Neutral Conductor Size Selection for Balanced and Harmonic Infested Electrical System

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Abstract-Basically neutral currents are absent in a balanced 3-phase system. However, in the presence of harmonics, neutral currents are naturally flowing. These harmonic-rich currents have been known to negatively affect the current carrying capability or ampacity of the neutral conductor. The effect can be due to two factors. One is due to the magnitude of the harmonic neutral current itself and the other is due to the presence of high frequencies in the current. It has been shown that neutral current magnitude has a direct relationship with content of harmonics in the phase currents. High frequency currents, on the other hand, lead to derating of cable ampacity. This paper study the effect on sizing of neutral conductor due to both factors. The study was done based on several available methods using simulated data.

Keyword-balanced 3-phase system, cable derating, conductor sizing, harmonic analysis, neutral current

I. INTRODUCTION

For a balanced 3-phase system connected with a perfect sinusoidal supply, neutral current must be zero [1],[2]. However, the same system with a harmonic-rich supply will exhibit neutral current [3], [4]. Neutral current under this condition is a composite of triplen harmonic orders. Triplen harmonics are defined as 3h+3 orders, with h is integer 0, 1, 2, …. In fact, the existence of the current is due to the fact that triplen harmonic currents are accumulated and flown in neutral conductor [5],[6]. This condition takes place because triplen harmonics are in phase [5].

One of the characters of the neutral current created under the above situation is the dependency of its magnitude to harmonic contents in supply or phase currents [3],[7]-[9]. It has been shown that the neutral current can exceed phase current [3],[7],[8]. At this point, selection of neutral conductor size solely based on phase conductor may not be adequate.

The neutral current is also rich in harmonic contents. This is owed to the creation of the current from triplen harmonic currents from all phases. One of the effects caused by the harmonic current presence is cable derating [10]-[13]. Derating of cable, in turn, expose the cable to overloading. This situation can lead to breakdown of cable's integrity. Again selection of neutral conductor size must consider other factors on top of basing it on phase conductor.

This paper will present how these two factors eventually affect the determination of the neutral conductor. Using data from computer simulation, several selected methods for both factors will be employed. From the result, neutral cable sizing can be determined.

II. NEUTRAL CURRENT RELATIONSHIP WITH HARMONIC CONTENTS IN PHASE CURRENTS

Relationship of neutral current, I_n, and harmonic contents in phase currents, I_p, is strong. Another form to gauge the relationship is by measuring the ratio of neutral current to phase current and harmonic contents. By using this relationship, evolution of neutral current based on phase current over changes in harmonic contents can be seen much clearer. Efforts to describe the relationship mathematically have been done by [3],[7],[8]. According to Arthur & Shanahan (1996), the researchers described the relationship in term of THDi only and assumed that 3rd harmonics as the only important component while ignoring the rest of the harmonics. The relationship is shown as Eq. (1) [7].

$$\frac{I_n}{I_p} = 300 \times \frac{\%THD}{\sqrt{10{,}000+\%THD^2}}, up\ to\ 173\% \qquad (1)$$

Eq. (1) Valid until the ratio reaches 173%.

Fig. 1 shows the line of the curvilinear which is derived from Eq. (1). Several data were taken from electrical supply boards down to unit of computers. It was found that all data lie beneath the curvilinear. Therefore, Arthur and Shanahan (1996) proposed that the curvilinear is the minimum value for neutral current-phase current ratio at any given THD_i [7].

