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Control of Solid-State Lamps Using a Multiphase Pulse width Modulation Technique and AC side Power Factor Correction

B. Jyothi,
M-Tech Scholar,Power Electronics & Drives,
Department Of Electrical And Electronics Engineering,
KL University, Guntur(A.P) ,
India. **e-mail**:

Dr. P. Linga Reddy,
Professor, control systems,
Department Of Electrical And Electronics Engineering,
KL University, Guntur(A.P) , India.
e-mail:

Abstract- This paper describes a multiphase pulse width modulation (MPWM) technique used for controlling the luminance of a solid-state lamp (SSL). In conventional pulse width modulation (PWM) and pulse code modulation techniques, the average HBLED string current is controlled by simultaneously varying the "ON" time duration of each current regulator circuit, resulting in large current transients and pulsating light output. The proposed MPWM technique operates by uniformly time-shifting the individual ON/OFF control signal pulses, thus avoiding large current transients. When compared to conventional PWM dimming, MPWM dimming reduces the risk of visible flicker and lowers the magnitude of audible noise. The reduced magnitude of output current transients results in lower electromagnetic interference and enables optimization of the size of passive components. In this paper, the operation of the MPWM technique is explained in detail. Finally a flyback converter topology with input side power factor correction topology is proposed and simulation results are presented.

Index Terms—Digital control, LED dimming, LED lamp driver, multiphase pulse width modulation, solid-state lamp luminance control.

Introduction:

Solid state lamps (SSLs) built using multiple high brightness LEDs (HBLEDs) are characterized by a high efficiency, long-operating life, and wide range of control over the lamp luminance [1], [2]. As the luminous flux generated by HBLED at a constant operating temperature is a direct function of the device current, the SSL luminance can be accurately controlled by varying the amplitude of the current. A number of techniques, such as AM, pulse width modulation (PWM), and pulse code modulation (PCM) of the HBLED current along with the associated driver circuit, have been proposed in [3]–[5] to achieve HBLED lamp luminance control. The focus of this paper is on the development of an alternative luminance control technique for a SSL implementation, as shown in Fig. 1.The lamp architecture is commonly used in many applications that require a large number of HBLEDs to generate the desired light output, such as liquid crystal display TV backlights, streetlights, or commercial lighting fixtures [6]–[8]. In this architecture, the current through each parallel string consisting of series-connected HBLEDs is controlled by a series-current regulator circuit. For low-power BLEDs, a linear current sink circuit is preferred because of its small area and low cost [9], [10].Buck converter-based current regulator circuits are used for high-power HBLEDs to achieve higher system efficiency.The complete array is powered by a single regulated dc–dc converter. For applications that are connected to a low-voltage supply, a boost dc–dc converter is generally used to step-up the input voltage Vg , to a value greater than the HBLED string forward voltage drop Vo

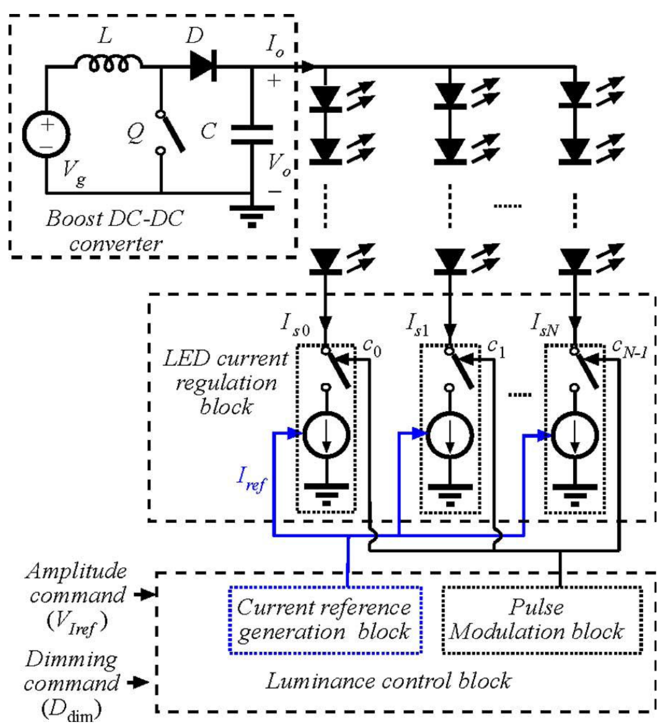

Fig. 1. Block diagram representation of a SSL

Selection of the desired dimming technique is based on the specified luminance range, the total number of HBLEDs used and the end-lighting application. AM is implemented by continuously varying the reference signal *VI* ref , of the current regulator circuit to adjust the average value of the current flowing through the HBLED string.

