THREE PHASE INVERTER FOR INDUCTION MOTOR BY USING PI-REPETITIVE CONTROLLER WITH ARDUINO

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ALLAH S.W.T, PROPHET MUHAMMAD S.A.W

For my beloved mothers and late father..

My dearest wife..

Norhayati.*Abd Kadir*

My beloved sons ..

Muhammad A'li Imran and Muhammad Arif Faruqi.

My beloved daughters..

Nurul Aimi Ifhami, Nur Anis Sofiyyah and Nurul Ain Nuha.

&

My friends for their support and encouragement.

Special gratitude to my supervisor..

Dr. Shamsul Aizam Bin Zulkifli

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ABSTRACT

The proportional integral (PI) repetitive controller that is applied to the three phase inverter for the three phase induction motor is developed. This project is about to design a combination of PI-Repetitive controller simulation and fabricating the hardware to control the speed of a three phase induction motor. The controller eliminates the periodic errors on the output current due to inverter current nonlinearity and load disturbances. The controller is implemented on a gate driver, three phase inverter and filter prototypes which are constructed in laboratory. Open-loop and closed-loop condition are verified by means of simulation and experiments in order to investigate the stability of controller. The result of the controller's performance between simulation and hardware are explained in this report in terms of the PWM output and three phase inverter output waveform. The PI-Repetitive controller will solve the starting problem of the three phase induction motor and minimizes the line current error to maintain the required steady state condition.

ABSTRAK

Kawalan motor aruhan tiga fasa jenis *'Proportional Integral Repetitive'* yang diaplikasikan pada penyongsang tiga fasa dibangunkan. Projek ini adalah untuk merekabentuk gabungan pengawal PI-berulang secara simulasi dan seterusnya memfabrikasi perkakasan bagi tujuan ujikaji di makmal. Pengawal ini menghapuskan gangguan-gangguan berkala ke atas arus keluaran yang disebabkan oleh ketaklelurusan penyongsang dan gangguan semasa pada beban. Pengawal ini kemudiannya diaplikasikan pada prototaip yang dibina iaitu di litar *'gate driver'*, litar penyongsang tiga fasa dan litar penapis di dalam makmal. Kaedah gelung buka dan keadaan gelung tertutup secara simulasi dan eksperimen digunakan bagi mengkaji kestabilan pengawal PI-berulang. Hasil ujikaji direkodkan dalam laporan ini dari segi keluaran bentuk gelombang PWM dan keluaran penyongsang tiga fasa. Pengawal PI-berulang akan menyelesaikan masalah motor induksi tiga fasa yang tidak stabil diawal permulaan pengoperasiannya dan meminimumkan gangguan pada arus semasa untuk mengekalkan keadaan motor agar lebih stabil.

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LIST OF SYMBOL AND ABBREVIATIONS

ABS -	Automatic Brake System
AC -	Alternating Current
ADC –	Analogue to Digital
DAC -	Digital to Analogue
DC -	Direct Current;
DOL -	Direct On Line
DTC -	Direct Torque Control
DSP -	Digital Signal Processing
FFNN -	Feed Forward Neural Network
FOC -	Field Oriented Control
GA -	Genetic Algorithms
MV -	Manipulated Variable
PCB -	Printed Circuit Board
PD –	Proportional Derivative
PI -	Proportional Integral
PID -	Proportional Integral Derivative;
PWM -	Pulse Width Modulation;
VVVF -	Variable Voltage Variable Frequency

CHAPTER 1

INTRODUCTION

1.1 Project background

Induction motor or asynchronous motor is an AC electric motor in which the rotor torque produced is caused by electromagnetic induction from the stator winding of the magnetic field. Rotor induction motor can either type of wound or squirrel-cage. Its are the most widely used motors for appliances, industrial control, and automation, and often called the workhorse of the motion industry because of its robustness, reliable, low cost, high efficiency and durable [1, 2]. Three-phase induction motors are widely used in industrial drives and single-phase induction motors are widely used for smaller loads especially in domestic appliances, such as washing machines and fans. Conventionally, mechanical gear system is used to obtain variable speed. Recently, electronic power and control systems have matured to allow these components to be used for motor control in place of mechanical gears. These electronics not only control the motor's speed, but can improve the motor's dynamic and steady state characteristics.