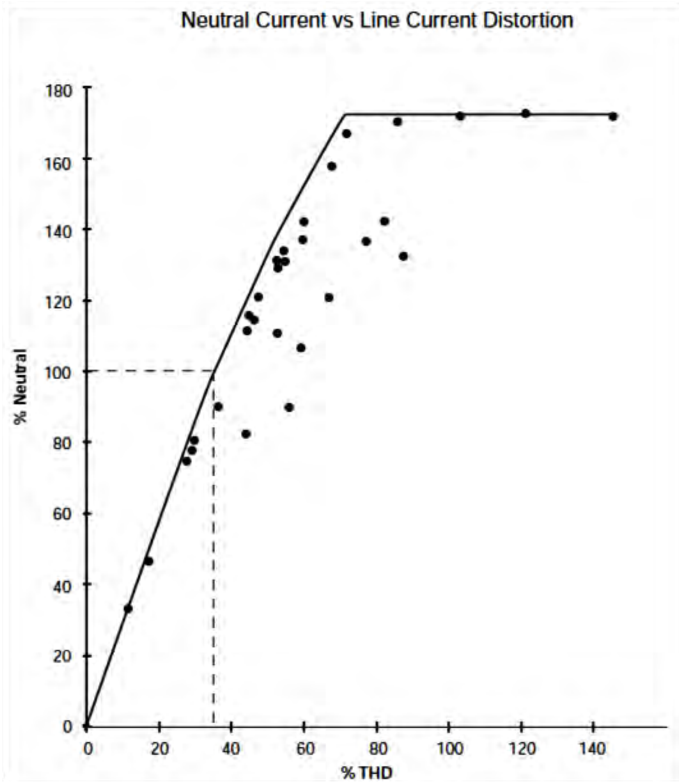

Fig. 1: I_n/I_p ratio versus THD_i [7].

Another study proposed a correlation that includes all triplen harmonic components. The relationship is described in Eq. (2) [3].

$$\frac{I_n}{I_p} = \frac{3\sqrt{\sum_{h=1}\gamma_{3h}^2}}{\sqrt{1+(THDi)^2}} = b_{harm} \tag{2}$$

The authors introduced term b_{harm} to represent I_n/I_p.

Where $\gamma_h = \frac{I_h}{I_1}$. (3)

When considering greater harmonic component only [3],

$$\frac{3\gamma_{max}}{\sqrt{1+(THDi)^2}} \leq b_{harm} \leq \frac{3}{\sqrt{1+(THDi)^2}} \tag{4}$$

With γ_{max} is the level of the most important triplen harmonics. If only third harmonic order is considered, the minimum value of Eq. (2) is exactly the same as Eq. 1.

Desmet et al. (2003) [8] derived a formulation between neutral current to phase current ratio relation with operator q. Operator q used fundamental current, I_1 as the reference so that $I_3=qI_1$, $I_5=q^2I_1$, $I_7=q^3I_1$ and so on. Considering only odd harmonics [8]

$$\frac{I_n}{I_p} = \frac{3q}{\sqrt{1+q^2+q^4}} \tag{5}$$

From Eq. 5, the ratio of the neutral conductor current and the phase current is maximum when q=1 which is equals to $\sqrt{3}$ [8].

A. *Cable Ampacity Derating*

In this paper, two methods are selected in order to demonstrate factors which affect derating of conductor ampacity. Skin and proximity effects are usually considered to be taken place simultaneously. An example of method using the effects was developed by Ajit Hiranandani which is harmonic derating factor (HDF) [13],[14].

One example of techniques which is using additional heating effect is developed by [15]. The method, simply called heating effect method, uses information such as harmonic content and cable resistance at different harmonic frequencies.

One established method of estimating derating of cable ampacity due to harmonic presence is selected as reference. The method is attached in IEC 60364-5-52 as a guide to select conductor size for both phase and neutral lines under the harmonic influence [11].

B. *Harmonic Derating Factor (HDF)*

HDF is a 3-step method using several factors in calculating the derating effect. The first step is what is called harmonic signature (HS). HS is given by Eq. (6) [15].

$$HS = \left(I_1, \alpha_h = \frac{I_h}{I_1}, \alpha_{h+1} = \frac{I_{h+1}}{I_1}, \alpha_{h+2} = \frac{I_{h+2}}{I_1}, \ldots\right). \tag{6}$$

Where h = harmonic order, equal to 2 and I_1 is fundamental current in phase conductor. For neutral conductor, current at h-th must be from neutral current while fundamental current is still referred to the component in the phase current.

The next step involved calculation of the skin and proximity effects. Its formulation is rather long. Alternative shorter, but limited calculation can be found in several sources [17] -[19]. Formulations of these effects are given in IEC 287-1-1 [16]. Skin effect, y_s, can be determined using Eq. (7) [16].

$$y_s = \frac{x_s^4}{194 + 0.8x_s^4}. \tag{7}$$

Factor x_s is given by Eq. (8).

$$x_s^2 = \frac{8\pi f}{r'_{dc}} 10^{-7} k_s. \tag{8}$$

Constant k_s is taken as 1 in [16], while f is frequency. Transformed direct current (d.c.) resistance (r'_{dc}) at maximum operating temperature is given using Eq. (9).

$$r'_{dc} = r_{dc}(1 + \tau_{20}(\vartheta - 20)). \tag{9}$$

Where ϑ is the maximum operating temperature, τ_{20} is a resistance temperature coefficient at 20°C that is 0.00393 l/°C for copper. While d.c. resistance (r_{dc}) for each conductor size can be determined using data sheet produced by manufacturers or other references [11],[20].

