Journal of Theoretical and Applied Information Technology
15th December 2011. Vol. 34 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

DESIGN OF POWER TRANSFORMER FOR SINUSOIDAL AND NONSINUSOIDAL CURRENT CONDITIONS

[1]MUHAMMAD MOKHZAINI, [2]SYAFRUDIN MASRI, [3]MOHAMAD KAMAROL

[1,3]Power Research Group, Department of Electrical Engineering, School of Electrical and Electronics Engineering, Universiti Sains Malaysia, Penang, Malaysia

[2]Assoc. Prof., Department of Electrical Engineering, School of Electrical and Electronics Engineering, Universiti Sains Malaysia, Penang, Malaysia

E-mail: [1]mokhzainiazizan@yahoo.com.my, [2]syaf@eng.usm.my, [3]eekamarol@eng.usm.my

ABSTRACT

Harmonics in current has become an apparent and important consideration in designing a power transformer. This is due to the fact that the loads now have become nonlinear in character. These new generations of loads are invented to assist various functions in homes, factories, offices, and factories. However they created distortions at the current shape thus causing terrible consequences toward power transformers. Most of transformers are designed, manufactured, and calibrated using only sinusoidal shape current. Thus the existence of harmonics clearly upset the operation parameters such as the increased losses the transformer experienced. This paper tends to look into designing a power transformer that considers harmonics in current. Steps in designing a particular transformer are shown to emphasis the areas needed to be change whenever the current consist harmonics. An initial design is made with only sinusoidal current while the second design would consider harmonic components in current, up until the 11^{th} order. Some recommendations on enlarging size of the core dimension is made at the end of the paper.

Keywords: *Core Dimensions, Current Harmonics, Nonlinear Load, Total Harmonic Distortion, PowerTransformer Loss*

1. INTRODUCTION

The raised concern over the health of power system is caused by rapid growth of electronic devices available at consumer's disposal. Booming electronic industries in the last millennium certainly made human's life easier as these devices work with high precision and great accuracy. Industrial players started to utilize motor drives, heaters, computers and others in generating stable and large output, offices are full of electronic lighting system, power supplies, and others to ensure productivity remains high, while at home consumer benefits from invention of televisions, refrigerators, and others for the easiness of their life. However, knowing how the power being delivered in the system, these electronics existence means trouble to some parameters such as power transformers and power cables.

The electronic devices are capable of distorting voltage and current shape in the power system. The equipments draw distorted, non-sinusoidal current waveforms thus they are also known as nonlinear loads. In many equipments there are switch mode power supply where the mode of current is change from AC to DC in order to feed them. The conversion is made by power converters and rectifiers where by definition change electrical energy from one form to another [1]. These types of loads create harmonics in current where its component exist and mix with the fundamental component of current. As the result, RMS value of a harmonic current is considerably higher than non-harmonic, sinusoidal current [2],[5], [11]. In power transformer, harmonics causes additional loss on almost all loss type such as stray loss, eddy current loss, copper loss, and harmonic in voltage causes the core loss to add up. Known solutions towards selecting power transformer for harmonic application include de-rating and oversizing an available unit [2]. De-rating means the power

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

transformer capacity is reduced to a new lower kVA value so that it can still operates without exceeding nameplate rating loss values. Oversizing means selecting a bigger capacity unit to be installed at harmonic surroundings. However these two are temporary solutions as harmonics are bound to increase again and again.

This paper tries to make a case of comparing between designing a standard power transformer with sinusoidal current to designing another unit with harmonic current values. Designing step includes calculation upon the apparent power $P_{t,}$ selection of core geometry to manufacturer's E-I plate, number of primary/ secondary turns and their sizes, as well as the temperature rise T_r of the units[3]. Understandably the losses increase as current becomes more non sinusoidal of which harmonics are considered up until the 11th order in the calculation. Recommendations on copper dimension and winding wire properties are made in order to maintain operation whenever harmonic exist in current.

