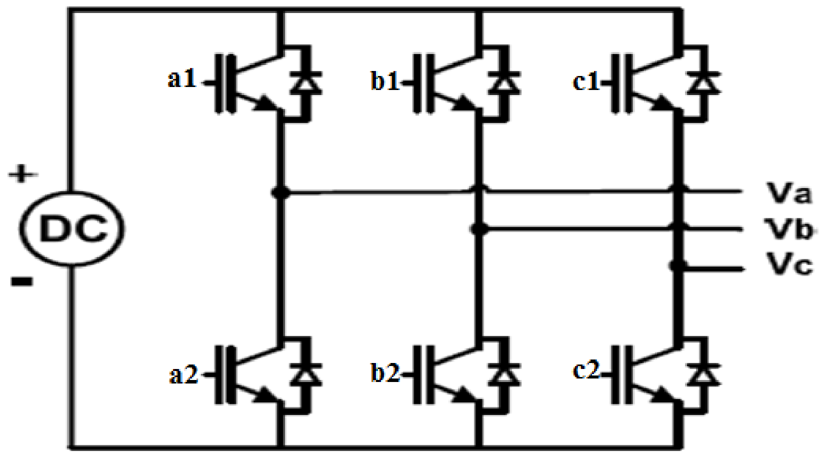


Figure 2.1: Schematic diagram of two-level conventional inverter

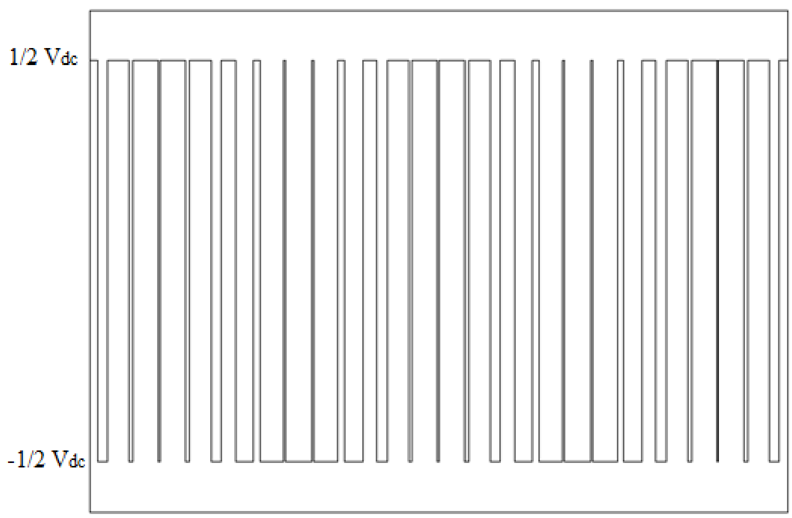
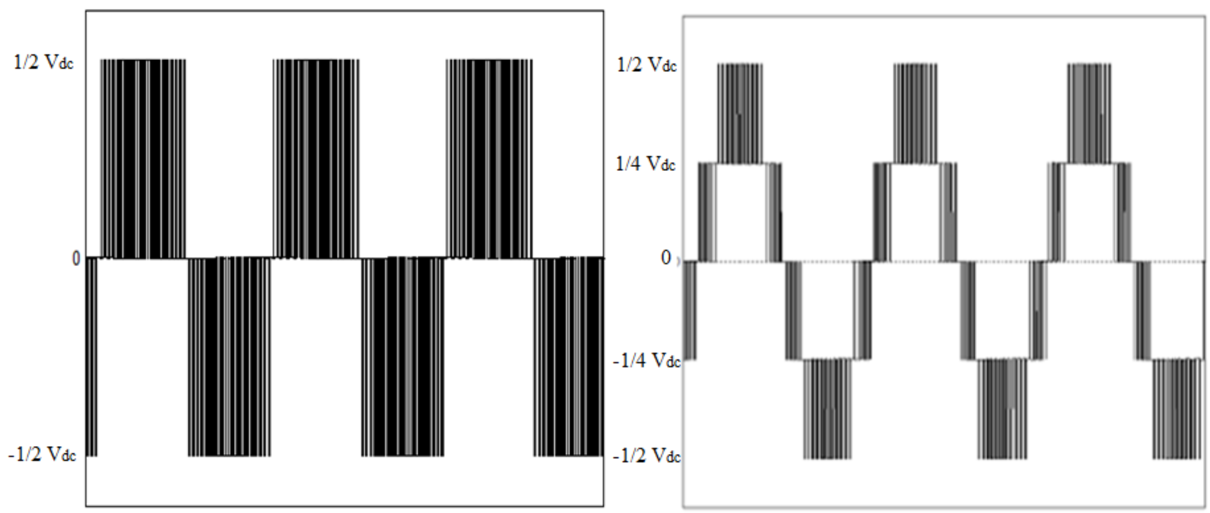


