

Analysis of Neutral Cable Sizing for Harmonic Current Distribution

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Abstract

Power quality is an important field in an electrical power system. Current harmonic pollution can be a problem to the system directly. Source of harmonic can be produced from the electrical non-linear load, and it became increasing each day to a low voltage system. Non-linear loads were due to the semiconductor component in electrical equipment. Research on this problem nowadays is declining due to awareness of this matter. The research was conducted on a low voltage system with a balanced three-phase source equipped with a non-linear load. To study cable sizing, a sequence of fundamental current applied with several methods.

Keywords: - *Internet of Things, emergency switch, remote access*

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1. Introduction

Harmonic is a phenomenon that occurs in the real-life power system. The presence causes distortion of voltage and current waveforms and creates problems (Kalair et al., 2017).

Nowadays study on harmonics has become an important aspect to make power quality efficient but at the same time, harmonics appear from many types of loads used. The most significant loads creating harmonic was electronic component (Aleem et al., 2011). These types of loads are called non-linear loads (Tomy & Menon, 2016) and they can divide into domestic loads, industrial loads and control devices (Aziz et al., 2015).

In modern technologies, nonlinear loads draw from switch mode power supply (SMPS) converting AC to DC supply using bridge rectifier causing power quality problems.

The effect of harmonic presence can be seen where the value of root mean square (RMS) for voltage and current as it increasing heat in cable (Kusko, 2007; Desmet et al., 2008 & Das, 2015). Significant changes in the neutral cable where the increase of neutral current is proportional to total

harmonic distortion current (THDi) (Belitskiy et al., 2018). The effect also reducing power cable ampacity carrying capability (Gandhare & Patil 2013 & Nair & Nithiyananthan, 2016).

In the end, a new cable size is required to adopt the increasing current. In 3-phase 4 wire system, neutral cable was seriously affected by the harmonic presence, making the cable sizing increasing to 1.73 larger than phases cable (Arthur & Shanahan, 1996).

From the point of view of the power system, this article aims to understand the effect of harmonic presence in selecting cable size using several methods of calculation with harmonic presence.

2. Literature Review

2.1 Neutral Current Under Harmonic

The harmonic content has a huge effect on the power system network especially influence to the power system, neutral current. Harmonic can exceed neutral current, lead to the firing of the zero current and ignition in the existing

power supply system. The relation between neutral current with the presence of harmonic distortion shows the increasing of neutral current proportional to harmonic distortion as shown in Fig. 1.

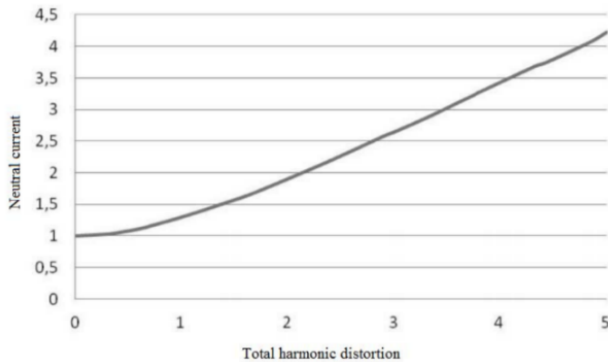


Fig. 1: Relationship of neutral current with total harmonic distortion (Belitskiy et al., 2018)

The three-phase four-wire distribution system has about the same amount of current in every 3-phase and neutral will have very little current. When a non-linear load is connected between the different phase conductors and the neutral conductor, the neutral conductor serves as the common return, and this may create an imbalance in the distribution system it produces harmonics causing damage of neutral conductors. Sometimes due to non-linear loads, the neutral current (I_n) may increase up to 1.73 times larger than the fundamental current (I_l) (Anuraj et al., 2015 & Stojanovic et al., 2009).

