ANALYSIS OF FAULTS IN THREE PHASE VOLTAGE SOURCE INVERTER

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ABSTRACT

This project presents the analysis of faults in 3 phase voltage source inverter (VSI). VSI is widely used in motor drive and power quality applications. The majority of fault related the power switches, such as open-circuit faults and short-circuit faults. The problem statement of this project is the high cost of maintenance, the power electronic damage and interrupt the manufacturing process. Then the objective is to identify and analyze generated fault using fast Fourier transform (FFT) and short time Fourier transform (STFT) technique. FFT is very useful in the analysis of harmonic and is an essential tool for filter design. It has some drawbacks such as losses of temporal information, so that it can only be used in the steady state and cannot show the moment when the event is produced. The STFT is applicable to non-stationary signals and it has been used in power quality analysis. The advantage of this technique is its ability to give the harmonic content of the signal at every time-period specified by a define window. But, this technique also has the limitation of fixed window width chosen a priority and this causes limitations for low-frequency and high-frequency non-stationary signal analysis at the same time. In this analysis, the parameter such as instantaneous rms current (*Irms*), average current and total harmonic distortion (THD) are used to identify the characteristic of the signals. Matlab software is used for simulation in this project.

ABSTRAK

Projek ini menganalisis tentang kerosakan yang berlaku dalam penyongsang sumber voltan tiga fasa. Penyongsang sumber voltan digunakan secara meluas dalam aplikasi pemacu motor dan kualiti kuasa. Majoriti kerosakan berkaitan dengan suis kuasa, seperti kerosakan litar terbuka dan litar pintas. Pernyataan masalah projek ini adalah kos penyelenggaraan yang tinggi, kerosakan kuasa elektronik dan mengganggu proses pembuatan. Kemudian objektif projek ini adalah mengenal pasti dan menganalisis kerosakan yang dijana menggunakan teknik 'fast Fourier transform' (FFT) *dan* 'short-time Fourier transform' (STFT). *Teknik* FFT *sangat berguna dalam menganalisis harmonik dan ia adalah alat penting bagi reka bentuk penapis. Ia mempunyai beberapa kelemahan seperti kehilangan maklumat yang berkenaan dengan masa, jadi ia hanya boleh digunakan dalam keadaan tetap dan tidak boleh menunjukkan keadaan ini dihasilkan. Manakala* STFT *berkebolehan dalam isyarat bukan pegun dan ia telah digunakan dalam analisis kualiti kuasa. Kelebihan teknik ini adalah keupayaannya untuk memberikan kandungan isyarat harmonik pada setiap tempoh masa. Tetapi, teknik ini juga mempunyai had lebar window tetap yang keutamaannya dipilih dan ini menyebabkan had untuk frekuensi rendah dan pada masa yang sama analisis isyarat tidak bergerak frekuensi yang tinggi. Dalam analisis ini, parameter seperti arus rms (*Irms)*, arus purata* (Iave) *dan jumlah herotan harmonik* (THD) *digunakan untuk mengenal pasti ciri-ciri isyarat. Perisian Matlab digunakan untuk simulasi dalam projek ini.*

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CHAPTER 1

INTRODUCTION

1.1 Overview

Inverter is circuits that convert DC input voltage to symmetric AC output voltage which both magnitude and frequency can be controlled. Voltage source inverters can be classified as an inverter. When input DC voltage remains constant, then it is called voltage source inverter (VSI). In industry, voltage source inverter (VSI) plays role in power supplies, motor drives, power quality application, etc. The percentage of failures in the power converter is estimated about 38% and mostly occur in power switches [1]. To overcome this situation, fast Fourier transform (FFT) and short-time Fourier transform (STFT) technique is used to analyze the signal.

The faults were related to power switches, such as open-circuit, short-circuit and gate misfiring fault [2]. The faults caused transistor failure, pulse width modulation (PWM) and inverter leg open [3].