II. MPWM DIMMING TECHNIQUE

The study of MPWM technique was motivated by the need to achieve dimming function, while reducing the output current transients and EMI generated by the power circuit.. In this section, the operation of MPWM dimming for controlling the luminance of SSL is first explained, and then, implementation details are provided. The performance of SSL is discussed and some of the key advantages of MPWM dimming technique are highlighted.

A. Operation and Implementation of MPWM Dimming Technique*:*

The MPWM technique achieves lamp dimming by uniformly phase shifting, each PWM control signal $\{c1, c2, c3, \ldots, cN\}$, such that at any given point in time only one string is turning "ON," while another is turning "OFF," as shown in Fig. 2(c). The "ON" time *t*ON of each individual PWM control signal *c{i}*, is modulated based on the input command *D*dim, such that the
duty cycle of each control signal *dc{i}* is as follows:

$$d_{c\{i\}} = \frac{t_{ON}}{T_{dim}} = D_{dim}$$

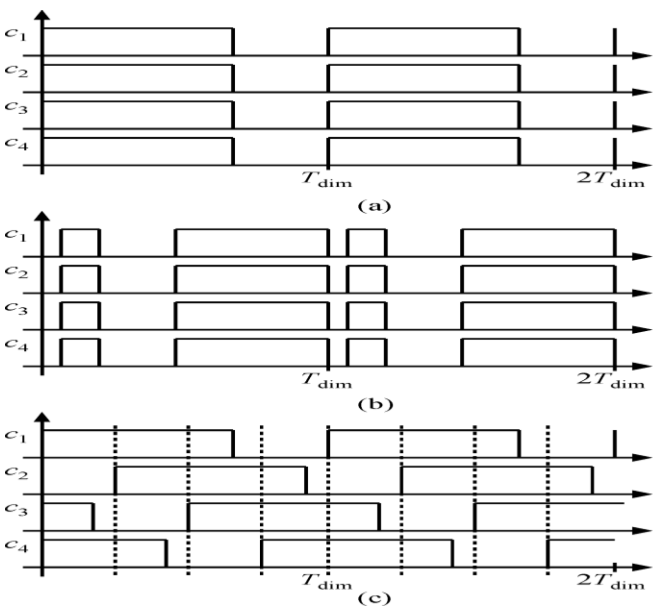

Fig. 2. Different pulse modulation techniques. (a) PWM. (b) PCM. (c) MPWM.

B. Performance Evaluation of MPWM Dimming Technique*:*

The visual flicker sensation caused by light modulation at a frequency as high as 75 Hz, is the leading cause of dissatisfaction in home and office environments . Other health problems related to eye stress and headaches have been reported at modulation frequencies as high as 120 Hz [. The human flicker sensation is reported to be a function of light modulation frequency and modulation amplitude . In case of PWM and MPWM dimming, the light modulation frequency is based on the choice of dimming frequency *f*dim, which determines the lamp optical performance and its impact on human visual perception. The visible flicker generated by the SSL can be minimized or eliminated by choosing the highest possible dimming frequency *f*dim. However, the response time *t*cr (*t*cr = *t*rise + *t*fall) of the linear-current regulator circuits, the optical response time of the HBLEDs *t*LED, and the resolution of the input-dimming command *D*dim, limit the maximum possible dimming frequency *f*dim max. In practice, the current regulator response time *t*cr exceeds the HBLED optical time constant *t*LED (*t*cr _*t*LED), and hence, limits the dimming frequency to a lower threshold is given by

$$f_{dim\_max} = \frac{1}{2^p t_{cr}}$$

The lower limit on the dimming frequency *f*dim min, is based on the critical flicker frequency *fcc* , threshold which for home and office environment is estimated to be approximately as *fcc* < 120 Hz. Therefore, lamp operation above the minimum dimming frequency *f*dim min = 120 Hz, is essential to prevent visible light flicker.

