IMPROVING WEIGHTING FILTER OF UIE/IEC FLICKERMETER - BUILDING THE LAMP MODEL

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ABSTRACT

The weighting filter is the key part to improve the accuracy of UIE/IEC flickermeter. The lamp response, which depends on specific lamp type, is an important part of the weighting filter. To improve the weighting filter, the lamp response model of different types of lamps should be used. A useful and simple mathematical lamp model built by system identification methods is presented in this paper. This model is derived from the measurement data without consideration of physical characteristics inside lamps. This model can be used for different lamp types with different parameter set. Thus, the measurement accuracy of the weighting filter and the flickermeter could be improved.

INTRODUCTION

Light flicker is the noticeable light intensity variation of lamp caused by voltage fluctuations in the electric power system. It is popular to measure flicker with the UIE/IEC flickermeter. The weighting filter is an important part of this flickermeter. It is described as equation 1[1] [2]:

$$F_{lamp-eye-brain}(s) = F_{lamp}(s) \times F_{eye-brain}(s) = \frac{k\omega_1 s \cdot (1 + s/\omega_2)}{(s^2 + 2\lambda s + \omega_1^2)\cdot(1 + s/\omega_3)\cdot(1+s/\omega_4)} \quad (1)$$

With k = 1.74802, $\lambda = 2\pi 4.05981$, $\omega_1 = 2\pi 9.15494$, $\omega_2 = 2\pi 2.27979$, $\omega_3 = 2\pi 1.22535$ and $\omega_4 = 2\pi 21.9$ for a 230V 60W incandescent bulb.

The weighting filter simulates the lamp-eye-brain system. This system can be considered as two independent parts: lamp response and eye-brain response to the flicker [3]. The eye-brain response depends on the physiological reaction of a human being to the flicker. It is assumed as constant for a human being. The lamp response is based on 230V/120V, 60W incandescent bulbs. However, nowadays there are many different types of lamps in the market. Those lamps have quite different responses to the same flicker [4] [5]. In order to get also for these other type of lamps accurate measurements of the flicker level, UIE/IEC flickermeter should be improved for different types of lamps. Improving the weighting filter by using the specific lamp responses of different lamp types is the easiest way.

Several lamp models already are presented in paper [6] - [8]. In this paper, a useful and simple lamp model by using system identification method will be presented. The proposed model is verified by the comparison of simulation and measurement results. The weighting filter is improved by the combination of the different lamp responses and the eye-brain response. The system identification lamp model described in this paper is built by using Matlab/system identification toolbox.

The derivation of the lamp model is described in section 2. Section 3 presents the comparison results between the model simulation and the measured data. The method to improve weighting filter are illustrate in section 4. Conclusions are given in section 5.

LAMP MODEL DERIVATION

Current lamp models

A specific lamp model represents the lamp response to the lamp input voltage. Several papers describe these lamp models. Basically, models are derived from two kinds of theories. One is the physics point of view. However, these models normally are quite complicated. They are affected by several factors, e.g. lamp temperature, certain chemical reaction factors. Paper [6] gives a complicated equation to describe the relationship between the lamp voltage and the light intensity of the incandescent bulb, as shown in equation 2:

$$\lambda = \beta \cdot e^{\frac{-t}{R_\theta C_\theta}} \cdot [\frac{1}{C_\theta}\int_0^t \frac{v^2}{52.05 v^{0.42} - 148.8} \cdot e^{\frac{-t}{R_\theta C_\theta}} dt + c]^{1.7} \quad (2)$$

Where: λ is the luminous flux, β is a constant number, $R_\theta C_\theta$ is the lamp thermal time constant, C_θ is the thermal capacitor of the lamp filament, v is the lamp supply voltage and c is the room temperature.

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For a fluorescent lamp, the physical description is totally different from above equation. Moreover, the equation is even more complicated because of its special lamp working characteristics [7]. In brief, the physics model is not so convenient to be used in our application – the flickermeter.

Paper [8] presents another simpler lamp model – a first order low pass filter. However, this filter model can only be used for incandescent bulb. For other type of lamps, this model is not proved to be correct.

In this paper, a useful and simple lamp model is proposed by using a linear dynamic system identification method.

System identification lamp model

The system identification deals with the problem of building mathematical models of dynamical systems based on observed data from the system [9]. Under flicker situation, paper [4] and [5] show us that the luminance amplitude always linearly varies with the voltage variation amplitude for different types of lamps. Thus, the lamp can be assumed as a linear dynamic system within the flicker frequency range. As mentioned above, the lamp model will be quite complicated if we consider it from physical point of view. For simplifying the problem, the lamp is assumed as a black box without considering internal components and physics characteristics, a so-called black-box model. The parameters of this model only aim for adjusting the fitting to the data and do not consider any physical meaning of the system. For the purpose of our application, first we should define the input-output of this black box model. Because our focus is only on the relationship between input lamp voltage and the luminance, the input of this black box model is the lamp input voltage (voltage variation). The output of the black box model is the luminous flux of the lamp.

