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REPORT

DESIGN THE LOW PASS PASSIVE FILTER FOR GRID CONNECTED SINGLE-PHASE VOLTAGE SOURCE INVERTER SYSTEM

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JUNE 2014

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DESIGN THE LOW PASS PASSIVE FILTER FOR GRID CONNECTED SINGLE-PHASE VOLTAGE SOURCE INVERTER SYSTEM

MUHAMMAD FAID BIN MUSTAFFA

A report submitted in partial fulfillment of the requirement for the degree of Bachelor in Electrical Engineering (Power Electronics and Drives)

Faculty of Electrical Engineering
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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I declare that this report entitle “Design The Low Pass Passive Filter for Grid Connected Single-Phase Voltage Source Inverter System" is the result of my own research except as cited in the reference. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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DEDICATION

This report is dedicated to my parents

(En. Mustaffa Bin Che Yusoff and Pn. Norshidah Binti Abdullah)

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I would like to gratitude to Allah S.W.T for His generous blessing and undying strength bestowed upon me during the completion of this project.

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ABSTRACT

In this project, the design and analysis of low pass passive filter for single-phase voltage source inverter (VSI) is presented. The VSI is operates in unipolar pulse width modulated which is the pulse width modulation (PWM) technique to eliminate the low order harmonics. To achieve low current and voltage total harmonic distortion (THD) that satisfies with IEEE-519 standard, the output VSI requires an output low-pass filter. This project is carried out the designing of low pass filter with calculation method which shortened the design time. In addition, the analysis of low pass filter at high order harmonic is presented. The analysis of each types of low pass filter such as L, LC and LCL is consists of criteria of switching frequency, variation of modulation index, the ripple current, and the transfer function. The calculation method is satisfied with the simulation results in MATLAB Simulink software.

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ABSTRAK

Projek ini membincangkan tentang proses mereka bentuk dan menganalisa ‘low pass passive filter’ yang digunakan kepada ‘voltage source inverter’ (VSI) yang berfasa tunggal. VSI beroperasi dengan menggunakan teknik ‘unipolar pulse width modulated’ iaitu salah satu teknik ‘pulse width modulation’ (PWM). Teknik ini berupaya membuang ‘harmonics’ bertahap rendah dalam sistem. VSI memerlukan ‘low pass passive filter’ untuk menghasilkan ‘total harmonic distortion’ (THD) arus dan voltan yang rendah. Kaedah kira-kira digunakan untuk mereka bentuk ‘low pass filter’ di dalam projek ini. Penggunaan kaedah ini boleh mengurangkan masa mereka bentuk ‘filter’. Tambahan pula, proses menganalisa L, LC dan LCL ‘filter’ dilakukan berdasarkan beberapa kriteria seperti ‘switching frequency’, perubahan ‘modulation index’, ‘ripple current’, dan ‘transfer function’. Secara keseluruhanya, perbandigan antara proses mereka bentuk ‘filter’ menggunakan kaedah kira-kira dengan keputusan simulasi di dalam perisian MATLAB Simulink adalah memuaskan.

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CHAPTER 1

INTRODUCTION

1.1 Project Background.

An electrical grid is a system that consists of electricity generation, transmission, distribution and control networks. This interconnected network is very important to deliver electricity from suppliers to consumers. In this network system, there are power stations that generate electrical power, transmission lines that transmit power from the power stations to the housing area and industrial area, and distribution lines that supply electrical source to the consumers. The acquisition of the electrical energy from renewable sources is very popular these days and the applications for renewable energy generation undergo rapid development. The using of renewable energy can help reduce the greenhouse gases in atmosphere. These benefits of using renewable energy has make Distribution Resources (DR) rapidly growing in modern distribution network. Many of these resources provide electrical energy in the form of Direct Current (DC) voltage source.

Most of power plants produce electrical energy in the form of Alternating Current (AC) voltage source. Consequently, the connection of such resources to the utility grid needs an AC/DC/AC conversion stage. In AC/DC stage, converter is used, and during DC/AC stage, inverter is needed. Voltage source inverter (VSI) is mostly used in industry application because its design has been proven to be more efficient, have higher reliability and faster dynamic response. VSI fully integrated design saves money with higher efficiencies,

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minimizing install time, eliminating interconnected power cabling costs, and reducing building floor space [1].

The filter is very important to be added at the output of VSI in order to limit the current harmonics supplied to the grid system. This makes filtering of non-sinusoidal nature voltage output of VSI is crucial. Basically, filters are used to improve the output waveform of VSI and make it a sinusoidal waveform. A passive ac low pass filter is the most suitable type of filter for this purpose. Basically, to design a good low pass filter, the best filter must produce a total harmonic distortion (THD_i) current which satisfies the power quality standard IEEE-519. Based on standard of IEEE-519, the THD current is limited to 5 % [2].