The use of MPWM technique also simplifies the light sensing network used in a feedback control loop designed to regulate the luminance and color temperature of a SSL . For a light sensing circuit, consisting of a photopic-vision-corrected photodiode and a transimpedance amplifier, a low bandwidth low-pass filter is required to remove the large amplitude of photodiode current variations caused by the pulsating nature of conventional PWM dimming.

C. Lamp Design Procedure When Using MPWM Dimming Technique:

An outline of lamp design procedure to achieve optimal performance when using MPWM dimming is provided next,

Step 1 (Determination of HBLED forward current):

The selection of the forward current *Is* , flowing through the HBLED depends on the maximum power rating of the HBLED, the rated lumen output of the SSL, the geometry of the lamp, and the thermal solution used to limit the worst-case junction temperature of the device.

Step 2 (Determination of HBLED array configuration):

Selection of the number of series connected HBLEDs in a single string and the number of such parallel strings within an HBLED array is based on various design parameters, such as the target system efficiency, the maximum allowable

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solution size, the HBLED binning process, and the requirements placed by safety standards and institutes.

III. DESIGN OF THE DC–DC BOOST POWER CONVERTER

The impact of MPWM on the design of boost dc–dc converter is studied in this section. As the variation in output current is limited to a value less than one HBLED string current *Is* , it is now possible to optimize the size of energy storage elements in the boost converter. For the design of closed-loop feedback control, the complete HBLED array can be modeled as an equivalent current sink and converter transfer functions can be derived by making the small-signal approximation. Based on the linear small-signal model, the equations are derived for calculating the value of boost converter inductor and capacitor value. A simple proportional integral compensator *Gc* based on voltage-mode feedback, is proposed for regulating the output voltage and rejecting external disturbances, such as fluctuations in input power supply *Vg* , changes in load current based on the dimming command, *D*dim, and variations in ambient temperature.

The boost converter is designed to meet the specifications based on the allowed variation in inductor current and the output voltage. The inductor current ripple value is generally specified in terms of a parameter *κ*, which denotes the ratio of peak-to average inductor current Δ*iL* ,to the maximum inductor current *IL*max, and determines that boundary between the continuous conduction mode (CCM) and discontinuous conduction mode (DCM). Based on *κ*, and assuming no losses (ideal operation), the inductor value is calculated using

$$L = \frac{V_g^2\,(V_o - V_g)}{2V_o^2 I_{o\,\max} f_s}\,\frac{1}{\kappa}$$

where *Vg* is the nominal input voltage, *Vo* is the regulated output voltage, *Io*max is the maximum output current (*Io*max = *NIs*), and *fs* is the switching frequency.

B. Design of Voltage-Mode Feedback Compensator

Voltage-mode feedback control can be used along with MPWM dimming to regulate the output voltage and reject the disturbance created by the slow variation in input-dimming command *D*dim, and hence, the output current *io* (*t*), the input voltage *Vg* , and HBLED forward voltage drop. This is a key advantage over PWM dimming, where large period steps in output current necessitate the use of current-mode control techniques to achieve wide bandwidth and fast settling time. The design of voltage-mode feedback control is based on the transfer function *Gvd*(*s*), from duty cycle *D*(*s*) to the output voltage *Vo* (*s*), derived using linear small-signal model of the boost converter operating in CCM, as shown in Fig. 4. The expression for boost control to output transfer function is as

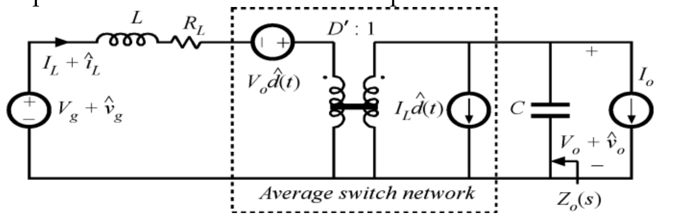

Fig. 4. Small-signal model of the CCM duty-cycle controlled boost converter derived based on averaged switch modeling technique.

follows:

$$G_{vd}(s) = \frac{V}{D'}\left(1 - \frac{I_o R_L}{D'^2 V_o}\right) \times \frac{(1 - s(I_o L/(D'^2 V_o - I_o R_L)))}{(1 + s(R_L C/D'^2) + s^2(LC/D'^2))},\quad I_L \geq \Delta i_L .$$

