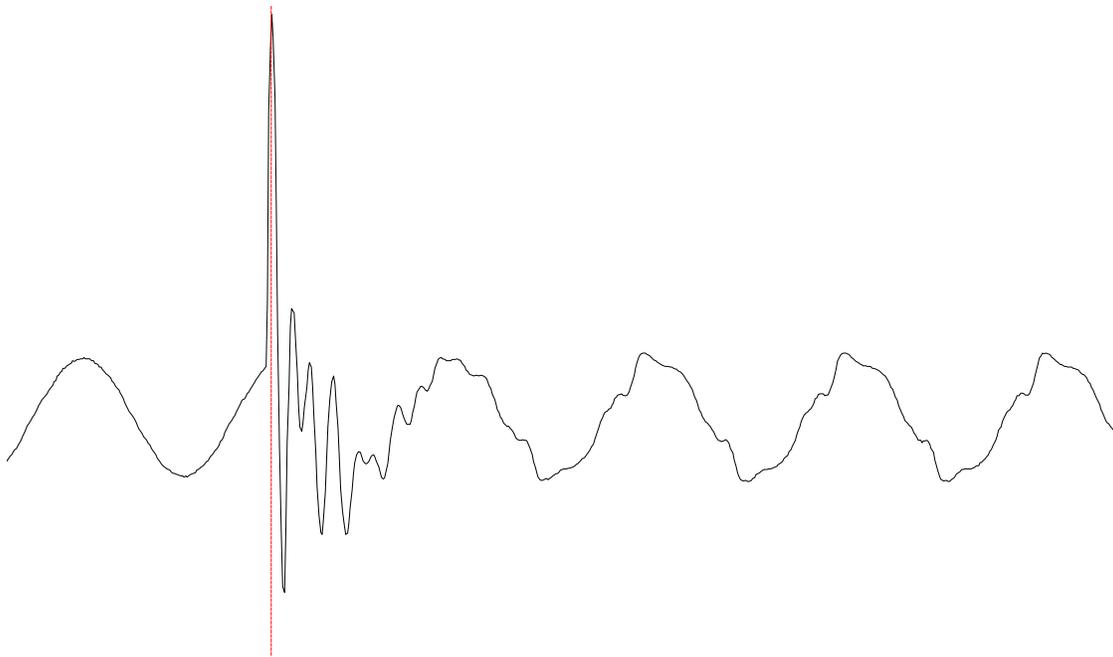


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Harmonics and Transients Tech Notes



Issue # 98-2

July 1998

Editor: Dolly Blaydes

Project Manager: Tom Grebe

In this issue:

Letter from the Project Manager.....	2
Benchmarking SuperHarm.....	3
Voltage Flicker Measurement, Part 1 Digital Implementation of the IEC Flicker Meter	19

From the Project Manager,

The past few months have been a time of transition for the PATH Users Group. As many of you know, we have had several key employees leave Electrotek and their support duties for the PATH Users Group. This has necessitated my returning to the position of PATH Users Group Project Manager, a position I held when the group was first organized. We have altered our support staff for PATH, bringing in Wade Eckler and Surya Santoso to serve as support engineers; and Sandy Smith and Dolly Blaydes to handle day-to-day administration of the group and production of such items such as *The PATHFinder* and *Tech Notes*.

Electrotek is hard at work getting the 32-bit version of HarmFlo+/SuperHarm ready for release this Fall. This issue of *Tech Notes* features a description of the benchmarking process for the newest version of this software. This issue also features the first part of a discussion of voltage flicker. Authored by new Electrotek employee Jeff Smith, this topic is one that will undoubtedly be of interest to many of our members.

We are making preparations for our annual PATH Users Group meeting and workshop, held October 19-20 in Knoxville. This promises to be a productive event where you can learn more about the 32-bit versions of HarmFlo+ /SuperHarm and TOP. We will also be looking for active participation from you as we determine membership priorities and activities for next year.

I also want to take an opportunity to welcome our new EPRI Project Manager for PATH, Dominic Maratukulam. Dominic has a strong background in power systems analysis and engineering, and brings a wealth of expertise to the Users Group.

We appreciate your membership in PATH, and promise that we will do everything we can to make your membership a productive experience.

Sincerely,

A handwritten signature in cursive script, appearing to read 'Thomas Grebe'.

Thomas Grebe, P.E.
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PATH Users Group Project Manager

Benchmarking SuperHarm

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Introduction

This article provides a brief overview of the benchmarking process currently being completed as part of the SuperHarm[®] 32-bit Conversion Project.

SuperHarm is a tool designed to assist the electric power engineer in evaluating harmonic concerns for electric power systems. The program allows a user to develop a computer model of the system of interest and explore variations on system loads and configurations along with the resulting impact on system frequency response and distortion levels.

SuperHarm is available with a wide variety of device and source models. The program contains a generic harmonic voltage and current source model, long-line corrected pi model, a simple RL branch model, a capacitor model, and a balanced three-phase coupled line model. Also included are models for the modal representation of geometrically-specified lines and cables, advanced load representations, induction and synchronous machines, and three-phase equivalents.

The program can solve both balanced and unbalanced three-phase systems. This is accomplished by using phase domain nodal admittance matrix techniques rather than sequence component solution methods.

The SuperHarm solution engine (Solver) reads a text file created by the user that describes the system to be simulated. SuperHarm's Circuit Description Language (CDL) consists of keywords representing device models as well as control commands. The devices are "connected" together by specifying alphanumeric names for the power system buses.

SuperHarm utilizes TOP, The Output Processor[®] to visualize the simulation results. The program takes advantage of the Microsoft Windows[®] Graphical User Interface and clipboard to allow the user to easily transfer data to other Windows programs such as Microsoft Excel[®] and Microsoft Word[®].

This article provides a summary of the methodology developed to verify SuperHarm's component models. The verification datacases that have been developed will be completed whenever a new version or error correction is completed. Each of the component models is validated using hand calculations, MathCad analysis, or EMTP (Electromagnetic Transients Program) simulations. In addition, a number of "system cases" have been developed to assure the accuracy of component integration. Results from these cases are validated using the EMTP or other readily-available simulation tools.

Electrotek's Software Quality System

Description of the Electrotek Software Quality System

The goal of Electrotek's Software Quality System is to ensure that all our software products satisfy customer requirements. The system also ensures that software development is performed according to a standardized process. The Electrotek Software Quality System conforms to ANSI/ISO/ASQC Q9001-1994.

All processes that involve more than one person or that are not intuitive to the person who performs them are documented in procedures. The company's ISO management representative has the responsibility to periodically audit the quality system both to ensure that it is being followed correctly and to proactively find ways to improve it.

Because software development is by nature a creative activity, the quality system does not specify the design and development methodologies themselves. Instead, the quality system focuses on the management and review of each software project to ensure that the design and implementation meets the specified requirements. To this end, all work items (e.g., source code, design documentation, user documentation, et al.) are controlled.

The Electrotek Software Quality System is implemented on all Electrotek software projects, both internal and external, except for throwaway prototype work. Its procedures are designed to be flexible enough to be used on any software project. In exceptional cases, the project manager documents the necessary changes to the process in the project's quality and test plan and has them approved by the quality manager.

Under the system, every software project has documented, approved requirements, a project plan, a quality & test plan, and a build plan. These items are described below:

- Every project has documented, approved *requirements* before the beginning of design activities.
- Every project has a *project plan* that specifies all the planned development activities for the project. It is established at the beginning of the project, and it is updated as the project progresses. The project plan specifies the project objectives, management, organization, schedule, and deliverables.
- Every project has a *quality & test plan* that specifies the planned verification and validation activities for the project. It is established at the beginning of the project, and it is updated as the project progresses. The purpose of the quality & test plan is to ensure that the delivered product meets its stated requirements.
- Every project has a *build plan* that specifies the parts that combine to make the final product. It details the order in which the subproducts (modules) are combined along with their interrelationships. It is created at the beginning of the project; and at the end, it serves as the list of deliverables for the final software product.

For more information on Electrotek's Software Quality System, please contact Lee King at (423) 470-9222, extension 140, or send e-mail to lking@electrotek.com.

Using the Quality System to Complete the SuperHarm 32-bit Conversion Project

The objective of the SuperHarm 32-bit Conversion Project is to complete the conversion of the 16-bit version to 32-bit environment, including associated benchmarking of the SuperHarm Solver, testing of the SuperHarm user interface, and a manual and help file revision. The personnel directly involved in the SuperHarm 32-bit Conversion Project are the Project Manager, Thomas Grebe, and the Lead Developer, Erich Gunther. Tom is responsible for the management of the project, and Erich is responsible for leading the development activities.

Development activities (which are governed by standard Electrotek software development procedures) for the project include:

1. Internal requirement collection
2. Conversion of the SuperHarm Solver to the 32-bit environment
3. Component and system testing of the SuperHarm Solver as specified in the Test Procedure and SuperHarm Benchmarking Manual.
4. Manual and help file revision
5. Installation development
6. Integration testing
7. Release

Project documentation for the effort includes:

1. Project Plan
2. Quality and Test Plan
3. Build Plan
4. Test Procedure
5. SuperHarm Benchmarking Manual

Benchmarking Methodology

Quality Objectives

The *quality objective* of the SuperHarm 32-bit Conversion Project is to assure an accurate and successful completion of the conversion of the 16-bit version (Version 2.20, April 6, 1996) to the 32-bit Microsoft Windows 95/98[®] and/or Microsoft Windows NT[®] 4 environment. Associated tasks include benchmarking of the SuperHarm Solver, testing of the SuperHarm user interface, and manual and help file revision. Methods to assure quality of the software deliverable include an accurate Project Plan, Build Plan, and Test Procedure that utilizes the SuperHarm Benchmarking Manual.