Before the development of semiconductor power electronics, induction motors were mainly used in fixed speed applications because it was difficult to vary the frequency. There are 4 ways to control the speed of three phase induction motor from stator side which are further classified as V / f control or frequency control [3], changing the number of stator poles, controlling supply voltage and by adding rheostat in the stator circuit. The speed controls of three phase induction motor also can be done from rotor side which are by adding external resistance on rotor side, cascade control method and by injecting slip frequency emf into rotor side. There are a few methods for controlling the speed such as FOC and DTC. Another way is VVVF or V/*f* method which is most suitable for applications without position control requirements or the need for high accuracy of speed control [4].

There are many types of digital controller like a microprocessor, microcontroller and DSP are widely used to control algorithm in motor controller. PID, Fuzzy logic, and neural network are the examples of algorithm techniques used in induction motor drive applications. Common controller for induction motor is a Proportional-Integral, but with the more demanding and sophisticated application, a conventional PI controller is designed accordingly for PWM current controller to produce a better controller such as PI-Fuzzy controller, PI-Time Delay controller, PI-Neural Network and PI-Repetitive controller. Repetitive control is an iterative approach that improves the transient response performance of processes whose tasks are repetitive or periodic. The concept of repetitive control was first introduced in [5].

In this project, one method of controller with additional system will be implemented on a 3 phase 0.75kW, cage type induction motor. An Arduino Uno will be used to drive the gates at a logic output voltage of 5V. Then the gate driver will drive the voltage 15V to the inverter. The motor used in this project is rated for 1.5A so the current will most likely operate in the ranges most likely conducive to IGBTs implementation. For controller, a PI plus Repetitive controller will be implemented to control the current since the speed of the motor is proportional to it. The combination design method PI and Repetitive system controllers possess high performances in different areas. PI is used in the steady state area because it gives a zero error while closed-loop hybridization of Repetitive is a robust control strategy that able to track or reject unknown periodic signals of a known period. Repetitive control resembles what is called iterative learning control, where the error in tracking a finite-duration reference signal is reduced by means of correcting the input in each iteration, based on the error observed in the preceding iterations. For experimental analysis, matlab simulink version 2013a will be used.

