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ANALYZING VARIABLES BY USING SECOND-ORDER MODEL OF RESPONSE SURFACE METHODOLOGY (RSM)

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Bachelor of Electrical Engineering
(Control, Instrumentation and Automation)
June 2012

"I hereby declare that I have read through this report entitle "*Analyzing Variables By Using Second-Order Model of Response Surface Methodology (RSM)*" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Control, Instrumentation & Automation)"

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This report is submitted in partial fulfillment of requirements for the Degree of Bachelor in Electrical Engineering (Control, Instrumentation & Automation)

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JUNE 2012

I declare that this report entitle "*Analyzing Variables By Using Second-Order Model of Response Surface Methodology (RSM)*" is the result of my own research except as sited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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DEDICATION

To my beloved parents, brother, sister for their

supports and encouragements

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ABSTRACT

Response Surface Methodology (RSM) has been used to minimize the conditions of Total Harmonic Distortion (THD) produced in leakage current when the effect factors are tested on new insulation material. A 2^3 factorial design used to determine the number of eight samples of new insulator to be tested. THD is defined as a dependent variable in leakage current (LC) which is depend on three independent variables which are water flow rate (*f*), water conductivity (δ), and high voltage applied (V) to the sample. A fitting second-order model with second-degree approximate polynomial is employed to generate the fitted response surface of THD. The fitting model of THD is computed by using Design Expert software. The independent variables are varied such as *f* 3 ml/s and 6 ml/s, δ at 300 Ω/cm and 400 Ω/cm and lastly V at 3 kV and 4 kV. The expected optimized condition is about to locate the minimum THD response surface and the contribution of factors' values of water flow rate, water conductivity and high voltage stress which produce the minimum THD. From the fitted model, the best THD value is 46.4538% when the all factors (V, C and F) were at low level of high voltage stress = 3kV, conductivity of water = 300Ω/cm and flow rate of water = 3ml/s.

ABSTRAK

Response Surface Methodology (RSM) digunakan untuk meminimumkan Total Harmonic Distortion (THD) yang terhasil daripada 'leakage current' apabila faktor-faktor yang mempengaruhi diuji keatas sampel penebat baru. 2^3 'factorial design' digunakan untuk menentukan lapan sampel yang perlu diuji. THD diketegorikan sebagai pembolehubah yang bergantung kepada tiga pemboleh ubah tidak bersandar iaitu kadar aliran air (*f*), kekonduksian air (δ), dan voltan tinggi (V). 'Fitting second-order model' bersama dengan 'second-degree approximate polynomial' digunakan untuk menghasilkan 'THD fitted response surface'. Pembinaan model dilaksanakan dengan menggunakan Design Expert. Pemboleh ubah tidak bersandar diubah-ubah seperti *f* pada 3ml/s dan 6ml/s, δ pada 300Ω/cm dan 400Ω/cm dan akhir sekali V pada 3kV dan 4kV. Keadaan optimum yang dijangkakan adalah untuk mendapatkan lokasi minimum THD dan nilai-nilai faktor seperti kadar pengaliran air, konduktiviti air dan jumlah voltan tinggi yang menghasilkan minimum tindak balas THD. Berdasarkan fitted model, nilai THD terbaik adalah 46,4538% apabila semua faktor (V, C dan F) berada pada tahap yang rendah iaitu voltan tinggi = 3kV, kekonduksian air = 300Ω/cm dan kadar aliran air = 3ml/s.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

One of important part of all electrical systems is electrical insulation [4]. Nowadays, many newer insulators are developed using newer materials that able to give advantages over the older insulation material. From evaluation, these materials still face the problems of environmental degradation due to pollution and organic in nature which leads to aging behavior [5]. Flow of leakage current (LC) on the insulator's surface is caused by wet layer and conductive due to high humidity and light rainy condition. The existence of LC leads to the current flash over event which cause short circuits behaviour [10]. From studies conducted, the results have shown that LC is a good way to determine insulator surface condition [4]. The sample of insulator's leakage current (LC) waveform and the Total Harmonic Distortion (THD) correspond with degree of ageing. Because of these issues, it cannot be totally guaranteed that they can withstand for aging for long time while the behavior of aging happen fast. Hence, some analysis is considered to verify the quality of the newer material insulator.

