POWER CABLE SIZING FOR NON-LINEAR LOAD OPERATION

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

A	Ampere
AC	Alternating current
C	Capacitor
CB	Circuit breaker
D	Diode
DC	Direct current
DFT	Discrete Fourier Transform
FA	Fourier analysist
FFT	Fast Fourier Transform
HV	High voltage
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
LV	Low voltage
MV	Medium voltage
p.u.	Per unit
PVC	Polyvinyl chloride
RMS	Root mean square
SMPS	Switch mode power supply
THD	Total harmonic distortion
THDi	Total harmonic current distortion
THDv	Total harmonic voltage distortion
TNB	Tenaga Nasional Berhad
VAR	Voltage ampere reactive
XLPE	Cross link polyethylene

LIST OF SYMBOLS

P_R	Pure resistive load
I_n	Neutral current
I_1	Fundamental current
h	Harmonic order
S	Size cable
I_3	3rd harmonic current
I	current
rsA	Internal resistor A
rsB	Internal resistor B
rsC	Internal resistor C
$C\text{-}P_R$	Capacitor-resistive load pair
f	Frequency
a_0	d.c. term for Fourier series
a_h	h^{th} harmonic term for Fourier series
$f(t)$	Signal function in time domain
I_{rms}	Current root mean square
I_p	Phase current
$I_{3\text{-}p}$	3rd harmonic phase
THDv	Voltage THD
THDi	Current THD
W	Power unit in waat

Kabel Kuasa Untuk Kegunaan Operasi Bebaban Tidak Sekata

ABSTRAK

Pada masa kini, terdapat banyak alatan elektronik yang digunakan di dalam industri, pejabat dan perumahan. Peralatan tersebut bekerja sepanjang masa dengan kecekapan dan ketepatan yang tinggi dengan dibantu oleh sistem automasi. Walau bagaimana pun keadaan ini menyebabkan kesan yang sangat serius kepada sistem kuasa. Peralatan ini juga dikenali sebagai beban tidak sekata, dan dalam keadaan ia beroperasi peralatan ini akan memasukan denyut kepada sistem kuasa. Ini akan menyebabkan herotan terhadap gelombang sinus tulin dan menghasilkan harmonik dalam arus. Semakin tinggi kandungan harmonik, di mana kuantiti ini dikenali sebagai arus Total Harmonic Distortion (%THDi), semakin buruk kesan terhadap operasi kabel kuasa. Penebat untuk kabel kuasa mungkin akan rosak dan akan menyebabkan sistem pengagihan kuasa pincang tugas. Tesis ini melihat kepada saiz kabel kuasa yang terkesan kepada arus harmonik. Memandangkan nilai arus RMS meningkat kesan daripada harmonic, saiz kabel kuasa perlu dinilai semula bagi menampung tambhan kehilangan kuasa. Tesis ini juga akan melihat kaedah untuk memilih saiz kabel kuasa dibawah pengaruh operasi beban tidak sekata.bagi memudahkan analisis, tesis ini menggunakan sistem bekalan stabil 400V tiga fasa, dengan sistem 4 kabel model MATLAB. Beban yang dikenakan kepada sistem adalah tidak sekata dan kesan kepada %THDi kepada nilai arus RMS menghasilkan saiz kabel kuasa. Bagi menghasilkan dapatan yang lebih relative kepada keadaan sebenar, Politeknik Seberang Perai dipilih sebagai tapak kajian untuk medapatkan data. Hasil dalam tesis ini juga merangkumi kaedah untuk memilih saiz kabel kuasa Bersama arus harmonic. Keputusan yang diperolehi menunjukan bila %THDi meningkat, maka banyak kehilangan berlaku pada kabel. Sebuah persamaan matematik dihasilkan dimana persamaan ini akan mengambil kira %THDi. Hasil dapatan ini adalah penting untuk merekabentuk prancangan dan pengurusan sistem pengagihan kuasa dengan menjangka kesan yang terhasil daripada peralatan elektronik terhadap sistem.