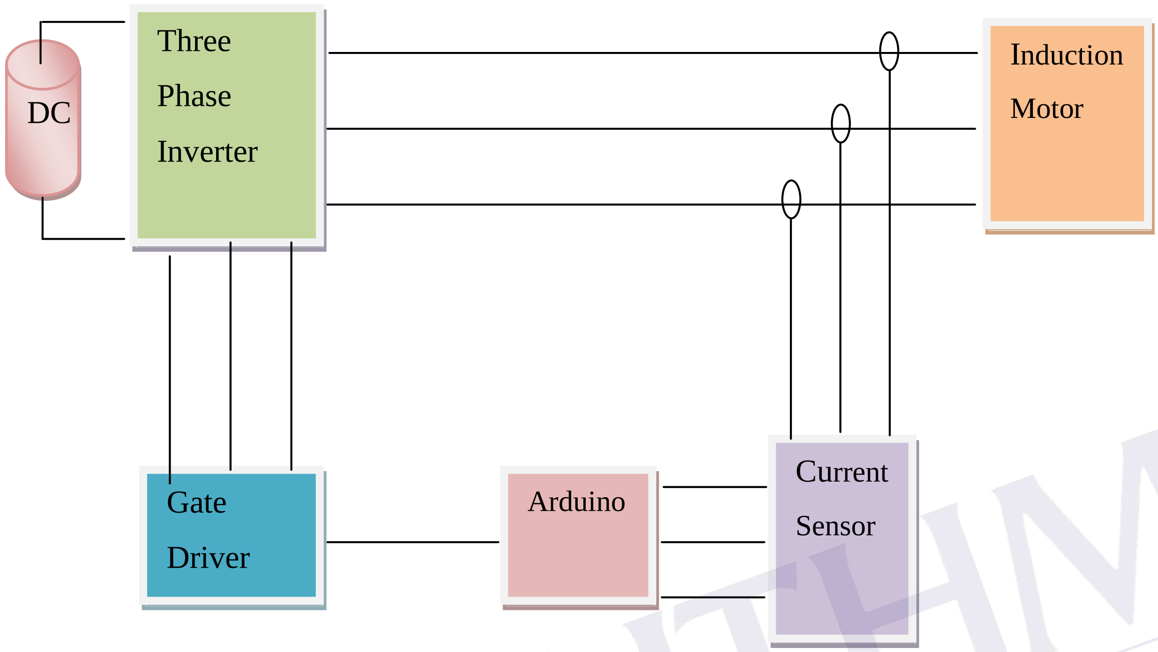

Figure 0.1: Hardware block diagram

Figure 1.1 shows the whole system of the project. They are three phase inverter, arduino and gate driver. which are working together with current sensor to make the induction motor function as needed. The PI-Repetitive controller will be connected to the Arduino where Arduino UNO is used as interface instrument to communicate between hardware and software. The computer simulation program, which will be used to predict the performance of the designed PI-Repetitive controlled system. The variables of the simulated program such as currents, voltages etc., are observed from the scope graphic window. The waveforms obtained from the simulation results are evaluated and compared with the output of experiment in laboratory.

1.2 Problem Statement

Induction motor which is also called asynchronous motor derive their name from the way the rotor magnetic field is created from the rotating stator magnetic field that induced currents in the short circuited rotor. The three-phase induction motor is the most widely used electric motor worldwide in industrial facilities and large buildings.

It is the most favourable drive solution in terms of price and quality. The three phase induction motor are classified into two types which are Squirrel cage induction motor and Slip ring induction motor or wound induction motor or phase wound induction motor [6].

Speaking of 3-phase induction motor, the main thing is concerned with how to control the speed and keep the motor speed maintain to the desired value. The speed control of induction motor is more important to achieve maximum torque and efficiency. Generally, to control the speed of three-phase Induction Motor is by using DOL, variable resister and frequency inverter. When focusing attention on the speed control segment of the three phase induction motor, conventional controller have some problems such as less efficiency due to slow respond, steady state error or sluggish response to the perturbation in reference setting.

The conventional control method such as PI, PD and PID controller is widely used in motor control system due to the simple control structure and easiness of design. However tuning the parameters of controller is a difficult task for varieties of plant parameters and the nonlinear operating condition, fixed gain PI controllers cannot provide the desired control performance [7]. The control and estimation of ac drives in general are considerably more complex than those of dc drives, and this complexity increases if high performances are demanded. The main reasons for this complexity are the need of variable-frequency, harmonically optimum converter power supplies, the complex dynamics of ac machines, machine parameter variations, and difficulties of processing feedback signals in the presence of harmonic PI controller can never achieve perfect control, that is, keep the speed of induction motor continuously at the desired set point value in the presence of disturbance or set point changes [8].

To enhance the capabilities of traditional controller, several approaches such as GA, fuzzy logic, Time Delay or Repetitive have been suggested to be add to the system in order to make speed more stable.

1.3 Objectives:

Objectives of this project are listed as follows:

i. To design a closed-loop control for a three phase induction motor.
ii. To design a combination of PI-Repetitive controller to control the speed of a three phase induction motor.
iii. To develop the hardware of gate driver and three-phase inverter to control the three phase induction motor.
iv. To successfully make a communication between computer and three phase induction motor using Matlab software and Arduino.

1.4 Scope:

In this project the scope of work will be undertaken in the following four developmental stages:

i. Design the closed-loop control with current feedback for the 0.75kWatt, 1.5A three phase induction motor type squirrel cage.
ii. Design the PI-Repetitive controller to control the current of a three phase induction motor. Design the PWM signals which enables the inverter to control the motor within a speed of 10% - 100% (V/F open loop control). This implied that the range of frequency used to control the motor varies between 5 Hz – 50 Hz.
iii. Build the hardware, which is the rating of three-phase induction motor squirrel cage types is 0.75kW, 50Hz, 1.5A, 1500 rpm with 4 poles, gate-driver that generate 15 volt for the inverter and the inverter is using Hex bridge of IRF530 MOSFET.
iv. Successfully make a connection between Matlab's Simulink and Arduino Uno.