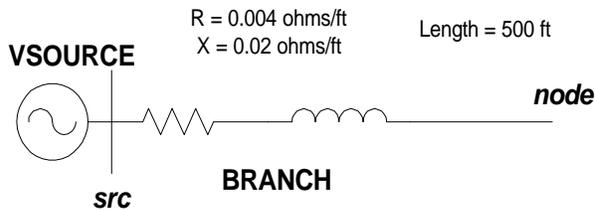
Development of the SuperHarm Benchmarking Manual

The SuperHarm Benchmarking Manual includes instructions for validation tests and supporting documentation for component and system modeling. Each component model is verified with supporting analysis, with a majority of the cases being verified using MathCad®.

The branch and two-winding transformer cases will be used to illustrate the process:

BRANCH - Definition:

The BRANCH model is an R and X series component. This device can be used for a single-phase model or three devices can be used for a three-phase uncoupled representation. The figure below illustrates the BRANCH model with the VSOURCE device model. This system will be used in the following cases for verification of the device tags unless otherwise noted.



Case List:

	NAME	FROM	TO	R	X	XRCON	LEN	TABLE	FREQMULT	FILE
DEFAULT	none	ground	ground	0.0	0.0	NO	1.0	none	1.0	none
case_1a	✓	✓	✓	✓	✓	✓	1.0	none	1.0	none
case_1b	✓	✓	✓	✓	✓	NO	1.0	none	1.0	none
case_1c	✓	✓	✓	✓	✓	NO	✓	none	1.0	none
case_1d	✓	✓	✓	0.0	0.0	✓	1.0	✓	✓	none
case_1e	✓	✓	✓	0.0	0.0	NO	1.0	none	1.0	✓

Results:

The table below illustrates voltages (impedances) at bus ‘node’ after performing a frequency scan at the same bus.

freq(h)	Case_1a		Case_1b		Case_1c		Case_1d		Case_1e	
	mag	ang								
1	10.198	78.7	10.198	78.7	10.198	78.7	10.198	78.7	10.198	78.7
2	20.3961	78.7	20.0998	84.3	20.0998	84.3	20.09	84.6	20.09	84.6
3	30.5941	78.7	30.0666	86.2	30.0666	86.2	30.054	86.6	30.054	86.6
4	40.7922	78.7	40.05	87.1	40.05	87.1	40.0281	87.9	40.0281	87.9
5	50.9902	78.7	50.04	87.7	50.04	87.7	50.0144	88.6	50.0144	88.6
6	61.1882	78.7	60.0333	88.1	60.0333	88.1	60.0105	88.9	60.0105	88.9
7	71.3863	78.7	70.0286	88.4	70.0286	88.4	70.0079	89.1	70.0079	89.1
8	81.5843	78.7	80.025	88.6	80.025	88.6	80.0059	89.3	80.0059	89.3
9	91.7823	78.7	90.0222	88.7	90.0222	88.7	90.0045	89.4	90.0045	89.4
10	101.98	78.7	100.02	88.9	100.02	88.9	100.003	89.5	100.003	89.5
11	112.178	78.7	110.018	89.0	110.018	89.0	110.003	89.6	110.003	89.6
12	122.376	78.7	120.017	89.0	120.017	89.0	120.002	89.7	120.002	89.7
13	132.575	78.7	130.015	89.1	130.015	89.1	130.001	89.7	130.001	89.7
14	142.773	78.7	140.014	89.2	140.014	89.2	140.001	89.8	140.001	89.8
15	152.971	78.7	150.013	89.2	150.013	89.2	150.001	89.8	150.001	89.8
16	163.169	78.7	160.012	89.3	160.012	89.3	160	89.9	160	89.9
17	173.367	78.7	170.012	89.3	170.012	89.3	170	89.9	170	89.9
18	183.565	78.7	180.011	89.4	180.011	89.4	180	89.9	180	89.9
19	193.763	78.7	190.011	89.4	190.011	89.4	190	90.0	190	90.0
20	203.961	78.7	200.01	89.4	200.01	89.4	200	90.0	200	90.0
VERIFY	MCAD		MCAD		MCAD		HAND		HAND	

Verification:

MathCad was used to verify the accuracy of SuperHarm’s BRANCH component. The following figures summarize the analysis:



BRANCH Model Verification:

$$r := 0.004 \quad x := 0.02$$

$$\text{Length} := 500$$

Case 1a: X/R constant = yes and length = 500ft .

$$R := r \cdot \text{Length} \quad R = 2$$

$$X := x \cdot \text{Length} \quad X = 10 \quad \text{Leq} := \frac{X}{2 \cdot \pi \cdot 60} \quad \text{Leq} = 0.027$$

$$Z := R + X \cdot j \quad Z = 2 + 10j$$

at 60 Hz:

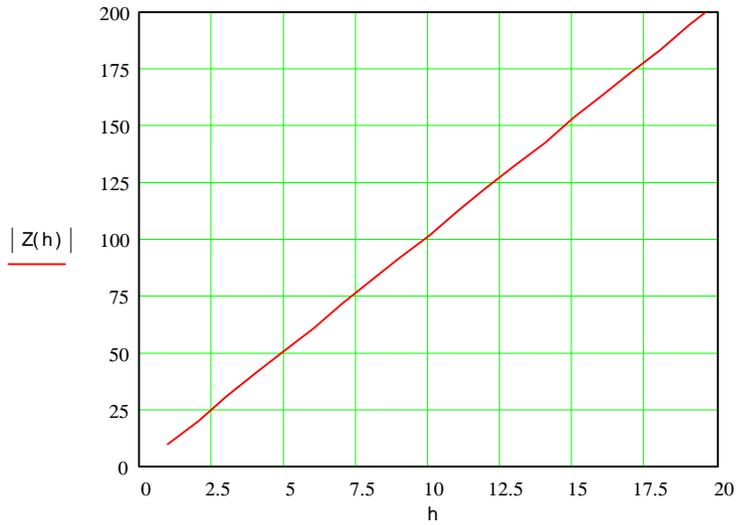
$$h := 1.. 20$$

$$|Z| = 10.198 \quad \arg(Z) = 78.69^\circ \text{deg}$$

$$R(h) := h \cdot R$$

$$X(h) := 2 \cdot \pi \cdot 60 \cdot h \cdot \text{Leq} \quad Z(h) := R(h) + X(h) \cdot j$$

h	Z(h)	$(\arg(Z(h))) \cdot \frac{180}{\pi}$
1	10.198	78.69
2	20.396	78.69
3	30.594	78.69
4	40.792	78.69
5	50.99	78.69
6	61.188	78.69
7	71.386	78.69
8	81.584	78.69
9	91.782	78.69
10	101.98	78.69
11	112.178	78.69
12	122.376	78.69
13	132.575	78.69
14	142.773	78.69
15	152.971	78.69
16	163.169	78.69
17	173.367	78.69
18	183.565	78.69
19	193.763	78.69
20	203.961	78.69



Dataset:

```

!
! BRANCH Model Benchmarking

!           Casela - xrconstant = yes
!           - length tag (default = 1)

vsource name=vsrc
      bus=src   freq=60
      mag=1     ang=0

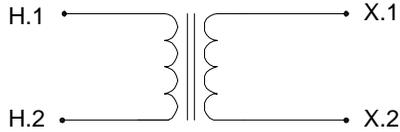
scan   name=scan1 bus=node
      fmin=60    fmax=1200
      finc=60    ang=0

branch name=zsrc
      from = src   to = node
      r = 2.0     x = 10.0
      xrconstant=yes

retain vtagelist = {node}
....
    
```

TRANSFORMER - Definition:

The TRANSFORMER is used to model a single-phase or three-phase transformer. It can accommodate up to three windings per phase. (Use ZYCMATRIX to model transformers with four or more windings.) Windings are designated as H, X, and T. For two winding transformers, all fields associated with the tertiary (T) winding should be omitted.



Case List:

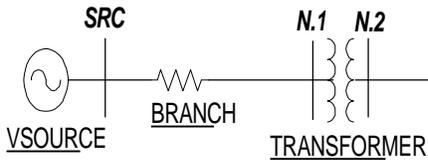
Single-phase representation

	NAME	X.1	X.2	H.1	H.2	T.1	T.2	MVA	%IMAG	XR CONSTANT	KV.H	KV.X	KV.T
<i>DEFAULT</i>	<i>none</i>	<i>ground</i>	<i>ground</i>	<i>ground</i>	<i>ground</i>	<i>ground</i>	<i>ground</i>	<i>0.0</i>	<i>1.0</i>	<i>yes</i>	<i>0.0</i>	<i>0.0</i>	<i>0.0</i>
Case_15a	✓	✓	ground	✓	✓	ground	ground	✓	1.0	✓	✓	✓	0.0
Case_15b	✓	✓	ground	✓	ground	✓	ground	✓	✓	yes	✓	✓	✓
Case_15c	✓	✓	✓	✓	✓	✓	✓	✓	1.0	yes	✓	✓	✓

	MVAB.HX	MVAB.XT	MVAB.HT	%R.HX	%R.XT	%R.HT	%X.HX	%X.XT	%X.HT
<i>DEFAULT</i>	<i>0.0</i>	<i>0.0</i>	<i>0.0</i>	<i>%X.HX/20</i>	<i>%X.XT/20</i>	<i>%X.HT/20</i>	<i>0.0</i>	<i>0.0</i>	<i>0.0</i>
Case_15a	0.0	0.0	0.0	%X.HX/20	%X.XT/20	%X.HT/20	✓	0.0	0.0
Case_15b	0.0	0.0	0.0	%X.HX/20	%X.XT/20	%X.HT/20	✓	✓	✓
Case_15c	✓	✓	✓	✓	✓	✓	✓	✓	✓

Results:

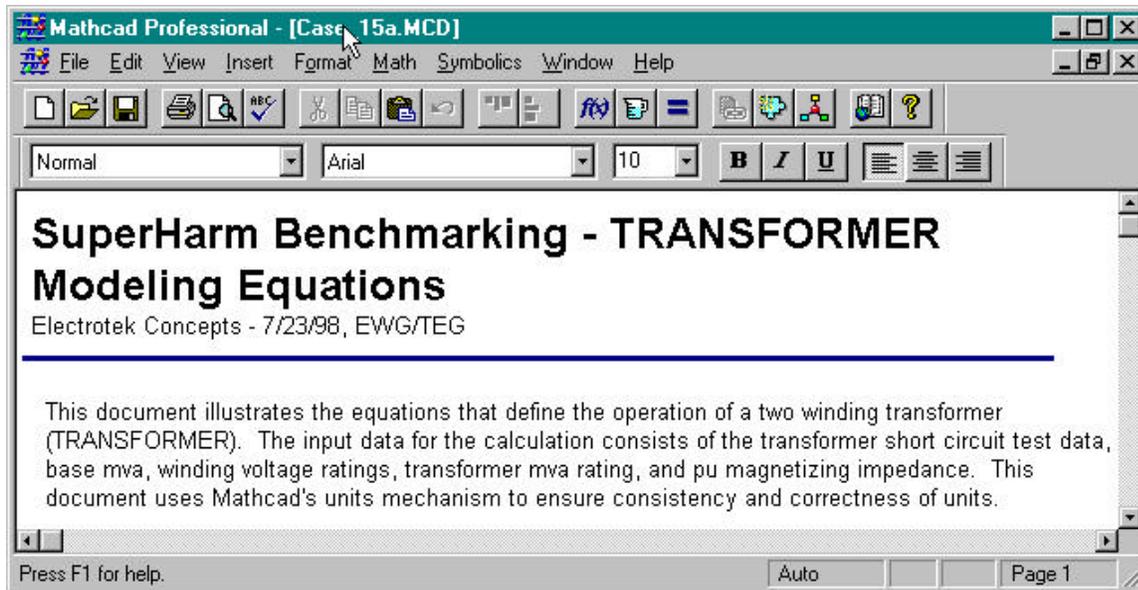
The one-line diagram shown below illustrates the system simulated for the verification of the single-phase TRANSFORMER model. A frequency scan was performed at N.2 and the equivalent impedances seen at the same bus are tabulated below.



	Case_15a		Case_15b		Case_15c	
freq(h)	mag	ang	mag	ang	mag	ang
1	2.28643	87.7	2.28654	87.7	2.28654	87.7
2	4.57286	87.7	4.57309	87.7	4.57309	87.7
3	6.85929	87.7	6.85963	87.7	6.85963	87.7
4	9.14572	87.7	9.14618	87.7	9.14618	87.7
5	11.4321	87.7	11.4327	87.7	11.4327	87.7
6	13.7186	87.7	13.7193	87.7	13.7193	87.7
7	16.005	87.7	16.0058	87.7	16.0058	87.7
8	18.2914	87.7	18.2924	87.7	18.2924	87.7
9	20.5779	87.7	20.5789	87.7	20.5789	87.7
10	22.8643	87.7	22.8654	87.7	22.8654	87.7
11	25.1507	87.7	25.152	87.7	25.152	87.7
12	27.4372	87.7	27.4385	87.7	27.4385	87.7
13	29.7236	87.7	29.7251	87.7	29.7251	87.7
14	32.01	87.7	32.0116	87.7	32.0116	87.7
15	34.2964	87.7	34.2982	87.7	34.2982	87.7
16	36.5829	87.7	36.5847	87.7	36.5847	87.7
17	38.8693	87.7	38.8713	87.7	38.8713	87.7
18	41.1557	87.7	41.1578	87.7	41.1578	87.7
19	43.4422	87.7	43.4443	87.7	43.4443	87.7
20	45.7286	87.7	45.7309	87.7	45.7309	87.7
VERIFY	MCAD		MCAD		MCAD	

Verification:

MathCad was used to verify the accuracy of SuperHarm's TRANSFORMER component. The following figures summarize the analysis:



TRANSFORMER Model Verification:

Cases 15a, 15b, & 15c:

Input Data:

$$f := 60 \quad \omega := 2 \cdot \pi \cdot f \quad \omega = 376.99112$$

$$MVA_r := 5.0 \quad MVA_b := 5.0$$

$$kv_H := 13.799249 \quad kv_H = 13.8$$

$$kv_X := 0.480 \quad kv_X = 0.48$$

$$X_{pu} := \frac{6.0}{100} \quad X_{pu} = 0.06$$

$$R_{pu} := X_{pu} \cdot 0.04 \quad R_{pu} = 0.0024$$

$$IMag_{pu} := 0.01$$

```
transformer      name = xfmr1
x.1 = n.1
h.1 = n.2
h.2 = ground
mva = 5
%x.hx = 6
kv.x = .480
kv.h = 13.8
xrconstant=yes
```

Calculate the base impedances for the impedance data from the supplied base MVA:

$$Z_{bH} := \frac{kv_H^2}{MVA_b} \quad Z_{bH} = 38.08385$$

$$Z_{bX} := \frac{kv_X^2}{MVA_b} \quad Z_{bX} = 0.04608$$

Calculate the high side base admittance for the magnetizing branch from the transformer rated MVA:

$$Y_{\text{mbase}} := \frac{MVA_r}{kv_H^2} \quad Y_{\text{mbase}} = 0.02626$$

Calculate the rated (base) current for the transformer on the high side:

$$I_{\text{bH}} := \frac{MVA_r}{kv_H} \quad I_{\text{bH}} = 0.36234$$

Calculate the high side magnetizing current:

$$I_{\text{Mag}} := I_{\text{Mag pu}} \cdot I_{\text{bH}} \quad I_{\text{Mag}} = 3.62339 \cdot 10^{-3}$$

Calculate the high side magnetizing admittance as a function of frequency (note that $I_{\text{pu}} = Y_{\text{pu}}$ in the per unit system):

$$Y_{\text{Mag pu}} := I_{\text{Mag pu}} \quad Y_{\text{Mag pu}} = 0.01$$

$$Y_{\text{m pu}}(\text{freq}) := \frac{Y_{\text{Mag pu}} \cdot 60}{j \cdot \text{freq}} \quad Y_{\text{m pu}}(f) = -0.01j$$

Create an equation for the pu leakage admittance as a function of frequency:

$$Y_{\text{pu}}(\text{freq}) := \frac{1}{R_{\text{pu}} + j \cdot X_{\text{pu}}} \cdot \frac{60}{\text{freq}} \quad Y_{\text{pu}}(f) = 0.6656 - 16.64004j$$

Create an equation for the pu primitive admittance matrix for the complete transformer as a function of frequency scaled to a single base MVA (1 MVA) to facilitate the conversion to engineering units:

$$S_{\text{base}} := 1$$

$$Y_{\text{prim pu}}(x) := \frac{1}{S_{\text{base}}} \cdot \begin{bmatrix} Y_{\text{pu}}(x) \cdot MVA_b + \frac{Y_{\text{m pu}}(x)}{2} \cdot MVA_r & -Y_{\text{pu}}(x) \cdot MVA_b \\ -Y_{\text{pu}}(x) \cdot MVA_b & Y_{\text{pu}}(x) \cdot MVA_b + \frac{Y_{\text{m pu}}(x)}{2} \cdot MVA_r \end{bmatrix}$$

$$Y_{\text{prim pu}}(f) = \begin{bmatrix} 3.32801 - 83.22521j & -3.32801 + 83.20021j \\ -3.32801 + 83.20021j & 3.32801 - 83.22521j \end{bmatrix}$$

Create an equation for the primitive admittance matrix for the transformer in system units:

$$Y_{\text{prim}}(\text{freq}) := S_{\text{base}} \cdot \begin{bmatrix} \frac{Y_{\text{prim pu}}(\text{freq})_{0,0}}{kv_H \cdot kv_H} & \frac{Y_{\text{prim pu}}(\text{freq})_{0,1}}{kv_H \cdot kv_X} \\ \frac{Y_{\text{prim pu}}(\text{freq})_{1,0}}{kv_X \cdot kv_H} & \frac{Y_{\text{prim pu}}(\text{freq})_{1,1}}{kv_X \cdot kv_X} \end{bmatrix}$$

$$Y_{\text{prim}}(f) = \begin{bmatrix} 0.01748 - 0.43706j & -0.50244 + 12.5611j \\ -0.50244 + 12.5611j & 14.44448 - 361.22054j \end{bmatrix}$$

Calculate the impedance matrix as a function of frequency:

$$Z_{\text{prim}}(\text{freq}) := Y_{\text{prim}}(\text{freq})^{(-1)}$$

$$Z_{\text{prim}}(f) = \begin{bmatrix} 0.02284 + 3.80896 \cdot 10^3 j & -7.94598 \cdot 10^{-4} + 132.45292 j \\ -7.94598 \cdot 10^{-4} + 132.45292 j & 2.76397 \cdot 10^{-5} + 4.60869 j \end{bmatrix}$$

Test the resulting admittance matrix by applying a voltage to the high side and calculating the resulting low side voltage.

$$V_H := 7.967431000$$

$$V_X := \frac{-Y_{\text{prim}}(f)_{1,0} \cdot V_H}{Y_{\text{prim}}(f)_{1,1}} \quad V_X = 277.05996 + 3.32372 \cdot 10^{-3} j$$