Power Cable Sizing for Non-Linear Load Operation

ABSTRACT

Nowadays, there are a lot of electronic devices are used in industrials, offices, and residential homes. The reasons include these devices work around the clock with great precision and accuracy, with the help of automations and systems. However, this alarming development causes serious concern over power system safety and reliability. These devices are also known as nonlinear loads, and during operation they inject pulses into the power system. This causes distortions in the initially pure sinusoidal waveforms, and produces harmonics in current. The higher harmonic contents in current, which is quantified as percentage of Total Harmonic Distortion in current (% THDi), the worse impact to the power cable operation. The insulation of power cable may fail, thus results in catastrophic malfunction of power distribution system. This thesis looked into power cable sizing by taking harmonics in current into account. As the value of current RMS increases due to harmonics, the power cable size needs to be calculated to sustain the additional losses. This thesis looked into producing a method to select power cable size under nonlinear load operation. To simplify the analysis, this thesis considers a balanced, 400V three phase four wire system by MATLAB modelling. The load attached to the system is of nonlinear in nature, and the impact of %THDi to the RMS value of current produces the power cable sizing method. To be more reflective to actual site condition, Politeknik Seberang Prai was chosen as site for data logging. The finding of this thesis includes the method of selecting power cable size with harmonics in current. Result shows that the greater %THDi, more losses occurs at the cables. A mathematical expression created as a sizing equation with the inclusion of %THDi. The finding is important for design of power distribution system planning and management in anticipating the effect of electronic devices to the system.

INTRODUCTION

1.1 Introduction

Electrical power generation, transmission and distribution are stages for supply electricity to consumers at their home. The supply of stable electricity to customer is the basic of the economic development of many nation. Due to the need for nowadays living with various functions and daily living requirements, the supply of electricity must be more efficient and reliable. Interruption of electricity supplies will have given effects on many resources that will limit the quality of life for people and their economic productivity (Wan, 2010).

Distributing power to customer needs a transmission system. A transmission line having several parts to support the line. The protect the cable transmission lines it also contained with shield wires and lightning protection (Osman, Abidin, Abdullah, & Marsadek, 2015). The transmission line for high-voltage is typically made from copper, aluminum, copper-clad steel, or aluminum-clad steel. These lines are hanging from several kinds of supporting structures like porcelain insulators. The best method to hang a line to structures is the self-supporting steel poles. As the process of distributing electricity, losses will appear in power transmission. The losses mainly occur due to temperature heat in the transmission line conductors and dielectric, and in objects near the line (Gibilisco, 2011). Kalair et al. mentioned in his research, harmonics, in which the one distorts the voltage or current waveforms in the distribution power system. Distorted waveform can be measured by how many total harmonic distortion (THD). The reading consists the value of harmonic voltage (THDv) or current (THDi).

The usage of power electronic components in today electrical and electronic equipment will increases the non-linear loads (Tomy & Menon, 2016a). The Power supplies rectifier and home appliances are the sources of nonlinear loads. These non-linear loads draw non-sinusoidal currents from ac mains and make current distortion known as 'harmonics' (Biricik & Özerdem, 2011). Due to the harmonics, there will be increasing heat in the system and the performances of sensitive equipment can be affected. It is also causing malfunctioning and damaging some devices (Kesharvani, Singh, & Badoni, 2014),(Singh, Badoni, & Singh, 2012).

The temperature change of the physical layer of transmission cable is due to the existence of the harmonic voltage and current losses. The physical layer conductivity is affected by the change of temperature, which makes the changes in the harmonic losses. The harmonic losses in each physical layer are the heat source, transferring by heat conduction, convection, and radiation heat transfer according to the environment and cable material. The main influencing factors of power cable dynamic temperature are as follows: the initial cable temperature, the initial soil temperature, and load. The initial temperature the sensor temperature measuring system getting joins the model as the initial condition. The load impacts the harmonic current and harmonic voltage significantly (Chenying et al. 2016).

1.2 Problem Statement

The non-linear loads increasing in in many electronic equipment because there are power electronic components present. This increase will become a power quality problem. These loads can distort reading such as value voltage and current (Tomy & Menon, 2016b). The distortion current, is the most dangerous effect to power system. The power cables are one of the power system parameters that effected directly from the harmonic current.

In a 3-phase power system feeding linear loads, the current in the neutral conductor is nearly zero. When non-linear loads are used, the RMS value current increase in the neutral conductor and this will make neutral current is not zero (Fatehy & Ahmed, 2015). The RMS current in the neutral conductor can be up to 1.5-2 times higher than phase conductor. The high value current of the neutral cable conductor can reduce its lifetime (Velayudhan & Yameni, 2012).

The increasing of RMS current actually making power cable heat up resulting many defects. Several cases reported on power cable incidents. The burning power cable on Penang bridge in 2010 is an incident that show failure of power cable. From the Star Malaysia report, three power cables caught fire on the Penang Bridge, making nasty traffic jams for several kilometres on the bridge. The power cable was located under the bridge. Due to the burning cable, electrical distribution was interrupted especially in Bayan Lepas area (Vinesh, 2010).