In this case, the type of insulator that will be analysed is a new design material of the type PPCWATH insulator which is made from main composition of clam shell ($CaCO_2$), glass, and polymer. The composition of clam shell and glass form a new material which is same with composition of limestone and being called as Artificial Wollastonite ($CaSiO_3$). The material was designed by Mr Aminudin Bin Aman. The distortion of the LC occurs when there are some values of harmonics that should not be in LC. Hence, the analysis is focused on behavior of the THD which indicate the harmonic content in LC. The THD can be explained by using formula of Fourier Series and Parseval Theorem [7],[14],[19],[A1],[A2],[A3]. An experiment is conducted for new insulation material testing to observe and analyze the insulation performance in sustaining for behavior of aging.

In this electrical insulation testing, the action of THD is observed on current signal that captured by oscilloscope whenever there are existence of leakage current on insulator surface. The leakage current appeared when some independent variable inputs are controlled to the specific values. In an experimental study, the potential factors screened for effects on THD are flow rate of water, conductivity of water, and amount of high voltage supply. The pressure, humidity and temperature are assumed to be constant because the insulation testing is developed in the same laboratory within the same time. Hence, they are not considered as the variables that could influence significantly to the THD.

Using a statistical test approach, the technique of Response Surface Methodology is used for data analyzing. RSM is a combination of mathematical and statistical techniques for modeling and analysis of response influenced by several variables. The expectation function is firstly represented in polynomial graduating function. After that, the ordinary least squares method is used to estimate the parameters in the approximating polynomial. Then, the fitted surface is used to implement the surface response analysis for accurately predicting the system optimum. The fitted surface analysis are approximately equivalent to actual system analysis if the fitted surface sufficiently approximate to the true response function [13],[14]. By then, the second-order model is used for designing fitting response surface to examine a contour plot of the fitted model and located the optimum. An analysis of variance (ANOVA) is used to check an adequacy of the proposed second-order model. If the proposed models are adequate, residual plots, contour plots can be usefully employed to study the response surface and located the optimum [12]. The contour plot of the fitted second-order model response surface are simulated by using RSM analysis in Design Expert software.

The main purposes of the analysis are to determine the minimum of THD and value of independent variables yield the minimum THD in which contribute to produce the good quality of newer insulation composite material.

1.2 Problem Statement

The ratios of suitable compositions are already determined for the best newer insulators withstanding from action of breakdown. However, the newer insulator materials are still experience pollution and environmental deterioration nature's problem which cause to the effect of leakage current (LC). Therefore, it cannot be totally guarantee that they can remain lasting from behavior of aging. Because of this issue, the aging behavior of the new type PPCWATH (Poly Phthalate Carbonate Wollastonite Alumina Trihydrate) insulator have to be analyzed in term of minimize total harmonic distortion of LC in order to guarantee the quality of the insulator by considering the effect from flow rate of water, conductivity of water and high voltage stress.

1.3 Objective

a) To find the THD with the specific value range of independent input variables.
b) To analysis the data of THD with the independent input variables by using method of fitting second-order model of RSM.
c) To determine the minimum THD and the best independent variables values that contribute the good quality of newer insulation material tested.

1.4 Scope

The testing of insulation is doing in high voltage laboratory at Faculty of Electrical Engineering, UTeM. The testing comes out with the distortion waveform when varying the values of three factors within specific level according to British Standard EN 60587 of insulator surface tracking and erosion test. Therefore, the collected data are in form of total harmonic distortion value. The project is focused to analyze the data by using statistical method of response surface methodology and will be computed by using Design Expert software. This analysis is provided in order to achieve the main purpose of determining the minimum THD which yield the good insulation characteristic.

CHAPTER 2

LITERATURE RIVIEW

In this chapter, the journals, articles, reference books and other research material sources were studied to gain the concepts, ideas and theories as well as to understand the project background. This section introduces the statistical testing method of Response Surface Methodology and followed by describing the technique for fitting second-order surface response modelling. Besides that, there are also a few description relates to the work and preparation for insulator test. These literature studies were reviewed for purpose to analyse the response of total harmonic distortion from collected THD data by using fitting second order model.

2.1 Leakage Current

2.1.1 Phenomenon of leakage current

Insulators in service expose to the forming of pollution layer on surface. The contaminants that cover the surface are non-conducting for the dry surface. However, the contaminants layers become conductive when the surface is wetted. The mixture of water and the contaminants yield the electrolyte solution which tends to be conductive. In general, the contaminants layers are not uniformly scattered on the insulator surface. The electrolyte solution on the insulator surface is heated once the conduction starts (several milliamps). The contaminants layers begin to be dried by the leakage current which resulting the rise of the layer resistivity in the highest current density area [6]. The air breakdown above the dry band can be happened since the high voltage that be applied across the insulators cross the resistivity dry band [2]. The insulation performance of polymeric insulator is significantly affected by the forming of leakage current where the leakage current is the main factor in surface tracking behaviour [3]. In order to evaluate the performance and aging degree of polymeric surface, the measurements of the leakage current are usually implemented in laboratory [11].