The proximity effect is made up of two sources. One is due to the proximity of vicinity conductors, $y_{sp}(h)$, while the other one is due to proximity to conduit, $y_{cp}(h)$ [21],[22]. In this paper only proximity effect due to vicinity conductors is considered. The proximity effect, y_{sp}, formulation is as Eq. (10) [13].

$$y_{sp} = \frac{x_p^4}{194 + 0.8x_p^4}\left(\frac{D_c}{S}\right)\left[0.312\left(\frac{D_c}{S}\right)^2 + \frac{1.18}{\frac{x_p^4}{194 + 0.8x_p^4} + 0.27}\right]. \tag{10}$$

With D_c is conductor diameter (mm), S is the distance between centres of the conductors in mm and x_p^2 is as given as Eq. (11) with k_p = 1 as per [13].

$$x_p^2 = \frac{8\pi f}{r'_{dc}} 10^{-7} k_s. \tag{11}$$

Finally, HDF can be calculated using Eq. (12) [10].

$$HDF = \left(1 + \sum_{h=2}^{\infty} \alpha_h^2 \beta_h\right)^{-1/2}. \tag{12}$$

Where α_h is as defined in HS and β_h is normalised harmonic ac resistance defined as Eq. (13).

$$\beta_h = {r_{ac}(h)}/{r_{ac}(1)}. \tag{13}$$

Where $r_{ac}(h)$ alternate current (a.c.) resistance at h-th harmonic. This factor can be determined using Eq. (14). While $r_{ac}(1)$ is a.c. resistance at fundamental frequency.

$$r_{ac}(h) = r'_{dc}(1 + y_s(h) + y_{sp}(h)). \tag{14}$$

An inverse of HDF value is then used to determine neutral current based on the initial harmonic-free design current. Formulation to calculate the neutral current is given by Eq. (15) [11].

$$I_m(i) = I_1(i) \times inverse\ HDF(i). \tag{15}$$

Where $I_m(i)$ is the RMS value of rated current in the presence of harmonics for i^{th} cable (conductor or current carrying component). While $I_1(i)$ is the RMS value of rated current at a fundamental power frequency as given by standard or manufacturers.

C. Heating Effect Method

Heating effect method is defined as per unit heat, denoted by *H*, for a given harmonic content. The formulation can be found in Eq. (16) [12].

$$H = \sum_{h=1}^{\infty} \left(\frac{I_h}{I_{RMS}}\right)^2 r_{ACh} \ . \tag{16}$$

Where, I_h is the h-th harmonic RMS current value, I_{RMS} is design current and r_{ACh} is the ratio of r_{ac} for h-th harmonic to r_{ac} for fundamental order. For a pure sinusoidal current waveform, it can be shown that heating effect is equal to 1, indicates no additional heating effect.

In order to choose a suitable cable size when heating effect is greater than 1, correction factor, C_f, is to be used. The correction factor is given by Eq. (17) [12].

$$C_f = \frac{1}{\sqrt{\sum_{h=1}^{\infty} \left(\frac{I_h}{I_{RMS}}\right)^2 r_{ACh}}}. \tag{17}$$

Where r_{Ach} is the ratio of a.c. resistance at *h*-th harmonic to a.c. resistance at fundamental frequency. It can be seen that if no harmonic current existed, C_f will be unity, which indicates to correction is needed. Application of C_f is the same as HDF. The inverse of the factor is used to calculate neutral current based on the initial design current [12]. This factor needs to be derated a further 0.8671 to cater for the heating effect due to the presence of an additional heat source [12].

D. Method IEC 60364-5-52

IEC produced an annex on the effect of harmonic currents on balanced 3-phase system [7]. The basis of the reduction factors, as the standard called it, is heating effect. However, it considers only third harmonic content in phase current to calculate the factors.

The factors are divided into four situations. The first is from 0 to 15% third harmonic content of the phase current. In this case, reduction factor of 0.86 is based on phase current. The second situation is for third harmonic content of 15 – 33%, followed by two other situations. Table I is the full tabulation of reduction factors.

TABLE I
Reduction factors in four-core and five-core cables [7]

Third harmonic content of I_n (%)	Reduction factor	
	Based on phase current	Based on neutral current
0-15	1.0	-
15-33	0.86	-
33-45	-	0.86
>45	-	1.0

III. ODD HARMONIC ORDER

For halfwave symmetrical waveform, only odd orders in FFT exist [23]. The waveform has the halfwave symmetrical character if function f(t) = -f(t+T/2). For a balanced but harmonic-infested 3-phase system, triplen harmonics flow as neutral current. Triplen are 3h+3 orders of harmonic, but leaving the even terms. Other harmonic orders cancelled out each other and do not appear in neutral current.