Figure 2.2: Phase voltage of two-level conventional inverter



(a) Three-level (b) Five-level

Figure 2.3: Phase voltage output waveform of multilevel inverter

2.2.2 Neutral Point Clamped Multilevel Inverter

Neutral point clamped (NPC-MLI) multilevel inverter was introduced by A. Nabae, I. Takahashi and H. Akagi in 1980 [3]. Multilevel inverters have become common and popular in medium voltage high-power applications. The NPC-MLI utilized several DC capacitors and clamping diodes to produce AC waveforms with multiple levels. Major advantages of NPC-MLI compared to two-level conventional inverter are improving power quality in terms of THD, and reduce the switching losses [9]. However, NPC-MLI still received a lot of attention from researcher due to the dc-link voltage imbalance problem. The DC input sources must divide equally between the series DC capacitors; the imbalance voltage between series DC capacitors would increase distortion of output waveforms. Figure 2.4 shows the three-level NPC inverter. Three-level NPC inverter consists of two series dc-link capacitors, four IGBTs connected in series and two clamping diodes in one phase [31].

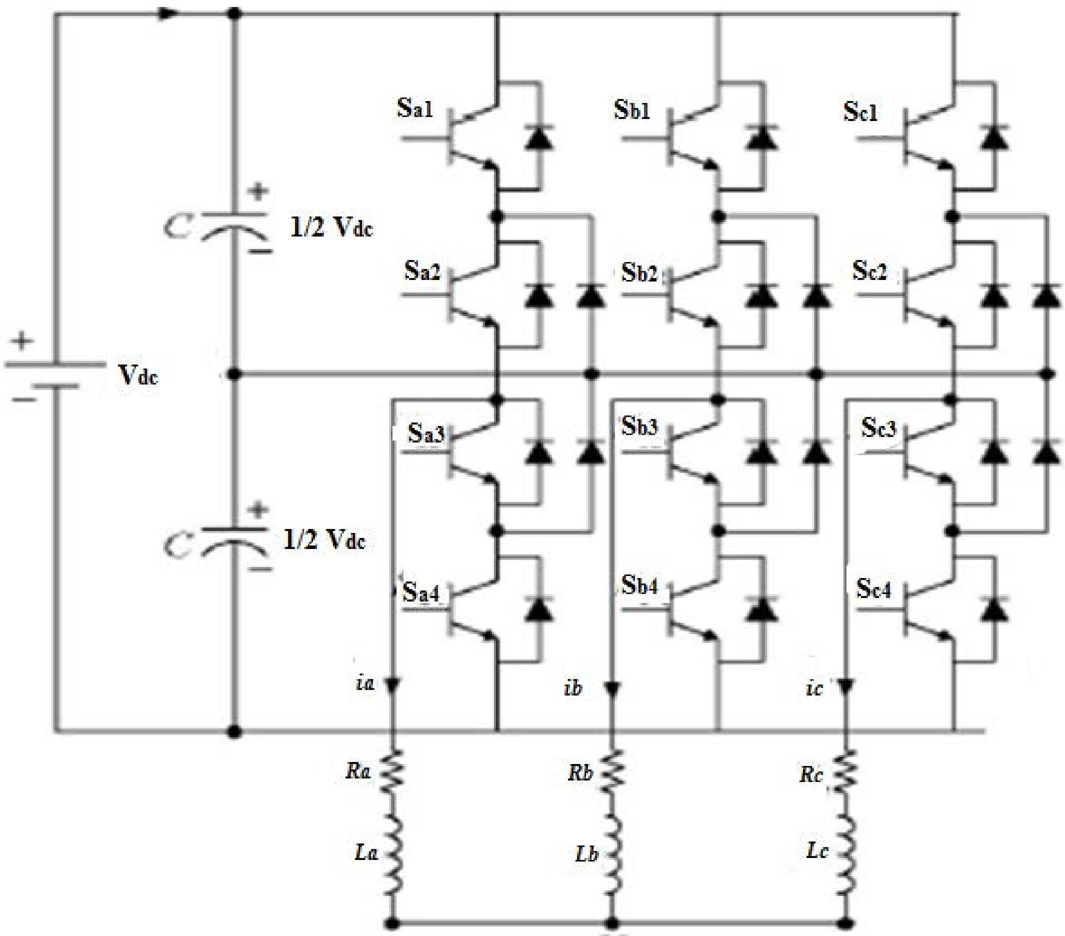


Figure 2.4: Schematic diagram of three-level NPC-MLI

The number of capacitors, N_c used depends on the number of output voltage levels of the inverters as given in Equation (2.1), where n is number of voltage level. The voltage across each capacitor, V_c must be balanced according to Equation (2.2).

$$\text{Number of capacitor in NPC, } N_c = (n - 1) \tag{2.1}$$

$$V_c = \frac{V_{dc}}{N} \tag{2.2}$$

As illustrated in Table 2.1, three possible switching states, P, O, N can occurs in each phase. When the upper two IGBTs, S_1 and S_2 are switched ON, the switching state is P. Then, when the middle two IGBTs, S_2 and S_3 are switched ON, the switching state is O. Later, when the lower two IGBTs, S_3 and S_4 are switched on, the switching state is N. Switches S_1 and S_3 are work in complementary manner. With one switched ON, the other switched must be switched OFF. Same operations work on switches S_2 and S_4 [32].