THREE PHASE INVERTER DEVELOPMENT USING COMMON MODE VOLTAGE PULSE WIDTH MODULATION (PWM) METHOD

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For my beloved father, mother, husband and son

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ABSTRACT

This master report presents a simulation voltage source control system for three phase inverter focusing on reducing the common mode voltage using diode clamped circuit. The model was implemented using MATLAB-Simulink with the SimPowerSystems Block set and also M-file. The twelve Insulated Gate Bipolar Transistor (IGBTs) was use as a switching device. In the three phase inverter circuit, an Alternating Current (AC) output is synthesized from a Direct Current (DC) input by closing and opening the switches in correct sequence or switching system. The Pulse Width Modulation (PWM) is a program in M-file to control the ON/OFF switching scheme of the IGBTs. An output voltage of an inverter with diode clamped before load and after load will be monitored, discussed and compared to the basic three phase inverter. This inverter circuit operate in open loop system where the inverter output and the load in series connection. The effectiveness of the method will be compared with the basic three phase inverter simulation model in MATLAB-Simulink program.

ABSTRAK

Laporan ini mengenai simulasi sistem kawalan voltan bekalan untuk penyongsang tiga fasa menumpu kepada mengurangkan mod voltan biasa menggunakan model litar diod diapit.Litar ini telah dilaksanakan menggunakan MATLAB-Simulink dengan *SimPowerSystems* blok dan juga M-fail. Dua belas *Insulated Gate Bipolar Transistor* (IGBTs) adalah digunakan sebagai suiz. Dalam litar penyongsang tiga fasa, keluaran arus ulang-alik (AU) diroses dari masukan arus terus (AT) dengan menutup dan membuka suis dalam susunan yang betul atau sistem pensuisan. *Pulse Width Modulation* (PWM) merupakan satu program M-fail untuk mengawal ON / OFF suis bagi IGBTs. Voltan keluaran penyongsang dengan model litar diod diapit sebelum beban dan juga selepas beban akan dipantau, dibincangkan dan dibandingkan dengan asas litar penyongsang tiga fasa. Litar penyongsang ini beroperasi dalam sistem gelung terbuka di mana keluaran penyongsang dan beban berhubung secara siri. Keberkesanan kaedah akan dibandingkan dengan asas penyongsang tiga fasa di dalam model simulasi program-MATLAB Simulink.

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LIST OF SYMBOLS AND ABBREVIATIONS

PWM	-	Pulse Width Modulation
VSI	-	Voltage Source Inverter
DC	-	Direct Current
AC	-	Alternating Current
SPWM	-	Sinusoidal Pulse Width Modulation
EMI	-	Electromagnetic Interference
CM	-	Common Mode
IGBTs	-	Insulated Gate Bipolar Transistors
NPC	-	Neutral Point Clamped
CSIs	-	Current Source Inverters
CPWM	-	Continuous Pulse Width Modulation
SVPWM	-	Space Vector Pulse Width Modulation
ASDs	-	Adjustable Speed Drives
FACTS	-	Flexible Alternating Current Transmission Systems
HVDC	-	High Voltage Direct Current
CMV	-	Common Mode Voltage
CMC	-	Common Mode Current
NPP	-	Neutral point Potential
MOSFET	-	Metal Oxide Field Effect Transistor
GUI	-	Graphical User Interface
R	-	Resistance
L	-	Inductance
C	-	Capacitance
VDC		Direct Current Voltage

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Today, the most of readymade inverter in the market are confidential and cover-up regardless single or three phase. This is to ensure that the product will not be duplicated or reproduced by the others and also to avoid the competition and rivalry. Generally inverter is used in application such as induction motor, automobile, air conditioner and etc.

In this era, an advance study in solid-state power electronic devices and microprocessors can cause various Pulse Width Modulation (PWM) techniques developed for industrial applications such as PWM-based three-phase voltage source inverters (VSI) convert DC power to AC power with variable voltage magnitude and variable frequency.The most widely used PWM schemes for three-phase voltage source inverters is sinusoidal PWM (SPWM).

Nowadays, many studies have been done focusing on renewable energy as alternative to generate the electricity. Examples of renewable energy from natural sources are such as sunlight, rain and waves. In Malaysia, government is working to accelerate the development of renewable energy, especially biomass.

So far, the majority of electricity in Malaysia is due to hydro power and generator power and it was the conventional power system. In addition, the inverter can be use to support hydro-power and generator power and it is quite recommendable.