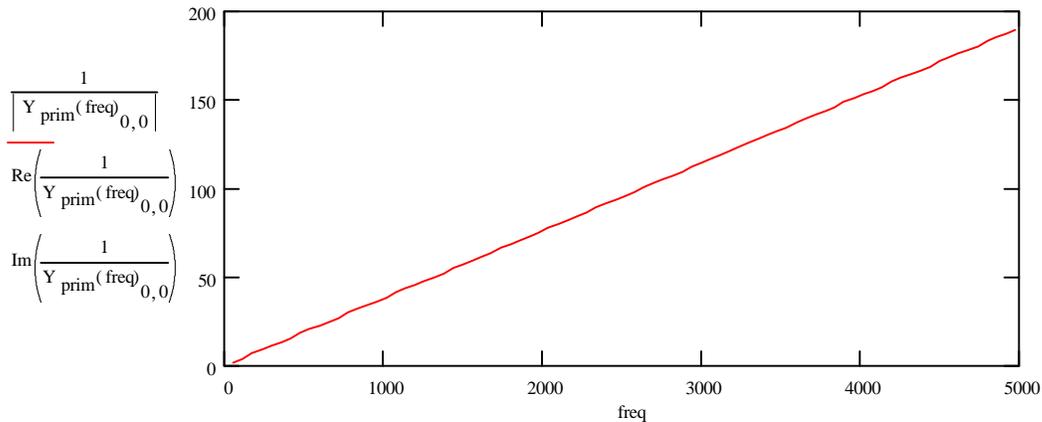
Now that we have calculated the terminal voltages, we can calculate the terminal currents and check for a match with the initial specified magnetizing current:

$$V := \begin{bmatrix} V_H \\ V_X \end{bmatrix} \quad V = \begin{bmatrix} 7.96743 \cdot 10^3 \\ 277.05996 + 3.32372 \cdot 10^{-3} j \end{bmatrix} \quad \begin{aligned} |V_0| &= 7967.43 \\ |V_1| &= 277.05996 \end{aligned}$$

$$I := Y_{\text{prim}}(f) \cdot V \quad I = \begin{bmatrix} 1.25449 \cdot 10^{-5} - 2.09176 j \\ 1.05027 \cdot 10^{-13} - 1.23396 \cdot 10^{-11} j \end{bmatrix} \quad |I_0| = 2.09176$$

Plot the short circuit impedance of the transformer:

$$\text{freq} := 60, 120, \dots, 5000$$



$$Z_{pu}(f) := \frac{1}{Y_{pu}(f)}$$

$$Z_{bX} = 0.04608$$

$$Z_{bH} = 38.08385$$

$$Z_{ls}(f) := Z_{pu}(f) \cdot Z_{bX}$$

$$Y_{pu}(f) = 0.6656 - 16.64004j$$

$$Z_{pu}(60) = 2.4 \cdot 10^{-3} + 0.06j$$

$$Z_{hs}(f) := (Z_{pu}(f)) \cdot Z_{bH}$$

freq := 60, 120.. 1200

freq	$ Y_{pu}(freq) $	$ Z_{ls}(freq) $	$ Z_{hs}(freq) $	$\frac{\arg(Z_{hs}(freq)) \cdot 180}{\pi}$	$ Z_{pu}(freq) $
60	16.65335	$2.76701 \cdot 10^{-3}$	2.2869	87.70939	0.06005
120	8.32667	$5.53402 \cdot 10^{-3}$	4.5737	87.70939	0.1201
180	5.55112	$8.30103 \cdot 10^{-3}$	6.8606	87.70939	0.18014
240	4.16334	0.01107	9.1474	87.70939	0.24019
300	3.33067	0.01384	11.4343	87.70939	0.30024
360	2.77556	0.0166	13.7212	87.70939	0.36029
420	2.37905	0.01937	16.008	87.70939	0.42034
480	2.08167	0.02214	18.2949	87.70939	0.48038
540	1.85037	0.0249	20.5817	87.70939	0.54043
600	1.66533	0.02767	22.8686	87.70939	0.60048
660	1.51394	0.03044	25.1554	87.70939	0.66053
720	1.38778	0.0332	27.4423	87.70939	0.72058
780	1.28103	0.03597	29.7292	87.70939	0.78062
840	1.18952	0.03874	32.016	87.70939	0.84067
900	1.11022	0.04151	34.3029	87.70939	0.90072
960	1.04083	0.04427	36.5897	87.70939	0.96077
1020	0.97961	0.04704	38.8766	87.70939	1.02082
1080	0.92519	0.04981	41.1635	87.70939	1.08086
1140	0.87649	0.05257	43.4503	87.70939	1.14091
1200	0.83267	0.05534	45.7372	87.70939	1.20096

Datacase:

```
!  
! TRANSFORMER model test  
!           Case_15a - single phase usage  
!           xrconstant = yes  
!           no tertiary winding  
!  
  
vsource name=vsrc  
        bus=src   freq=60  
        mag=7967   ang=0  
  
branch  name=zsrc  
        from = src   to = n.1  
        x = 0.00000001  
  
scan    name=scan1   bus= n.2  
        ang=0        fmin=60  
        fmax=1200    finc=60  
  
transformer  name = xfmr1  
            x.1 = n.1  
            h.1 = n.2  
            h.2 = ground  
            mva = 5.0  
            %x.hx = 6.0  
            kv.x = .480  
            kv.h = 13.8  
            xrconstant=yes  
  
.....
```

Implementing the Test Procedure

The Test Procedure for the SuperHarm 32-bit Conversion Project provides the method for testing of the SuperHarm component and system models. For those not directly involved in the testing, the document provides an overview of test procedures; for the testers, it provides a description of the tests. The test results are formally verified using the simulation results presented in the SuperHarm Benchmarking Manual. The Test Procedure assumes that the reader/tester is familiar with the functionality of SuperHarm 32-bit Solver (see the SuperHarm Users Manual). It also assumes that the tester is familiar with the general functionality of Microsoft Windows 95/98 and/or Microsoft Windows NT 4.

Results for a Sample Test: Version 4 Beta Test #7 – Complete Test

These tests were completed on June 26, 1998 using the Version 4 beta. Tests were completed on a Windows 95 machine.

Test cases reside in SourceSafe directory:

\$/SuperHarm/Benchmarking/ Simulation Input and Output Files/

Model/Case	Pass/Fail	Tester	Date	Comments
BRANCH				
Case1a	PASS	TEG	6/26/98	Using Results from Benchmarking Manual
Case1b	PASS	TEG	6/26/98	Using Results from Benchmarking Manual
Case1c	PASS	TEG	6/26/98	Using Results from Benchmarking Manual
Case1d	PASS	TEG	6/26/98	Using Results from Benchmarking Manual
Case1e	PASS	TEG	6/26/98	Using Results from Benchmarking Manual

-
-
-

<continued for each component model>

Model/Case	Pass/Fail	Tester	Date	Comments
SYSTEM CASE 1				
SC1a	PASS	TEG	6/26/98	Using Results from Benchmarking Manual
SC1a_sc	PASS	TEG	6/26/98	Using Results from Benchmarking Manual
SC1b	PASS	TEG	6/26/98	Using Results from Benchmarking Manual
SC1b_sc	PASS	TEG	6/26/98	Using Results from Benchmarking Manual
SC1c	PASS	TEG	6/26/98	Using Results from Benchmarking Manual
SC1c_sc	PASS	TEG	6/26/98	Using Results from Benchmarking Manual

-
-
-

<continued for each system model>

Model/Case	Pass/Fail	Tester	Date	Comments
Directives and Advanced Features				
Case_23a	PASS	TEG	6/26/98	Using Results from Benchmarking Manual

Voltage Flicker Measurement, Part I: Digital Implementation of the IEC Flicker Meter

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Abstract

Interest in voltage flicker has presently been on the rise as the result of industries utilizing large motors and/or arc furnaces. At the present time, there is no set standard for measuring voltage flicker that can be used by utilities in the United States. For this reason, individual utilities are often forced to develop their own criteria for flicker measurement, which are often based upon existing flicker meters (IEC, UHP/Schwabe, and Cooper, to name a few). This tech note is Part I of a two part series entitled “Voltage Flicker Measurement.” This first part presents various techniques that are used to measure voltage flicker, specifically the IEC flicker meter. Digital implementation of the IEC flicker meter is discussed along with results obtained from the developed model.

Introduction

Flicker is a relatively old subject that has gained considerable attention due to the increased awareness of issues concerning power quality. Power engineers first dealt with flicker in the 1880’s when the decision of using ac over dc was of concern [1]. Low frequency ac voltage resulted in a “flickering” of the lights. To avoid this problem, a higher 60 Hz frequency was chosen as the standard frequency in North America.

Voltage flicker can be defined as a sudden fluctuation in system voltage, which could result in observable changes in the output of lamps. Because voltage flicker is mostly a problem when it is observed by the human eye, usually voltage flicker is referred to as a problem of perception. There are, however, rare cases where voltage flicker can affect equipment operation such as electric drives and UPS systems [1].

In the early 1900’s, many studies were done on humans to determine the levels of voltage flicker which were observable and which were objectionable. Many curves, such as the one shown in Figure 1, were developed by various companies to determine the severity of voltage flicker. The flicker curve shown in Figure 1 was developed by C.P. Xenis and W. Perine in 1937, and was based upon data obtained from 21 groups of observers. In order to account for the nature of flicker, the observers were exposed to various waveshape voltage variations, levels of illumination, and types of lighting [2].