2. EFFECTS OF HARMONIC CURRENTS TOWARD POWER TRANSFORMERS

Losses experienced by power transformer may be termed as either no load loss or load loss. No load loss type is related to the excitation of the transformer where the linearity state of the material is crucial to produce sinusoidal output. It is also known as the core loss. Load loss of a transformer is a byproduct of supplying a load at its secondary end. It is also known as impedance loss. The combined between these two kinds of losses contribute to transformer's total loss.

$$P_{Total} = P_{NL} + l \quad (1)$$

The load loss can be further split into winding loss, winding eddy loss, and stray loss. The winding or I^2R loss is available at the copper that made up the windings. It is measured at the dc resistance of the copper and multiplying the current in amperes squared times to the resistance itself. Winding eddy loss is caused by the flowing of the eddy current into the winding. Electromagnetic field existed as byproduct of the alternating current, and it produces voltage across the conductors [4], [6]. Other stray loss can be found at the tank, walls, clamps, and structural parts of the transformer.

$$P_{LL} - P_{I2R} + P_{EC} + P_{G} \quad (2)$$

Harmonic Current Effect on Copper Losses

RMS value of current is the product of dividing peak current to the square of 2.

$$I_{rms} = \frac{i_p}{\sqrt{2}} \quad (3)$$

Where RMS value increases as harmonics exist in current is equal to

$$\sqrt{(I_1{}^2) + (I_{h3}{}^2) + (I_{h5}{}^2) + (I_{h7}{}^2) + \cdots (I_h{}^2)} \quad (4)$$

The equation (3) and (4) prove that the addition of harmonic current, the value of RMS increases. Which in turn, the winding (I^2R) loss is also increases.

$$P_{I2R} = I^2 \times R \quad (5)$$

However, if the RMS value is maintained even though after the existence of harmonics, obviously the winding loss is kept similar to its nameplate rating value. As result, thefundamental component in current of which is the essential real work producing component of power, will be reduced. This would create problems such as insufficient/instable power for the operation of other equipments. Thus in logic term whenever harmonic is added into current, the value of RMS of the current is increase, so does the I^2R loss of the power transformer.

Harmonic Current Effect on Eddy Current Losses

Eddy current loss occurs whenever the material of the core is conductive and low in resistance. Voltage is generated within the windings by electromagnetic flux, and in turn causes eddy current to flow inside the winding and conductors. Leakage flux that exist goes in the shape of radial across the windings and decreases as it get further away from the interchange between low and high voltage winding. This, in turn concentrates the electromagnetic fields which produce the eddy current at the ends of the windings. Due to skin effect, at high frequency applications electromagnetic flux may not be able to penetrate to the winding strands in total.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

$$P_{EC} = P_{EC-R} \times \sum_{h=1}^{h=max} h^2 \left(\frac{I_h}{I_1}\right)^2 \quad (6)$$

At this juncture it forms the greatest spot of temperature rise in the winding region. Eddy current loss in windings is considered to be proportional to the square of the electromagnetic field strength [7]. It is also assumed to be equivalent to the square of the ac frequency for each harmonic. Figure 1 shows eddy current circling the material sheets. The sheets are stacked up in large quantities in order to for the core of transformer.

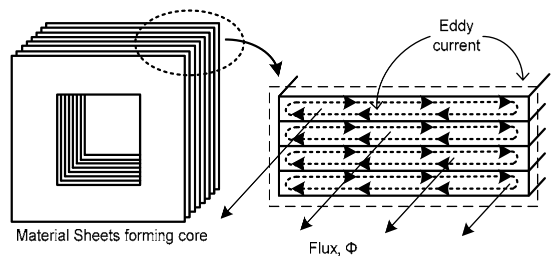

Fig. 1. Circulating eddy current at material sheets that form transformer core

In order to minimize the eddy current loss to an acceptable value, the material sheets need to have adequate resistivity. Therefore laminated material sheets are used for the purpose of building power transformer core. Both intra and inter laminar eddy current at the sheets are governed by total flux as well as the resistance of the overall stack of sheet. Lamination width, thickness, numbers, surface insulation resistance, and volume resistivity of the sheets also key factors.

Harmonic Current Effect on Stray Losses

Core clamps, structures, tanks, and enclosure walls are the usual spots for stray loss to occur. This loss, P_{OSL} generally proportional to current rose to a power slightly less than 2 (Kennedy and Ivey, 1990). Electromagnetic flux penetration depth into these spots' material varies with subject to the material's field strength. Thus, whenever there is a rise in frequency, the penetration depth decreases [9]. With harmonics in current, the frequency is understandably higher in double (120Hz, 180Hz, and so on). The transformer would be experiencing abnormal rise of temperature at core clamps, tanks, walls, and other structural parts, whenever it has to support nonlinear load [5]. The only way to get over this problem is to ensure the transformer dissipates heat more efficiently.