The traditional method based on the basic model IEC-60287 standard used by several manufactures and researchers to calculated the Cable Ampacity and loss (Nguyen, Vu, & Tlusty, 2010). However, under non-linear load influence, this calculated data of cable ampacity will not reliable as there are harmonic current and the fundamental current produced by the cable. As the additional current harmonic in the system, losses supposedly increased to a certain magnitude. The resultant of new losses found; new cable sizing calculated to exceed the losses parameter.

1.3 Objective

The main priority of this thesis is making a new finding on the power cable sizing that operates under non-linear load conditions. To complete the thesis, there are several objectives the thesis should meet;

i. To produce correct sizing of the neutral cable under nonlinear load operation
ii. To establish a mathematical expression between THDi and RMS current.

1.4 Scope

The scope of the thesis is about the power cable sizing problem. The most significant influence to power cable is harmonics which the one distorts the voltage and current waveforms in the distribution power system. The temperature change of the physical layer is due to the existence of the harmonic voltage and current losses. The increase of harmonics current in power cable caused by consumer usage will be a concern in this thesis. Furthermore, the thesis will focus on the determination of proper sizing of a neutral cable under nonlinear, balanced load conditions using power cable in the LV distribution(415V) transmission line. Also, the thesis will focus on conducting simulation on power system distribution system validate the new proposal of cable sizing that meets the requirement under harmonic influence using MATLAB software due to the performance in analyzing power system distribution. The circuit simulation conducted using a diode rectifier which is feeding a resistive inductive load to simulate harmonic conditions in three phase system. The result of simulation considers only the *Triplen harmonics* the odd multiples of the third harmonic (h = 3, 9, 15, 21, …).

1.5 Contribution

the power cable size depends on several factors. The correct sizing of the power cable can solve the effect of existing harmonics in the power cable. To meet the best acceptable power cable sizing, several experiments can be conducted. The finding in the thesis can be used to design a proper power distribution system due to the demand for the non-linear load that presents by consumers.

1.6 Research Gap

The power cable sizing problem is made by the influence of harmonics which the one distorts the voltage and current waveforms in the distribution power system. Many researchers made their conclusion about harmonic to power cable but studies about the neutral cable are less. Thus, the determination of proper sizing of the neutral cable under nonlinear, balanced load condition using power cable in LV distribution(415V) transmission line will be conducted in this thesis.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

At this point a brief literature review on past researchers that connected to this thesis. Electric power becomes a major problem in every day. They became an important need, so to full fill that needs power provider must distribute from the generation side to the customer side using a power distribution system. The power distribution system contains of a power cable network to deliver electricity. The effect of power quality problem of harmonic towards power cable is dangerous. If it is flowing in a cable, it can be higher caused by nonlinear load. Current harmonic appeared from nonlinear load may cause an increment of temperature power cable.

To determine the suitable size of power cable under nonlinear load which can sustain a certain amount of current and certain amount of harmonic current (THD_i), finding a relationship current of cable and percentage THDi. At the end of the chapter, a summary is given to briefly conclude the literature review done for this thesis.

2.2 Power Distribution System

Electrical power generation, transmission and distribution are the stages of providing electricity to people. The electric has been importance to everyday life usage, making the supply demand for electricity inscreased for society.

The distribution system can be defined as a low voltage under a 40 kV system that is generate at the distribution substation and transfer power to loads using a primary distribution system. Traditionally, the primary distribution system will be a circulating network with several feeders (Heydt, 2010).

Electric generated deliver to the consumer using power transmission. As explained by Sule in his research, Power transmission is the work in which a block of electric that carried from the generating stations to distribution stations. After the transmission process it will continued with distribution process. At distribution stations, the line voltage is step down to lower voltage using a three-phase secondary transformer or single-phase primary transformer (Sule, 2010).

The most common medium used in power transmission is the power cable. Copper, aluminum and copper-clad steel is comman material for power cable. These lines are hanging using different types of supporting structures by strings of porcelain insulators. Self-supporting steel towers or poles is the most common of structures used. As the process of distributing electricity, losses will appear in power transmission. The losses mainly occur due to temperature heat in the transmission line conductors and dielectric, and in objects near the line (Gibilisco, 2011). The power cable losses due to temperature heat can be minimized by resizing power cable to meet the standard temperature heat.