1.2 Project Motivation

High cost of maintenance is required when the drive system shuts down due to the fault occurrences. The presence of fault causes damage to the power electronics such as inverter. Furthermore, it also interrupts manufacturing process when the drive system has to be stopped. Fast Fourier Transform (FFT) and Short-Time Fourier Transform (STFT) techniques is used to solve this problem. FFT is an essential tool for filter design and very useful in the analysis of harmonic. It has some drawbacks such as losses of temporal information, so that it can only be used in the steady state and cannot show the moment when the event is produced [4]. STFT is applicable to non-stationary signals and it has been used in power quality analysis. The advantage of this technique is its ability to give the harmonic content of the signal at every time-period specified by a define window. But, this technique also has the limitation of fixed window width chosen a priority and this causes limitation for low-frequency and high-frequency non-stationary signal analysis at the same time [5].

1.3 Objectives

The objective of this project is:

i. To study fault in three-phase voltage source inverter (VSI).

ii. To identify and analyze generated fault using fast Fourier transform (FFT) and short-time Fourier transform (STFT) technique.

iii. To simulate by using Matlab software.

1.4 Scope

In order to achieve this objective, several scopes have been outlined. In this analysis, Matlab software is used as simulation purpose and RMS current (Irms), average current (Iave) and total harmonic distortion (THD) are used to identify the characteristic of the signals. The technique used in this analysis is fast Fourier transform (FFT) and short-time Fourier transform (STFT). FFT is suitable for stationary signal [6] while STFT is non-stationary signal [7]. The limitation of three-phase inverter is the frequency of the output voltage waveform depends on the switching rate of the semiconductor devices and the upper limit of the frequencies is fixed by the device capability [8].

1.5 Report outlines

After doing some research for this project, this report is written and discuss about the analysis of fault in three phase VSI.

In chapter 1, there will be an introduction about this project, project background, problem statement, the objective, scope and report outlines.

In chapter 2, the literature review will review on the theory, basic principles of the fault and overview of related published results of a fault in voltage source inverter. This chapter also includes the summary of the review.

In chapter 3, the methodology will show the process and simulation approach of fault detection. In chapter 4, the result and discussion will discuss about the whole project.

Finally, in chapter 5 the conclusion will conclude the project that has been done. This chapter will also discuss about the future work or recommendation and suggestion.

CHAPTER 2

LITERATURE REVIEW

2.1 Theory

2.1.1 Inverter

The inverters are DC to AC converters. The application of inverter such as standby power supply, induction heating and variable speed AC motor drives [9].

The output voltage of the inverter can be controlled with the help of the drives of the switches. To control the output voltages of the inverter, the pulse width modulation (PWM) technique is used. Some inverters are called as PWM inverters. It contains harmonic whenever it is non-sinusoidal. These harmonics can be reduced by using proper control schemes.

Voltage source inverters or current source inverters can be classified as an inverter [9]. When input DC voltage remains constant, then it is called voltage source inverter (VSI) or voltage fed inverter (VFI). When input current is maintained constant, then it is called current source inverter (CSI) or current fed inverter (CFI). Rarely, the DC input voltage to the inverter is controlled to adjust the output. Some inverters are called variable DC link inverters. It can have single phase or three phase output.

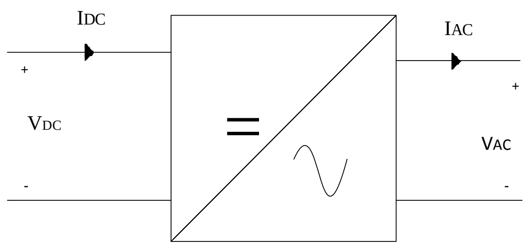

Figure 2.1: Inverter

2.1.2 Three-phase Inverter

The DC to AC converters are also known as an inverter, depending on the related topology of the power circuit and the type of the supply source. There are different basis of classification of the inverter. Inverters are broadly classified as a current source inverter (CSI) and voltage source inverter (VSI). Figure 2.2 and Figure 2.3 show the three-phase half bridge voltage source inverter and three-phase full bridge voltage source inverter. Single-phase VSIs cover low range power applications while three-phase VSIs cover medium to high power applications [10]. Three-phase full bridge voltage source inverter has six switches. The switching depends on the modulation scheme. The main objective of three-phase VSI topologies is to provide a three-phase voltage source, where the amplitude, phase and frequency of the voltages should always be controllable. Three-phase VSI are widely used in active filters, motor drives and uninterrupted power supplies to generate controllable frequency and AC voltage magnitudes using various PWM strategies [10].