3. LINEAR CURRENT HARMONIC APPROACH

In surrounding of harmonics, power converter is widely use where its function is to change electrical energy from one form to another. The switches in the system can be either diode rectifiers or phase controlled rectifiers (thyristors) [9]. [10]. In such system, the magnitude of the harmonic current is essentially inversely proportional to the harmonic number.

$$I_h = \frac{I_1}{h} \quad (7)$$

Where I_h is the harmonic current magnitude, I_1 is the known fundamental current the transformer operates on, and h is the number of harmonics. This is known as theoretical approach in defining harmonic current [9]. It is easier to use this approach for a few reasons such as its linearity that made it easier to be utilized for analyzing. The other reason is that it does not deviate from the definition of harmonics; that makes it valid to be use. Tabulation of theoretical values of harmonic current is as in Table 1.

TABLE 1
PER UNIT HARMONIC CURRENT THEORETICAL VALUES

Harmonic order, h	Harmonic Current Values
1	1.000
3	0.333
5	0.200
7	0.143
9	0.111
11	0.091

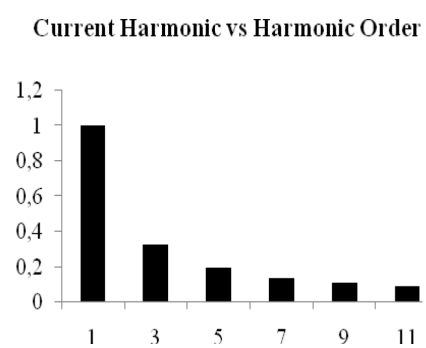

Fig. 2. Theoretical values of current harmonic as the harmonic order increases.

Total Harmonic Distortion (THD) is the term used to evaluate the degree of deviation of voltage or current, from its sinusoidal state. The unit is % and the bigger value THD means more distorted the

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

current or voltage is. For a current consist of fundamental value I_1, and harmonic components of I_3, I_5, I_7, I_9, and I_{11}, the percentage of THD_i can be calculated as follow.

$$I_H = \sqrt{[(I_1)^2 + (I_3)^2 + (I_5)^2 + \dots (I_{11})^2]} \quad (8)$$

Going by IEEE convention, the percentage of THD_i is calculatedably by dividing total of harmonic current, I_H to the fundamental current I_1 times 100.

$$THD_i = \frac{I_H}{I_1} \times 100\% \quad (9)$$

4. STEPS IN DESIGNING A POWER TRANSFORMER

There are a few parameters to be address in designing a power transformer. They are desired output power, P_o, selection of core material, volume of the unit to be specified according to user's application, and cost effectiveness of a particular design. However, it is impossible to balance out the parameters and create a perfect transformer. For example, application for aerospace program would emphasis on the size factor, rather than cost effectiveness. If a particular design is meant for low cost application, thus using only adequate core material however it comes at a price of lack in efficiency. In short, there will be one parameter that dominates the way the transformer to be designed. Manufacturers list always includes the core codes which represent the ability of the material to handle P_o. Cores also labeled as area product A_p, of which summarize physical and electrical properties.

In this paper, fundamental steps are used in determining the dimension of a power transformer, the size of primary and secondary winding wires, as well as loss calculation. The existence of eddy and stray loss is of course well documented in any transformerdesign cookbook. However this paper decides to only account the core and both primary and secondary copper loses in calculation. The inclusion of eddy and stray loss can best be presented with testing data of which may follow after completion of this design state. In order to highlight the danger of harmonics in current, the only change made in design steps is the state of current. First design concerns only with sinusoidal current, thus current is equal of fundamental component only; $I_T = I_F$. As for design that concerns with harmonic current, $I_T = I_F + \Sigma I_H$. Designs for this paper utilize the approach of core geometry K_g.

Desired Design Specification

Designers often have their preference in the specifications. They are input and output voltage, V_{in} and V_{out}, desired current output I_o, primary and secondary winding configuration (Delta/Delta for this paper), operating frequency (f), desired efficiency (η), transformer regulation (α), material flux density (B_{ac}) and window utilization factor K_u. These specifications are made out of designer's application need and reflect the loss and physical and electrical properties of the unit.

Calculation of apparent power P_o, electrical condition K_e, and core geometry K_g.