The 3rd harmonic current flow to neutral wire could create a production of heat due to I^2R losses throughout the distribution system. By assuming Fig. 2, the current drawn by the loads give a fundamental component of current with 3rd harmonic currents that are combining at the neutral point will be 3 times of the phase currents since they are equal phase and magnitude (Karthi et al., 2017 & Lowenstein, 2008).

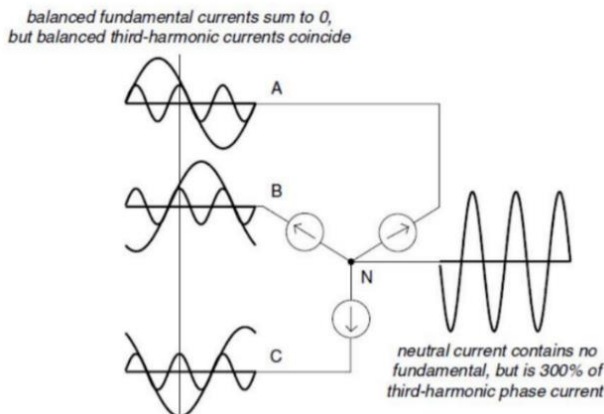


Fig. 2: High neutral currents in serving nonlinear loads (Karthi et al., 2017)

3. Methodology

Selecting cable sizing based on simulation result using 3 methods of calculation, the basic equation for cable sizing, technic proposed by Arthur & Shanahan (1996) and reduction factor by IEC Standard (Desmet et al., 2003 & IEC, 2001). Assuming cable characteristic used is polyvinyl chloride (PVC) type with B2 type installation as shown in Fig. 3, a multi-core cable in a conduit mounted on the wall, mention in IEC standard regulation (IEC, 2001).

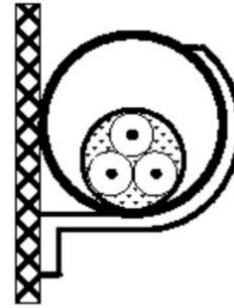


Fig. 3: Multi-core cable in conduit on a wooden as installation method type B2 (IEC, 2001)

3.1 Basic Equation for Cable Sizing

The basic calculation on determining cable provided in IEC Standard can be used to calculate the size of cable with the effect of harmonic. The calculation to cable sizing refers to the total ampacity of the cable. The expression of the calculation is shown in equation (1) (IEC, 2001).

$$I = A * S^m - B * S^n \quad (1)$$

Where I represent current carrying capacity, S is the nominal conductor size, A and B are coefficients and m and n are exponents referring to cable and method of installation.

3.2 Method Introduced by Arthur & Shanahan

The method introduced by Arthur & Shanahan (1996) focuses on calculating percentage I_n under 3rd harmonic content. The calculation is done with equation (2). The result for I_n can reach up to 173%.

$$\%Neutral = 300 \times \frac{\%THD}{\sqrt{10000 + (\%THD)^2}} \quad (2)$$

The result of I_n will then compare with Table 1 provided by IEC Standard to select suitable cable size for neutral under the harmonic influence.

Table 1: Multicore PVC cable sizing (IEC, 2001)

Conductor Size, mm ²	Installation Method, B2 Current (A)
1.5	15
2.5	20
4	27
6	34
10	46
16	62
25	80
35	99
50	118
70	149
95	179
120	206
150	-
185	-
240	-
300	-

3.3 Reduction Factor

The de-rating or also known as the reduction factor is the simplest way to calculate cable sizing by using IEC Standard 60364-5-52 as shown in Table 2. Using the standard, the simulation should assume the system is in a three-phase balance supply, only 3rd harmonic is to be considered, and cable is 4 core wire with neutral is the same material as the phase cable (Desmet et al., 2003).