2.1.2 Significant factor of leakage current behaviour

The appearance of surface tracking and erosion is significantly affected by electrical stresses such as leakage current and dry band discharge. The insulator surface condition also contributes the performance of the polymer insulator. Therefore, the environmental stress such as humidity affect the performance of the insulator since it influences the surface condition. The exposure of the polymeric insulator to the electrical and environmental stresses resulting the losing of polymeric material hydrophobicity characteristic to some degree. Therefore, the LC is increased due to the losing of hydrophobicity and thus encourages the surface tracking and erosion phenomenon [1].

The research of LC dependency, pulse current count and total charge flowing across the surface of silicone rubber (SR) coating on the flow rate of saline water under the salt fog test have been done by Kim and Hackam (1995). According to their finding, the increasing quantity of saline fog which is interacting with the SR coating causes to the increasing of hydrophobicity losses. Furthermore, the increased loss of hydrophobicity that increases water flow rate results the increase of LC [1]. According to the studied of electrical activities associated with inclined-plane tracking and erosion test on two different types of polymer materials that have been done by Chang and Mazeika (1996), the same findings are obtained where the dry band formation and the average current are significantly affected by the variation of water flow rate [1].

The environment contains many types of contamination particles. According to Devendranath and Channakeshava (2002) who have conducted a test on silicon rubber coating under polluted condition, the different level of LC also depends on the difference level of contaminants because the ionic component of the electrolyte also different [1]. Therefore, the different contamination level of electrolyte indicates the different conductivity of the conducting film on the insulator surface [1].

Many studies have been reported that the level of LC and deformed of waveform pattern are affected by development of dry band. Furthermore, the formation of dry band also can increase the harmonic contents of the waveform (Fernando, 1998; Fernando and Gubanski, 1996) [1]. Therefore, the Total Harmonic Distortion (THD) is implemented in order to analyse quantification of the harmonic content of the leakage current.

2.2 Experimental Work

2.2.1 Sample

The insulation testing will be conducted by using leakage current measurement for eight samples of new type of PPCWATH insulators. The PPCWATH insulator is made from main composition of clam shell ($CaCO_2$), glass, polymer of Poly Phthalate Carbonate (PPC) and Alumina Trihydrate (ATH) as filler. The dimension for the sample is 50 mm x 120 mm x 6 mm. The numbers of eight trials are determined accordingly to 2^3 factorial design which will be discussed later. A water solution or electrolyte that used for purpose to contaminate and wet the sample surface is produced from mixture of distilled water (H_2O) and Ammonium Chloride (NH_4Cl). The conductivity of water solution is varied by using substance of NH_4Cl and the water solution flow rate that being supplied to the sample surface is controlled by using peristaltic pam. At the same time, the high voltage stress that being supplied to the samples is varied by using variable high voltage transformer. The samples are mounted between terminals of high voltage supply while the electrolyte with setting rate flows on the sample surface.

2.2.2 The variables parameters

In this experiment, the water flow rate, water conductivity and high voltage stress is applied on a material for two values levels (low and high) in order to find their relationship toward behaviour of THD in LC. The values are defined as 3ml/s and 6ml/s for water flow rate, 300Ω/cm and 400Ω/cm for water conductivity and 3kV and 4kV for high voltage stress. The response of THD (indicate harmonic content in LC) is depend on the water conductivity (δ), water flow rate (*f*) and high voltage stress (V) meanwhile those three parameters are independent to each other. Therefore, the parameters δ, *f* and V are defined as independent variables and THD as dependent variable.

