HARMONIC CURRENT EFFECT ON THE SIZING OF NEUTRAL CONDUCTOR OF LOW VOLTAGE DISRIBUTION NETWORK

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Harmonic Current Effect on the Sizing of Neutral Conductor of Low Voltage Distribution Network

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LIST OF ABBREVIATIONS

AC	alternating current
AH	Ajit Hiranandani
BS	British Standard
DC	direct current
DFT	Discrete FT
DSM	Department of Standard Malaysia
FA	Fourier Analysis
FS	Fourier Series
FT	Fourier Transform
FFT	Fast FT
HDF	harmonic derating factor
HS	harmonic signature
ICT	Information and Communication Technology
IEC	International Electrotechnical Commission
IEE	Institution of Electrical Engineers
IEEE	Institution of Electrical and Electronics Engineers
IT	Information Technology
MCMC	Malaysian Communications and Multimedia Commission

MS	Malaysian Standard
NEC	National Electrical Code
NEV	neutral earth elevated voltage
NFPA	National Fire Protection Association
NM	Neher-Meyer
p.u.	per unit
PVC	polyvinyl chloride
PC	Personal Computer
RCD	residual current device
RMS	root means square
SI unit	International Standard unit
SMPS	switched mode power supply
THD	total harmonic distortion
TNB	Tenaga Nasional Berhad
TRIAC	Triode for Alternating Current
UPS	uninterruptible power supply
VAR	voltage-ampere reactive
VSD	variable speed drive
WT	wavelet transform

XLPE	cross-linked polyethelene

LIST OF SYMBOLS

a_0	d.c. term for Fourier series
a_h	h-th harmonic term for Fourier series
α_h	harmonic signature for h-th harmonic order
b_h	h-th harmonic term for Fourier series
b_{harm}	ratio of neutral current to phase current
β_1	phase shit for fundamental waveform
β_H	phase shit for h-th harmonic order waveform
C	capacitor, µF
C_f	correction factor (heating effect method)
C-P_R	capacitor-resistive load pair
CS	conductor size
D_c	diameter of a conductor's conductor
f	frequency, Hz
f_k	function at k-th harmonic order for discrete signal
$f(t)$	signal function in time domain
$f(t_n)$	signal function in time domain at n-th sample in discrete signal
$F(f_k)$	discrete Fourier Transform function
$F(\Omega)$	signal function in frequency domain

γ_{3k}	ratio of harmonic current at h-th harmonic order to fundamental current
h	harmonic order, h = positive integer number
H	total per unit heat
i	current instantaneous value
i_1	fundamental current instantaneous value
i_H	total harmonic current instantaneous value
i_n	current instantaneous value at n-th for samples of periodic signal
I	current root means square value
I_b	full load design current
I_{rms}	current root means square value
I_0	direct current current root means square value
I_1	fundamental current root means square value
I_3	third harmonic current
$I_{3\text{-}p}$	third harmonic phase current
I_d	distortion current
I_{design}	design current (IEC method)
I_h	h-th harmonic current
I_H	total harmonic current root means square value
$I_{mn}(i)$	RMS value of rated current in the presence of harmonics for i^{th} cable

I_n	neutral current
I_{op}	operating current
I_p	phase current
I_{RMS}	design current (in heating effect method)
k	k-th harmonic order in discrete signal
k_s	coefficient in skin effect
k_p	coefficient in proximity effect
N	number of samples per period in discrete signal
ω	angular frequency $2\pi f$
$\mathrm{P_R}$	pure resistive load, W
r_{AC_h}	ratio of r_{ac} for h-th harmonic to r_{ac} for fundamental order
r_{ac}	a.c. resistance.
r_{dc}	d.c. resistance
r_{dc}’	d.c. resistance at maximum operation temperature
rsX	internal resistance for cable. X is A, B or C to indicate phase A, B or C,
S	distance for two adjacent cables (measured from centre to centre)
t	time, second
T	period
THD_v	voltage THD

THD_i	current THD
τ_{x}	metal resistance temperature coefficient at x degree celcius
ϑ	maximum operating temperature for cable
ϑ_A	ambient temperature
ϑ_{op}	operating temperature
Θ	phase angle
Θ_h	signal phase shift for h-th harmonic content
W	rotary matrix (in DFT)
x_s	coefficient in skin and proximity effects (?)
$y_s(h)$	skin effect at h-th harmonic order
$y_{sp}(h)$	proximity effect due to vicinity conductor at h-th harmonic order
$y_{cp}(h)$	proximity effect due to vicinity metallic conduit at h-th harmonic order

Kesan Arus Harmonik ke Atas Saiz Pengalir Kabel pada Rangkaian Pembahagian Voltan Rendah