Table 2: Reduction factors (Desmet et al., 2013 & IEC, 2001)

3 rd Harmonic content of line current, %	Reduction Factor	
	The value selected based on the line current	The value selected based on the neutral current
0-15	1.00	-
15-33	0.86	-
33-45	-	0.86
>45	-	1.00

The standard provided a standard correction factor for the current capacity of cable to calculate the capacity of the ampacity of the cable where the current in the neutral cable is multiplied to the standard provided. For 0-15% harmonic, there is no increase in the neutral cable as mentioned in the standard. For 15%-33%, the neutral cable is expected to be the same as a phase, but it must be multiplied with 0.86 de-rated factor. For 33%-45%, a determination must be made based on neutral cable but de-rated by factor 0.86. For harmonic above 45%, the cable size is determined absolutely by the neutral current because the de-rated factor is 1.0 (Desmet et al., 2013).

Using this method, the current ampacity for cables should be matched with the current carrying capacity table to select a suitable cable size. The table provided used as a standard in determining cable selection as shown in Table 1 (IEC, 2001).

4. Results and Discussion

Determining cable sizing for neutral could be done using several methods introduced by many researchers. Most of the methods are using formulation and calculation to find I_n as it influences by harmonic contents. The I_n obtains will then compare with a suitable available cable size provided by the commercial side. Within this research, three methods were used to obtain cable size by calculating and comparing. All these three method findings by calculation on I_n will then compared with cable sizing Table 1 as mentioned before.

4.1 Basic Equation for Cable Sizing

The basic cable size equation introduced by IEC Standard 60364-5-52 as mentioned in equation (1), the size cable was calculated. From all calculations in Table 3 and Table 4 with different I_l , there are several observations that can be seen. The measured in can be seen increased significantly. The increasing pattern is also followed by calculated size cable. By using the calculated cable size, the most suitable cable size could be selected.

Table 3: Cable sizing using equation (1) for $I_l=10A$

THDi (%)	I_n (A)	Calculated size (equation (1)) (mm ²)	Available size (mm ²)
0.59	0.1858	0.0013	1.5
5.08	2.285	0.0817	1.5
10.13	3.813	0.1904	1.5
15.61	5.284	0.3265	1.5
20.16	6.390	0.4471	1.5
25.09	7.458	0.5772	1.5
30.44	8.895	0.7723	1.5
35.08	9.917	0.9244	1.5
40.32	11.22	1.1336	1.5
45.03	11.75	1.2235	1.5
50.13	12.21	1.3037	1.5

Table 4: Cable sizing using equation (1) for $I_l=20A$

THDi (%)	I_n (A)	Calculated size (equation (1)) (mm ²)	Available size (mm ²)
0.52	0.2219	0.0017	1.5
5.02	4.614	0.2610	1.5
10.08	7.572	0.5918	1.5
15.03	10.12	0.9559	1.5
20.41	12.75	1.4004	1.5
25.32	15.09	1.8501	2.5
30.71	17.61	2.3881	2.5
35.07	19.69	2.8721	2.5
40.36	21.67	3.3650	4
45.00	22.88	3.6812	4
50.36	24.59	4.1469	4

From 2 types of results obtain between calculation size and selecting size from available sizing cable, there is a marginal difference in the finding. Observation found that the higher value of I_n and I_l resulting in a bigger size of cable selected corresponding to bigger THDi. Fig. 4 shows

the increase in size cable calculation using equation (1) compared to THDi.

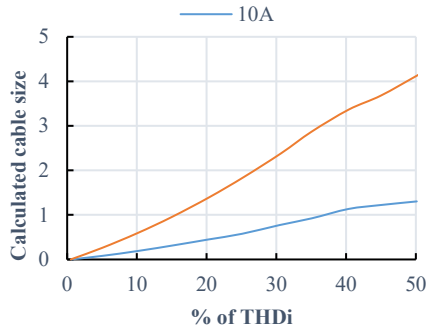


Fig. 4: Result of THDi cable size using equation (1)

4.2 Method Introduced by Arthur & Shanahan

Arthur & Shanahan (1996) introduce a method to determine cable sizing using equation (2) to find the percentage of I_n under the influence of 3rd harmonic content. The result of the I_n can be taken as a basis to find a suitable cable size. Table 5 and Table 6 show the result for cable sizing with a different value of I_r .