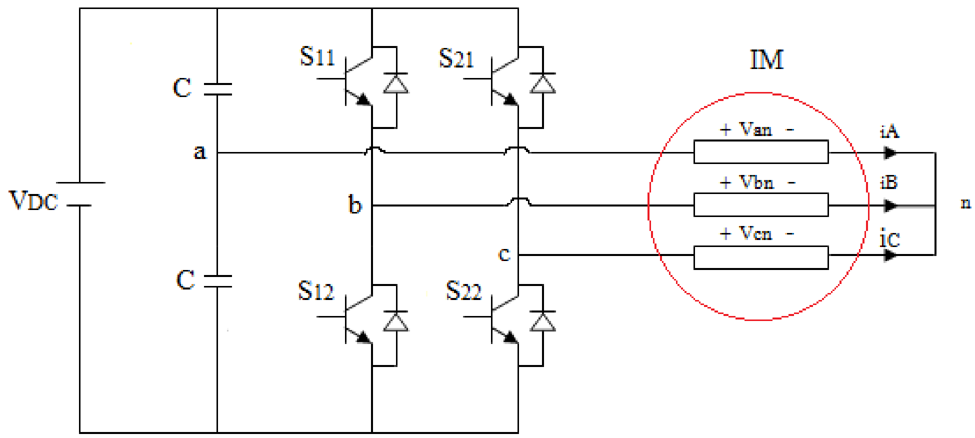

Figure 2.2: Three-Phase Half Bridge Inverter

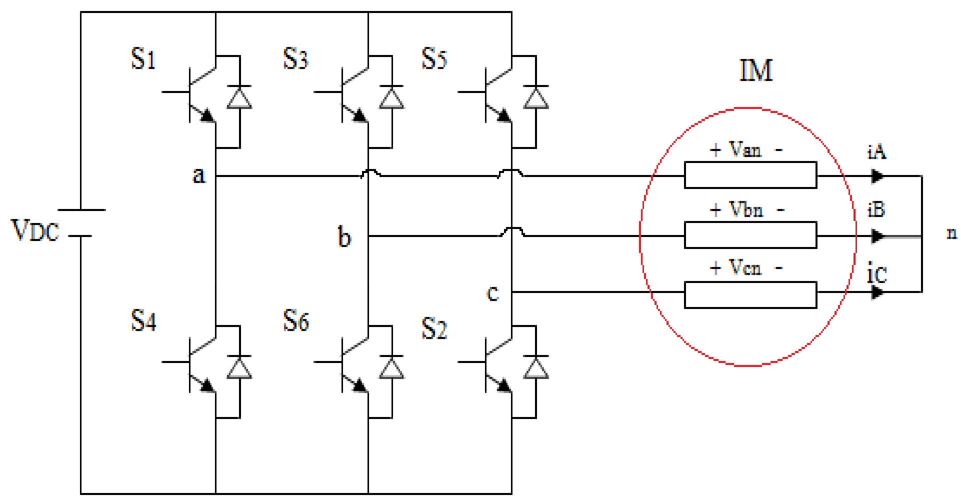

Figure 2.3: Three-Phase Full Bridge Inverter

2.1.3 Pulse Width Modulation

The output voltage of an inverter can also be adjusted by exercising a control within the inverter itself. The most efficiency method of doing this is by using pulse width modulation (PWM) control in inverter. In this method, a fixed DC input voltage is given to the inverter while controlled AC output voltage is obtained by adjusting the on and off periods of the inverter components [11]. The PWM provides a way to decrease the total harmonic distortion (THD) of load current. A PWM inverter output with some filtering can generally meet THD requirements easier than the square wave switching scheme. The unfiltered PWM output will have a relatively high THD, but the harmonics will be at higher frequency than for a square wave, result to ease to be filtered.

Besides, the advantage of PWM for three phase inverter is reduced filter requirements for harmonic reduction and controllability of the amplitude of the fundamental frequency. Then, the other advantages of PWM techniques are the output voltage control with this method can be obtained without any additional components. The lower order harmonics can be eliminated or minimized along with its output voltage control. In most AC motor loads, higher order harmonic voltage distortion can be filtered by the inductive nature of the load itself.

PWM inverter is most popular in industrial application. PWM technique is characterized by constant amplitude pulses. The width of these pulses is however modulated to obtain inverter output voltage control and reduce. The figure below shows the pulse width modulated signal.