Apparent power P_t is the power capability of transformer and measured in watts. It poses great importance to designers due to the fact it determines the operating limitation of the transformer. As for user, output power Po is of greatest interest. Electrical condition K_e is determined by magnetic and electrical operating conditions namely flux density, operation frequency, and waveform coefficient. In turn Ke determines the core geometry K_g. The value of K_g then is referred to manufacturer's core datasheet for the purpose of choosing the best suit core. Once a core is chosen, designer can access information about the iron weight W_{tfe}, mean length turn MLT, iron area A_c, window area W_a, area of product A_p, core geometry K_g, and surface area A_t.

Determine number of turns, total current, wire size, and copper loss of primary and secondary side.

The number of turns, N_p and N_s can be calculated using Faraday' Law. Current going into the primary side is assumed to be perfect sinusoidal due to the fact it comes from the grid. However, as for secondary side, for a unit to supply nonlinear load, harmonic component is accepted to exist and cause distortion. Thus in designing a unit to work with nonlinear load, this paper takes secondary current as the combination of fundamental and harmonic components. Wire size for both sides can be determined through availability of the window area and the window utilization factor K_{up}. Selection of the wire size is referred to manufacturer's wire

Journal of Theoretical and Applied Information Technology
15th December 2011. Vol. 34 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

datasheet which also available at many transformer design cookbook. Copper loss at both sides can be theoretically calculated by obtaining the MLT value from step B.

Determine transformer regulation, α, watts per kilogram, core loss, total loss, efficiency, watts per unit area, and temperature rise of the unit while in operation.

Transformer regulation means the amount of power the copper lost. Calculation of core loss is related to the core weight Wtfe provided in step B, with the watts/kilogram of the unit is known. Summarization of loss is made by adding the core and copper loss on both sides. Efficiency of transformer points to the accuracy the unit operates. The unit temperature rise also can be calculation as the watts per unit area is known.

5. DESIGN OF THREE PHASE POWER TRANSFORMER WITH LINEAR AND NONLINEAR LOAD

This paper tends to focus at the changes to be made upon a particular power transformer whenever it has to supply nonlinear load instead of linear load. Additional loss is certain due to the fact now current is no longer consisting of only fundamental component, but it has combination of fundamental and harmonic components. A design of three phase power transformer is made by following the steps provided in the earlier chapter. Table 2 shows the specification intended for the purpose of this paper.

TABLE 2
3 PHASE POWER TRANSFORMER DESIGN SPECIFICATION

Specification	Values
I/O voltage Vin/ Vout	415/240
Output current Io	10A
Winding configuration	Delta/Delta
Operating frequency	50Hz
Efficiency Regulation	95%
Material flux density	1.4T
Window Utilization	0.4 (assumed)

By subjecting to the calculation steps, the lamination core can be selected from manufacturer's catalogue. Table 3 and 4 show the laminated core properties as well as the dimensional data for the chosen parts. Figure 3 shows the dimensional description to the selected part.

TABLE 3
3 PHASE E-I LAMINATION CORE PROPERTIES

Properties	Description
Part No. / Manufacturer	1800 E-I / Thomas and Skinner Ltd
Iron weight W_{tfe}	12.017kg
Mean Length Turn, MLT	26.3
Iron Area, A_c	19.858cm^2
Window Area, W_a	52.26cm^2
Area Product, A_p	1556.61cm^4
Core Geometry, K_g	470.453cm^5
Surface Area A_t	1630cm^2

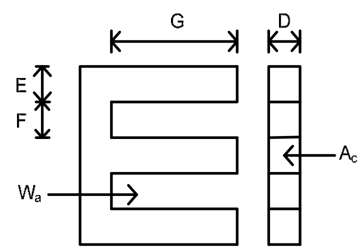

Fig. 3. Dimension of Part No. 1800 E-I

TABLE 4
PART 1800 E-I DIMENSIONAL DATA

Area	Measurement (cm)
D	4.572
E	4.572
F	4.572
G	11.430

For the initial design transformer, the current at the secondary side is considered to be free of harmonic. Thus I_s consists of fundamental component. Related operational parameters including wire size, secondary copper loss, total transformer loss, efficiency, and temperature rise determined by fundamental secondary current. Abiding with design steps in Chapter IV, theoretical operation

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

parameters can be calculated and tabulated in Table 5.It is within the interest of this paper that harmonics in current to be included to designing calculation. With that in mind, harmonics up until the 11th order are inserted into secondary current equation. Thus now the secondary current is $I_S = I_F + \Sigma I_H$ where I_H is up until 11th order. With the change on secondary current value, calculations based on the design steps are redone. Table 6 compares the operational values of transformer under both sinusoidal current and operation with harmonics (up until 11th order).