By using the inverter, fuel consumption cost reduced and service for generator also be reduced, so that there is no contamination of the environment will occur.

In this era of technological advancement and communication produced many highly sophisticated equipment which uses digital control technology as well. To meet the needs of this growing, then society must create the smart way in using technology to distribute electric energy efficient, more economical and safer to use. This project will help because the system use has the advantage of not needing additional hardware circuit so the design will be simpler, easy to implement and more efficiency. In this project, MATLAB/Simulink is used as a platform in designing the inverter. MATLAB/Simulink simulation model is built to study the effect of the common mode voltage for inverter circuit.

1.2 Problem statement

Recently research has identified damage to electric machines caused by bearing currents. These currents are created by the common mode voltage applied to the machine by the inverter. In typical three-phase power inverter drives, there exists substantial common mode voltage between the load neutral and earth ground. As modulation frequencies increase and machine zero-sequence impedances decrease, the common mode voltage causes larger common-mode currents, worsening electromagnetic interference (EMI) problems and potentially damaging the network or the machine.

This project presents a power converter (inverter) which realizes sinusoidal balanced three-phase-output voltage with respect to earth ground with essentially low common-mode voltage. A complete model of a PWM inverter is presented and used to simulate.

1.3 Project Objective

The objectives of the project are:

i. To develop three-phase inverter using diode clamped circuit with common mode voltage PWM method.

ii. To compare the analysis for three phase inverter with the three phase inverter diode clamped.

1.4 Project Scope

The scope of the project is to simulate the proposed method of three-phase inverter by using common mode voltage with MATLAB Simulink software. To reduce the common mode voltage diode clamped circuit will be added to three phase inverter circuit.

1.5 Thesis Overview

Chapter 1 describes about the motivation, project background, problem statement, project objectives, project scope and thesis overview. Chapter 2 covers the literature review with the detailed explanation and classification of voltage source inverter (VSI), pulse width modulation (PWM) and common mode (CM) in PWM, Insulated Gate Bipolar Transistors (IGBTs) and MATLAB/ Simulink.

Chapter 3 gives a detail study of methodology to build a three phase inverter consist of introduction, project block diagram and project parameters. Chapter 4 shows result and analysis for the phase inverter circuit.

Chapter 5 discusses the conclusion of advantages of the method had been implemented into the project. This chapter also gives the recommendation about the future development of the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Most modern power inverters produce either modified square (or modified sine) waves, or pure sine (or true sine) waves. Modified square wave inverters don't provide the smooth peaks and valleys that AC power from a home's electrical outlet does, but it can deliver power that is consistent and efficient enough to run most devices. This type of inverter is relatively inexpensive, and probably the most popular type.

Pure sine wave inverters are the most expensive, but they also deliver the smoothest and most even wave output. Any device will run on a pure sine wave, but some sensitive equipment, like certain medical equipment and variable speed or rechargeable tools, requires this type of inverter to operate correctly. Radios, for example, work better with pure sine wave inverters because the modified square wave inverter's less smooth waves disrupt the radio's reception, causing static and other noise.

Today, the multilevel inverters are considered as the most suitable power converters for high voltage capability and high power quality demanding applications with the voltage operation above classic semiconductor limits, lower common-mode voltages and near-sinusoidal outputs.

The multilevel converter has found widespread applications in industry. They can be used for pipeline pumps in the petrochemical industry, as fans in the cement industry, pumps in water pumping stations, traction applications in transportation industry, steel rolling mills in the metals industry, grid integration of renewable energy sources, for reactive power compensation and other applications.

Multilevel inverter systems are generally classified as diode-clamping inverters, cascade inverters, and flying-capacitor inverters. Among multilevel inverters, the three-level diode clamped inverter, which is called the neutral point clamped (NPC) inverter is commonly used in the design. (R. Chibani et. al., 2011)

2.2 Inverter

The dc-ac converter, also known as the inverter, converts dc power to ac power at desired output voltage and frequency. The dc power input to the inverter is obtained from an existing power supply network or from a rotating alternator through a rectifier or a battery, fuel cell, photovoltaic array or magneto hydrodynamic generator. The filter capacitor across the input terminals of the inverter provides a constant dc link voltage.