Table 5: Cable sizing based on Arthur & Shanahan (1996) for $I_r=10A$

THDi (%)	$I_{3(phase)}$ (%)	Calculated I_n (A)	Selected cable size (mm ²)
0.59	0.36	0.11	1.5
5.08	1.90	0.57	1.5
10.13	4.85	1.45	1.5
15.61	8.76	2.62	1.5
20.16	12.51	3.72	1.5
25.09	16.83	4.98	1.5
30.44	21.91	6.42	1.5
35.08	26.32	7.64	1.5
40.32	31.74	9.08	1.5
45.03	36.54	10.30	1.5
50.13	41.56	11.51	1.5

Table 6: Cable sizing based on Arthur & Shanahan (1996) for $I_r=20A$

THDi (%)	$I_{3(phase)}$ (%)	Calculated I_n (A)	Selected cable size (mm ²)
0.52	0.35	0.21	1.5
5.02	1.92	1.15	1.5
10.08	4.92	2.95	1.5
15.03	8.47	5.06	1.5
20.41	12.98	7.72	1.5
25.32	17.46	10.32	1.5
30.71	22.66	13.26	1.5
35.07	27.09	15.69	2.50
40.36	32.60	18.60	2.50
45	37.34	20.99	4.00
50.36	42.82	23.62	4.00

As shown in the result in Fig. 5, cable sizing will be bigger when an I_n increase. The increase does have a

connection with the content of I_1 and the value of 3rd harmonic content in the phase.

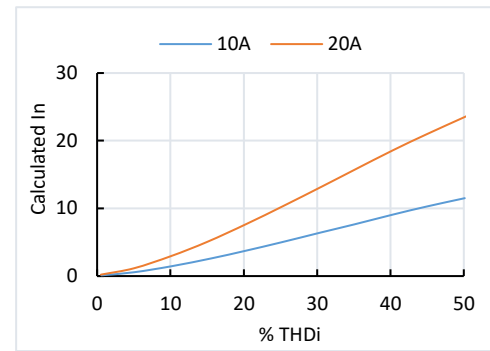


Fig. 5: Result correlation of calculated I_n with THDi

4.3 Reduction Factor

Determination of calculation in this method required rated current (I_r) and 3rd harmonic (I_3) of phase cable. Table 7 and Table 8 show the result. From the reduction factor, I_3 below 33% was calculated based on phase current. Beyond that calculation was made based on I_n using $3 \times I_3$. The result on the calculated current mark as new rated current ($I_{r(new)}$) latter used to find suitable cable size. For example, at $I_3 = 73.53\%$ the new rated current will be 22.06A, $I_{r(new)}$ for a basis $I_r = 10A$. Cable size of 4 mm² selected to transmit current safely.

Table 7: Cable sizing using reduction factor for $I_r=10A$

THDi (%)	$I_{3(phase)}$ (%)	I_n (A)	I_r (A)	$I_{r(new)}$ (A)	Selected cable size (mm ²)
0.59	0.36	0.1858	10	10.00	1.5
5.08	1.90	2.285	10	10.00	1.5
10.13	4.85	3.813	10	10.00	1.5
15.61	8.76	5.284	10	10.00	1.5
20.16	12.51	6.390	10	10.00	1.5
25.09	16.83	7.458	10	11.63	1.5
30.44	21.91	8.895	10	11.63	1.5
35.08	26.32	9.917	10	11.63	1.5
40.32	31.74	11.22	10	11.63	1.5
45.03	36.54	11.75	10	12.75	1.5
50.13	41.56	12.21	10	14.50	1.5