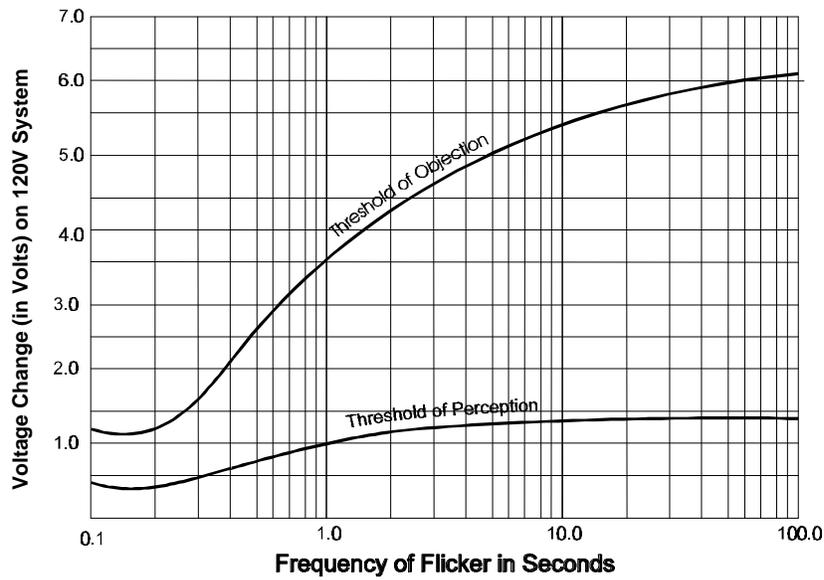


Figure 1. General Flicker Curve

Voltage flicker can be separated into two types: cyclic and noncyclic. Cyclic flicker is a result of periodic voltage fluctuations on the system, while noncyclic is a result of occasional voltage fluctuations in the system voltage. An example of sinusoidal-cyclic flicker is shown in Figure 2.

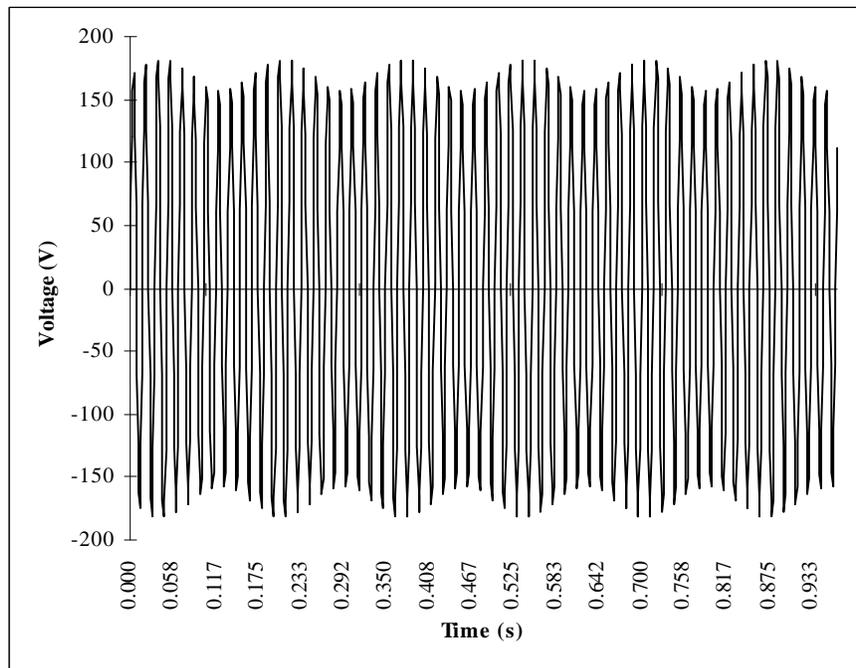


Figure 2. Example Graph of Voltage Flicker

As shown in Figure 2, flicker is simply amplitude modulation where the main signal (60Hz for North America) is the carrier signal and flicker is the modulating signal. Modulation is usually specified as a percentage of the carrier signal. By using a percentage, the flicker signal is

independent of peak, peak-to-peak, rms, line-to-neutral, etc. Typically, percent voltage modulation is expressed using Eq. 1, being sure

$$\text{Percent Voltage Modulation} = \frac{V_{MAX} - V_{MIN}}{V_0} \cdot 100\% \quad (1)$$

where

- V_{MAX} = maximum value of modulated signal
- V_{MIN} = minimum value of modulated signal
- V_0 = average value of normal operating voltage

to use consistent units throughout. For example, if the minimum, maximum, and average peak line-to-neutral voltages in Figure 1.2 are 168.86V, 170.55V, and 169.7V respectively, then the percent voltage modulation would be 1.0%.

The usual method for expressing voltage flicker is similar to that of percent voltage modulation. Voltage flicker is usually expressed as a percent of the total change in voltage with respect to the average voltage ($\Delta V/V$) over a certain period of time. This method for describing voltage flicker will be used throughout the remaining portion of this paper.

The magnitude of the modulation signal has been described as essentially being the magnitude of the flicker signal, but the frequency content of flicker has yet to be addressed. The frequency content of voltage flicker is extremely important in determining whether or not flicker levels are observable (or objectionable). Describing the frequency content of the flicker signal in terms of modulation would mean that the flicker frequency is essentially the frequency of the modulating signal. The typical frequency range of observable flicker is from 0.5Hz to 30.0 Hz, with observable magnitudes starting at less than 1.0%.

As shown in Figure 1, the most sensitive frequency range for voltage flicker is approximately 5-10 Hz. In essence, this means that the human eye is more susceptible to voltage fluctuations in this 5-10 Hz range. As the frequency of flicker increases or decreases away from this range, the human eye generally becomes more tolerable of luminance fluctuations.

One issue that was not considered in the development of Figure 1 is that of multiple flicker signals. Generally, most flicker-producing loads contain multiple voltage flicker signals (of various magnitudes and frequencies), thus making it more difficult to use flicker curves in evaluating the levels of voltage flicker.

Present Measurement Techniques

Currently, a standard method for measuring voltage flicker does not exist in the United States. In Europe, however, the International Electrotechnical Commission (IEC) has developed standards for measuring voltage flicker. The IEEE Task Force on Light Flicker is presently considering modifications necessary to the IEC standards for them to be used in the United States. Because there is presently not a standard in the United States, many methods have been implemented for

trying to measure flicker. These methods have ranged from using basic rms strip charts to actual flicker meters. The prices for such methods range from a few hundred dollars to \$20,000.00.

RMS Strip Charts

Historically, voltage flicker has been measured using rms meters, load duty cycle, and a flicker curve. If sudden rms voltage deviations occurred with specified frequencies exceeding values found in flicker curves, such as the one shown in Figure 1, the system was said to have experienced voltage flicker. An example graph of rms voltage variations is shown in Figure 3, where large voltage deviations up to 9.0V rms ($\Delta V/V = \pm 8.0\%$ on 120V base) are found. Upon comparing this to the flicker curve in Figure 1, the feeder would be experiencing voltage flicker, regardless of the duty cycle of the load producing the voltage flicker because any sudden total change in voltage greater than 7.0V rms results in objectionable flicker, regardless of the frequency. The advantage to such a method is that it is quite simple in nature and the rms data required is rather easy to acquire. The apparent disadvantage to such a method would be the lack of accuracy and inability to obtain the exact frequency content of the voltage flicker.

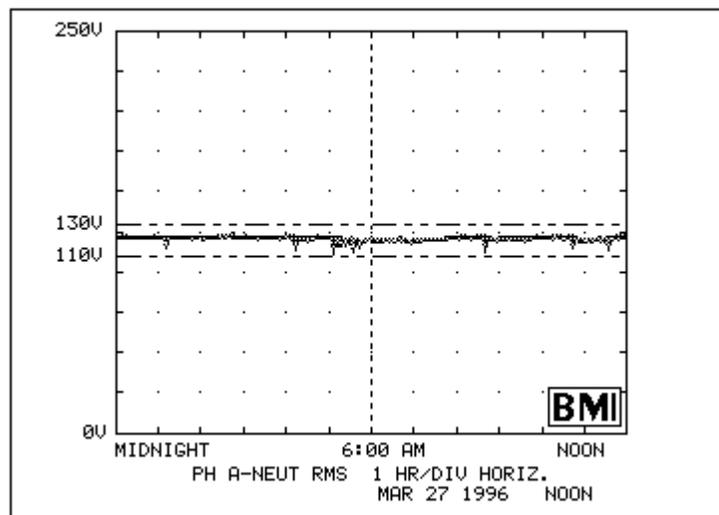


Figure 3. RMS Voltage Variations

Fast-Fourier Transform

Another method that has been used to measure voltage flicker is to take raw samples of the actual voltage waveforms and implement a fast-fourier transform on the demodulated signal (flicker signal only) to extract the various frequencies and magnitudes found in the data. This data would then be compared to a flicker curve. This method is similar to that of the V-Flicker meter that is addressed later in this paper. Although similar to using the rms data, this method more accurately quantifies the data measured due to the magnitude and frequency of the voltage flicker being known. The downside to implementing this method is associated with quantifying voltage flicker levels when the flicker-producing load contains multiple flicker signals. Some instruments address this issue by displaying only the dominant frequency and discarding the rest.

The most accurate method for measuring flicker is to use what are known as flicker meters. Generally, these meters can be divided up into three sections. In the first section the input

waveform is demodulated, thus removing the carrier signal. As a result of the demodulator, a dc offset and higher frequency terms (sidebands) are produced. The second section removes these unwanted terms using filters, thus leaving only the modulating (flicker) signal remaining. The second section also consists of filters that weight the modulating signal according to the particular meters specifications. The last section usually consists of a statistical analysis of the measured flicker. The following three flicker meters will be addressed: IEC Flicker Meter, UHP/Schwabe Flicker Analyzer, and the V-Flicker meter.

Flicker Meters:

IEC Flicker Meter

The first flicker meter to be addressed is the IEC flicker meter presented in the IEC 868 Standard [3]. (Note that the IEC 868 has recently been replaced with the IEC 1000-4-15 Standard. For clarity, all references to the IEC flicker meter will be based upon the IEC 868 publication). The IEC flicker meter is the standard for measuring voltage flicker in Europe and other countries currently adopting IEC standards. The IEC flicker meter consists of five blocks which are shown in Figure 4.