The input and output data are obtained from measurement. In this paper, the Philips classictone 60W, 230V incandescent bulb is measured in the power quality lab of TU/e. The measured lamp input voltage and luminance are treated as the estimated data set of the lamp model for the incandescent bulb. The luminance of the lamp is measured by a photodetector and a luxmeter. An oscilloscope collects all data. The measurement set-up is given in Fig.1. Based on the measurement data, the parameters of this black box model are estimated.

For the black box model, several model structures can be used, e.g. Auto-Regression with extra inputs (ARX) model, State-space model etc. [9] [10]. However, the most suitable model structure depends on the purpose of application. The goal of our application is to find a simple and least effort model that could represent the luminance variation under flicker situations. The property of the feedback and the white noise of the model are not of main concern in our application. Thus the best fitting rate becomes the first criterion to select the model structure in our case. Moreover, the size and complexity of the model structure is also an important selection criterion. According to these rules, four model structures: ARX model, output error model (OE), Box-Jenkins model (BJ) and state-space model are tested by using the same estimated data set. The average fitting rates within the flicker frequency range are showed in Table 1.

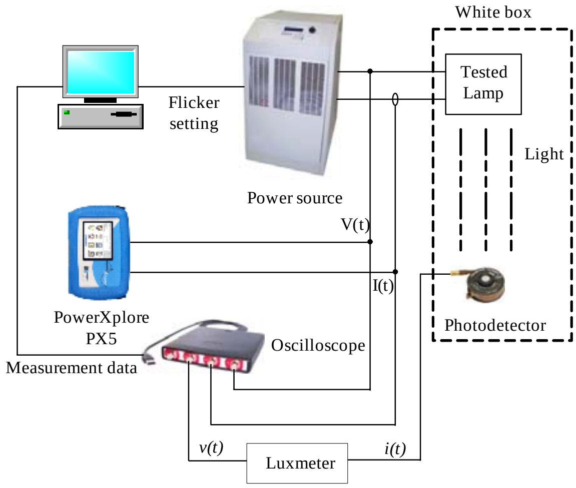

Fig.1 The measurement set-up of flicker test in the lab

Table 1 Average fitting rate between simulation results of different model structures and measurement results

Model structure	ARX	OE	BJ	State-space
Order	2	2	2	6
Average fitting rate (%)	97.44	79	63	93.15

The results show that only the ARX model can be used to describe the lamp system with high correctness. The state-space model has also relative high fitting rate but a higher order of 6 is used in the model. This means the state-space model will be more complex and sizable than ARX model. By balancing the model structure selection rules, the ARX model is selected as the most suitable model structure in our application. Fig.2 shows the simulation results of a 2 order ARX model and the measurement result for 10Hz flicker. The blue dash line is the simulation result. The black solid line is the measurement result. The fitting rate between them is 98.13%. This figure shows that they fit quite well.

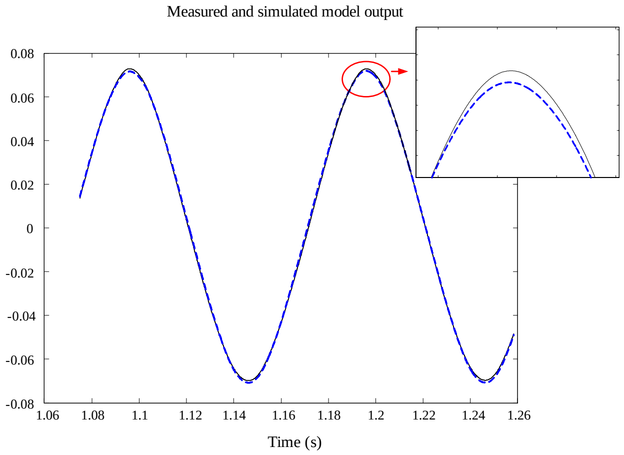

Fig.2 Simulation results of 2 order ARX model and measurement results for 10Hz flicker for an incandescent bulb lamp (blue dash line: simulation results, black solid line: measurement results).

LAMP MODEL VALIDATION

After having determined the model structure, it has to be validated. This is model validation problem.

Incandescent bulb model

Different orders of ARX model are tested by using a Matlab/system identification toolbox. An overlap between the poles and zeros of the model is found when higher order is selected. Therefore, the best order of the model is determined as 2. Table 2 shows the fitting rate between simulation and measurement results for different flicker frequencies by using a 2 order ARX incandescent bulb model.