IV. MATLAB/SIMULINK MODEL AND SIMULATION RESULT

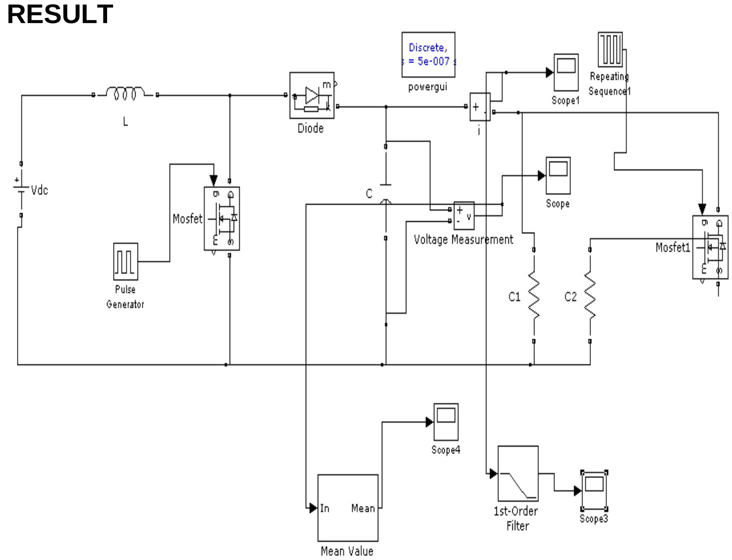

Fig. 5 Matlab/SImulink Model of Open loop control

Fig. 5 shows the Matlab/Simulink model of open loop boost converter.

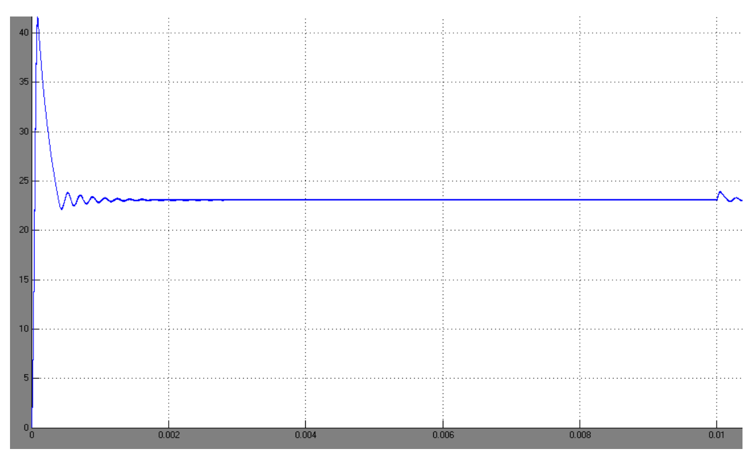

Fig. 6 Output Voltage

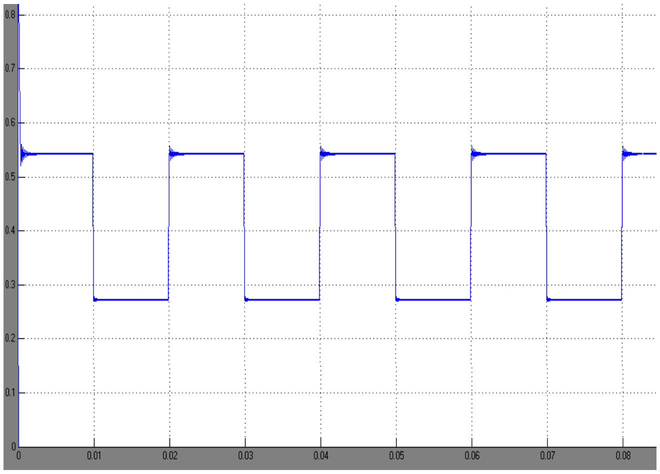

Fig. 7 Output Current without Filter

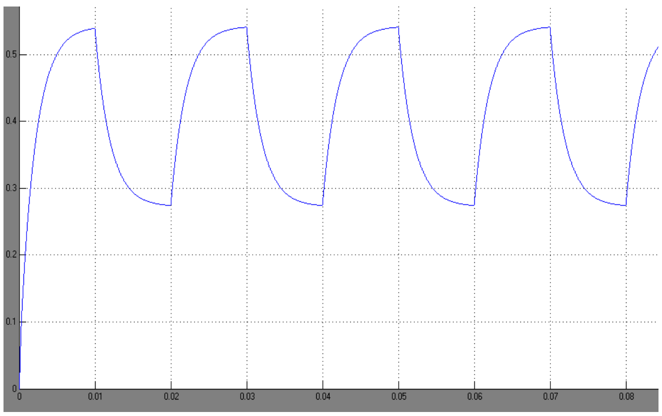

Fig. 8 Output Current with Filter

Fig. 6 shows the output capacitor voltage, Fig.7 and Fig.8 shows the output current without and with filter.