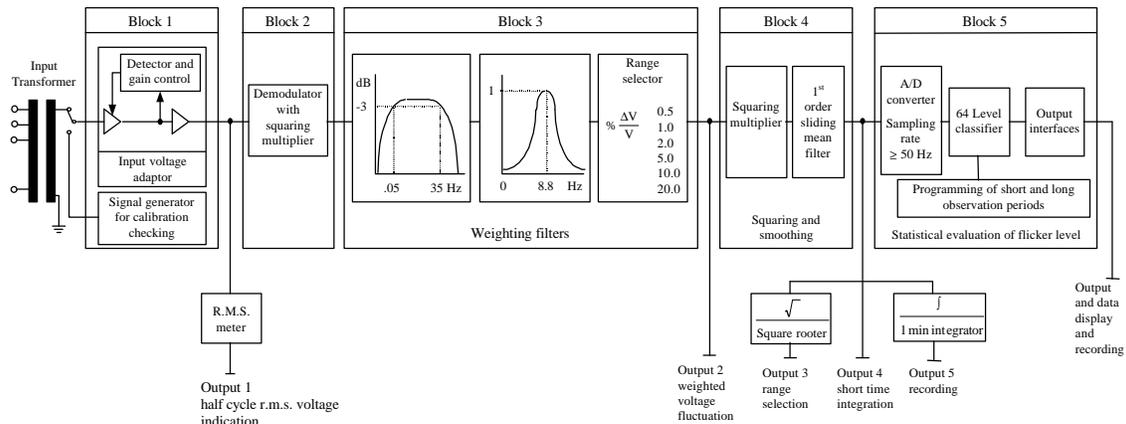


Figure 4. Diagram of the IEC Flicker Meter

Block 1 is an input voltage adapter which scales the input half-cycle rms value to an internal reference level. This allows flicker measurements to be made based upon a percent ratio rather than dependent upon the input carrier voltage level. The adapter has a response time of 60 seconds from 10% to 90% for a step change in the input rms voltage. Block 2 is simply a squaring demodulator which squares the input to separate the voltage fluctuation (modulating signal) from the main voltage signal (carrier signal), thus simulating the behavior of the incandescent lamp.

Block 3 consists of multiple filters which serve to filter out unwanted frequencies produced from the demodulator and also to weight the input signal according to the incandescent lamp eye-brain response. The first filter is a bandpass filter which consists of a 1st order high pass filter with a 3dB breakpoint at 0.05 Hz and a 6th order low-pass Butterworth filter with a 3dB breakpoint at 35.0 Hz.

The lamp eye-brain response is represented with a 4th order bandpass filter, also known as the weighting filter. This filter has the purpose of weighting the input based upon the particular characteristics of the lamp, whether it be a 230V/60W, 120V/60W, or any other voltage/wattage combination or possibly even fluorescent lamps. It may also be noted that the weighting curve for the IEC 120V/60W lamp is very similar to that of Figure 1. The basic transfer function for the weighting filter is shown in Eq. 2.

$$H(s) = \frac{k\omega_1 s}{s^2 + 2\zeta s + \omega_1^2} \cdot \frac{1 + s/\omega_2}{(1 + s/\omega_3)(1 + s/\omega_4)} \tag{2}$$

Because the filament for the 120V lamp is larger, resulting in a larger thermal time constant, the transfer functions for the 120V lamp and the 230V lamp are slightly different. The lower the thermal time constant is, the more susceptible the lamp is to voltage flicker. Typically, the time constant for 120V and 230V incandescent lamps rated at 60W have time constants of approximately 28ms and 19ms, while that of a typical fluorescent lamp has time constant of about 5ms. Table 1 gives the coefficients for both the 230V lamp and the 120V incandescent lamp [4], while Figure 5 demonstrates the frequency response of both.

Variable	120V lamp	
K	1.74802	1.6357
λ	$2\pi \cdot 4.05981$	$2\pi \cdot 4.167375$
ω_1	$2\pi \cdot 9.15494$	$2\pi \cdot 9.077169$
ω_2	$2\pi \cdot 2.27979$	$2\pi \cdot 2.939902$
ω_3	$2\pi \cdot 1.22535$	$2\pi \cdot 1.394468$
ω_4	$2\pi \cdot 21.9$	$2\pi \cdot 17.31512$

Table 1 Filter Coefficients for Weighting Filter

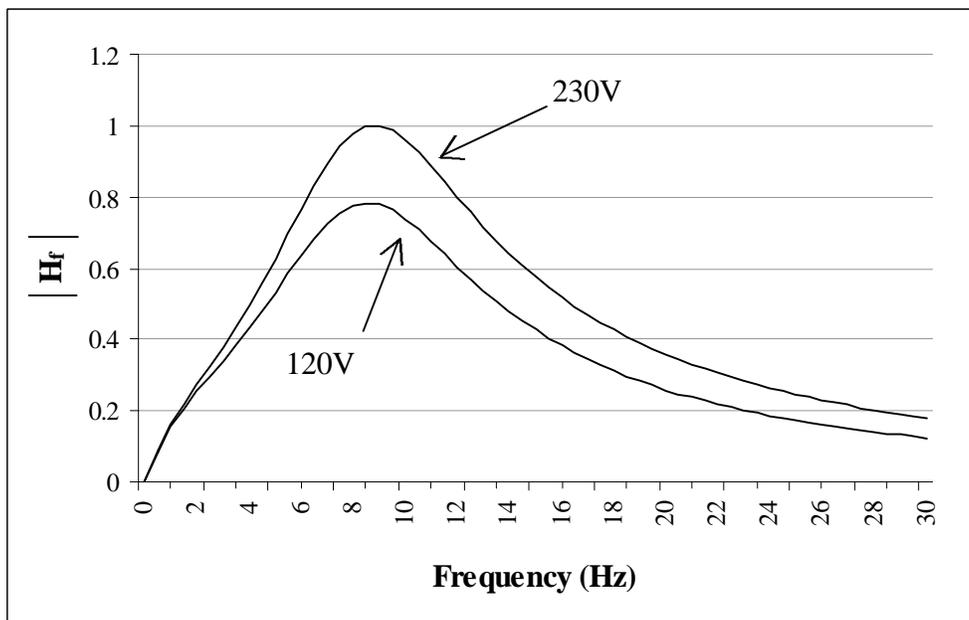


Figure 5. Frequency Response of Weighting Filters

Block 4 consists of a squaring multiplier and sliding mean filter. The voltage signal is squared to simulate the non-linear eye-brain response, while the sliding mean filter averages the signal to simulate the short-term storage effect of the brain. The filter consists of a 1st order low pass filter with a time constant of 300ms. The output of this block is considered to be the instantaneous flicker level. A level of one on the output of this block corresponds to perceptible flicker.

Block 5 consists of a statistical analysis of the instantaneous flicker level. The minimum sampling rate for the output of Block 4 should be the main frequency. For 50 Hz systems, the minimum would be 50 Hz, and for 60 Hz systems the minimum would be 60 Hz. This output is divided into suitable classes, thus creating a histogram. A probability density function (PDF) is created based upon each class and from this a cumulative distribution function (CDF) can be formed. The CDF can be thought of as the probability that the instantaneous flicker sensation will not exceed a certain level. Figure 6 gives a graphical demonstration of both the probability density and cumulative distribution functions.

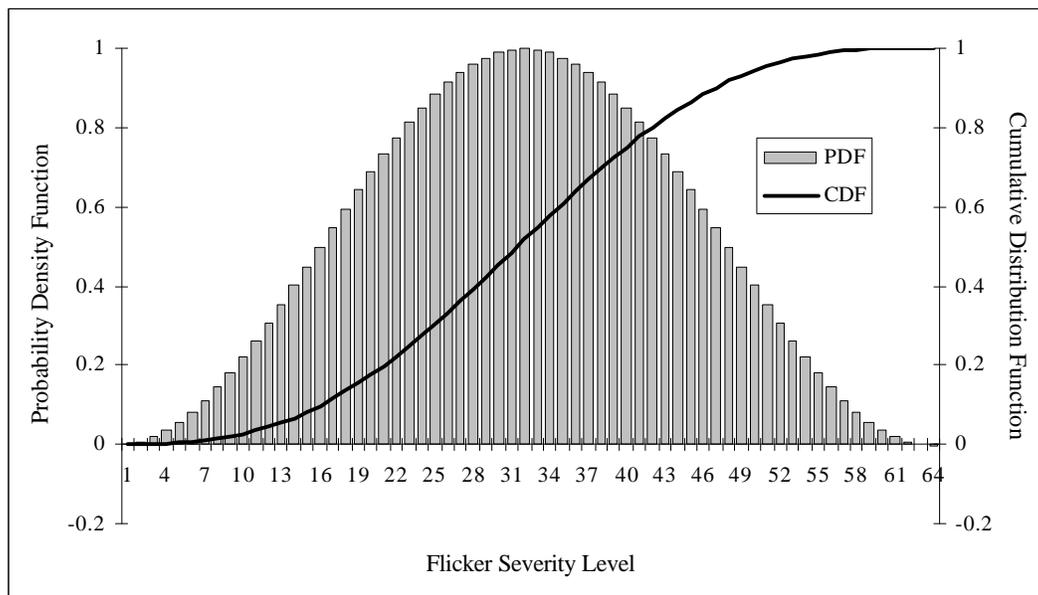


Figure 6. Cumulative Distribution and Probability Density Curves

Flicker level evaluation can be divided into two categories, short-term and long-term. Short-term evaluation of flicker severity, P_{ST} , is based upon an observation period of 10 minutes. This period is based upon assessing disturbances with a short duty-cycle or those which produce continuous fluctuations. P_{ST} can be found using Eq. 3.