ABSTRAK

Fenomena harmonik dalam sistem elektrik kuasa merupakan satu masalah yang telah lama tetapi pada hari ini mula kembali menjadi isu penting. Isu ini pelu diberi perhatian memandangkan penggunaan beban tidak linear, antara punca harmonik, meningkat terutamanya pada sistem voltan rendah. Meskipun demikian, kajian terhadap masalah ini dilihat semakin menurun. Pertamannya kajian dilakukan untuk melihat bagaimana arus harmonik mendatangkan kesan tertentu pada sistem beban seragam voltan rendah 3-fasa. Saiz kabel antara 2.5 mm^2 hingga 16.0 mm^2 telah dipilih. Pada tahap voltan ini, pangguna, samada terlatih atau tidak, begitu banyak berinteraksi dengan sistem. Ini menjadikannya penting untuk dikaji. Seterusnya kajian dibuat untuk memahami akhirnya arus harmonik mempengaruhi saiz kabel pengalir neutral. Adalah didapati peningkatan harmonik dalam sistem membawa kepada pertambahan arus neutral. Di samping itu, harmonik juga menyebabkan keupayaan mula membawa arus sesebuah pengalir menjadi berkurangan. Beberapa kaedah seperti kaedah pengurangan harmonik, kaedah kesan pemanasan, teknik yand diperkenalkan oleh Arthur dan Shanahan seterusnya oleh Chindris, serta kaedah daripada piawai IEC dan NEC telah dipilih bagi mendapatkan saiz pengalir neutral di bawah pengaruh harmonik. Keputusan yang didapati daripada setiap kaedah dianalisa serta dinilai keberkesanannya. Simulasi dan analisis telah dilakukan menggunakan Fast Fourier Transform yang dilaksanakan menggunakan MATLAB. Perbandingan bagi setiap keputusan terhadap pengiraan asas saiz pengalir juga telah dilakukan. Adalah didapati setiap kaedah, termasuk yang dicadangkan oleh badan piawai, mempunyai kekurangan sendiri. Analisa lanjut ke atas keputusan daripada dua kaedah terpilih membuahkan kaitan matematik antara harmonik dan saiz pengalir neutral. Satu daripada formula matematik tersebut dikenalpasti sebagai terbaik berdasarkan beberapa criteria. Menggunakan formula berkenaan, proses mengenalpasti saiz konduktor neutral boleh dilakukan dengan tepat, cepat dan menggunakan langkah pengiraan yang pendek.

Harmonic Current Effect on the Sizing of Neutral Conductor at Low Voltage Distribution Network

ABSTRACT

Power system harmonic phenomenon was an old problem, but with renewed and unprecedented threat. This matter deserved to get a refreshing look as proliferation of non-linear loads, one of the harmonic sources, has been increasing exponentially especially at low voltage network. Despite this fact, research into the problem seemed to be declining. Firstly the effect of harmonic current in low voltage, balanced three-phase system has been researched. Cable sizes involved in this study were 2.5 mm^2 to 16 mm^2. This level of system has been thought to be important since interaction between users, trained or not, and systems was commonly taken place. Secondly how harmonic eventually neutral conductor sizing has been studied. It has been confirmed that with the increased of harmonic content, neutral current value would be increased. In addition, neutral conductor initial ampacity has been found to be de-rated under the presence of harmonic. Harmonic derating factor, heating effect method, proposed techniques by Arthur and Shanahan, followed by Chindris as well as guidelines from IEC and NEC standards have been identified to be applied to determine the neutral conductor sizing under harmonic presence. Analysis of results from each method as well as their performance has been done. Simulation and analysis using Fast Fourier Transform has been carried out using MATLAB environment. Comparison between each method including comparison to the basic conductor sizing formulation has also been carried out. It has been concluded that each method, including those proposed by standards, had its own shortcomings. By further analysing results from two of the methods, two new mathematical relationships that correlate harmonic content and neutral conductor sizing have been developed. One of the two formulations has been identified as the best based on several criteria. This formula contributes towards correct, faster and shorter step of determining neutral conductor sizing under harmonic presence.

CHAPTER 1

INTRODUCTION

1.1 Power System Harmonic and Power Quality

Quality is a moving target that becomes finer as the society advancing. It has never been out of fashion. Power quality enjoyed the same evolution. Nowadays, more users asking for better power quality due to several reasons. However, sometimes the same users contribute to poorer power quality, the very opposite attribute they are looking at the first place.

One of the phenomena in power quality is harmonic (Bollen, 2003). One of the harmonic sources is non-linear loads. It is a class of load that mainly consists of the commonly used electronic-based equipments and other not so common loads such as electric furnace. It was and is now increasingly becoming a primary source of power quality problems, especially in the low voltage system.

