

# **EFFECT OF THD TOWARDS TEMPERATURE PROPERTIES OF POWER CONDUCTOR UNDER HARMONIC INFLUENCE**

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# Effect of THD towards Temperature Properties of Power Conductor under Harmonic Influence

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**Abstract** – Power delivery system is having a great effect upon the existence of harmonic in power system. The ability of harmonic to influence some variable on power cable such as temperature and current has been a main issue regarding the safety of power cable as many electronic types of equipment are being introduced today, compared to the past. They are nonlinear loads which tend to inject harmonic into whenever system they are in. Harmonic current tends to raise current magnitude into certain level and that adds extra burden of heat to the power cable. This paper investigated power loss component in a power cable, where an experiment designed to enable the component of harmonic being injected at will. The effect of THD towards temperature of the cable is analyzed and documented in form of graphical evidences. The pattern of current and temperature raise also taken into account and analyzed with great interest.

**Keywords:** Conductor, Current, Harmonic, Non linear load, Temperature, THD

## I. INTRODUCTION

There is an immense need to redefine the safety of power distribution system nowadays as human's activities become more complicated and hectic. Many inventions evolved around electronic devices that being used for many purposes, including lightings, independent power supplies, and many more. The problem is that, these electronic devices are the nonlinear loads, which are generally associated with harmonic which in turn, yield high current in conductors [1]. By doubling the number of those electronic loads to meet today's modernization needs, means the problem of harmonic current in power system has worsen.

The power distribution system currently designed as to suit the yesteryears' requirements, including the limitation of current that the power cables are able to contained, and the heat issues resulted off harmonic problem that the system addressed are also measured at a time where there were less electronic devices. In short, the system only applicable perfectly to the less harmonic content or has limited margin of capability to take the additional harmonic current magnitude and resulted heat, unlike the current situation where almost everything is related to electronic devices and more harmonic content.

Indeed there must be an urgent need now to readdress the capability of power distribution system to contain harmonic

influence. Therefore, this paper conducted an experiment to look at the effect of raised current and harmonic content (THD). The final variable that relates current and THD content is the temperature of the cable, which is measured at the interval of current and THD changed. A pattern of temperature raise should be recognized and identified. It is important to examine whether high THD content in a power cable would jeopardize the system. It is essential to examine such variable, so the power distribution system reliability remains high and exclusive.

The concept of harmonic distortion, nonlinear load characteristics, and harmonic loss in conductor are highlighted at the early part of the paper, followed by results and discussion.

### A. Total Harmonic Distortion

The current magnitude in RMS value can be determined as:

$$\begin{aligned} I_{rms} &= \sqrt{\frac{1}{T_h} \int_0^{T_h} (v_h(t))^2 dt} \\ &= \sqrt{\frac{1}{T_h} \int_0^{T_h} [I_{max\ h} \sin(h\omega t + \alpha_h) dt]} \\ &= \sqrt{\frac{1}{T_h} I_{max\ h} \left[ \int_0^{T_h} \frac{1}{2} (1 - \cos 2h\omega t) dt \right]} \\ &= I_{max\ h} \sqrt{\frac{1}{T_h} \left[ \frac{1}{2} t - \frac{\sin 2h\omega t}{4\omega} \right]_0^{T_h}} \end{aligned} \quad (1)$$

The RMS value of current of all frequency can be determined as:

$$I_h = \frac{I_{max\ h}}{\sqrt{2}} (h = 1, 2, 3 \dots m) \quad (2)$$

$$\begin{aligned} I &= \sqrt{\left[ \left( \frac{I_{max1}}{\sqrt{2}} \right)^2 + \left( \frac{I_{max2}}{\sqrt{2}} \right)^2 + \left( \frac{I_{max3}}{\sqrt{2}} \right)^2 + \dots + \left( \frac{I_{maxm}}{\sqrt{2}} \right)^2 \right]} \\ &= \sqrt{\sum_{h=1}^m \left( \frac{I_{max\ h}}{\sqrt{2}} \right)^2} \end{aligned} \quad (3)$$

