UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A DIGITAL CALIBRATION TEST SYSTEM FOR FLICKERMETER

SIA LIH HUOY

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SIA LIH HUOY

August 2007

Chairman: Professor Sudhanshu Shekhar Jamuar, PhD

Faculty: Engineering

Over last few decades, there has been deterioration in the power quality due to the increase in non-linear domestic and industrial loads usage. There may be a systematic low frequency variation of the voltage envelope or a series of random voltage changes, which the magnitude may not normally exceed the voltage regulations laid down by the supply authority. These phenomena known as voltage flicker have severe effect on power quality. Flickermeter is the power analyzer for measuring the voltage flicker, flicker sensation and flicker severity index. International Electrotechnical Commission (IEC) has published IEC 61000-4-15 standard describing the functional and design specifications for flickermeter.

Most of the flickermeter and flickermeter calibration test systems presented in the literature are based on analog signal processing techniques. In this thesis, a digital calibration test system for flickermeter based on digital signal processor (DSP) is

presented. The system has been developed around DSP TMS320 and test signals required as per IEC 61000-4-15 standard to test a flickermeter is generated.

A DSP based waveform generator, which can give sine, square, triangular waveform with frequency of operation from 0.01 Hz to 24 kHz has been described in this thesis. The DSP starter kit (DSK) TMS320C6713DSK with Code Composer Studio and C programming language had been used in obtaining the desired signal. Amplitude modulated test signals with different modulation index as per IEC 61000-4-15 standard had been generated using DSP based waveform generator. A measurement system was developed to capture the analog signals generated by DSP starter kit. LabVIEW had been used to perform the data analysis and from which voltage fluctuation for P and Pst measurement was obtained.

For the voltage fluctuation of P measurement, it was found that the percent modulation of test signals measured by the oscilloscope is from 2.15% to 8.20% for sinusoidal modulating frequency; and 0.67% to 7.65% for rectangular modulating frequency. The average of the difference between the test signals generated and IEC standard value was 4.6% for sinusoidal voltage fluctuation; and 3.9% for the rectangular voltage fluctuation. For the voltage fluctuation of Pst measurement, it was found out that test signals generated are 2.8% deviated from IEC standard. The digital calibration test system developed was able to generate test conditions which were within 5% from the standard values required for testing.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

PEMBANGUNAN SISTEM UJIAN PENENTUKUR DIGIT BAGI METER KERDIPAN

Oleh

SIA LIH HUOY

Ogos 2007

Pengerusi: Profesor Sudhanshu Shekhar Jamuar, PhD

Fakulti: Kejuruteraan

Dalam beberapa dekad yang lalu, terdapat kemerosotan dalam kualiti kuasa disebabkan oleh pertambahan beban tidak lelurus dalam bidang domestik and industri. Terdapat kemungkinan variasi frequensi rendah sistematik pada sampul voltan atau siri perubahan voltan secara rawak, di mana magnitudnya tidak melebihi tahap voltan yang ditetapkan oleh penguatkuasa bekalan. Fenomena ini dikenali sebagai kerdipan voltan yang memberi kesan teruk kepada kualiti kuasa. Meter kerdipan ialah alat analisis kuasa untuk mengukur kerdipan voltan, indeks sensasi kerdipan dan keparahan kerdipan. International Electrotechnical Commission (IEC) telah mengumumkan standard IEC61000-4-15 yang menyatakan fungsi dan spesifikasi reka bentuk bagi meter kerdipan.

Kebanyakan meter kerdipan dan sistem ujian penentukur bagi meter kerdipan yang dibentangkan menggunakan teknik pemprosesan isyarat analog. Dalam tesis ini, sistem

ujian penentukur digit yang berdasarkan pemprosesan isyarat digit (DSP) diperkenalkan. Sistem ini dibina menggunakan DSP TMS 320 dan isyarat ujian mengikut standard IEC 61000-4-15 bagi menguji meter kerdipan telah dijanakan.