Among triplen harmonic orders, third harmonic (I_3) is single out as a most important one. Much research has shown that I_3 alone is enough to represent the harmonic analysis [7],[24]. Even standard such as IEC 60364-5-52 employs only I_3 in determining harmonic current influence on conductor sizing [11]. The analysis in this paper will follow this convention.

IV. SIMULATION CIRCUIT

In order to demonstrate harmonic presence in a balanced 3-phase system, a circuit as shown in Fig. 2 is employed. This circuit is commonly used to study the harmonic condition [25],[26]. Size of conductor for phase line is 2.5 mm^2. It is polyvinyl chloride (pvc), multicore cable. Each phase in the circuit is modelled using related internal impedance. Each phase is connected to a load which is powered using a single switch mode power supply (SMPS) model.

Initially, capacitor C and the load P_R pair are selected so that harmonic presence is very minimum or close to zero. Phase current at this stage is largely made of fundamental current, I_1. This is the initial design current when no harmonic is presented. The C – P_R pair is then progressively changed so that harmonic content is increased but at a constant I_1.

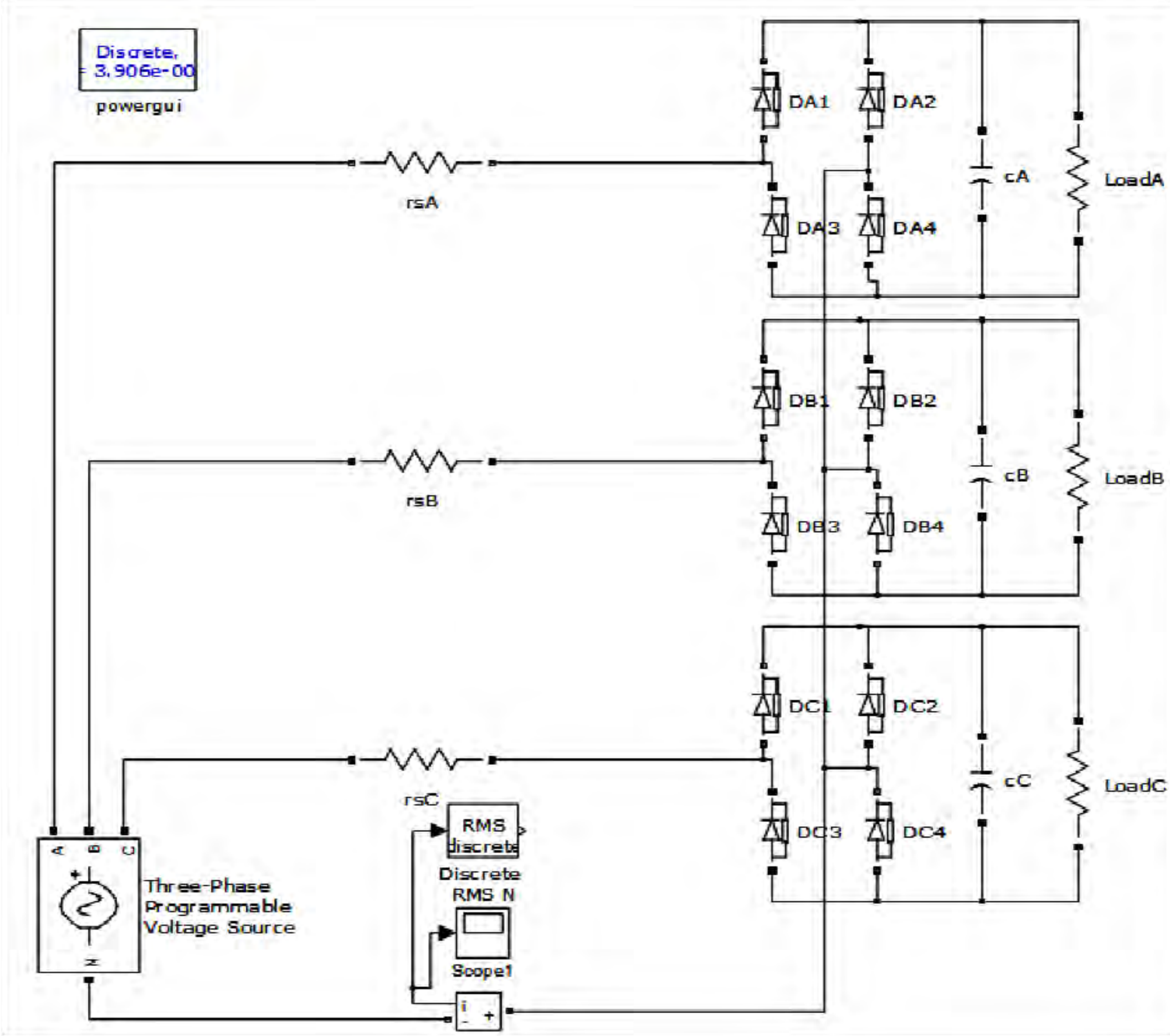

Fig. 2: Circuit used in the simulation

Harmonic analysis using Fast Fourier Transform (FFT) is also done using the same computer package. Related data, such as harmonic magnitude, phase angle can be presented using graphical or numerical mode. Examples of such representation of data are shown in Fig. 3 and 4. In Fig. 2 is the phase current waveform with the harmonic presence of C – P_R pair of (2000 µF, 2687 W). Notice that the waveform is Fig. 2 has halfwave symmetry.

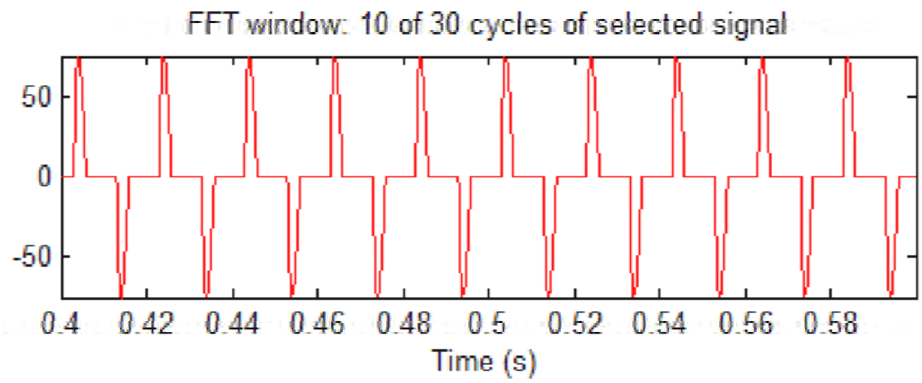

Fig. 3: Waveform for pair C-P_R (2000 µF, 2687 W).

Fig. 4 is the FFT analysis of Fig. 3. As can be seen, only odd-harmonic orders exist in phase currents as expected. Apart from the fundamental order, third harmonic has the second highest magnitude.

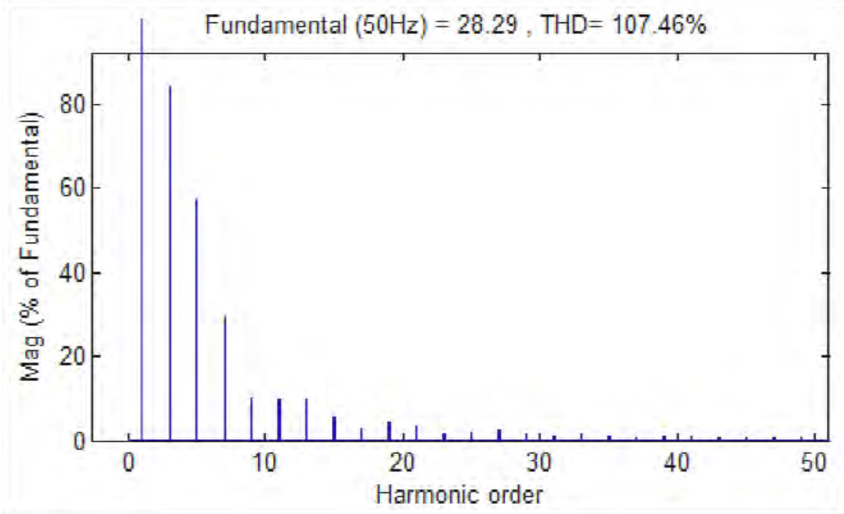

Fig. 4: FFT spectrum for waveform in Figure 3.

Fig. 5 is the resultant neutral current for phase currents in Fig. 3 while Fig. 6 is the FFT spectrum of neutral current for phase current waveform shown in Fig. 5. As anticipated, only triplen harmonic orders present.