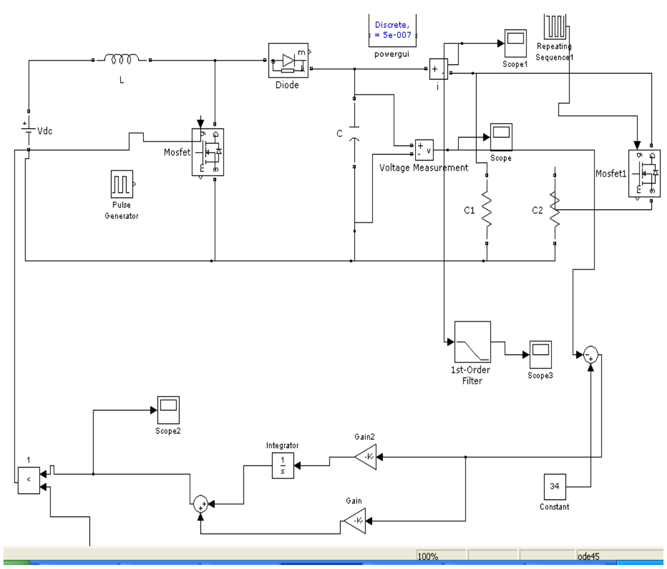

Fig. 9 Matlab/SImulink Model of closed loop control

Fig. 9 shows the Matlab/Simulink model of closed loop boost converter. Here we are using PI controller.