The inverter therefore is an adjustable-frequency voltage source. The configuration of ac to dc converter and dc to ac inverter is called a dc-link converter. Inverters is, referring to the type of the supply source and topology relationship of the power circuit, can be classified as voltage source inverters (VSIs) and current source inverters (CSIs). In this project only the voltage source inverter will be discuss.

Furthermore, the power inverter can produce different types of output wave form such as square wave, modified sine wave, and pure sine wave signal. These signal outputs represent different qualities of power output. Square wave inverters result in uneven power delivery that is not efficient for running most devices. Square wave inverters were the first types of inverters made and are obsolete.

Modified sine wave inverters deliver power that is consistent and efficient enough to run most devices fine. Some sensitive equipment requires a sine wave signal, like certain medical equipment and variable speed or rechargeable tools. Modified sine wave signal or quasi-sine wave inverters were the second generation of power inverter. These popular types of inverters represent a compromise between the low harmonics (a measure of waveform quality) of a true sine wave inverter and the higher cost and lower efficiency of a true sine wave inverter.

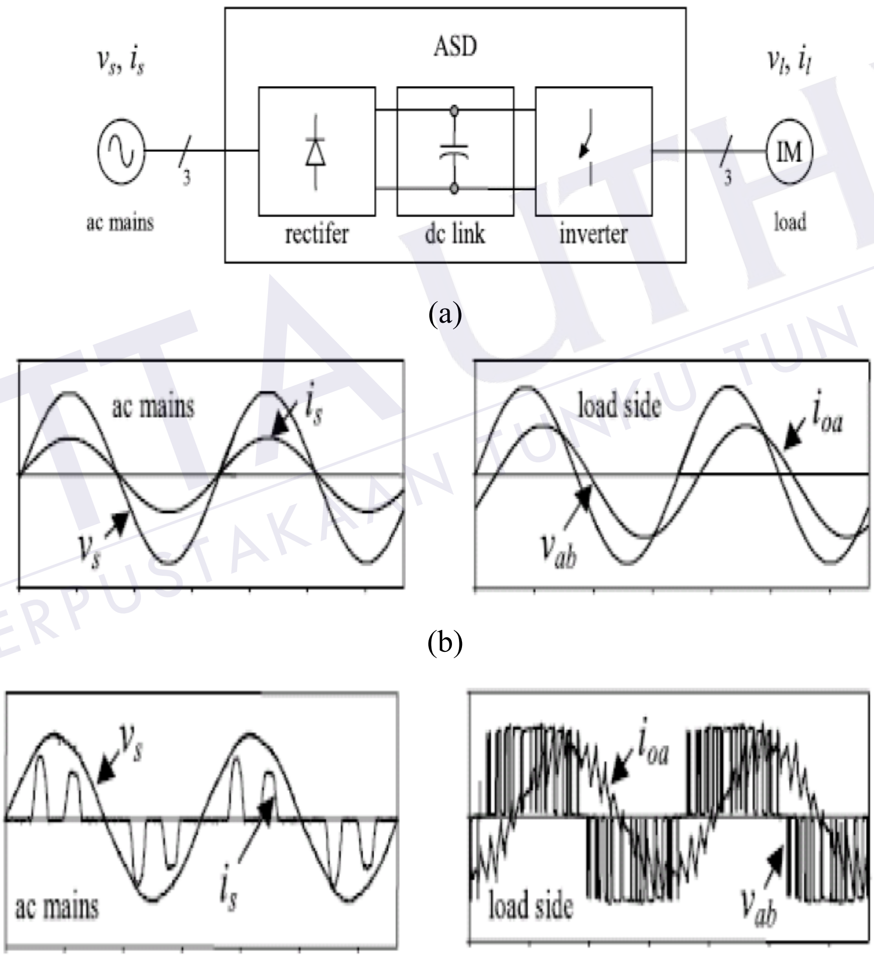
Modified sine wave inverters approximate a sine wave and have low enough harmonics that they do not cause problems with household equipment. They run stereos, induction motors (including capacitor start), universal motors, computers, microwave, TVs and more quite well. The main disadvantage of a modified sine wave inverter is that the peak voltage varies with the battery voltage. Inexpensive electronic devices with no regulation of their power supply may behave erratically when the direct current voltage fluctuates.

