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DESIGN THE VOLTAGE ACCEPTABILITY CURVES FOR ENERGY EFFICIENT LED LAMPS

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ABSTRACT

This paper presents the design and develops of voltage acceptability curves for LED lamps. It is done with the mathematical representation of DC bus voltage of LED lamps internal ballast circuit during voltage sags. First, experimental analysis was done to determine the effect of voltage sag of LED lamp. From the findings on the variation of DC bus voltage during voltage sag, a mathematical equivalent of DC link voltage is then obtained to construct a voltage acceptability curve for the tested lamp. Hence, the design of voltage acceptability curves for LED lamp with internal electronic ballast is sensitive to voltage sag.

Key Words: Voltage acceptability curves, LED lamp, Voltage sags.

INTRODUCTION

With the development of semiconductor technology, the use of Light Emitting Diodes (LED) is increasing in display, signaling as well as lighting applications. Now a days, crisis of power is increasing all over the world, so power companies and governments are trying to improve energy efficiency to cover extra demand. To promote energy saving, many governments in the world already banned energy inefficient incandescent light bulbs and replace it with other technologies like LED lamps.

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In spite of various advantages, it is important to identify some hidden issues of LED lamps and make comparison with other type of bulbs. In view of the fact that LED lamps are based on semiconductor technology, they are susceptible to power system disturbances like CFLs. Among various disturbances voltage sag is an important issue. During sag, the voltage suffers a sudden reduction of voltage between 10-90% of the nominal voltage that lasts in the range of 10 milliseconds (ms) to 1 minute (IEC 2004). Voltage sag may cause lamps to extinguish or flicker that will likely to cause nuisance and damage in some cases.

Although there are some fast research found about the voltage sag sensitivity on other non linear loads such as CFLs and helium lamps (Saksena et al. 2005 and Shareef et al. 2010). Almost no research can be found about voltage sag performance of LED lamps.

Voltage sag sensitivity of the equipment can be represented by voltage acceptability curves. One of these curves is CBEMA (Computer Business Equipment Manufacturers Association) curve (CBEMA 1970). Later it is modified by the Information Technology Industry Council (ITIC). However, different load showing different type of voltage acceptability characteristics (Heydt & Jewell 1998).

This paper developed a voltage acceptability curve for LED lamps and analyzed the voltage tolerance level of LED lamps for a pre-defined zero illuminance malfunction criteria. This is performed by experimental test using available LED bulbs in local market. The tests are carried out to observe variation of intensity level of light during voltage sag and map there malfunction voltages into the developed voltage acceptability curves.

DESIGN CONCEPT OF VOLTAGE ACCEPTABILITY CURVES

The concept of 'standard' must be employ before a similar voltage acceptability curve is developed for LED lamp. The basic concept for various loads type and the required design methodology are described in Kyei et al. (2002).

Figure-1. Rectifier load voltage variation due to an interruption on the ac mains at *t=0*

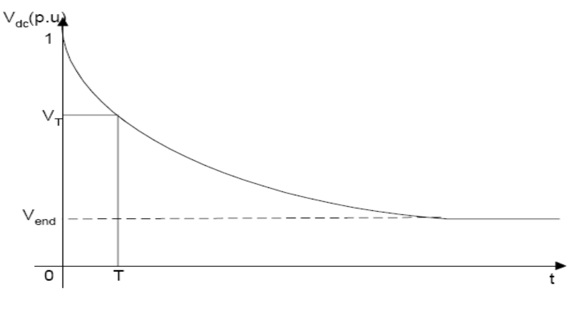


Figure 1 illustrate the dc voltage of a rectifier under fault conditions of ac voltage supply at time t=0. The equation of this dc voltage response can be described as

$$V_{dc}(t) = A + Be^{-bt} + Ce^{-ct} \qquad (1)$$

At time t=0

$$A = 1 - V_{end} - B \qquad (2)$$

Let $t=T$ is the time to reach the threshold value of the dc bus voltage V_T. Now substituted equation (2) into (1), result in

$$V_T = V_{end} + (1 - V_{end} - B)e^{-bT} + Be^{-cT} \qquad (3)$$

From Figure 1 the voltage sag ΔV become

$$\Delta V = V_{end} - 1 \qquad (4)$$

Combining equations (3) and (4), the voltage sag ΔV is obtained as

$$\Delta V = \frac{V_T + B(e^{-bT} - e^{-cT}) - 1}{1 - e^{-bT}} \qquad (5)$$

Equation (5) is the equation of the ΔV-T locus of the under voltage limb of a CBEMA-like voltage acceptability curve.