Table 8: Cable sizing using reduction factor for $I_r=20A$

THDi (%)	$I_{3(phase)}$ (%)	I_n (A)	I_r (A)	$I_{r(new)}$ (A)	Selected cable size (mm ²)
0.52	0.35	0.2219	20	20.00	2.5
5.02	1.92	4.614	20	20.00	2.5
10.08	4.92	7.572	20	20.00	2.5
15.03	8.47	10.12	20	20.00	2.5
20.41	12.98	12.75	20	20.00	2.5
25.32	17.46	15.09	20	23.26	4
30.71	22.66	17.61	20	23.26	4
35.07	27.09	19.69	20	23.26	4
40.36	32.60	21.67	20	23.26	4
45	37.34	22.88	20	26.05	4
50.36	42.82	24.59	20	29.87	6

Fig. 6 shows the analysis of $I_{r(new)}$ with %THDi. Note that all rated current was shown in the graph to see the difference of $I_{r(new)}$. As shown in the graph $I_{r(new)}$ calculated became to increase from I_r using the formula. The bigger the I_r , the bigger the $I_{r(new)}$ became. As a result, cable size selection became bigger.

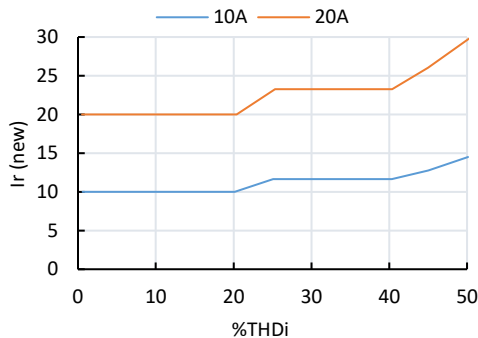


Fig. 6: Analysis of $I_{r(new)}$ with %THDi

4.4 Comparison Between All Method

Finding a new size of cable based on harmonic content is very crucial. The method selected to be used as a medium of selecting cable size was wisely done. Different methods resulting in different sizes of cable. Fig. 7 shows the comparison of cable size that have been selected for all method used in $I_l = 20A$. Only 20A current are shown for comparing purpose.

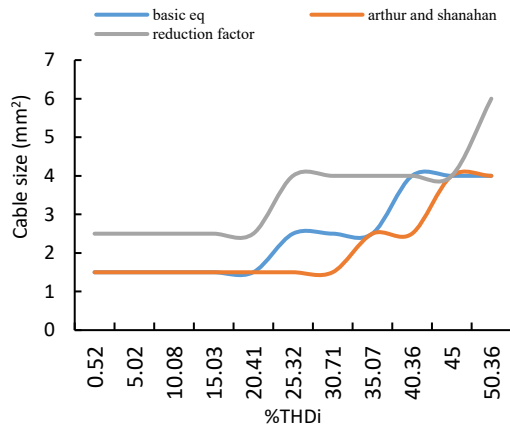


Fig. 7: Comparison of cable size for all methods

5. Conclusion and Recommendations

Modern electrical usage, there are many pollution effects of loads continue to grow in the electrical power system. Non-linear loads are one of sources entering the low power system due to the usage of the semiconductor device. The load introduces harmonic that jeopardizes the power system and it very important to understand the harmonic presence in the electrical system also expecting the effect it gives.

The study on harmonic presence to power system demonstrates the harmonic effect to the power cable in a 3-phase balanced system especially the effect changing on neutral cable. Results obtain showing the harmonic effect

in mathematical calculation and experimental results. It is proven that harmonic presence leads to produce a neutral current which may cause overrating to the cable.

Selecting size cable in this study focus on harmonic content which is the 3rd harmonic content, the most significant content among others. The increase of 3rd harmonic in neutral cable eventually increased THDi and it is parallel with studies before this showing the percentage of THDi neutral cable can increase up to 173% compare to phase. Recalculating on cable size must be done to support the increasing current.

The presence of harmonic also affected the cable current carrying capacity. As demonstrated in this work, neutral cable indicates if current increased. Therefore, the ability of cable reduces to carry ampacity and this brings bad consequences.

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