Satu penjana gelombang berdasarkan pemprosesan isyarat digit yang boleh menghasilkan gelombang sinus, segi empat tepat, dan segi tiga dengan frekuensi dari 0.01 Hz ke 24 kHz telah dibentang dalam tesis ini. *DSP starter kit (DSK)* TMS320C6713DSK dengan *Code Composer Studio* dan bahasa program C telah digunakan untuk mendapatkan isyarat ujian yang dihendaki. Penjana isyarat berasaskan pemprosesan isyarat digit telah digunakan bagi menjana isyarat modulasi amplitud dengan indeks modulasi yang berlainanan berdasarkan standard IEC 61000-4-15. Satu sistem pengukuran telah dibina bagi mendapatkan isyarat analog yang dijana oleh *DSP starter kit.* LabVIEW telah digunakan bagi analisis data di mana indeks modulasi bagi ukuran P dan Pst telah diperolehi.

Untuk indeks modulasi bagi ukuran P, didapati bahawa peratus modulasi bagi isyarat ujian yang diukur oleh osiloskop adalah dari 2.15% ke 8.20% bagi frekuensi modulasi sinusoidal; dan 0.67% ke 7.65% bagi frekuensi modulasi segi empat. Purata bagi perbezaan antara isyarat ujian dengan standard IEC adalah 4.6% bagi perubahan voltan sinusoidal; dan 3.9% bagi perubahan voltan segi empat. Untuk indeks modulasi bagi ukuran Pst, diperhatikan bahawa isyarat ujian adalah dalam 2.8% dari standard IEC. Sistem ujian penentukur yang dibina dapat menghasilkan keadaan ujian dalam 5% dari senarai nilai yang diperlukan bagi ujian.

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I certify that an Examination Committee has met on 24th August 2007 to conduct the final examination of Sia Lih Huoy on her Master of Science thesis entitled "Development of A Digital Calibration Test System for Flickermeter" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the student be awarded the degree of Master of Science.

Members of the Examination Committee were as follows:

Samsul Bahari Mohd Noor, PhD
Deputy Dean (Development)
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Borhanuddin Mohd Ali, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Syed Javaid Iqbal, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Ruzain Hj Abdul Rahman, PhD
Professor
Faculty of Electrical Engineering
Universiti Teknologi Malaysia
(External Examiner)

HASANAH MOHD. GHAZALI, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

S. S. Jamuar, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Roslina Mohd Sidek, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Mohd Hamiruce Marhaban, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

____

AINI IDERIS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 13th December 2007

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

SIA LIH HUOY

Date: 8th October 2007

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LIST OF ABBREVIATIONS

ADC	Analog-to-digital converter
AM	Amplitude modulation
ACSII	American Standard Code for Information Interchange
CCS	Code Composer Studio
DAC	Digital-to-analog converter
DFCTS	Digital flickermeter calibration test system
DMA	Direct memory access
DSP	Digital signal processor
EMIF	External memory interface
EPROM	Erasable programmable read only memory
FFT	Fast Fourier Transform
FIFO	First In, First Out
GPIB	General Purpose Interface Bus
IEC	Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
IVD	Inductive voltage divider
LC	Inductor-capacitor
M	Percent modulation
m	Modulation index
McBSP	Multi-channel buffered serial port
NI	National Instrument

P	Instantaneous flicker sensation
Plt	Long-term flicker severity
Pst	Short-term flicker severity level
PU	IEC perceptibility unit
RAM	Random access memory
RC	Resistor-capacitor
RMS	Root mean square
SCR	Silicon controlled rectifiers
THD	Total harmonic distortion
TI	Texas Instrument
UIE	International Union for Electroheat
Vpp	Peak-to-peak voltage
Vp	Peak voltage