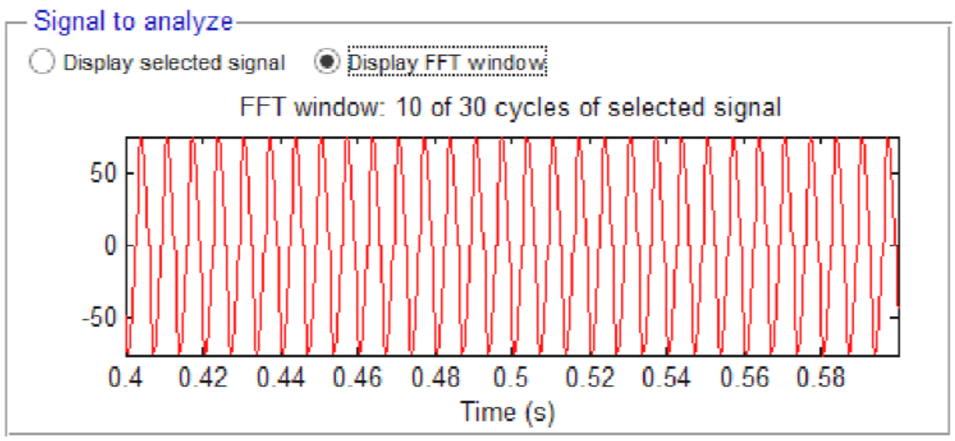

Fig. 5: Resultant neutral current for phase currents in Fig 4.

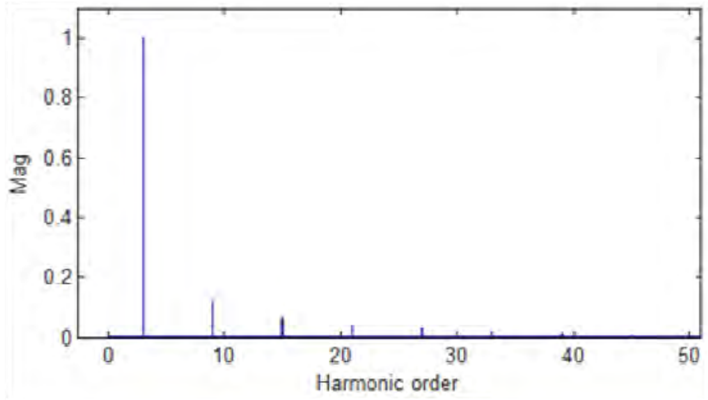

Fig. 6: FFT spectrum of neutral current in Figure 4.

V. RESULTS

Table II is the result of the simulation using several C-P_R pair selections. Notice that by increasing C and adjusting PR so that I_1 is constant at 20 A, current total harmonic distortion (THDi) percentage is increasing. In other words harmonic content is becoming larger. It can also be observed that third harmonic current in phase current is also growing as THDi becomes larger.

Due to the existence of harmonic current, neutral current gaining its value as THDi keeps on increased. Using this information alone, at some point 2.5 mm^2 conductor, which has an initial current carrying capacity of 20 A [11],[20] must be replaced with bigger cable size. The selection of the suitable cable size is done using [11],[20]. However, caution must be made that according to existing theory, conductor ampacity will be derated due to the existence of harmonic. Therefore, the stated cable size on the most right hand-side column in Table II may not be suitable after all.

Note that that suitable cable sizes for neutral current lower than 20 A are selected to be 2.5 mm^2. This is to follow the convention that for a system with phase conductor is equal or lower than 16 mm^2, no reduction in neutral conductor is allowed [11]. Table II follows the guide set out by the standard.

TABLE II
C-P_R pair selection with constant I_1

THDi [%]	Third harmonic in phase current	Neutral current [A]	Suitable cable size [mm^2]
6.05	2.38	2.2890	2.5
9.05	4.13	3.4630	2.5
15.64	8.90	6.3480	2.5
22.73	14.93	9.7810	2.5
26.26	18.24	11.7000	2.5
29.75	21.63	13.7100	2.5
36.53	28.39	17.9500	2.5
42.74	34.79	21.9400	4.0
45.69	37.78	23.7300	4.0
52.42	44.54	27.6900	6.0
58.40	50.28	31.0400	6.0
63.58	55.07	33.9400	6.0
68.17	59.07	36.4200	10.0
72.22	62.43	38.5500	10.0
75.83	65.26	40.3700	10.0
79.04	67.67	41.9100	10.0
84.49	71.46	44.2800	10.0
88.84	74.27	45.9200	10.0
93.97	77.27	47.4600	16.0
107.46	83.79	50.8500	16.0

A. Harmonic Derating Factor (HDF) Method

Table III to Table VII are the calculation related to HDF. Table III is the HS for the neutral conductor. Notice that at as THDi getting bigger, so is the HS. From the theoretical introduction of HDF, HS covers for the whole spectrum of harmonic orders. However, for this paper only α_3 is considered.