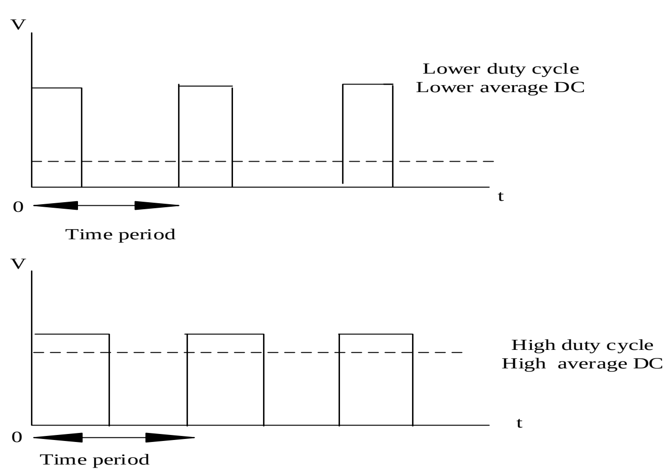

Figure 2.4: Pulse Width Modulation signal

2.1.4 Short-Time Fourier Transform

The short-time Fourier transform (STFT) is a transform. It involves both time and frequency and allows a time-frequency analysis [12]. The time-frequency analysis is motivated by the analysis of non-stationary signal that is characteristic of the spectrum is changing in time [13]. The objective of STFT is to capture the time variation in the frequency content of the signal. It represents a compromise between time and frequency based on signal perspectives and it also provides some information about when and what events occur. The basic principle of STFT is to slice up the signal into suitable overlapping time segments and then to perform a Fourier analysis on each slice to ascertain the frequencies contained in it [7]. It is defined as in Equation 2.1.

$$S(t, f) = \int_{-\infty}^{\infty} x(\tau) w(\tau - t) e^{-j2\pi ft} \, d\tau \qquad (2.1)$$

$x(\tau)$ is the input signal and $w(t)$ is the window function. Some limitation of STFT is window length. In STFT, narrow window gives good resolution in time but poor resolution in frequency. Wide window gives good resolution in frequency but poor resolution in time [14].

2.1.4.1 Performance Parameter

i. Instantaneous Average Current

Instantaneous Average Current is the mean value of a signal that corresponds to a specific time, *t* and it can calculate as:

$$I_{ave}(t) = \frac{1}{T} \int_{0}^{T} x(\tau) w(\tau - t) d\tau \qquad .(2.2)$$

Where T is the period measured, $x(\tau)$ is the input signal and $w(t)$ is the window function.

ii. Instantaneous RMS Current

$$I_{rms}(t) = \sqrt{\int_{0}^{f_{max}} S(t, f)\,df} \tag{2.3}$$

$S(t, f)$ is the time-frequency representation (TFR) of the signal and f_{max} is the maximum frequency

iii. Instantaneous RMS Fundamental Current

$$I_{1rms}(t) = \sqrt{2\int_{f_{lo}}^{f_{hi}} S(t, f)\,df} \tag{2.4}$$

$$f_{hi} = f_1 + \frac{\Delta f}{2} \tag{2.5}$$

$$f_{lo} = f_1 - \frac{\Delta f}{2} \tag{2.6}$$

Where f_1 is the fundamental frequency that corresponds to the power system frequency and Δf is the bandwidth.

iv. Instantaneous Total Harmonic Distortion

$$I_{THD}(t) = \sqrt{\frac{\sum_{h=2}^{H} I_{h,rms}(t)^2}{I_{1rms}(t)}} \tag{2.7}$$

$I_{h,rms}(t)$ is the RMS harmonic current and H is the highest measured harmonic component.

2.1.5 Fast Fourier Transform

Fourier transform is mathematical technique which convert the signal from time to frequency domain. It is very useful for many applications where the signals are stationary, as in diagnostic faults of electrical machines [6]. The stationary signal is frequency or spectral contents are not changing with respect to time. Function of fast Fourier transform (FFT) is localized in the frequency domain; providing the user useful information on the operating conditions of the power distribution network. Not advisable to apply a methodology associated with FFT as the analysis tool if the signal is a stationary signal associated with a wide range of frequencies superimposed to the power frequency component. FFT has various obstacles and limitations associated with time-frequency resolution where it is not possible to identify at what times these high frequency components occurred [15]. It can be defined as:

$$X(f) = \int_{-\infty}^{\infty} x(t) e^{-j2\pi f t t} dt \tag{2.8}$$

$x(t)$ is the signal of interest, t is the time and f is the signal frequency.