TABLE 5
3 PHASE TRANSFORMER WITH LINEAR LOAD THEORETICAL OPERATION PARAMETERS

Parameter	Value
Winding turns (Np/Ns)	778 / 101
Selected wire size for primary winding	AWG #21
Selected wire size for secondary winding	AWG #13
Regulation α	4.41%
Core Loss	8.95watts
Total Loss	70.1watts
Operational efficiency	95.2%
Operational Temperature Rise	33.45°C

TABLE 6
OPERATIONAL PARAMETER AREAS COMPARISON BETWEEN SINUSOIDAL CURRENT AND NON SINUSOIDAL CURRENT

Sinusoidal Current	Compared Areas	Harmonic Current (up until 11th order)
4.41	Regulation of transformer, α (%)	10.77
70.1	Total Loss P_T(W)	158.3
95.2	Efficiency (%)	89.73
33.45	Temperature Rise T_r(°C)	65.56

The transformer temperature rise T_r increased almost double compare to its operation under sinusoidal current. So do the other type of losses. This means, if the same core 1800 E-I to operate under non sinusoidal current, it would be operating at higher loss and dissipates twice as much heat. To rectify this, adjustment to either winding wire size or core size is needed. This is to ensure the operational temperature rise is similar to its operation under sinusoidal current. This paper chooses to made changes to the core size. To choose another core with the appropriate dimension to cater the extra loss, rollback design steps need to be conducted. State the temperature rise at 33.45°C, rollback the design steps until the core dimension determination step. This paper tried and new dimension is as tabulated at Table 7.

TABLE 7
COMPARISON BETWEEN NEW AND OLD CORE DIMENSION FOR HARMONIC CURRENT OPERATION OF TRANSFORMER

Core Properties	New Dimension	Old Dimension
Parts No./Manufacturer	3600 E-I (T&S Ltd)	1800 E-I (T&S Ltd)
Iron Weight W_{tfe}	96.81kg	12.02kg
Mean Length Turn MLT	52.2cm	26.3cm
Iron Area A_c	79.43cm^2	19.86cm^2
Window Area W_a	209.03cm^2	52.26cm^2
Area Product A_p	24905.75cm^4	1556.61cm^4
Core Geometry K_g	14174.6cm^5	470.45cm^5
Surface Area A_t	6522cm^2	1630cm^2

The enlargement of core size is needed in order for the transformer to operate at both sinus and non sinusoidal current without the massive temperature rise. This is due to the fact that bigger dimension means bigger surface area so that the loss caused by harmonic current can be absorbed into the core material. Thus the operation of transformer is kept at low temperature.

6. DISCUSSIONS

Mainly manufacturers of power transformer test and calibrate their units with sinusoidal current. Operation margins are allocated in case of the unit needs to operate at higher capacity. However, with the rise of electronic loads in the system, the margin has never been in sufficient. Existence of

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

harmonic causes the unit to operate at considerably high RMS value in current, thus making it vulnerable during operation. Additional losses in the winding wires are direct consequences. Magnetizing ability of its core can be permanently damage if the supply of voltage is too much nonlinear. Several short term solutions are in place in order to combat high harmonics content in system's current. Derating the capacity of the transformer in the event of current harmonics may present a likely solution. However by reducing the ability of the unit, it may result lack of power it be able to deliver. Thus making it a real risk for some equipment to be unable to operate at all. Over sizing the transformer is basically choosing a bigger capacity unit to work under harmonic content. This may sound quite a solution; however it may come with unnecessary high cost because the bigger the capacity more money needs to be spent. The question of under utilize may be too much a justification to be made when presenting the case of needing a bigger capacity transformer.

This paper looked into designing a specific unit that may work under nonlinear current condition. The only way to make this happen is to test and calibrate the unit with nonlinear/ harmonic current itself. Thus, by operating it with harmonic current, the additional loss it experiences may be calculated or measured. This gives the crucial understanding of the changes needed to be perform at the unit and the size of changes needed. As been shown in the calculation, the massive increase of loss in the winding is caused by harmonics. A bigger amount of harmonics in current means there is much of harmonic components in it. The selected wire is previously determined by only sinusoidal current. It works well within that type of current because the resistance and loss limit is well within the needed amount. However with harmonics in current, the amount of current component rises and with the resistance stays constant, it is logically the power at the wire increased. Loss increased at amazing rate of 125.83% and the unit operates at 2 times hotter than its operation under sinusoidal current.