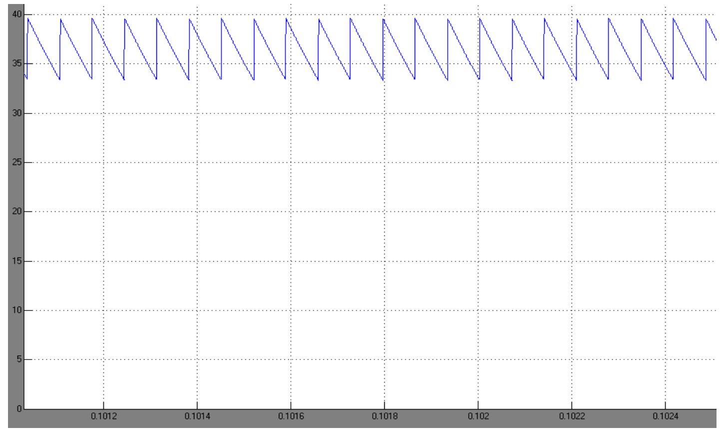

Fig. 10 Output Voltage

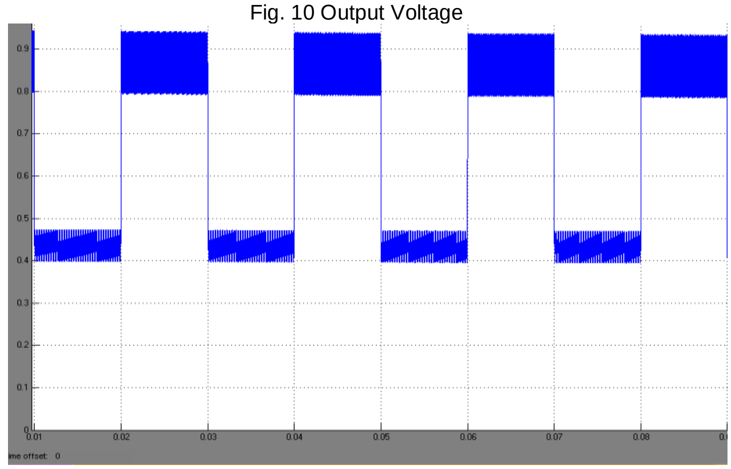

Fig. 11 Output Current with filter

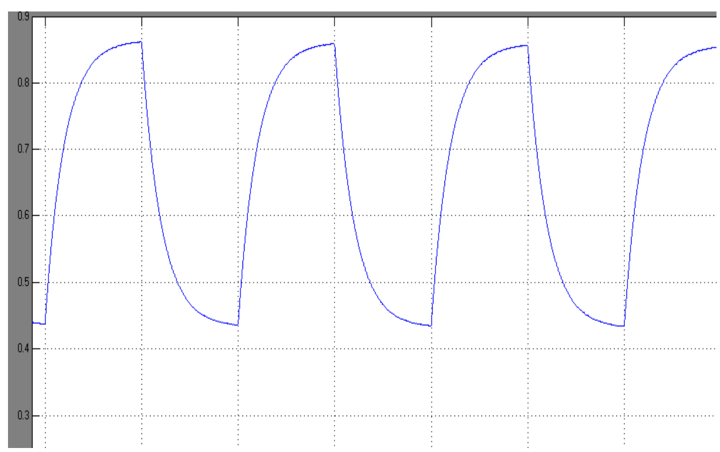

Fig. 12 Output Current with Filter

Fig. 10 shows the output capacitor voltage, Fig.11 and Fig.12 shows the output current without and with filter.

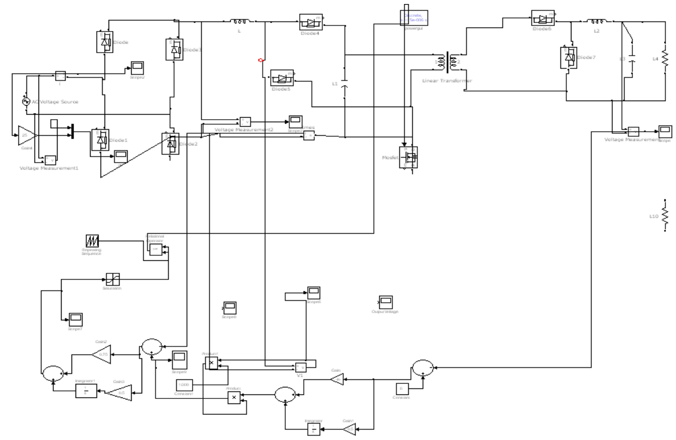

Fig. 13 Matlab/SImulink Model of Flyback converter closed loop control

Fig. 13 shows the Flyback converter with closed control and AC side power factor correction.

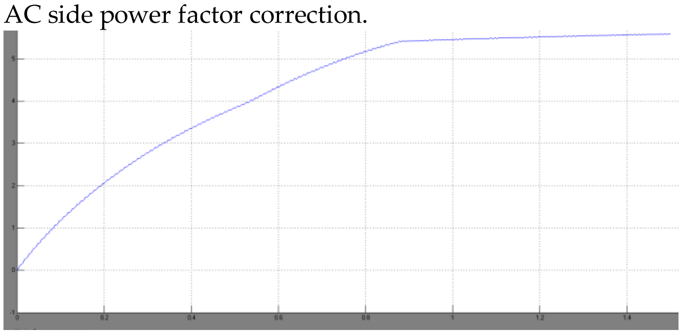

Fig. 14 Output Capacitor Voltage

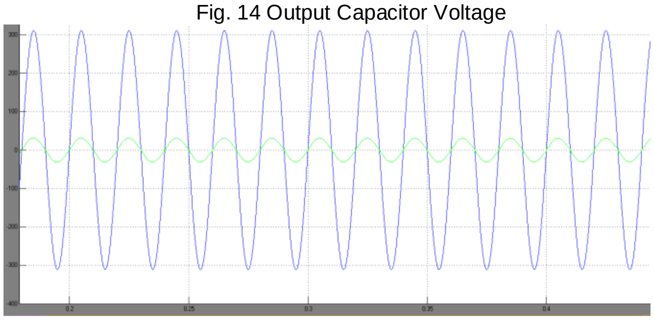

Fig. 15 Input AC side power factor

Fig. 14 shows the output capactor voltage. Here input voltage is 230v AC and output DC voltage is 5v. Fig.15 shows the input AC side power factor. From the figure it is clear that power factor is unity.