Individual Harmonic Distortion (IHD) is the basic component, where the total of IHD makes up to the Total Harmonic Distortion (THD). IHD at such harmonic frequency

is the RMS of the harmonic under consideration to the rms value of the fundamental.

$$IDH_i = \frac{I_h}{I_1} \times 100\% \quad (4)$$

Thus, the Total Harmonic Distortion (THD) is the total of each IHD:

$$THD_i = \frac{\sqrt{(I_2^2 + I_3^2 + I_4^2 + \dots + I_m^2)}}{I_1} \times 100\% \quad (5)$$

$$= \frac{\sqrt{\sum_{h=2}^n I_h^2}}{I_1} \times 100\%$$

Total Harmonic Distortion (THD) in short, is used to show how badly a waveform is distorted with respect to a pure sinusoidal sine wave [2]. The distorted current or voltage may result in losses and jeopardize the operation of some electrical and electronic components.

### C. Nonlinear Load Characteristic

The experiment uses triple single phase rectifiers, which is configured to have filtering capacitor at the dc end. The term 'non-linear' is defined at this point, as the waveform of the input current is significantly distorted compared to the ideal sinusoidal current waveform [3]. The input current waveform is a result of a switching action that takes place between the rectifier diodes and the dc bus capacitors. The rectifier diodes are forward biased only when the input voltage exceeds both the capacitor voltage plus the forward voltage drop required by the diodes.

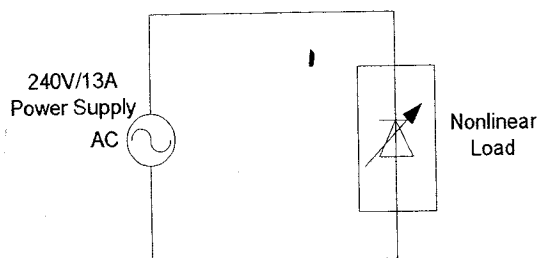


Fig. 1. Nonlinear load

Fig. 1 shows one particular example of a nonlinear load that is a rectifier. As a pure sinusoidal sign enters the diodes, the current will be distorted as the switching of the diodes take place.

### E. Losses Occurred as Harmonic Presence in Conductors

Primarily, the harmonic currents caused the increase of ohmic losses of the current carrying conductor. In turn, this event is due to:

- An increase in current carrying components

- An increase in conductor resistance due to frequency dependence – skin effect and proximity effect [4].

Harmonic characteristic includes higher frequency of current magnitude and substantially resulted in further increase of conductor operating temperatures. A conductor which carries high alternating currents would result with the emergence of skin effect. The distribution of current inside the conductor also is not even through out its cross sectional area [5]. Circular conductors are prone to skin effects because of high frequency of harmonic currents. The centre portion of the conductor would be enveloped by greater magnetic flux, forcing the current density to be much on the conductor surface. This extra concentration of current caused skin effect which would contribute greatly towards conductor heating and further damages the insulation of the conductor, and finally the system itself.

## II. RESULT

The desired design of experiment to observe the effect of harmonic content (THD) towards temperature of power conductor includes the source or injection of harmonic by any chosen nonlinear load, the adjust-ability of harmonic (THD) by exploiting the dc filtering capacitor, temperature measuring device as such a thermo coupler, and other measuring apparatus.

A single phase rectifier is used to play the nonlinear load role, and it is extremely important to mention the characteristics of such nonlinear load. Single phase electronic power supplies are typically configured with a front-end full-wave bridge rectifier. A significant dc end filtering capacitance follows at the other end [4]. The input current waveform would be significantly distorted as the results of a switching action that takes place between the rectifier diodes and the dc bus capacitors. Switching loads on and off during part of near the peak of the voltage waveform results in short, abrupt, nonsinusoidal current pulses during a controlled portion of the incoming peak voltage waveform. These abrupt pulsating current pulses introduce unanticipated reflective currents (harmonics) back into the power distribution system. The resulting harmonic current do operates with different frequency rather than fundamentals.