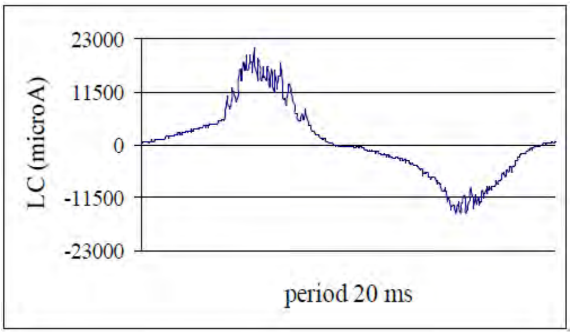
2.2.3 Leakage current measurement

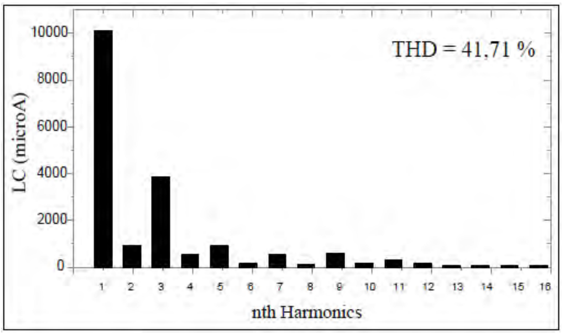
An AC high voltage of 50 Hz is applied to the insulator. By using digital oscilloscope, the leakage current flowed on the surface of insulator is measured by measuring the voltage drop across a resistor of 140Ω. Figure 3 shows the example of measurement system. Harmonic content of LC is derived using Fast Fourier Transform (FFT).The leakage current on the insulators usually distort from its sinusoidal form under polluted conditions as shown in Figure 3. The harmonic contents of the leakage current signal are measured by using Total Harmonic Distortion (THD). The degree of distortion is expressed as:

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} {I_n}^2}}{I_1}$$

where $I_1 = 1^{st}$ harmonic (fundamental current) and $I_n = n^{th}$ harmonic.

Figure 2.1 shows how the harmonic content was sort-out from LC signal by using LabVIEW in order to find the THD. The magnitude of LC for nth harmonic was used to calculate the degree of distortion in LC by using equation (2.1).





(a) (b)

Figure 2.1: Example of: LC on insulator surface (a) and harmonic component in LC (b)

2.3 Response Surface Methodology (RSM)

The technique discussed is compatible to the study of behaviour that could not be well understood by mechanistic approach [14]. As an important method in the statistical design and test of experiments, the Response Surface Methodology is a comprised of statistical and mathematical techniques used for exploring independent variables' space, the empirical modelling for development of suitable approximation relationship response and input variables, and for determining the input variables which produce the desirable optimized response using optimization method [8],[14],[17]. By attentive analysis of problems, it attempts to relate response to the levels of a number input variables that affect it [14].

The response and variables depend on real or specific field of application. As for example, response in a textile investigation might be yield of worsted yarn, and the input variables influencing the yield might be length of specimen and amplitude of load cycle. In mathematical term, it is useful to find the functional relationship between response of interest and design variables. The mean response and the levels of the *k* input variable can be written as:

$$E(y) = \eta = f\left(\xi_{1,}\xi_2, \dots \dots, \xi_k\right)$$

with the relationship to the response y

$$y = f\left(\xi_{1,}\xi_2, \dots \dots, \xi_k\right) + \varepsilon$$

where observation response, y as a function of k level input variables ξ_k. The mean response functional form f is unknown and, ε is expressed as statistical error.

As recall to the textile example, η is yield of worsted yarn and ξ_1, ξ_2 are expressed for length of test specimen and amplitude of load cycle. If the input is only one ξ_1 , the relation of output response η to a single input ξ_1 can be associated by a curve response such as in Figure 2.2(a). If two input variables ξ_1 and ξ_2 are related to output response η, the surface response as shown in Figure 2.2(b) is obtained in which the graph $\eta\ versus\ \xi_1\ and\ \xi_2$ plotted in three dimensional space. When level of input greater than 2, *k* = 3,.., the response surface is still discussed in (*k+1*) dimensional space of the variables even though only three-dimensional space is actually available to be displayed [14].