TABLE III
Harmonic signature (HS) for 2.5 mm^2 neutral conductor

THDi [%]	I_1 [A]	α_3
6.05	20	0.071
9.05	20	0.124
15.64	20	0.267
22.73	20	0.448
26.26	20	0.547
29.75	20	0.649
36.53	20	0.852
42.74	20	1.044
45.69	20	1.134
52.42	20	1.336
58.40	20	1.508
63.58	20	1.652
68.17	20	1.773
72.22	20	1.873
75.83	20	1.958
79.04	20	2.030
84.49	20	2.144
88.84	20	2.227
93.97	20	2.317
107.5	20	2.508

Table IV is the Transformed d.c. resistance, r'_{dc}, at maximum operating temperature. Original r_{dc} at 20^{o}C are given [11],[20]. Maximum operating temperature of 70^{o}C is taken from [20]. The value is for copper conductor with pvc as cable insulation material. In this paper, the length of the cable is assumed to be 50 m.

TABLE IV
Transformed d.c. resistance, r'_{dc}, at maximum operating temperature

Cable [mm^2]	r_{dc} at 20^{o}C [Ω/km]	r'_{dc} at 70^{o}C [Ω/km]
2.5	7.41	0.0089
4.0	4.61	0.0055
6.0	3.08	0.0037
10.0	1.83	0.0022
16.0	1.15	0.0014

Table V is the skin effect for 2.5 mm^2 cable. The calculation was done for all triplen harmonic from third to forty-fifth and includes fundamental frequency. Notice that the effect has higher value for higher harmonic frequencies. The differences of skin effect values between first few harmonic orders are quite high. For example, the value of the effect between third and fundamental order is about nine times. These differences are progressively becoming smaller at higher frequencies.

The same pattern can be observed for proximity effect where its value is getting larger as the frequency is getting bigger.

TABLE V
Skin effect, y_s and proximity effect, y_{sp}, for 2.5 mm^2 cable

Frequency [Hz]	50	150	450	750	1050	1350	1650	1950	2250
y_s	1.0E-6	9.4E-6	8.4E-5	2.3E-4	4.6E-4	7.6E-4	1.1E-3	1.6E-3	2.1E-3
y_{sp}	1.8E-6	1.6E-5	1.4E-4	4.0E-4	7.9E-4	1.3E-3	1.9E-3	2.7E-3	3.6E-3

Table VI is the result of HDF calculation. Using HDF, neutral current can be determined. Subsequently, cable size can be calculated using [11]. Available cable size is the most suitable nearest size. For example, for calculated 6.6 mm^2 cable, the nearest suitable size would be 10.0 mm^2.

Note that as THDi getting bigger, larger neutral cable size needs to be used. This is consistent with the effect of harmonic content on the neutral current as shown in Table II. However, HDF calculation includes skin and proximity effect. It can be seen that using this method, proposed final cable sizes (the most right hand side of Table VI are found to be different from Table II.

TABLE VI
HDF value and calculated cable size

THDi [%]	HDF	Calculated cable size [mm^2]	Available cable size [mm^2]
6.05	0.99747	2.4699	2.5
9.05	0.99241	2.4909	2.5
15.64	0.96617	2.6046	4.0
22.73	0.91262	2.8640	4.0
26.26	0.87727	3.0588	4.0
29.75	0.83886	3.2955	4.0
36.53	0.76127	3.8736	4.0
42.74	0.69179	4.5429	6.0
45.69	0.66147	4.8949	6.0
52.42	0.59911	5.7724	6.0
58.40	0.55258	6.6044	10.0
63.58	0.51779	7.3596	10.0
68.17	0.49132	8.0319	10.0
72.22	0.47090	8.6201	10.0
75.83	0.45480	9.1343	10.0
79.04	0.44194	9.5812	10.0
84.49	0.42271	10.3180	16.0
88.84	0.40963	10.8722	16.0
93.97	0.39625	11.4906	16.0
107.5	0.37040	12.8567	16.0

B. Heating Effect Method

Table VII is the result of cable size using the heating effect method. According to the technique, cable ampacity is derated due to harmonic presence. It is then further derated by a factor due to addition heat released by neutral conductor.

It can be seen in Table VII that cable sizes proposed for lower THDi is 1.5 mm^2. This is to be consistent with the smallest conductor size for power and lighting circuit [11]. Nevertheless, this method shows that smaller cable is possible to be used as a neutral conductor at lower THDi.