A set of variable capacitors are connect at the load end of the single phase rectifier, so that the capacitance size of filtering capacitor can be adjusted. The charging and discharging characteristic of the capacitors plays a big part in this experiment. By adjusting the size of dc capacitor, the resultant distortive measure on the current waveform can be varied, meaning, the harmonic content can be adjusted. A K-type thermo coupler is chosen as for temperature measuring device for its flexibility of temperature ranges. A 13B Fluke digital multimeter is used to monitor every related waveforms such as voltage's and current's and also the content of harmonic (THD) in percentage. Below is the experiment diagram designed for the purpose of the paper:

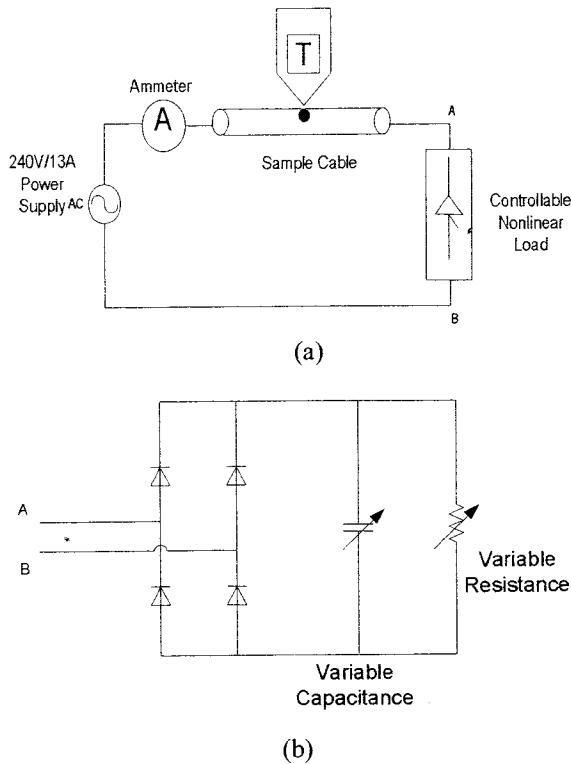


Fig. 2: (a) The general designation of experiment, and (b) the nonlinear load components

The samples of cable are of American Wire Gauge (AWG) 30, 28, and 26. It is known that these sizes are of small current which have current carrying capacity ranged from 2.6A, 3.4A, and 4.5A respectively and this experiment would open the door for high current testing of higher ampacity power cable, once the method is proven reliable as conducted in this paper. It is important to mention that, the samples are tested at the maximum ampacity during sinusoidal current, and also under distorted current which understandably, occurred as the harmonic is injected to the system. As loss of conductor is by  $I^2R$ , where current is either fundamental or with harmonic current, the temperature of additional harmonic into sinusoidal component can be mathematically mentioned as [6]:

$$P = I^2 R = \left( I_1 + \sum_{i=2,3,4,\dots}^{\infty} I_h \right)^2 \times R \quad (6)$$

While  $I_1$  is the fundamental, the total harmonic current will determine the full extend of power loss (heat dissipated) at conductor, and thus prove the effect of harmonic towards temperature of power conductor. The result of experiment is as follow:

Table 1: Experimental Results classified accordingly to wire gauge size

THD (%)	Temperature of Conductor (°C)		
	AWG 30	AWG 28	AWG 26
0	32.6	37.6	41.2
10	32.9	38.3	42.0
20	33.4	39.7	45.2
30	34.3	40.4	47.0
40	37.0	42.7	48.2
50	39.8	46.0	50.8
60	43.0	49.5	53.9
70	47.7	51.8	58.6
80	51.9	56.0	64.1
90	57.1	61.1	70.6
100	64.5	69.0	76.3