True sine wave inverters represent the latest inverter technology. The waveform produced by these inverters is the same as or better than the power delivered by the utility. Harmonics are virtually eliminated and all appliances operate properly with this type of inverter. They are, however, significantly more expensive than their modified sine wave. (Alias I, 2007)

2.2.1 Three Phase Voltage Source Inverters (VSIs)

Voltage Source Inverters (VSIs) especially three phase, are widely utilized to drive AC motors with high motion control quality and energy efficiency, to provide clean current waveform and regenerative operation in AC-DC power converter applications, and to supply high quality AC power in uninterruptible power supply systems as AC-DC-AC power converter units.

Pulse Width Modulation (PWM) is the standard approach to operate the inverter switches in order to generate the required high quality output voltages. However, there is a large variety of PWM methods that exhibit unique performance characteristics and the choice and utilization of a specific PWM method among many is not a simple task. The tremendous amount of the literature published on PWM mostly involves the standard Continuous PWM (CPWM) methods such as the Sine PWM (SPWM) and Space Vector PWM (SVPWM).



(c)

Figure 2.1: The ac output voltage produced by the VSI: (a) the electrical power conversion topology; (b) the ideal input (ac mains) and output (load) waveforms; and (c) The actual input (ac mains) and output (load) waveforms.

The ac output voltage produced by the VSI of a standard Adjustable Speed Drives (ASDs) can be seen in Figure 2.1. Although this waveform is not sinusoidal as expected (Figure 1(b), its fundamental component behaves as such. This behaviour should be ensured by a modulating technique that controls the amount of time and the sequence used to switch the power valves on and off.

Single-phase VSIs cover low-range power applications and three-phase VSIs cover the medium- to high-power applications. The main purpose of these topologies is to provide a three-phase voltage source, where the amplitude, phase, and frequency of the voltages should always be controllable. Although most of the applications require sinusoidal voltage waveforms (e.g., ASDs, uninterruptible power supplies and flexible ac transmission systems), arbitrary voltages are also required in some emerging applications (e.g., active filters, voltage compensators).

The standard three-phase VSI topology is shown in Figure 2.2 and the eight valid switch states are given in Table 1. As in single-phase VSIs, the switches of any leg of the inverter (S1 and S4, S3 and S6, or S5 and S2) cannot be switched on simultaneously because this would result in a short circuit across the dc link voltage supply. Similarly, in order to avoid undefined states in the VSI, and thus undefined ac output line voltages, the switches of any leg of the inverter cannot be switched off simultaneously as this will result in voltages that will depend upon the respective line current polarity.

Of the eight valid states, two of them (7 and 8 in Table 2.1) produce zero ac line voltages. In this case, the ac line currents freewheel through either the upper or lower components. The remaining states (1 to 6 in Table 2.1) produce non-zero ac output voltages. In order to generate a given voltage waveform, the inverter moves from one state to another. Thus the resulting ac output line voltages consist of discrete values of voltages that are Vi, 0, and -Vi for the topology shown in Figure 2.2. The selection of the states in order to generate the given waveform is done by the modulating technique that should ensure the use of only the valid states. (Panda S. et. al., 2009)

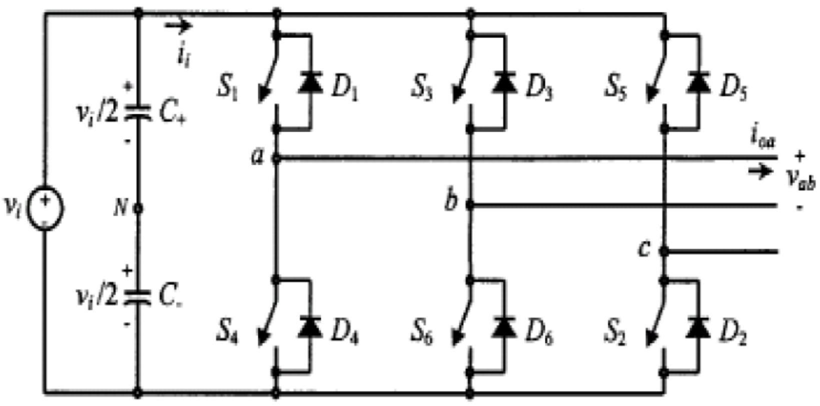


Figure 2.2: Three-phase VSI topology.