$$P_{ST} = \sqrt{0.0314P_{0.1} + 0.0525P_{1s} + 0.0657P_{3s} + 0.28P_{10s} + 0.08P_{50s}} \quad (3)$$

where the percentages $P_{0.1}$, P_{1s} , P_{3s} , P_{10s} , P_{50s} are the flicker levels that are exceeded 0.1, 1.0, 3.0, 10.0, and 50.0 percent of the time. These values are taken from the cumulative distribution curve discussed previously. The suffix s represents the smoothed value obtained using Eqs. 4 - 7.

$$P_{1s} = \frac{P_{0.7} + P_1 + P_{1.5}}{3} \quad (4)$$

$$P_{3s} = \frac{P_{2.2} + P_3 + P_4}{3} \quad (5)$$

$$P_{10s} = \frac{P_6 + P_8 + P_{10} + P_{13} + P_{17}}{5} \quad (6)$$

$$P_{50s} = \frac{P_{30} + P_{50} + P_{80}}{3} \quad (7)$$

For cases where the duty cycle is long or variable, such as in arc furnaces, or disturbances on the system that are caused by multiple loads operating simultaneously, the need for the long-term assessment of flicker severity arises. Therefore, the long-term flicker severity, P_{LT} , is derived from P_{ST} using Eq. 8.

$$P_{LT} = \sqrt[3]{\frac{\sum_{i=1}^N P_{STi}^3}{N}} \quad (8)$$

where N is the number of P_{ST} readings. The number of P_{ST} readings (N) is determined by the duty cycle of the flicker producing load. The purpose is to capture one duty cycle of the fluctuating load. If the duty cycle is unknown, the recommended number of P_{ST} readings is 12 (two hours of measuring).

UHP/Schwabe Flicker Analyzer

The second flicker meter addressed is the UHP/Schwabe Flicker Analyzer [5]. The UHP meter is very similar in nature to the IEC flicker meter. The input signal is demodulated, filtered and weighted according to user specification. The input voltage adapter is replaced with 20 cycle sliding rms calculator that normalizes the input. The signal is then demodulated using a squaring multiplier. Using similar filters as the IEC, the dc-offset and higher frequency components as a result of the demodulator are filtered out. The user then has the option to choose from various weighting filters. The filters available from which the user can choose are the 230V IEC (discussed previously), General Electric, Japanese V_{10} , or no weights at all. The output smoothing filter is similar to the IEC with the exception of having a longer two second time constant. The UHP also displays the dominant flicker frequency.

V-Flicker Meter

The third flicker meter is the V-Flicker meter developed by Cooper Power Systems [6]. The V-Flicker Meter is similar to the IEC in that it demodulates the input signal, filters out the unwanted components, weights the input based upon certain lamp characteristics, and calculates a P_{ST} based upon this data. Similar to the UHP meter, the V-Flicker meter has the flexibility of the user supplying the weighting filter to be used. Being that the V-Flicker meter is digital, it samples at 1920 Hz using a 12 bit A/D card.

Unlike the IEC, the V-Flicker meter performs an FFT on the signal once it has been demodulated and filtered. This FFT returns a type of average of the frequency components measured in the window. A weighted average flicker level is calculated using a weighted rms type of calculation

that is expressed relative to the user specified flicker weighting curve being used. The equation for the weighted average rms flicker level is shown in Eq. 9.

$$W = \sqrt{\sum_n \left[\frac{F_n * C_{LO}}{C_n} \right]^2} \quad (9)$$

where:

- W = Weighted average flicker level
- n = Frequency step counter (0.46875 Hz increments)
- F_n = Measured flicker magnitude at the nth frequency increment averaged over the sampling period (approximately 2 seconds)
- C_{LO} = Lowest flicker level on the flicker weighting curve
- C_n = Flicker value of the flicker weighting curve at the nth frequency increment.

The short term flicker severity, P_{ST}, is calculated similarly to the IEC meter except the flicker levels that are exceeded a certain percentage of the time are actually squared. These values are squared in an attempt to simulate the effect of the squaring multiplier in Block 4 of the IEC meter. This is shown in Eq. 10.

$$\text{Weighted Average } P_{ST} = \sqrt{0.0314P_{0.1s}^2 + 0.0525P_{1s}^2 + 0.0657P_{3s}^2 + 0.28P_{10s}^2 + 0.08P_{50s}^2} \quad (10)$$

IEC Meter Implementation

In order to study the behavior of the IEC flicker meter, one must be constructed based upon the IEC 868 standard [3]. The standard that exists currently for this meter is based upon an analog model of the meter. Due to the power and flexibility of computers today, it is much more efficient to construct such meters using discrete methods. Doing so allows flexibility to vary elements within the meter without having to physically change components within a circuit.

The IEC meter basically consists of a few simple mathematical functions such as squaring and taking the square-root, low-pass, bandpass, and high-pass filters, and statistical analysis. The basic mathematical functions are simple to handle, and the statistical analysis is relatively simple within itself. The only challenge lies in recreating the filters in the discrete-time domain. Because the Laplace transfer functions for the various filters are known, the bilinear transformation can be used to convert the transfer functions to difference equations, which can be implemented in a programming language relatively easily. The bilinear transformation can be implemented using Eq. 11, where T is the time step.

$$s = \frac{2}{T} \left[\frac{z-1}{z+1} \right] \tag{11}$$

The purpose of Block 1 is to keep the normal operating voltage scaled to an internal reference value. The IEC 868 standard specifies that the voltage adapter should have a response time of 60 seconds from 10% to 90% for a step change in the input rms voltage. This can be achieved by calculating the rms value of the input voltage and sending this value through an adapter filter based upon the 60 second response time. This value can then be used to scale the input voltage. Eqs. 12-14 describe the filter used in s-domain, z-domain, and in difference equations, respectively, while the step response for the adapter filter is shown in Figure 7 using Eq. 14.

$$H(s)_{Adapter\ Filter} = \frac{1}{As^2 + Bs + 1} \tag{12}$$

$$H(z)_{Adapter\ Filter} = \frac{z^{-2} + 2z^{-1} + 1}{Cz^{-2} + Dz^{-1} + E} \tag{13}$$

$$y_k = \frac{x_k + 2x_{k-1} + x_{k-2} - Dy_{k-1} - Cy_{k-2}}{E} \tag{14}$$

where:

$$A = 319.0689$$

$$B = 35.725$$

$$D = \left[2 - \frac{8A}{T^2} \right]$$

$$C = \left[\frac{4A}{T^2} - \frac{2B}{T} + 1 \right] \quad E = \left[\frac{4A}{T^2} + \frac{2B}{T} + 1 \right]$$

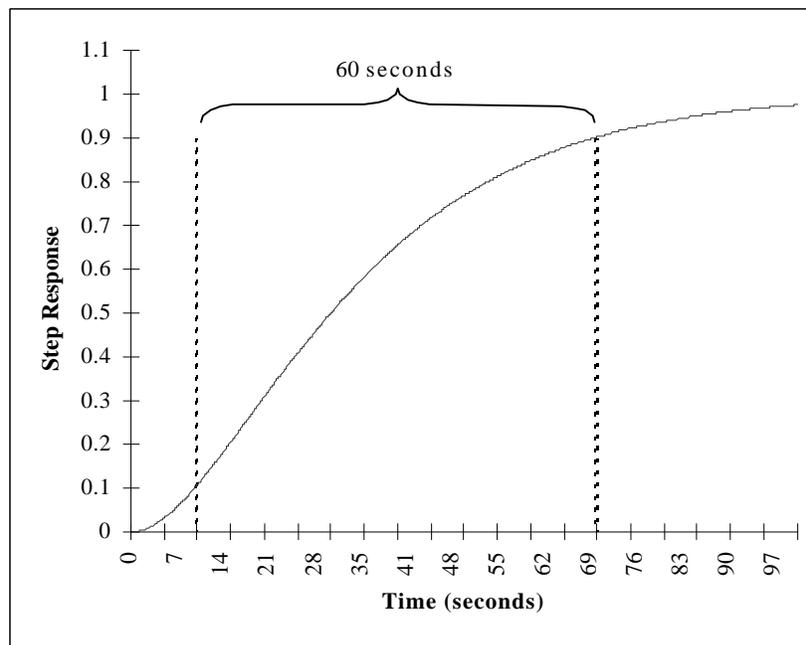


Figure 7. Step Response of Adapter Filter

Blocks 2, 3, and 4 can be implemented as difference equations similarly to Block 1. Block 2 is implemented by simply squaring the output of the voltage adapter. Block 3 consists of three filters: high-pass, low-pass, and bandpass. The frequency response of the demodulator filters is shown in Figure 8.

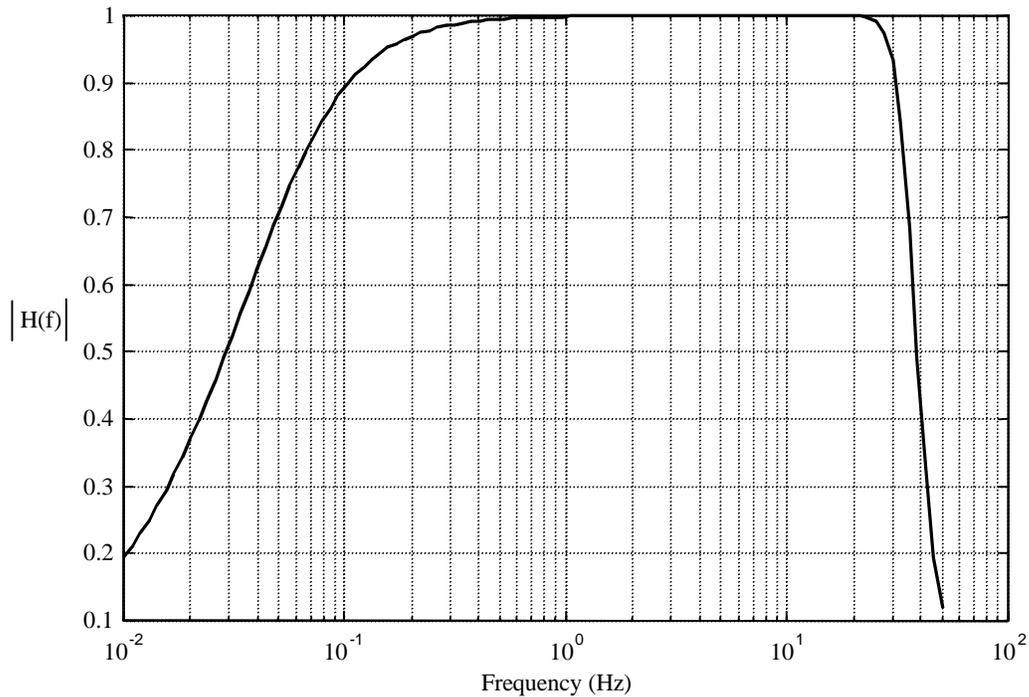


Figure 8. Frequency Response of Demodulator Filters

Block 4 is implemented by squaring the output of Block 3 and passing this value through a 1st order low-pass filter with a time constant of 300ms.