Our temptations to use these non-linear loads keep on increasing. At the home level, entertainment set has become more complex with the emergence of audio and visual enhancer. Automation also has been the norm even for ordinary home, not to mention the craze for information and communication technology (ICT) ‘gadgets’. All these, and plus plenty other examples, are non-linear loads.

The same occurred in the work places. For example, more electronic-based equipments are utilised in general offices as well as in health care facilities than ever. The need to use energy-efficient apparatus in the name of the green movement and economic reason also introduces many harmonic-producing equipments such as uninterruptable power supply (UPS) and variable speed drive (VSD). Non-linear loads sometimes overwhelmingly overrun a workplace; an excellent example is computer centres. All these examples are evident about harmonics as an old problem, but with a renewed and higher level threat.

Like any other bad quality attribute, harmonic brings harmful influence to the environment it sits in – electrical power system (IEEE, 2009). Several modern equipments have been found to be susceptible to distortion in the power supply waveform caused by harmonic. These equipments may stall as the result of such poor condition of supply. Harmonic also has been blamed for unnecessary tripping. Tripping alone is already annoying, let alone tripping due to not-so genuine reasons. Harmonic also can physically attacks electrical equipments. Harmonic has been known to cause overheating in equipments and resulted in unwanted consequences.

That effect also extends to the safety-related; take an example of return path of a 3-phase alternating current (AC) supply system – neutral conductor. Under balanced condition, a neutral conductor carries zero return current. However, once harmonics gets in, neutral current will naturally build up. Adequate knowledge must be developed to understand the relationship between harmonic content in phase conductors and effect on neutral current.

Clearly neutral conductor is directly affected by the presence of the harmonic. Effect on a neutral conductor due to the presence of harmonic has been considered and inspected on this report. This matter is important as it also has safety consequences.

1.2 Problem Statement

The formal problem statement of this research indicates development for understanding the effect of harmonic presence on neutral current. Following the fact that harmonics influenced the overall neutral current, it is also important to determine whether the neutral conductor sizing also affected. The study focused on the low voltage system since it may affect the safety, well-being and economic aspect of the power supply system. This is important since at his level more users are directly in close contact with the system's environment.

1.3. Research Objectives

In this study, two objectives have been designated:

1. To investigate the sizing of the neutral conductor under the presence of harmonic.
2. To establish a relationship between harmonic and corresponding neutral conductor sizing selection.

1.4 Scope of Research

1. To investigate how harmonic phenomena affects neutral conductor sizing for a balanced loads system. However, all other ampacity derating factors were neglected.
2. Cable sizes investigated for this study were 2.5 mm^2 to 16.0 mm^2 due to the fact that this range of cable sizes has a unique neutral conductor sizing selection guideline as stated in standard IEC 60364-5-52.
3. Cables were assumed to be laid in non-metallic conduit located on wall surface.
4. A 50 m length of cable was also assumed for calculation purposes.
5. Fast Fourier Transform (FFT) had been chosen as the harmonic analysis technique due to its suitability for issues in this study.
6. MATLAB Release 2010b had been selected to do the simulation, analysis and related calculation.

1.5 Arrangement of Report

This report consists of five chapters. Several sub-chapters may make up the chapters. The arrangement of the chapters is as the following.

‘Chapter 1: Introduction’ consisted of the basis of this study. It began with a brief write up about the core issue of this research. In this chapter the research problem statement, objectives as well as scopes were introduced.

‘Chapter 2: Literature Review’ made up by relevant information, opinion, ideas, facts and theories from various reputable sources. Here, brief discussions on selected topics have also been incorporated. The emphasis has been on the issue of how harmonics presence is affecting neutral current. Effect on neutral conductor current carrying capability under the harmonic condition was another focus. Both issues were imperative in developing the harmonic-neutral conductor ampacity relationship.

‘Chapter 3: Research Methodology’ laid theoretical and mathematical framework used in the analysis for this study. Among the important points in this chapter was the derivation of harmonic-neutral conductor size formulation.

‘Chapter 4: Results and Discussion’ was the chapter where all the theories and formulae were called into practical application. All data that have been processed, transformed into information and developed into knowledge. Comparison between results from selected techniques were presented. Apart from that, discussion about the new mathematical formulation and its performance could also be found.

Chapter 5: Conclusion is where all the discussions and findings would be digested and understood. Available in this chapter was a list of contribution related to this. Also a lenghty discussion was carried out in highlighting how the objectives of the study were fulfilled. Finally, future direction of this thesis was drawn.