The method used to design ac low pass filter is very important criteria in order to get the best design by using the easiest technique. There are many method can be used in designing the ac low pass filter such as transfer function method, calculation method and bode plot method. Each method used must fulfil the recommended THD_i requirement based on IEEE-519 standard.

1.2 Problem Statement.

The technology advancements in industrial control processes have increased the demanding requirements on the power quality from the industrial power consumers. Among the arising power quality problems, harmonics is one of the problems that need to be control in electrical power systems. In designing an ac low pass filter, harmonics is one of the important power quality problems which needed to be considered. In designing ac low pass filters, it is difficult to propose a design that can meet the THD current requirement of IEEE-519 (THD_i < 5%) [2]. Besides that, there must be the easiest method that can be used to design ac low pass filter among many methods available such as the calculation method.

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1.3 Objectives.

The objectives of this project are:

- To design the L, LC and LCL low pass filters by using calculation method.
- To design low pass passive filters that can satisfy the requirement of THD current based on IEEE-519 which stated that total harmonic current and voltage THD_i and THD_v must be less than 5%.
- To analyse the performance of L, LC and LCL low pass filter using the MATLAB/Simulink software and also by using transfer function and bode plot in MATLAB M-files.

1.4 Scope.

This project is carried out to study the various types of low pass passive filters such as L, LC and LCL filter. The L, LC and LCL low pass filter are designed using the calculation method. The designed circuits must meet the harmonic voltage distortion regarding to the IEEE-519 standards which require that THD current must be less than 5%. To prove the best circuit design of ac low pass filter, the MATLAB software is used for simulation. By using MATLAB Simulink and transfer function & bode plot in MATLAB M-files, the criteria and performances of L, LC and LCL filter are analysed.

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1.5 Report Outlines.

Chapter 1: Introduction.

This chapter presents the background of electrical grid system, voltage source inverter (VSI), passive low pass ac filter, and the various methods to design low pass filter. Moreover, problem statement, objectives, report outlines are been explained in this chapter.

Chapter 2: Literature Review.

In this chapter, theory about electrical grid system, VSI, ac low pass filter, and method of designing low pass filter is been discussed. Related previous works that has been done by others over the past few years also been reviewed and the summary of that review is created.

Chapter 3: Design Methodology.

Project methodology is described in this chapter. The circuits design of ac low pass filter such as L, LC and LCL are presented. The method used to design low pass filter that is the calculation method are analysed. MATLAB software is used for the simulation approach of low pass filter circuits design.

Chapter 4: Result and Discussion.

Chapter 4 shows the output result of from MATLAB simulation and discussions on which type of circuit design ac low pass filter can give THD current that satisfy IEEE-519 standard ($THD_i < 5\%$). Besides that, the analyses of L, LC and LCL filter are made by using the circuit designed in MATLAB and the performances of each filter circuit are examined by using transfer function and bode plot.

Chapter 5: Conclusions.

This chapter concludes the overall aspect of the project. Finally, recommendation or possible future works are proposed.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction.

This chapter reviews all the theory that related to this project. The systems or components that involve in this project such as electrical grid connected system, VSI, and low pass filer topology are explained in this chapter. Furthermore, the MATLAB software which is used to simulate the circuit design of low pass filter is been exposed in this chapter. In this chapter, the previous works or researches that related to this project are also been presented. Finally, all the important information gathered from theory and previous related works are summarised in 'Summary of Review' section.

2.2 Theory.

This section discuss about the components or systems which involve in this project such as electrical grid system, voltage source inverter (VSI), low pass filter, pulse width modulation (PWM), total harmonic distortion (THD), and MATLAB software.

2.2.1 Electrical Grid System.

Electricity is supplied from the supplier to consumers through an interconnected network called electrical grid connected system. It consists of generating station, transmission

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line, and distribution line. Generating stations are the place where electrical power is produce. Transmission line is the high voltage line that carries power from distant sources to demand centres, while distribution line is the line that distributes electricity to many types of consumers.

Normally, the electricity is generates by fossil fuels which produce ac voltage source. Considering the high consumption of fossil fuels in recent years and this will make this type of source quickly finish. Since fossil fuels consumption increases emission of carbon dioxide, this will results in global warming. Energy crisis and increasing of greenhouse gases have caused the renewable energy resources to be the better power source for modern distribution network [3]. These renewable sources of energy such as water, wind and solar should be used. The dispersed nature of these resources, sometimes called Distribution Resources (DR). Most of DRs produce electrical energy in the form of dc voltage source [3].