Verification of the Digital IEC Meter Model

Various tables are given in the IEC 868 standard which allow for the testing and verification of a flicker meter's accuracy. Table 1 and Table 2 of the IEC 868 standard give the input relative voltage fluctuation ($\Delta V/V$) using sinusoidal modulation and square-wave modulation, respectively, to receive one unit of perceptibility at the output of Block 4 for 230V lamps. In order to receive 1.0 on the output of Block 4, the signal must be scaled by a number based upon the internal reference to which the input is scaled and the type of lamp weighting filter used.

Confusion has arisen as to what the $\Delta V/V$ value from Tables 1 and 2 of the IEC 868 standard actually represents. The equation that is used for modulating the mains is

$$V_{\text{Flicker}} = V_{AC} \left[1 + 0.5 \cdot \left(\frac{\Delta V}{V} \right) \cos(\omega_F t) \right] \quad (15)$$

where V_{AC} is the mains and ω_F is the corresponding flicker frequency.

In Table 3 of the proposed amendment [7] to the current IEC standard, $\Delta V/V$ values which result in a P_{ST} of 1.0 are given for both the 230V and 120V lamps. The relative voltage change $\Delta V/V$ is for square-wave modulation. Currently, a $\Delta V/V$ table is not available for calibrating the output of Block 4 to $1.0 \pm 5\%$ for the 120V lamps. Comparing the 230V tables in both the IEC standard and the amendment yield the following: the $\Delta V/V$ values used to receive a P_{ST} of 1.0 (Table 3 of the amendment) are greater than that used to receive an instantaneous flicker level of 1.0 (Table 2 of the IEC standard) for the 4.0, 10.0, and 20.0 Hz entries by a factor of $\sqrt{2}$. Based upon this knowledge, the values in Table 3 of the amendment (for 120V P_{ST} calculations) can be used to determine approximately the scaling factor needed to receive an instantaneous flicker level of 1.0 by dividing the value in Table 3 by $\sqrt{2}$. The extremely low frequency values in Table 3 can not be used for calibration purposes because the $\sqrt{2}$ relationship does not apply. For low frequency fluctuations, the instantaneous flicker levels have to be extremely high relative to 1.0 (much greater than $\sqrt{2}$) to receive a P_{ST} of 1.0. Therefore, frequency values less than 1.4667 were not considered for calibration purposes.

Upon implementing the entire IEC meter in C/C++, the output of Block 4 (instantaneous flicker level) is shown in Figure 9 over the range of input values given in Table 3 of the amendment [7] to the IEC standard for the 120V lamp. The flicker phase shift is from 0^0 to 360^0 . The sampling rate chosen is 1920 Hz (32 samples/cycle). The values plotted are the maximum values measured from Block 4 for the particular $\Delta V/V$ given in Table 3 of the amendment. As discussed previously, the instantaneous flicker level has to be extremely high in order to receive a P_{ST} of 1.0. Figure 10 demonstrates the calculated P_{ST} values from the developed IEC meter using a statistical sampling frequency of 1920 Hz. The flicker phase shift is held constant at 0^0 in Figure 10. As shown in Figure 10, the calculated P_{ST} values using the developed IEC meter are well within range of $1.0 \pm 5\%$ criteria.

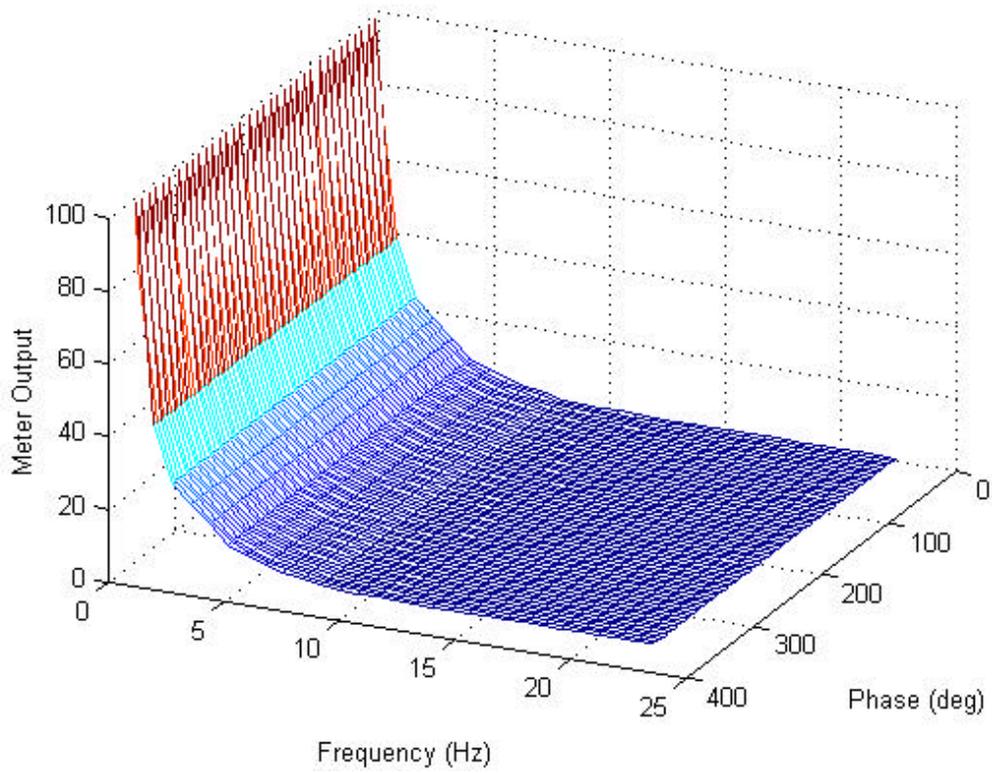


Figure 9. Developed IEC Meter: Instantaneous Flicker Level for 120V Lamps

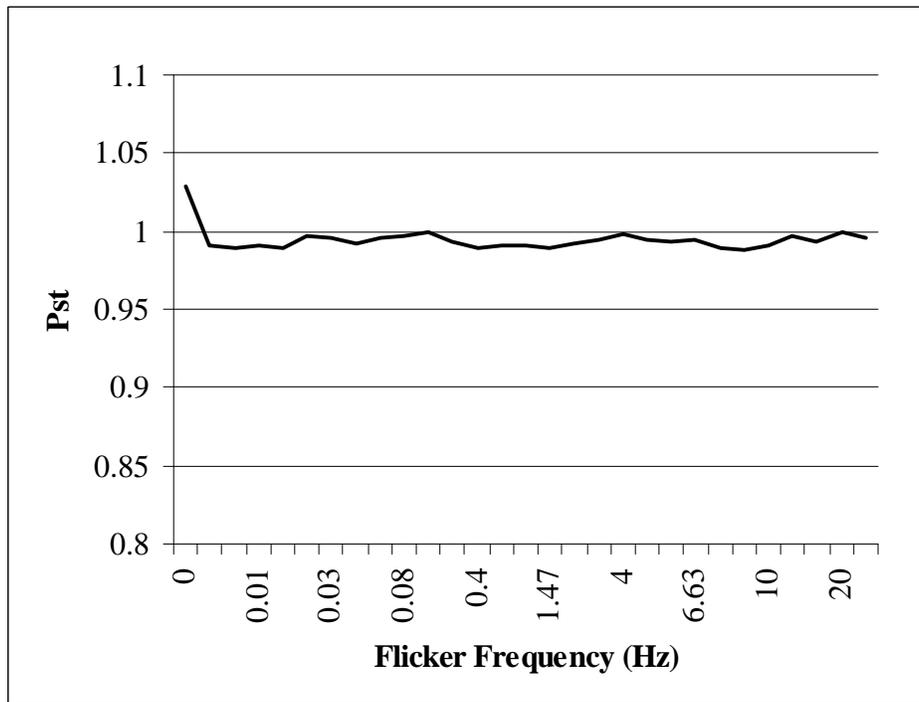


Figure 10. Developed IEC Meter: 10 Minute P_{ST} at Output of Block 5 for 120V Lamps

Conclusion

Various methods for measuring voltage flicker have been presented, with increased focus on the IEC flicker meter. This paper has described and presented a discrete model of the IEC flicker meter. A complete description of the each element of the flicker meter is presented along with the equations needed to simulate the meter in the discrete-time domain. The IEC flicker meter was developed using C/C++ and its accuracy verified according to IEC standards.

Developing the meter in software has allowed the flexibility to take it one step further. The code could be used along with a laptop, data acquisition card, and power conditioning device to create a complete real-time voltage flicker meter, or the algorithms could be used to adapt present measuring techniques to measure voltage flicker. The latter is chosen for Part II of this series, entitled “Adapting RMS Meters for Measuring Voltage Flicker.”

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