Table 2.1: Valid switch states for a three-phase VSI

State		State	Vab	Vb	Va	Space Vector
1, 2 & 6 are ON	4, 5 and 3 are OFF	1	V	0	-V	$V_1 = 1 + j0.5$
2, 3 & 1 are ON	5, 6 and 4 are OFF	2	0	V	-V	$V_2 = j1.155$
3, 4 & 2 are ON	6, 1 and 5 are OFF	3	-V	V	0	$V_3 = -1 + j0.5$
4, 5 & 3 are ON	1, 2 and 6 are OFF	4	-V	0	V	$V_4 = - 1 - j0.5$
5, 6 & 4 are ON	2, 3 and 1 are OFF	5	0	-V	V	$V_5 = - j1.155$
6, 1 & 5 are ON	3, 4 and 2 are OFF	6	V	-V	0	$V_6 = 1 - j0.5$
1, 3 & 5 are ON	4, 6 and 2 are OFF	7	0	0	0	$V_7 = 0$
4, 6 & 2 are ON	1, 3 and 5 are OFF	8	0	0	0	$V_8 = 0$

2.3 Pulse Width Modulation (PWM)

With advances in solid-state power electronic devices and microprocessors, various inverter control techniques employing pulse-width-modulation (PWM) techniques are becoming increasingly popular in AC motor drive applications. These PWM-based drives are used to control both the frequency and the magnitude of the voltages applied to motors.

Many PWM strategies, control schemes, and realization techniques have been developed nowadays. PWM strategy plays an important role in the minimization of harmonics and switching losses in converters, especially in three-phase applications. The first modulation techniques were developed in the mid-1960s by Kirnnich, Heinrick, and Bowes. The research in PWM schemes has intensified in the last few decades. The main aim of any modulation technique is to obtain a variable output with a maximum fundamental component and minimum harmonics. (K.V. Kumar et. al., 2010)

2.3.1 Basic Operation of Single Phase PWM

Figure 2.3 shows circuit model of a single-phase inverter with a center-taped grounded DC bus. Figure 2.4 illustrates principle of pulse width modulation. (Jin-Woo. J, 2005). As depicted in Figure 2.4 the inverter output voltage is determined in the following:

- When Vcontrol > Vtri, VA0 = Vdc/2
- When Vcontrol < Vtri, VA0 = −Vdc/2

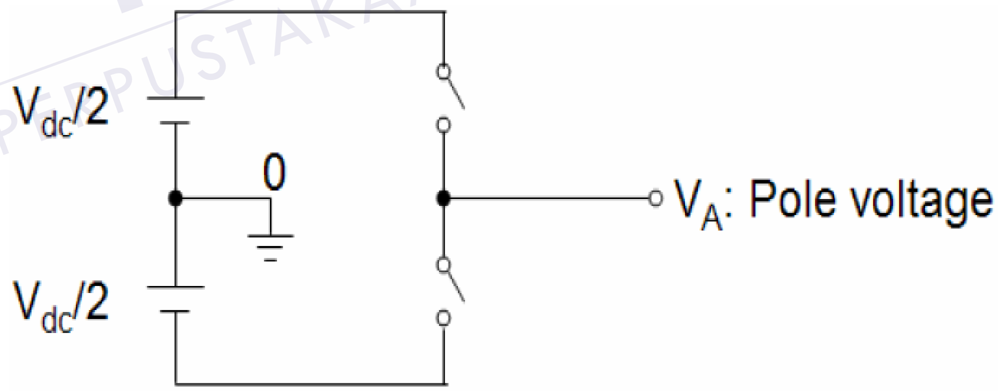


Figure 2.3: Circuit model of a single-phase inverter

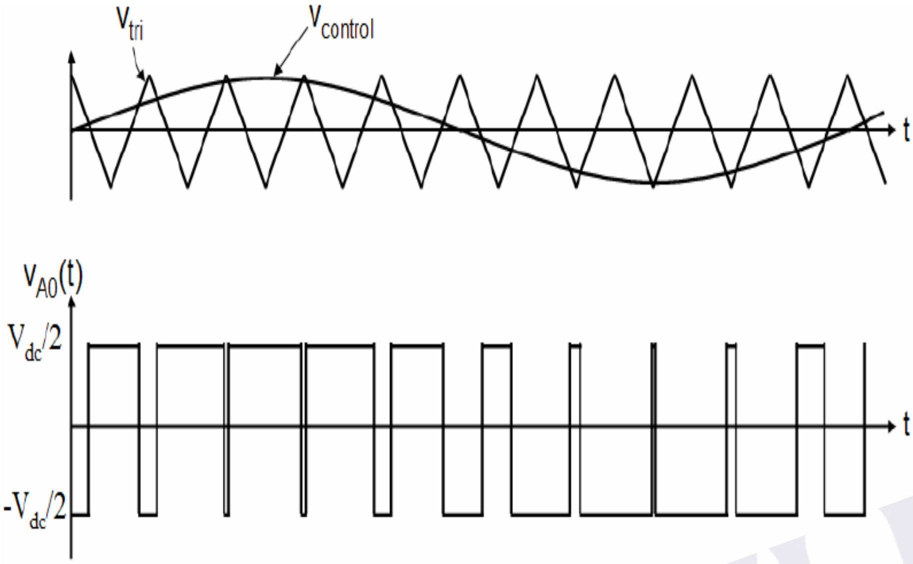


Figure 2.4: Pulse width modulation signal (PWM)

Also, the inverter output voltage has the following features:

- PWM frequency is the same as the frequency of Vtri
- Amplitude is controlled by the peak value of Vcontrol
- Fundamental frequency is controlled by the frequency of Vcontrol

Modulation index (m) is defined as:

$$\therefore m = \frac{v_{control}}{v_{tri}} = \frac{peak \quad of \quad (V_{A0})_1}{V_{dc} / 2},$$

where, (VAO)1 : fundamental frequecny component of VAO

2.3.2 Basic Operation of Three Phases PWM

Figure 2.5 shows circuit model of three-phase PWM inverter and Figure 2.6 shows waveforms of carrier wave signal (Vtri) and control signal (Vcontrol), inverter output line to neutral voltage (VA0,VB0, VC0), inverter output line to line voltages (VAB, VBC, VCA), respectively. (Jin-Woo. J, 2005)

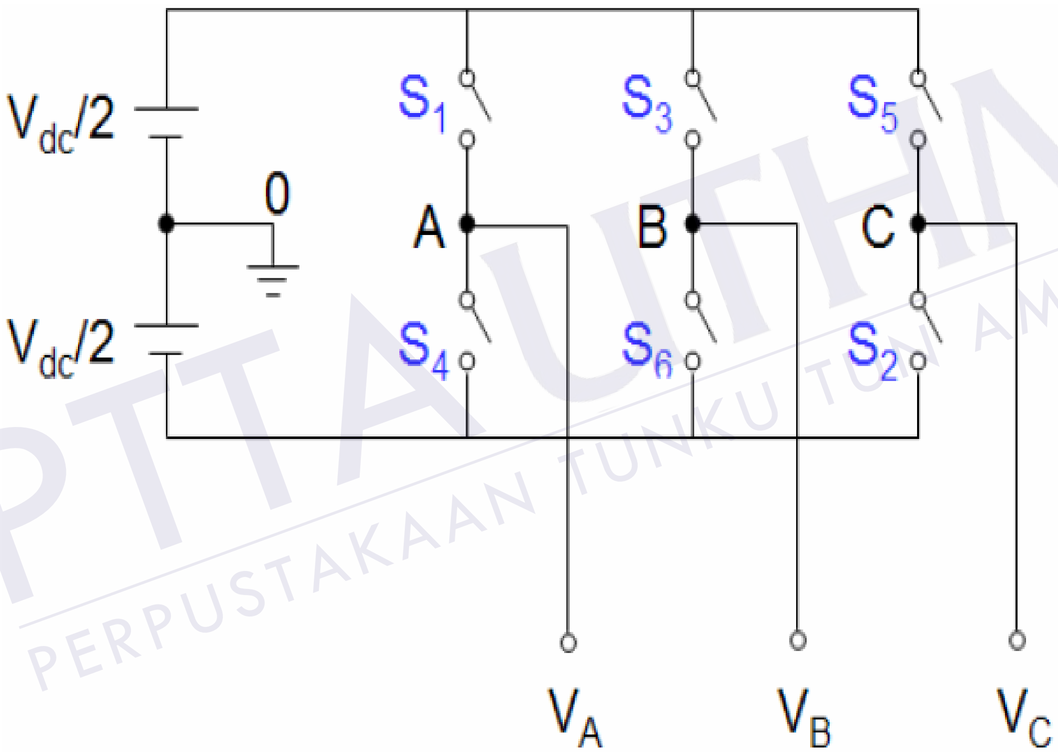


Figure 2.5: Three-phase PWM inverter

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