CHAPTER 1

INTRODUCTION

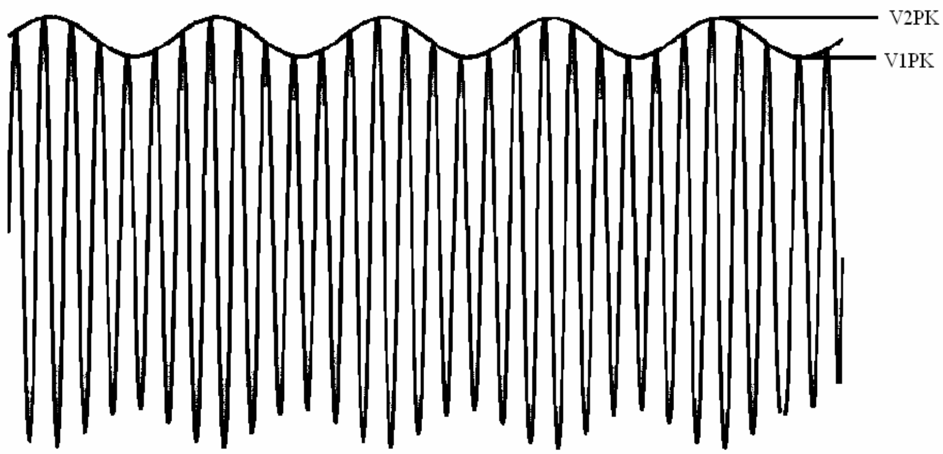
1.1 Introduction

Power quality issues are mostly considered as very high speed events such as voltage impulses / transients, high frequency noise, wave shape faults, voltage swells and sags [1]. These problems have become worse over past few decades with the growth of non-linear load usage in domestic and industry field [2]. Voltage supplied to the electrical equipment is a sine wave operating at 50 Hz. Incandescent lamps, heaters and motors are linear systems as the applied voltage sine wave will cause a sinusoidal current to be drawn. Resistance in the system is consistence. However, some of the modern equipment such as computers, variable frequency drives, electronic ballasts and uninterruptible power supply systems do not have consistent resistance and the resistance varies during each sine wave. These non-linear systems affect the stability of the voltage supply causing voltage fluctuations. The foremost effect caused by voltage fluctuations is light flicker.

Voltage fluctuations are repetitive or random variations in the magnitude of the supply voltage due to sudden changes in the real and reactive power drawn by a load. Effects of voltage fluctuations depend on the type and magnitude of loads and power system capacity. For example, switching operations of industrial processes or electrical appliances connected to the power supply. These operations generate voltage depression to the power system. The voltage depression becomes more obvious with the increase in uses of heavy electrical equipment and appliances, and is more prominent with uses of modern electrical equipment using solid state devices like Thyristors, silicon controlled rectifiers (SCRs) to control its operation. This equipment, acting as non-linear load on the power line, might cause a voltage drop across the electricity supply network, resulting in a lower voltage supplied to the lightning system. The varying of voltage, which causes light flicker, will influence the visual perception of light and create annoyance to human eye. The light flicker can be sufficiently large to affect people from minor irritation to health risk if the flicker occurs too often. Furthermore, voltage changes caused by non-linear loads might propagate in an attenuated form throughout the distribution system and would affect many users [2].

Effects towards improving quality of the power supply have led electricity supply companies and regulatory bodies to identify flicker problem and type of equipment which causes these problems. The International Electrotechnical Commission (IEC) has published some standards concerning the power quality issues. In November 2005, IEC 61000-3-2 has issued standards relating to limit the harmonics currents that an electrical appliance can inject into the mains supply. It specifies limits of harmonic components of the input current which might be produced by equipment tested under specified conditions. Another standard published in the same year, IEC 61000-3-3 imposes limits on voltage changes, voltage fluctuations and flicker that can be impressed on public supply system. It specifies limits of voltage changes which may be produced by equipment tested under specified conditions and gives guidance on methods of assessment [3].

Measurement of voltage flicker involves the derivation of RMS (root mean square) voltage variation and the frequency at which the variation occurs. Voltage flicker is usually expressed as the change in RMS voltage divided by the average RMS voltage [4]. Figure 1.1 shows the sample voltage flicker waveform and the mathematical relationships.