Table 2 Fitting rate of 2 order ARX model for an incandescent bulb in whole flicker frequency range

Flicker Frequency (Hz)	Fitting Rate (%)		Flicker Frequency (Hz)	Fitting Rate (%)
0.5	94.52		10.0	98.13
1.0	96.05		10.5	98.18
1.5	96.54		11.0	97.95
2.0	96.8		11.5	97.97
2.5	97.21		12.0	98.08
3.0	97.36		13.0	97.98
3.5	97.4		14.0	98.05
4.0	97.67		15.0	97.95
4.5	97.65		16.0	97.84
5.0	97.79		17.0	97.58
5.5	97.76		18.0	97.49
6.0	97.83		19.0	97.32
6.5	97.89		20.0	97.05
7.0	97.95		21.0	97.11
7.5	97.97		22.0	96.84
8.0	98.09		23.0	96.75
8.8	98.14		24.0	96.36
9.5	98.06		25.0	96.48

The fitting rate for flicker frequency 0.5Hz is relative low. This is due to the fact that the measurement data did not contain enough cycles. Thus the estimate information was not good enough.

Fluorescent lamp model

The measurement for Philips TL-D 36W/33 – 640 fluorescent lamp is also done. The measured lamp input voltage and corresponding luminance are used as validation data set for fluorescent lamp model. Due to the fluorescent lamp does not work as ideal linear resistance as incandescent bulb, 2 order ARX model is not suitable to it any more. After testing the ARX model structure with different orders, the 4 order ARX model is determined finally because of relative high fitting rate as showed in Table 3.

Table 3 Fitting rate of 4 order ARX model for a fluorescent lamp in whole flicker frequency range

Flicker Frequency (Hz)	Fitting Rate (%)		Flicker Frequency (Hz)	Fitting Rate (%)
0.5	70.88		10.0	96.2
1.0	78.66		10.5	96.55
1.5	84.3		11.0	95.69
2.0	87.09		11.5	95.7
2.5	89.4		12.0	95.66
3.0	91.23		13.0	95.62
3.5	92.71		14.0	95.22
4.0	94.23		15.0	94.44
4.5	95.36		16.0	93.6
5.0	96.3		17.0	93.19
5.5	96.86		18.0	92.15
6.0	97.53		19.0	90.89
6.5	97.42		20.0	89.95
7.0	97.05		21.0	89.35
7.5	97.12		22.0	88.08
8.0	95.97		23.0	86.14
8.8	96.02		24.0	84.6
9.5	96.3		25.0	81.59

The fitting rate of the fluorescent lamp model is not as good as incandescent bulb model. Some low disturbance frequencies (not main flicker frequency) signals are found in the measured luminance waveform of the lamp. These disturbances affect the accuracy of the model parameter when the measured data is used as estimated data set. It will be improved in future work..

IMPROVING WEIGHTING FILTER

The lamp model is obtained from a system identification method. The following step is transferring this lamp model to a mathematical equation, i.e. a transfer function. The ARX incandescent bulb model that is derived for 60W, 230V incandescent bulb can be written as transfer function, as given in equation (3):

$$F_{lamp\_inc}(s) = \frac{0.0002167s - 0.0002167}{s^2 - 1.998s + 0.9982} \qquad (3)$$

The bode plot of this transfer function is shown in Fig. 3. The shape of the amplitude response is similar with the models derived in other papers. The value is not the same. This is due to the fact that the model derivation methods are different.

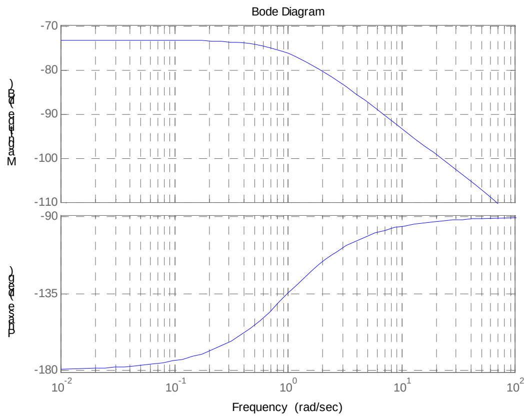

Fig.3 Bode diagram for incandescent bulb transfer function

The ARX fluorescent lamp model that is derived for a 36W, 230V fluorescent lamp can be written as transfer function, showed in equation (4):

$$F_{lamp\_flu}(s) = \frac{0.0205s^3 - 0.05629s^2 + 0.05125s - 0.01546}{s^4 - 1.996s^3 + 0.9956s^2} \qquad (4)$$

The weighting filter for every type of lamps can be found by multiplying the lamp response with the eye-brain response, e.g the weighting filter for fluorescent lamp can be written as :

$$F_{flulamp-eye-brain}(s) = F_{lamp\_flu}(s) \times F_{eye-brain}(s) \qquad (5)$$

The accuracy of the two models' parameters derived in this paper still needs to be improved by more measurements. The accuracy of the system identification lamp model also will be proved by evaluating the flicker level that is measured by the flickermeter, in which this lamp model is used. These will be done in future work. More models of other lamp types and their weighting filters will be worked out in the future.

CONCLUSION

This paper presents two lamp models (incandescent bulb and fluorescent lamp model) built by using linear dynamic system identification methods. These lamp models give a useful and simple method to improve the weighting filter and UIE/IEC flickermeter. The flicker measurement will be more accurate by using this improved flickermeter in the future.

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