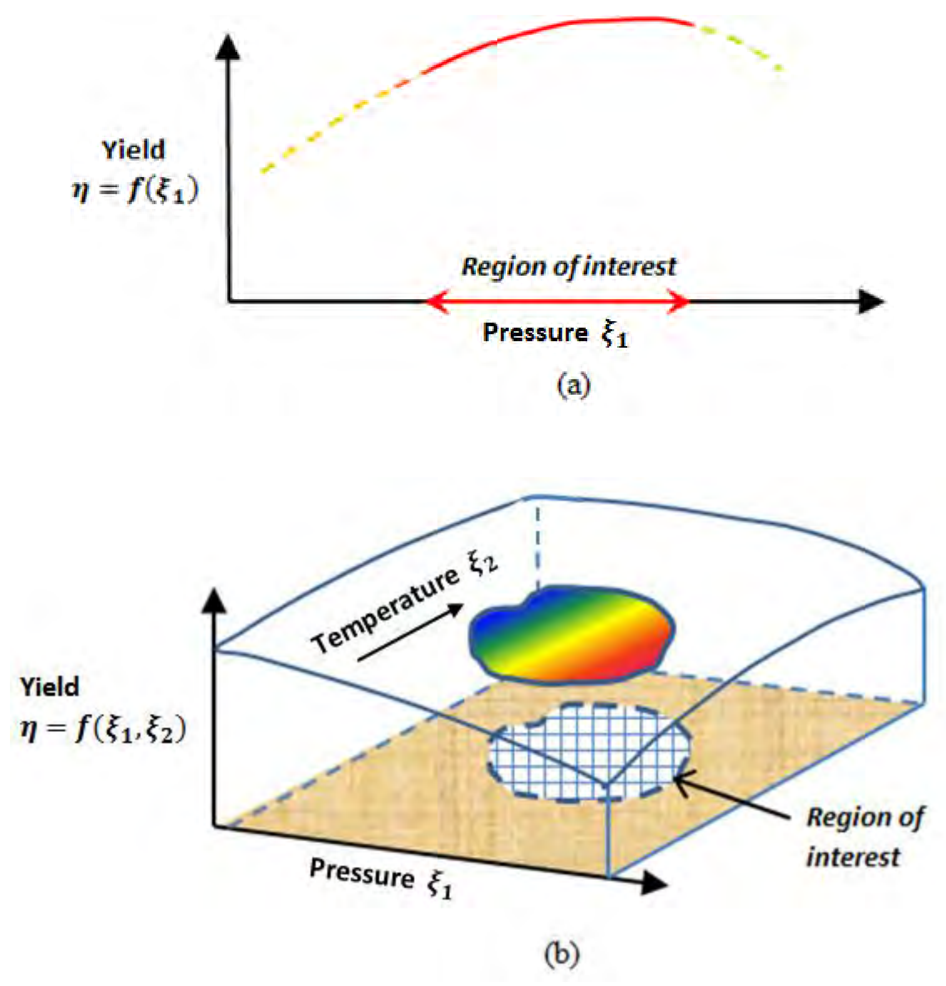


Figure 2.2: (a) A response curve. (b) A response surface [16]

The natural variables are usually referred to the variables, because they are stated in the natural unit measurement, such as meter, gram, degree Celsius, etc. The approximation model is firstly represented in graduating function. By handling with RSM, it is convenient to standardize the natural variables to coded variables x.

$$\eta = f(x_{1,} x_2, \dots \dots, x_k)$$

After that, the least squares method is used to estimate the parameters in the approximating polynomial model. Then, the fitted surface is used to implement the surface response analysis with objective of accurately predicting the system optimum.

2.4 The 2^k Factorial Design

For two levels of input values (low and high) associate with three independent variables, the design will be 2^3 factorial. Thus, the numbers of treatment design that will be test are eight samples.

Let f = Flow rate of water, δ = Conductivity of water and v = High voltage stress. The table of 2^3 factorial design with eight combinations of treatment are shown as in Table 2.1 and Figure 2.3 shows the geometrical cube for the eight combinations of treatment.

Table 2.1: Table of 2^3 Factorial Design

Treatment Designing	**THD**
f =low, δ =low, v =low	THD_1
f =low, δ =low, v =high	THD_2
f =low, δ =high, v =low	THD_3
f =low, δ =high, v =high	THD_4
f =high, δ =low, v =low	THD_5
f =high, δ =low, v =high	THD_6
f =high, δ =high, v =low	THD_7
f =high, δ =high, v =high	THD_8

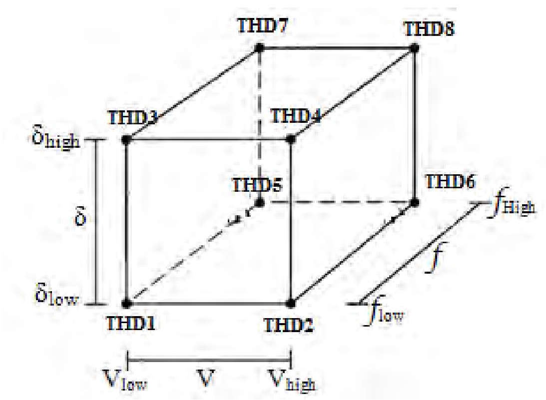


Figure 2.3: Geometric View of 2^3 Factorial Design