CHAPTER 2

LITERATURE REVIEW

2.1 Induction motor

Three-phase induction motor is a very popular motor and most widely used in the electrical industry. They run at a constant speed from no load to full load. However, speed is frequency dependent and so the motor cannot be easily adapted to control the speed. That's why it is essentially be known as a constant speed motor and its speed cannot be changed easily. For this factor, the DC motor is said to be even better when dealing with the factor of speed variations. However, 3-phase induction motors is simple, durable, low price, easy to maintain and can be made with features to suit most requirements of the industry [9]. The most popular type is the 3-phase, squirrel-cage AC induction motor. It is a maintenance-free, less noisy and efficient motor. The stator is supplied by a balanced 3-phase AC power source [10]. The synchronous speed ns of the motor is calculated by Equation 2.1:

$$\mathrm{ns} = \frac{120\mathrm{fe}}{\mathrm{p}}\ \mathrm{rpm} \tag{2.1}$$

Where;

ns = synchronous speed fe = the synchronous stator frequency

p = the number of stator poles.

The principle of operation of three phase induction motors is based on creating a rotating magnetic field in the air gap between the stator and rotor. The rotating field can be obtained by feeding the stator windings from a three phase alternating current source. Thus, the currents in the windings generate are revolving magnetic field having the same angular speed of the source frequency in the air gap. Meanwhile, the continuous change in the stator field induces currents in the rotor's squirrel-cage bars causing another field in the rotor. Both the rotor and stator fields interact with each other in the air gap causing the rotor to rotate. The rotor flux lags that of the stator causing the rotor speed to slip. The ratio of slip and synchronous speeds is called the motor slip as Equation 2.2 below.

$$s = \frac{\omega_{sl}}{\omega_s} = \frac{\omega_s - \omega_m}{\omega_s} \tag{2.2}$$

Where;

s = slip $\qquad \omega_{sl}$ = slip speed

ω_s = synchronous speed $\qquad \omega_m$ = rotor speed

The motor speed is controlled by variation of a stator frequency with the influence of the load torque.

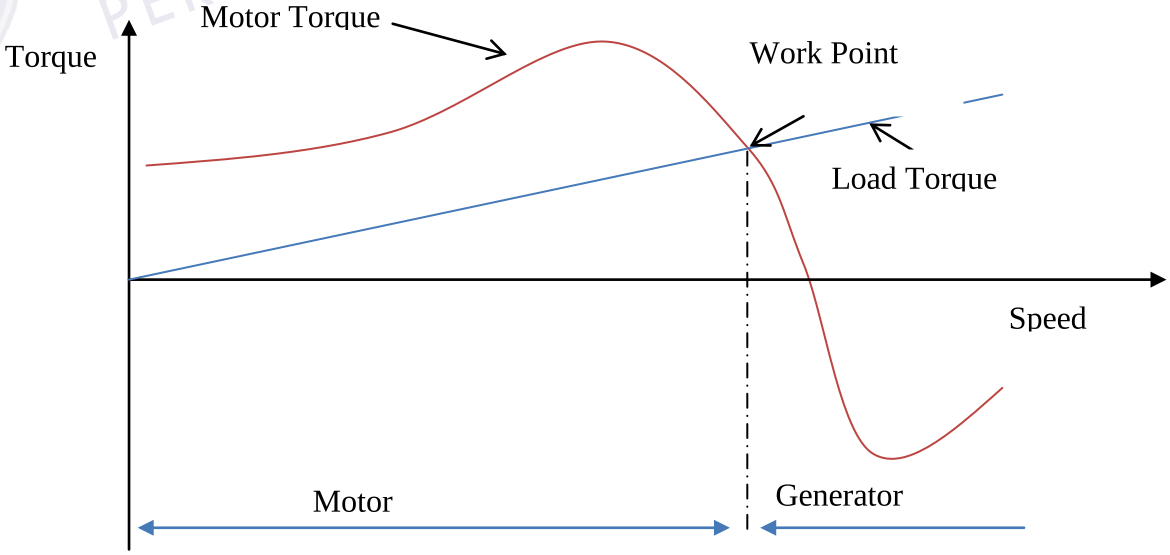

Figure 2.1: Torque-speed characteristic at constant voltage and frequency

2.2 Inverter DC to AC

Power converter which is known as inverter is an electrical device that can change direct current DC to alternating current AC. The converted AC can be at any required of voltage and frequency usually used in transformer , switching and control circuit. It also be used from small switching power supplies to large high-voltage electric equipment applications that transport bulk power and solid-state inverters have no moving parts. Commonly inverter is used to supply solar panels or batteries and it perform the opposite function of a rectifier. The electrical inverter is high-power electronic oscillator because generally AC to DC converter was made to work in reverse and thus was inverted which is to convert DC to AC.