In order to keep the operation temperature rise at least similar to the operation under sinusoidal current, rollback design steps need to be performed. Using the steps shown at Chapter IV, the temperature rise is set to be similar to 33.45°C that is the value of the rise as it operates with sinus current. A new core can be selected when rollback design calculation completes. A bigger core means it has higher temperature margin and with that, the operational temperature can be kept down although harmonic contents are giving additional stress/ loss. Bigger and heavier core means the surface area is larger and sufficient to absorb the losses caused by harmonics in current.

7. CONCLUSION

A power transformer operating under non sinusoidal current performs with higher amount of loss. However this condition can be rectify by making changes to some of the parts that form the transformer. This paper has successfully determined that for the transformer to operate with harmonic currents without any temperature rise, the change needed is the dimension of the core. A bigger core means it has bigger heat containing capacity thus be able to absorb more heat into its material and results the operation of transformer to be reliable.

ACKNOWLEDGMENT

The work for this research is made possible with Research University (RU) grant 1001/PELECT/814104. It also wants to thank all the fellow researchers and technicians at the Power Laboratory PPKEE USM for their contributions.

REFERENCES:

[1] S.P. Kennedy and C.L. Ivey, "Application, Design, and Rating of Transformers Containing Harmonic Currents," presented at the Pulp and Paper Industry Technical Conference, Seattle,SA, Jun. 18–22, 1990

[2] Pierce, L.W. (1996) "Transformer Design and Application Considerations for Nonsinusoidal Load Currents". *Proceedings of the IEEE Trans. On. Industry Applications. Vol. 32 (3). Pp. 633-645*

[3] Ekekwe, N., Ndubah, J.E., White, K., Oni, B.O., "Practical Process in High Frequency Distribution Transformer Design", EMCWA Annual Conference, Indianapolis, IN, Sept. 23-25, 2003

[4] Barranger, J., "Hysteresis and Eddy-Current Losses of A Transformer Lamination Viewed as An Application of the Poynting Theorem," (Lewis Research Center, Cleveland, OH. NASA TN D-3114

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

[5] A.A. Elmoudi, "Evaluation of Power System Harmonic Effects on Transformers (Hot Spot Calculation and Loss of Life Estimation)," Ph.D. dissertation, Dept. Elect. and Comm.Eng., Helsinki Tech. Univ., Finland, 2006.

[6] L.H. Dixon Jr, "Eddy Current Losses in Transformer Windings and Circuit Wiring," Unitrode Seminar Manual SEM600, 1988

[7] G.B. Finke, "Transformer Lamination, Design Considerations", Magnetic Metals Corporation.

[8] K.W. Klontz, "Skin and Proximity Effects in Multi Layer Transformer Windings of Finite Thickness," presented at the IEEE Industry Application Conference, Orland, FL, Oct. 8–12, 1995,

[9] *IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems*, IEEE Standard Std 519-1992

[10] *IEEE Guide For Harmonic Control and Reactive Compensation of Static Power Converters*. IEEE Std 519-1981

[11] Grady., M. (2006) "Understanding of Harmonics in Power System". Shared online http://www.scribd.com/doc/29041761/Understanding-of-Harmonics-in-Power-System-Mack-GradyAccessed on 23rd Feb 2011

AUTHOR PROFILES:

Muhammad Mokhzaini received his Bachelor and Master degree in Electrical Engineering in year 2006 from Universiti Teknikal Malaysia (UTeM) and 2009 from Universiti Sains Malaysia (USM) respectively. Currently he is pursuing doctorate degree in USM and his work relates to power transformer and harmonics. His interest in research includes power system and quality, and renewable and conservation of energy.

Syafrudin Masri is Associate Professor at Department of Electrical Engineering, Universiti Sains Malaysia. He obtained his Bachelor, Master and Doctorate degrees from Universiti Tanjungpura, Indonesia, and Institut Teknologi Bandung (ITB) respectively. His major interest in research includes power system and quality, electric machines, energy conversion, and green and renewable energy.

Mohamad Kamarol obtained his diploma in Natural Science and Electrical and Electronics Engineering in 1991 and 1994 from Japan's International Student Institute and Ibaraki National College of Technology respectively. He received Bachelor of Engineering in year 2000 from Universiti Teknologi Mara, and his Master and Doctorate degrees from Kyushu Institute of Technology Japan in year 2005 and 2008. His interest of research is in partial discharges in dielectrics, and studying properties of palm oil as liquid insulation medium.