2.1.5.1 Performance Parameter

i. Current Measurement

$$I_{rms} = \sqrt{\frac{1}{N}\sum_{n=0}^{N-1} |i(n)|} \tag{2.9}$$

ii. Instantaneous Total Harmonic Distortion

$$I_{THD}(t)=\sqrt{\frac{\sum_{h=2}^{H} I_{h,rms}(t)^2}{I_{1rms}(t)}} \quad (2.10)$$

$I_{h,rms}(t)$ is the RMS harmonic current and H is the highest measured harmonic component.

2.1.6 Stationary Signal and Non-stationary Signal

Stationary signal is a signal whose frequency content does not change in time. In this signal all frequency components exist at all time [16]. There is 10 Hz , 50 Hz and 100 Hz at all time.

Example for stationary signal. It has frequencies of 10, 25, 50 and 100 Hz at a given time instant. The signal is plotted in Figure 2.5.

x(t) = cos (2*pi*10*t) + cos (2*pi*25*t) + cos (2*pi*50*t) + cos (2*pi*100*t)

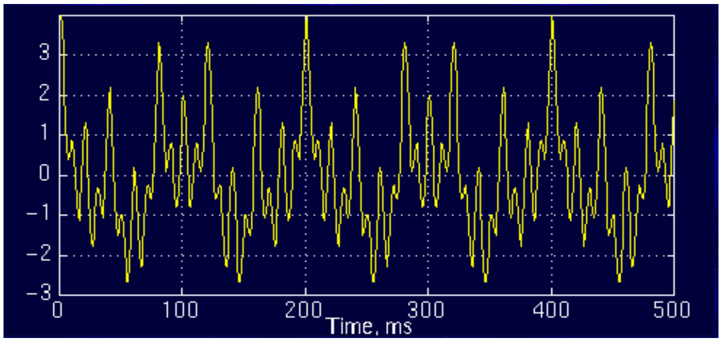

Figure 2.5: Example of stationary signal

Non-stationary signal is a signal whose frequency constantly changes in time [16]. Figure 2.6 is an example of a non-stationary signal. This figure shows a signal with four different time intervals. The interval 0 to 300 ms has a 100 Hz sinusoid, the interval 300 to 600 ms has a 50 Hz sinusoid, the interval 600 to 800 ms has a 26 Hz sinusoid and lastly the interval 800 to 1000 ms has a 10 Hz sinusoid. In this signals the frequency components do not appear at all time.

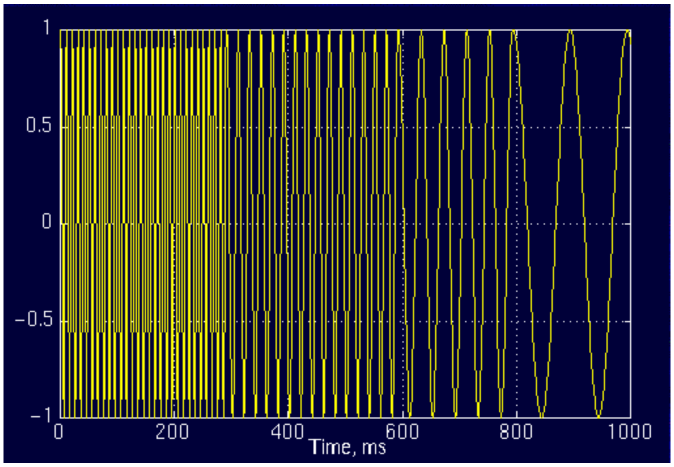

Figure 2.6: Example of non-stationary signal

2.1.7 Detection of Fault for Voltage Source Inverter (VSI)

2.1.7.1 Switching Function Model for VSI

Three-phase full bridge inverter consists of a classical three-leg inverter. To operate the power transistor such as an IGBT, an appropriate gate voltage must be applied in order to drive transistor into the saturation mode for low on-state voltage. The gate drive circuit generates the control voltage. The control voltage should be applied between the gate and source terminal. [17].