2.2.1 Three phase inverter

The standard three-phase inverter has as its genesis, the hex-bridge [11]. There are two kinds of switches that were considered for this range of power applications, Insulated Gate Bipolar Transistors (IGBTs) or MOSFETs. The hex-bridge takes a DC voltage and uses six switches (MOSFETS) arranged in three phase legs as shown in Figure 2.2**.** The power circuit consists of six self-commuted semiconductor switches S1 to S6. The switch pairs (S1, S4), (S3, S6), and (S5, S2) form three legs of the inverter. The switches in the same leg conduct alternately. Sometime must elapse before the turn-off of one switch and turn on of another to ensure that both do not conduct simultaneously.

Their simultaneous operation will cause a short circuit of the dc source resulting in a very fast rise in current. This fault, known as short-through fault can only be cleared by fast-acting fuse links [12].

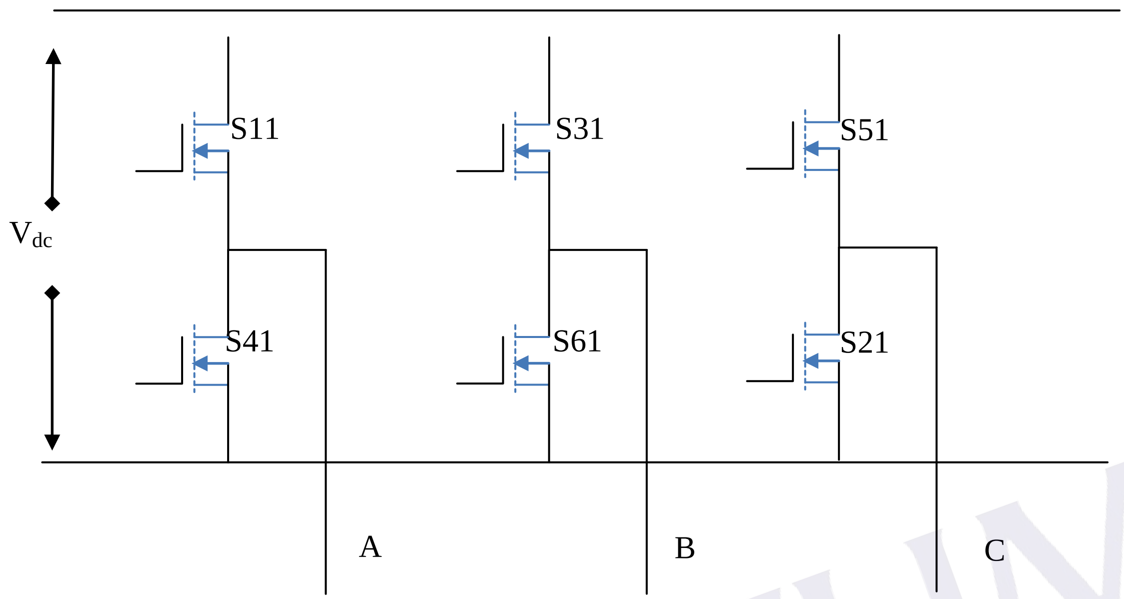

Figure 2.2: Hex bridge of inverter

The single phase voltage source inverters PWM technique can be used in three-phase inverters, in which three sine waves phase shifted by 0°, 120°, 240° with the frequency of the desired output voltage is compared with a very high frequency carrier triangle, the two signals are mixed in a comparator whose output is high or wide in time range when the sine wave is in positive side of the triangle and the comparator output is low or thin in time range when the sine wave signal is in negative side of the triangle. This phenomenon is shown in Figure 2.3. As is explained the output voltage from the inverter is not smooth but is a discrete waveform and so it is more likely than the output wave consists of harmonics, which are not usually desirable since they deteriorate the performance of the load, to which these voltages are applied [13].