TABLE VII
Cable size determination using the heating effect method

THDi (%)	Calculated conductor size according to heating effect method	Available conductor size (mm^2)
6.05	0.0384	1.5
9.05	0.0964	1.5
15.64	0.3458	1.5
22.73	0.8189	1.5
26.26	1.1427	1.5
29.75	1.5181	2.5
36.53	2.3880	2.5
42.74	3.3502	4.0
45.69	3.8448	4.0
52.42	5.0558	6.0
58.40	6.1845	10.0
63.58	7.1979	10.0
68.17	8.0934	10.0
72.22	8.8730	10.0
75.83	9.5519	10.0
79.04	10.1404	16.0
84.49	11.1078	16.0
88.84	11.8334	16.0
93.97	12.6414	16.0
107.46	14.4205	16.0

VI. COMPARISON

Table VIII is the comparison of results from two methods together with calculation from technique available in standard IEC 60364-5-52.Essentially, HDF results are about the same with those from IEC except after THDi equal to 42.74%. At this point and beyond, HDF is generally proposing bigger cable sizes than IEC at smaller THDi. For example, at HDF is predicting a suitable 10 mm^2 cable at for a system with THDi of 58.4%, while IEC arrived at the same size only at THDi equal to 68.17%.

For heating effect method, it is generally proposed greater cable size, especially for THDi equal or more than 52.42% compared to results from IEC. This method calls for the neutral conductor of the size of 6.0 mm^2, 10.0 mm^2 and 16.0 mm^2 at 52.42%, 58.40% and 79.04% THDi respectively. This is way earlier than predicted by IEC at 58.40%, 68.17% and 93.97% THDi for the same cable sizes.

However, this technique allows for smaller cable size for lower THDi. For example 1.5 mm^2 conductors are proposed by the method for THDi of 26.26% and lower even though IEC has called for 2.5 mm^2 or even the larger 4.0 mm^2 cables. This method also allowed 2.5 mm^2 cables to be used as a neutral conductor for THDi of 29.75%. Compare this to IEC which stated that the suitable conductor size as a neutral conductor at this level of THDi must be at least 4.0 mm^2.

TABLE VIII
Comparison of results of HDF, heating effect method and IEC

THDi (%)	Cable size according to different methods (mm^2)		
	HDF	Heating effect	IEC
6.05	2.5	1.5	2.5
9.05	2.5	1.5	2.5
15.64	4.0	1.5	4.0
22.73	4.0	1.5	4.0
26.26	4.0	1.5	4.0
29.75	4.0	2.5	4.0
36.53	4.0	2.5	2.5
42.74	6.0	4.0	4.0
45.69	6.0	4.0	4.0
52.42	6.0	6.0	4.0
58.40	10.0	10.0	6.0
63.58	10.0	10.0	6.0
68.17	10.0	10.0	10.0
72.22	10.0	10.0	10.0
75.83	10.0	10.0	10.0
79.04	10.0	16.0	10.0
84.49	16.0	16.0	10.0
88.84	16.0	16.0	10.0
93.97	16.0	16.0	16.0
107.46	16.0	16.0	16.0

VII. DISCUSSIONS AND CONCLUSIONS

The method by IEC has been introduced quite a while now. It has been adopted in Malaysian standard as MS IEC 60364-5-52: 2003 [27]. From the result, cable sizes proposed by this method are the same as those calculated using formulations by [7] and [3] (if only third harmonic is considered). These formulations have not taken into account any derating factor. They only dealt with the evolution of neutral current due to the simple arithmetic summation of triplen harmonic currents from phase conductors.

HDF method, on the other hand takes into account effects related to higher frequencies – skin and proximity effects. From the calculation, it is clear that those effects are not negligible. The comparison made between this method and IEC shows that bigger cable size is needed at certain THDi in order to overcome the derating of ampacity due to skin and proximity effects. However, this method requires a lengthy calculation process.

Heating effect technique predicts how much additional heat will be dissipated at certain harmonic content and proposed method for compensation. This compensation is necessary so the selected cable size could be transmitting additional current safely. This method also takes into account the fact that additional vicinity current carrying conductor, in this case neutral conductor, will derate the overall ampacity of cables in the circuit.

Cable sizes determined by heating effect method are generally bigger than IEC. However, at lower THDi, this method allows for the smaller neutral conductor to be used. This is actually consistent with the fact that at lower harmonic contents, only small neutral current exists. The heating effect technique also is found to be consistent with results from HDF despite the former has a simpler calculation process. Results from this method are also found to be consistent with IEC. The word consistent here means that the results from this method are better than IEC in term of taking into account derating factor of conductor’s ampacity due to the presence of harmonics.

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