EXPERIMENTAL PROCEDURE

This section illustrates the design of the experiment setup and testing procedures to obtain the results on the performance of LED lamps during voltage sags.

Experimental setup

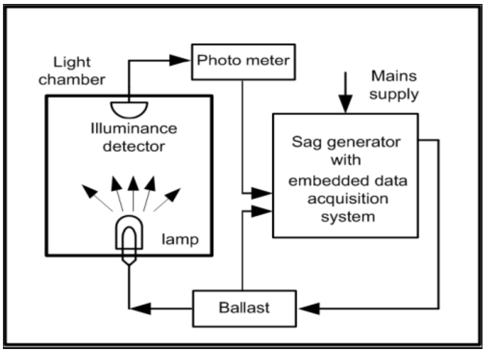
To analyze the characteristics of the LED lamps during voltage sag, one LED lamps as shown in Table 1 were tested. The lamps have build in internal electronic ballast is available in Malaysian local market.

TABLE-1. Specification for tested LED lamps

Trade name	Nominal power)	ıvalent to ıcandescent, (W)	ıminous lux, (lm)	Life span (Years)
Bright			230	

The experimental set up consists of five components namely sag generator, light meter, equipment under test (EUT), data acquisition system, and a personal computer to analyze the signals. For generate sag, an industrial power corruptor (IPC) is used which combined with built-in data acquisition system. Moreover, it has ability of generating and interrupting voltages up to 480V. The experiment is related to know the variation of light output of LED lamps during voltage sags, therefore the light meter in the test system must be fast enough to capture the variation of light intensity of the corresponding lamps correctly. The experimental setup shown in Figure 2 has been built to perform the voltage sag disturbances and measure the light output levels from the lighting source.

Figure-2. Experimental setup for voltage sag



EXPERIMENTAL ANALYSIS AND DISCUSSION

Numerous test results are analyzed and discussed in this section. This investigation is performed by obtaining signals from photo sensor, different parts of lamp ballast circuit and supply voltage.

Analysis of LED lamp Sensitivity

In order to understand the sensitivity of LED lamps to voltage sags, Figure 3 illustrate the waveforms obtained from the photometer and supply voltage for the lamp were analyzed. It shows the effect of varying the sag depth starting from 15% to 12.5% remaining voltage for 6 cycles, on light output variation of the lamp. From figure it is revel that lamp goes to off condition for sag having 12.5% remaining voltage at 6 cycles. However, the disturbance starts from 15% remaining voltage but the lamp hold on condition. The lamp does not experience any malfunction up to 5 cycles.

Now observe the effect of lamp when duration of sag is increase with sag depth. Figure 4 depicts the immunity level of LED lamp during voltage sag event for several durations whereas upper portion of this curve represent acceptable region while lower portion is unacceptable region. It is clear that the lamp introduce zero illumination condition at 12.5% remaining voltage start from 6 cycles.

Figure-3. Effect of sag depth on the light output at 6 cycles for LED lamp

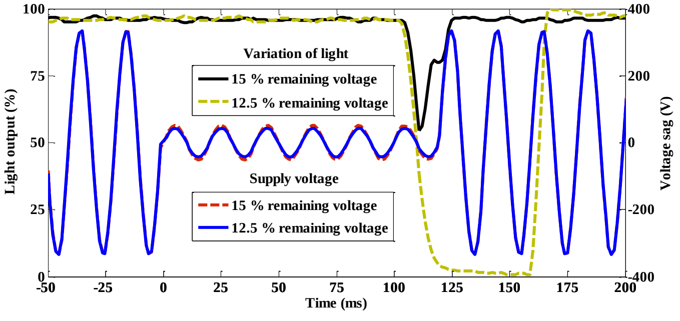
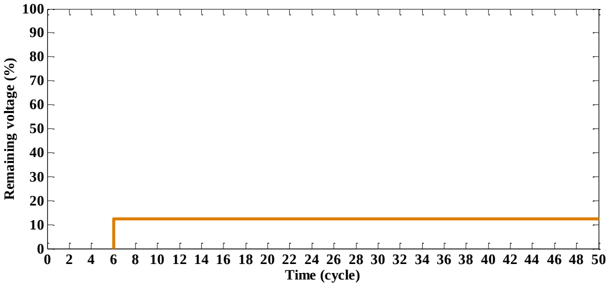