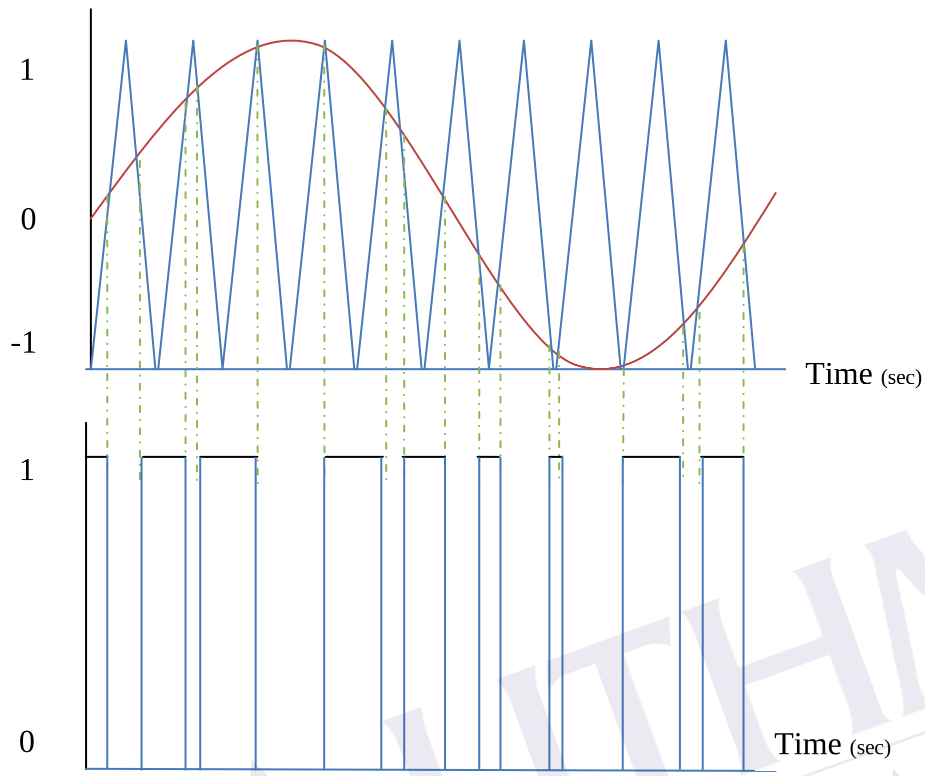

Figure 2.3: PWM illustration by the sine-triangle comparison method (a) sine triangle comparison (b) switching pulses

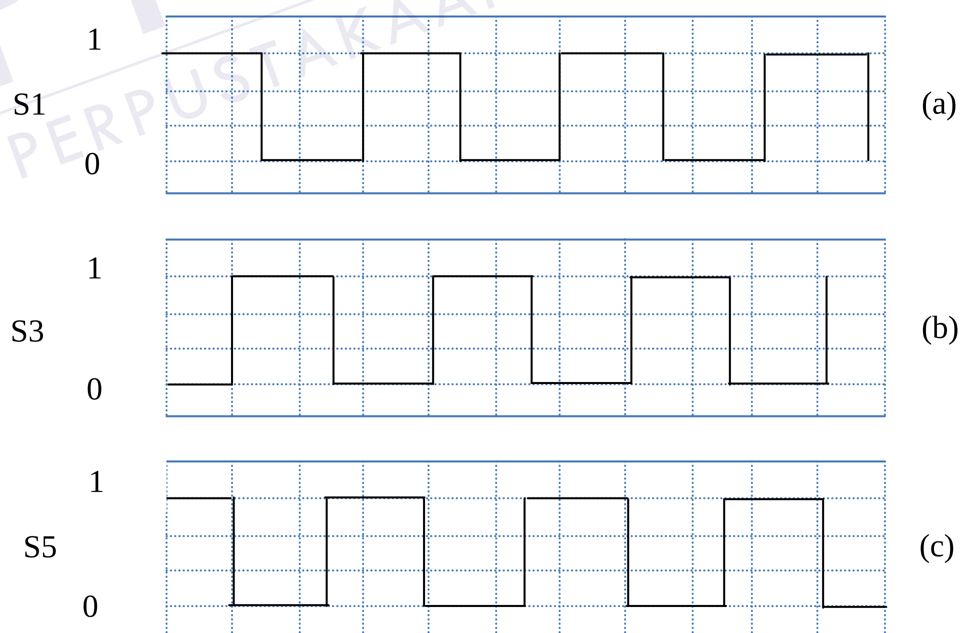

Figure 2.4: Generation of the switching signals for top devices (a) S1 (b) S3 (c) S5

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