Table 1 show the result of experiment which has been grouped according to the wire gauge size of cable samples. While THD with 0% indicates the samples are running with sinusoidal current, meaning no harmonic content is injected to the system, the 100% THD indicates that the samples are tested with distorted current flow in them. Graphical evidence in form of graphs of the result is as follows:

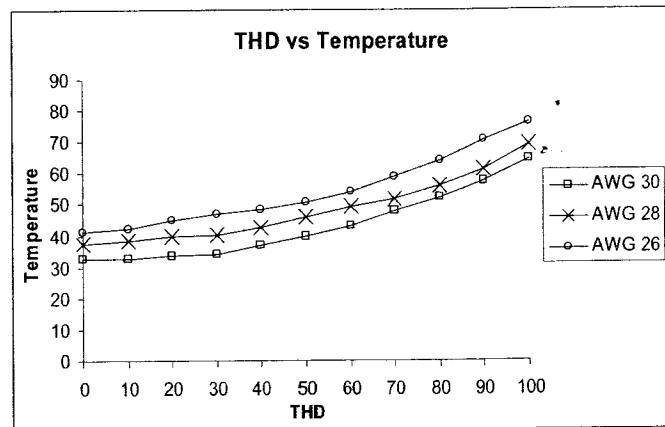


Fig. 3: THD versus temperature graph

Fig. 3 show the graphical evidence of experiment result plotted with respect to the AWG size of sample. The pattern of temperature increase is almost the same for each conductor size, indicating that harmonic rises the temperature at the same rate even the conductor size is not the same. The resulting equation of graph in Fig. 2 can be expresses as:

$$y = 0.003510 x^2 - 0.03778 x + 32.71 \quad (7)$$

$$y = 0.002992 x^2 - 0.00218 x + 38.01 \quad (8)$$

$$y = 0.003127 x^2 + 0.02866 x + 41.98 \quad (9)$$

Equation (7), (8), and (9) are of conductor size AWG 30, 28, and 26 respectively. The curve of graph is indeed quadratic as for the temperature to build up to certain level, time is needed. Note that the y axis is the temperature, while the x axis is for the THD.

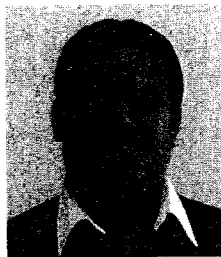
### III. CONCLUSION

This paper initial objective is to investigate whether harmonic content has the ability to increase the current and the effect of it towards the temperature of power conductor. At THD is equal 0%, the temperature for sample AWG 30, 28, and 26 are of 32.6°C, 37.6°C, and 41.2° respectively. However, as harmonic is increased to 50%, the temperature raised about 22.09%, 22.34%, and 23.30% to sample AWG 30, 28, and 26 respectively. Although it is not much in temperature increase, the additional burden to conductor is proven. As harmonic content is increased to 80%, there are 59.20% more of heat compared to sinusoidal state current for sample AWG 30, 48.94% for the AWG 28, and 55.58% for AWG 26.

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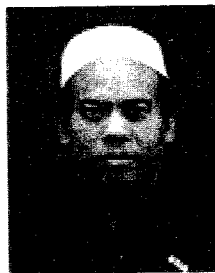
### V. BIOGRAPHIES



**Muhammad Mokhzaini Azizan** was born in Guar Chempedak, Kedah Darul Aman in 1983. He graduated from Universiti Teknikal Kebangsaan Malaysia Melaka (UTeMM) in Electrical Engineering in 2006. His B.Eng research revolved around Power Quality and Power System. He currently is pursuing Master Degree in Electrical Engineering (Power) at the School of Electrical Engineering, Universiti Sains Malaysia (USM), Penang. His interest of research includes Power System and Power Quality.



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