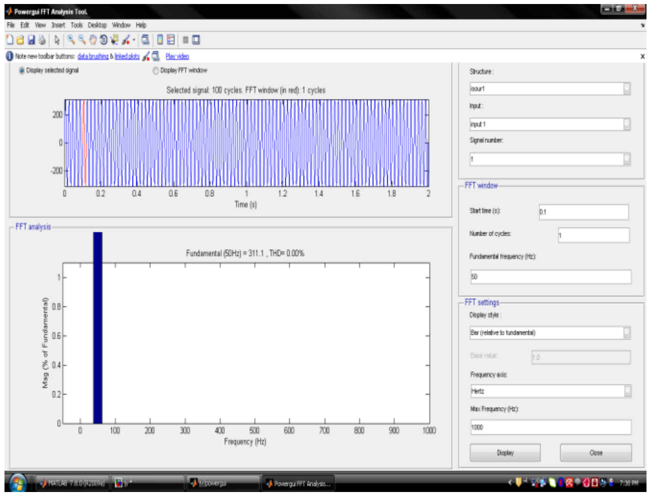

Fig.16 TOTAL HARMONIC DISTORTION AT UNITY POWER FACTOR

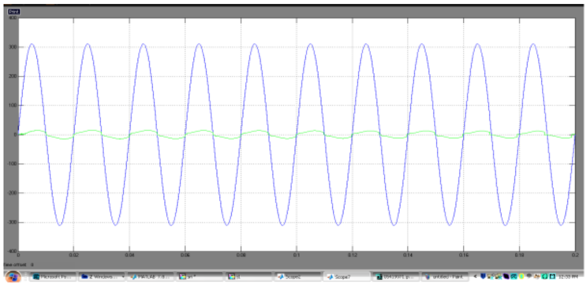

Fig.17 VOLTAGE AND CURRNT AT 0.8 POWER FACTOR

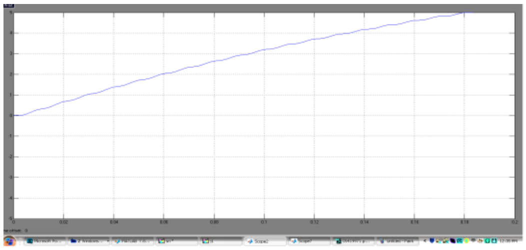

Fig .18 OUT PUT VOLTAGE AT 0.8 POWER FACTOR

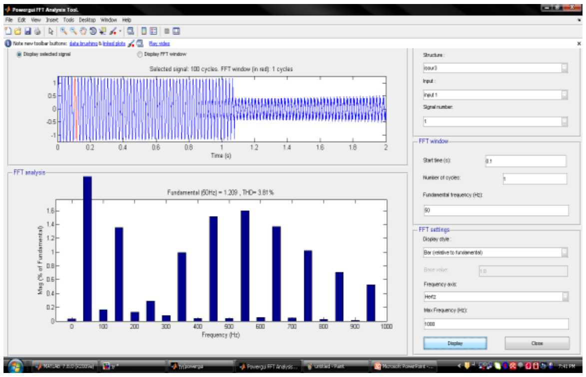

Fig .19 TOTAL HARMONIC DISTORTION AT 0.8 POWER FACTOR

V.CONCLUSION

A MPWM dimming technique is introduced for controlling output luminance of a SSL consisting of a number of parallel strings of series-connected HBLEDs. A significant reduction in the magnitude of peak-to-peak variation of the total lamp luminance and the output current drawn from the power supply is obtained by uniformly phase shifting the control signals used to pulse the current through each HBLED string. Compared to the conventional PWM dimming technique, an improvement in the quality of light output is observed when MPWM dimming is used, along with a reduced magnitude or eliminationof visible flicker perception. Further improvements, in terms of light sensing circuit, accuracy and linearity of lamp luminance to input-dimming command, are obtained. The impact of MPWM dimming on the design and performance of boost dc–dc converter is explained. A reduced output capacitor value is required to meet the desired output voltage ripple specifications when compared to the conventional PWM dimming.Finally a FLYBACK converter topology with input side power factor correction topology is proposed. A reduced output capacitor value is required to meet the desired output voltage ripple specifications when compared to the conventional PWM dimming. In FLYBACK converter total harmonic distortion will be reduced to 0% for unity power factor,2.74% for 0.9 power factor and 5.73% for 0.8 power factor. The total harmonic distortion is allowed upto 10%.

VI. REFERENCES

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