2.3 Consumer Load Characteristics

The electrical loads commonly define by usage in industrial, commercial, and residential power systems (Yong & Xu, 2016). The voltage and current waveforms are purely sinusoidal and a circuit containing only linear elements, the current will flow proportional to the applied voltage. This makes the current flow is sinusoidal. In real life, current that flows along the load is nonlinear due to the applied voltage (Aziz, Nandi, Rahman, & Riadh, 2015).

2.3.1 Linear Load

As we know electric power system load are known as a load that generates current from the supply which is corresponding to the applied voltage (Hernández, Castro, Carpio, & Colmenar, 2017).

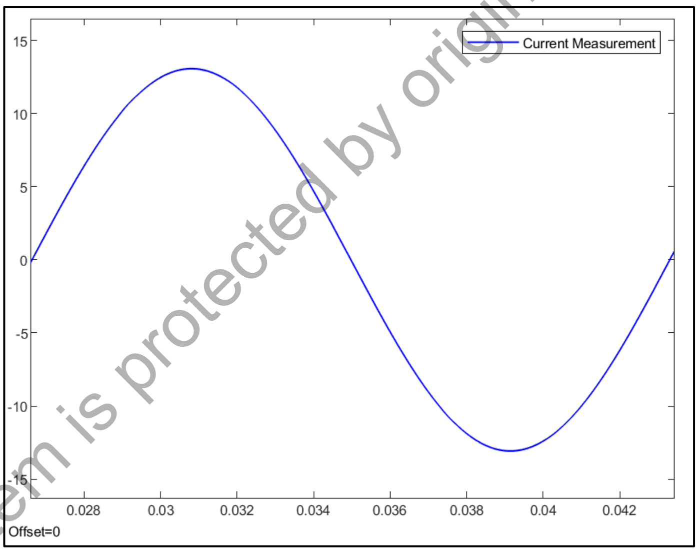

Figure 2.1 Current waveform of a linear load

A sample of current shape of a linear load can be represented in Figure 2.1. As the linear load are corresponding to the applied voltage, the waveform can be sinusoidal. The general equation of a sine wave can be used to describe a sinusoidal voltage mathematically:

$$V(t) = V_{Max}\, sin\big(\alpha(t)\big) = V_{Max} sin\,(\omega t) \tag{2.1}$$

$$I(t) = I_{Max}\, sin\big(\alpha(t)\big) = I_{Max} sin\,(\omega t) \tag{2.2}$$

2.3.2 Nonlinear Load

The non-linear loads in electrical and electronic equipment, because of power electronic components (Tomy & Menon, 2016b). The command usage of nonlinear loads like rectifier and home appliances in electrical distribution system. These loads giving un sinusoidal currents generate from ac supply and harmonics appeared as voltage and current distortion (Biricik & Özerdem, 2011).

Additional power losses corresponding with the RMS value of current and the flow of harmonics current inside of power cable, which lead to insulation temperature and shorter cable service life (Topolski, Warecki, & Hanzelka, 2018). The current distorted of a non-linear load are given in Figure 2.2.

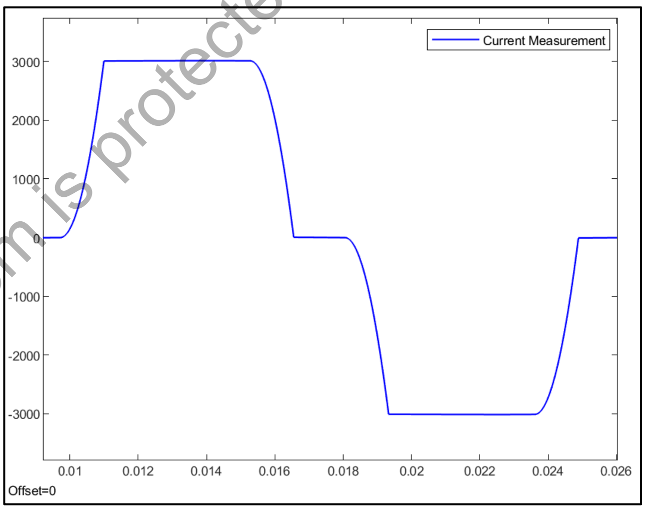

Figure 2.2 Distorted waveform of a nonlinear load

The nonlinear loads consist within the network create current and voltage harmonic. The harmonic frequencies can be several integers of the frequency which is introduced by fundamental frequency. The superposing of the harmonic currents contribute to the non-sinusoidal waveforms (Elazrag, Mnif, Bsissa, & Sbita, 2017). The mathematical expression of RMS for current can be shown as below:

$$i(t) = I_0 + \sum_{n=1}^{\infty} I_n \, sin(n\omega_0 t + \emptyset_n) \tag{2.3}$$

$$I_{rms} = \sqrt{\sum_{n=0}^{\infty} I_{n,rms}^2} \tag{2.4}$$

$$I_{rms} = \sqrt{I_0^2 + \sum_{n=1}^{\infty} \left(\frac{I_n}{\sqrt{2}}\right)} \tag{2.5}$$