2.2.2 Voltage Source Inverter (VSI).

The connection of DR to the grid needs a dc/ac conversation stage. With the latest technology, many DRs need a DC/AC conversion stage for energy transfer to the grid [3]. The DC/AC converter or well known inverter is used to 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, battery, fuel cell, photovoltaic array or magneto hydrodynamic generator [4]. Inverters can be broadly classified into two types, voltage source and current source inverters. A VSI is one in which the dc source has small or negligible impedance. It has a constant voltage at the input terminals. On the other hand, current source inverter (CSI) is fed with adjustable current from the dc source of high impedance that is from constant dc source [4]. A voltage source inverter that employing thyristors as switches required forced commutation, but a VSI that made up of GTOs, power transistors, power MOSFETs or ICBTs as switches, has a self commutation with base or gate drive signals for their controlled turn-on and turn-off. A standard single-phase VSI can be in the half-bridge or full-bridge

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configuration. These inverters have mostly used in industrial applications such as adjustable-speed ac drives, induction heating, standby aircraft power supplies, uninterruptible power supplies (UPS) for computers and others. The inverter is used to control the fundamental voltage magnitude and the frequency of the AC output voltage. AC loads such as induction motor is required constant or adjustable voltage at their input terminals. This requirement can be fulfilled when such loads are fed by inverter. The schematic diagram for half-bridge circuit for single-phase VSI is shown in Figure 2.0 [4].

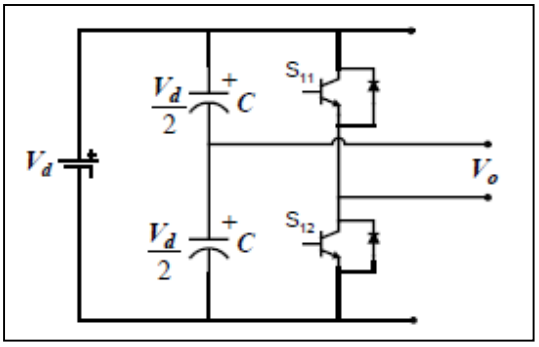

Figure 2.0: Schematic Diagram of Half-Bridge VSI.

The pulse width modulation (PWM) scheme is illustrated in Figure 2.1 [4], in which v_c is the peak value of triangular carrier wave and v_r is the reference or modulating signal. The switches S_{11} and S_{12} are controlled based on the comparison of sinusoidal signal and the triangular wave which mixed in a comparator. When sinusoidal wave has magnitude higher than the triangular wave the comparator output is high, otherwise it is low. The switching pulse after comparison is shown in Figure 2.2 [4].

$$v_r > v_c \quad S_{11} \text{ is on}, v_{out} = \frac{Vd}{2} \tag{2.0}$$

and

$$v_r < v_c \quad S_{12} \text{ is on}, v_{out} = -\frac{Vd}{2} \tag{2.1}$$

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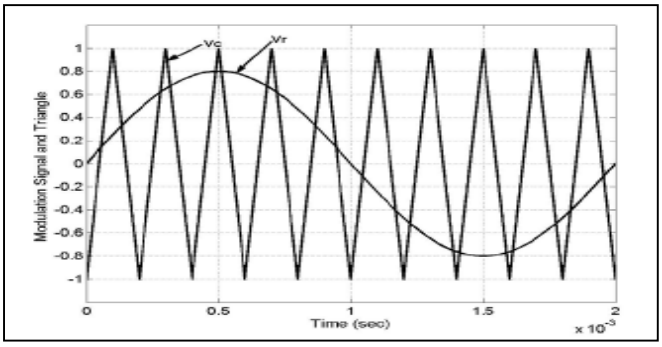


Figure 2.1: Sine-Triangle Comparison.

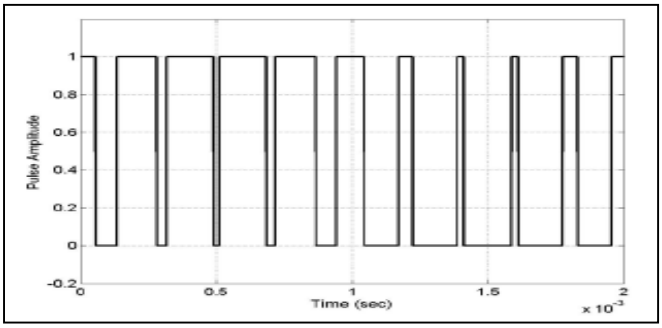
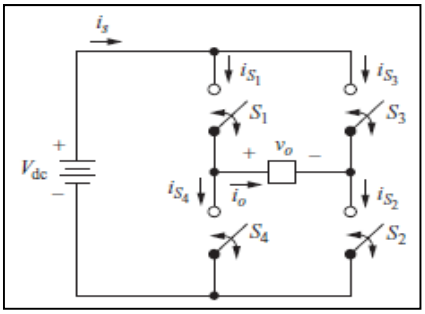


Figure 2.2: Switching Pulses after Comparison.

A full-bridge circuit of single-phase VSI is shown in Figure 2.3 [5] which consists of four switching devices is the basic circuit to convert DC to AC. This type of VSI can produce an output power twice that of half-bridge VSI with the same input voltage. The switching determines the output voltage, v_o whether $+V_{dc,}$ - V_{dc} or zero. Table 1.0 shows the output voltage, v_o based on switches condition and Figure 2.4 [5] shows the equivalent circuits for switch combinations.



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