Figure-4. Voltage immunity level for LED lamp during voltage sags



Voltage acceptability curve for LED lamp

The concept of 'standards' to construct voltage acceptability curves is that many different processes may be represented. In order to obtain the standard of LED lamp and design the voltage acceptability curve, the voltage waveforms of DC link capacitor are first normalized then plotted to derive the mathematical equivalent of the actual DC bus variations. Figure 5 shows the normalized DC link voltage waveform and light output variation of LED lamps ballast circuit during voltage sag having 12.5% remaining voltage that last for 50 cycles. It can be seen from figure, the locus of DC bus voltage for LED lamp could be represented as a double exponential equivalent in the form of equation (3). Now the crossing point between DC link and light output variation of this lamp could be 0.34 per unit, where lamp is observed to malfunction according to the experiments, the crossing points of the corresponding curve with the stated conditions and few other points in Figure 5 can be consider to determine the values of the constants *B*, *b* and *c* in equation (3) by solving a set of nonlinear equations iteratively.

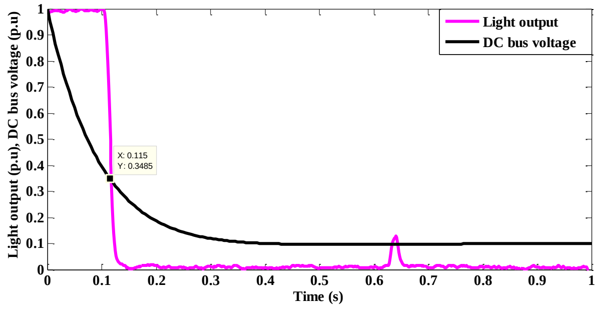
By replacing the values of *B, b* and *c* in equation (3) the DC link voltage during sag for the tested LED lamp can be expressed

$$V_{dc}(t) = V_{end} + (1 - V_{end} + 170.7)e^{-8.275t} - 170.7e^{-8.288t} \qquad (6)$$

The expression given in equation (6) is also plotted in Figure 5. Note that it is possible to approximately represent the actual waveform obtained from experiments with equation (6). After that, the equation of the voltage acceptability curve for the PC can be approximately given by

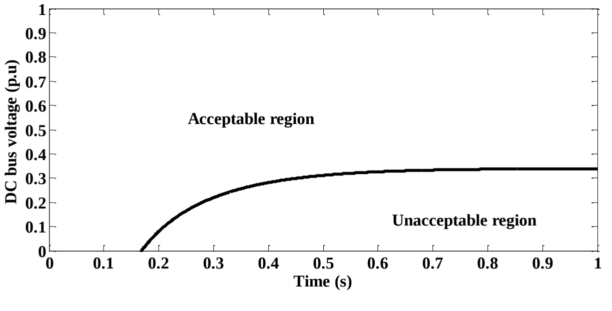
$$V_{end} = \frac{0.34 - e^{-8.275T} - 170.7(e^{-8.275T} - e^{-8.288T})}{1 - e^{-8.275T}} \qquad (7)$$

Figure-5. DC bus voltage and light output variation during voltage sag



Finally, the designed voltage acceptability curve of LED lamp that standard greater than 0.34 p.u is plotted in Figure 6 as typical CBEMA-like curves by equation (7). The upper region of these curves represents proper operation region while the lower region indicates unacceptable region for LED lamp operation.

Figure-6. Design of voltage acceptability curves for LED lamp



CONCLUSION

An experimental investigation has been done to determine the effect of voltage sag on LED lamp. From the analysis of the variations of DC link voltage, it is possible to conclude that the DC voltage decreases exponentially during voltage sag and it can be expressed as exponential time varying function. This paper also conducts with LED lamp standard. According to the mathematical expression of DC bus voltage variation of the LED lamp ballast circuit, it is possible to develop voltage acceptability curves to describe the sensitivity of LED lamp to voltage sags.

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