Where, $\Delta V = V_{2pk} - V_{1pk}$

RMS Voltage of Modulating Wave = $\dfrac{\Delta V}{2\sqrt{2}} = \dfrac{V_{2pk} - V_{1pk}}{2\sqrt{2}}$

Average RMS Voltage = $\dfrac{V_{2pk}/\sqrt{2}}{2} + \dfrac{V_{1pk}/\sqrt{2}}{2} = \dfrac{V_{2pk} + V_{1pk}}{2\sqrt{2}}$

Percent (%) Voltage Flicker = (RMS Voltage of Modulating Wave) / (Ave RMS Voltage)

$$= \frac{V_{2pk} - V_{1pk}}{V_{2pk} + V_{1pk}} \times 100\%$$

Figure 1.1: Sample Voltage Flicker Waveform and Mathematical Relationship [4]

The flicker produced by equipment is measured using flickermeter, which is a power analyzer designed to monitor the voltage changes of the mains supply and to qualify to what degree the light intensity variation caused by voltage changes will irritate test subjects. IEC in the standard 61000-4-15 gives a functional description and design specification for flickermeter.

Flickermeter is designed to detect voltage fluctuation in the range of 0.5 – 30 Hz frequency and indicate the impression of visual observer. The device considered the limited visual sensitivity and the effect of thermal time-constant of incandescent lamps [5]. Flickermeter output is given in units of flicker severity (Pst), a value which is acceptable by human tolerance limit. This device mimics the way that a human perceives flicker and simulates the lamp-eye-brain chain of human. Generally, flickermeter has the design and functionality as shown in Figure 1.2. Square law demodulator, weighting filters and squaring and smoothing filters perform the signal conditioning operation on the measured voltage waveform V(t). These blocks represent how the voltage fluctuations are transformed into light fluctuations. Perceptibility of light fluctuation to human eye is determined, which gives the instantaneous flicker sensation (P) index.

One unit of P (P=1.0) corresponds to the reference human flicker perceptibility threshold, which is based on a criterion that flicker levels created by voltage fluctuations will annoy 50% of persons tested. The test is carried out by varying the amplitude of modulation input to maintain the unity for the peak value of output reading to P=1.0.

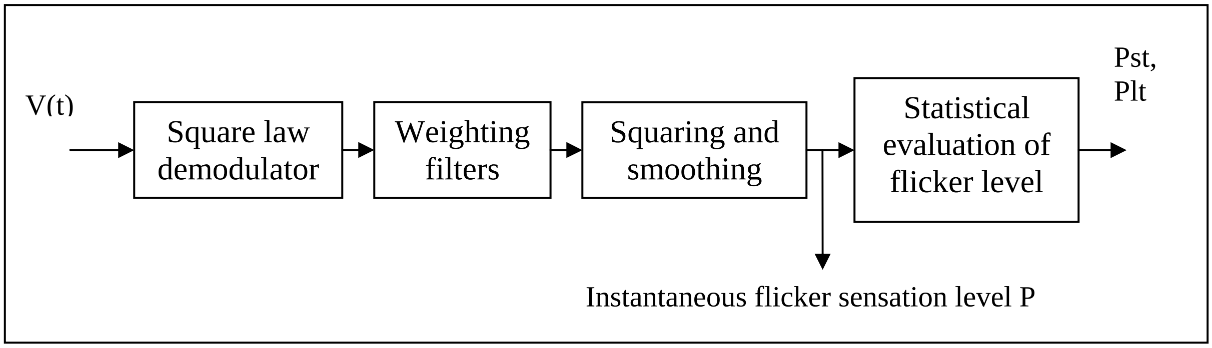


Figure 1.2: Functional Block Diagram of Flickermeter [2]

Statistical evaluation block is used to obtain short-term flicker severity level (Pst), which represents the irritation level of the flicker caused. It is based on an observation period of 10 minutes and normalized to a value of 1.0 to stand for the reference threshold of flicker severity. As a P and Pst index of 1.0 indicates that the flicker will be annoying to human eye, equipment or appliances must ensure that flicker level arises as a result of voltage fluctuations remain below 1.0 [2]. Long-term flicker severity (Plt) is the long-term assessment of flicker severity derived from the Pst over a certain period of time, for example a few hours [6]. This index is necessary as human’s tolerance to flicker over longer periods is less than the tolerance for the short term.

1.2 Problem Statement

In order to gain acceptance in the important markets, equipment have to meet the flicker requirements of the standards suggested by the national or the international standard organizations. Equipment, which do not meet the desired standard, need to be redesigned to comply with the desired requirements. This causes unnecessary delay in introducing