The losses in the distribution system parts increases with present of harmonics. This will make an extra heating and useful life for the system parts can be jeopardize (Patil & Gandhare, 2012). These losses describe as Joule's losses, it happen when the current running inside a conductor. The basic words can be used to show the condition is the value of current square and conductor resistance (I^2R) (Topolski et al., 2018). Therefore, harmonic content in the current is related to the increase in losses. The relation of RMS current is direct to the percentage of Total Harmonic Distortion (THD_i). When THD_i increase higher, the RMS current also increase resulting the operating temperature also increase and cause additional losses.

2.4 Harmonics in Distribution System

The most important factor in the electrical distribution system is the power quality problem caused by many types of loads as explain by Aleem et al. Furthermore, harmonic pollution is developed by most electronic loads. Harmonic created caused by these electronic loads (Abdel Aleem, Zobaa, & Abdel Aziz, 2012). Kalair et al. mentioned in his research, harmonics, which the one distorts the waveforms in the distribution power distribution system. The usage of Total harmonic distortion (THD) are the effective value of voltage (THDv) or current (THDi). The heating value of the harmonics is created along with the fundamental (Kalair, Abas, Kalair, Saleem, & Khan, 2017).

2.4.1 Harmonics Source

From Aziz et al. in their research the harmonic came from many sources such as industrial, commercial, and residential facilities. Domestic loads, Industrial loads, Control devices is the basic sources of harmonics (Aziz et al., 2015). Figure 2.3 describes this classification clearly.

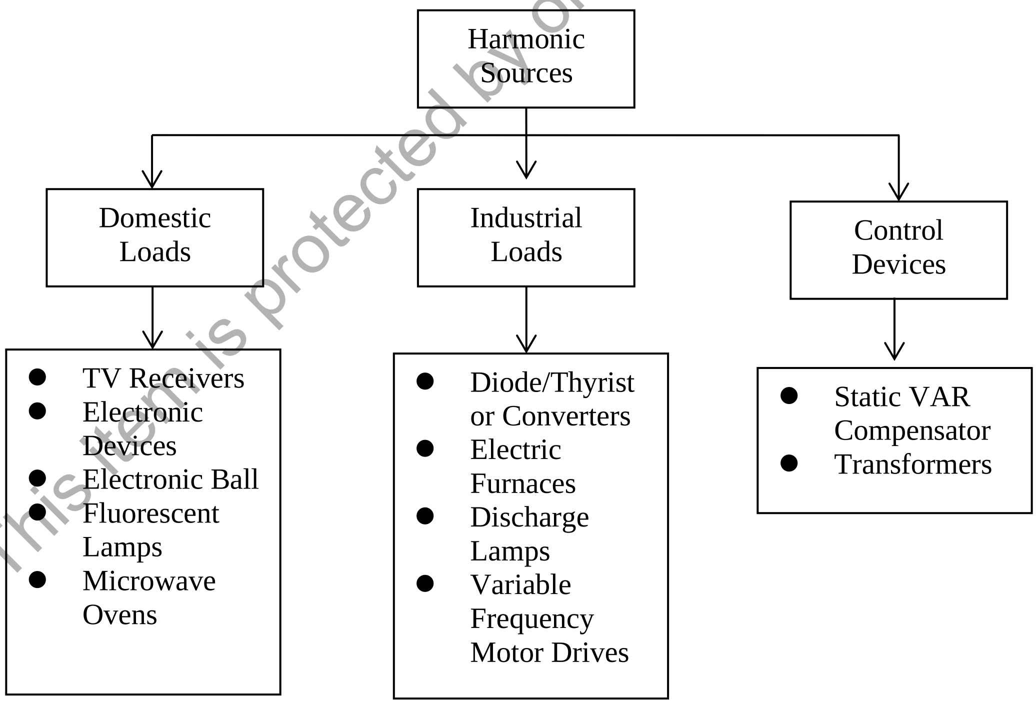

Figure 2.3 Classification of the source of harmonic