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Design and Analysis of Modified SEPIC Converter for LED Lamp Driver Applications

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ABSTRACT: This project proposes Modified SEPIC converter based LED(Light Emitting Diode) lamp driver with power factor correction. The proposed topology is composed of Modified Single Ended Primary Inductances Converter(M-SEPIC) used as a power factor correction stage which operates in Discontinuous Conduction Mode(DCM) and to drive the LED lamp load. The converter is designed such that solid state switches are working under Zero Voltage Switching (ZVS) to reduce switching losses. An inverter is designed to convert the dc output of Modified SEPIC converter to ac which is fed to the LED lamp. Proportional Integral (PI) controller is designed. The power quality indices are calculated such as harmonic distortion in ac mains current (THD), power factor (pf) to evaluate the performances of proposed LED lamp driver. The analysis, design, modeling and simulation of LED driver are carried out using MATLAB/Simulink tool for universal AC mains

KEYWORDS: Modified SEPIC converter, PI controller, power factor correction (PFC), Discontinuous conduction mode(DCM).

I. INTRODUCTION

The concern with the development of a sustainable society is currently one of the major goals for the scientific community. The growing demand in electricity consumption fits in this context. In this way, new forms of energy generation, as well as its rational and efficient use, should be adopted in order to meet this request.

The current lighting systems represent a large parcel of electricity consumption world -wide.About 20% of the total electricity generated in the planet was consumed by artificial lighting systems.

The continuous research and development resulted in the creation of various types of lamps with different characteristic and application. Light Emitting Diode(LED) is a two- lead semiconductor light source. It is a p-n junction diode which emits light when activated. When a suitable voltage is applied to the leads, electrons are able to recombine with electron holes within the device, releasing energy in the form ofphoton. This effect is calledelectro luminance and the color of light is determined by the energy band of the semiconductor.

LEDs are typically small and integrated optical components may be used to shape the radiation pattern. Earlier LEDs were used as an indicator lamp for electronic devices replacing some small incandescent bulb. They are soon packed into numeric read outs in the form of seven segment displays and were commonly seen in digital blocks. Recent development in LED permit them to be used in applications such as automatic head lamp, advertising,general lighting,traffic signals,camera flashes and lighted wallpaper.LED lights home lightning are as cheap or cheaper than compact fluroscent lamp sources of comparable output. They are also significantly more energy efficient and arguably have fewer environmental concerns linked to their disposal.

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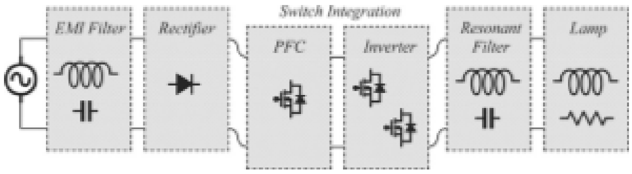

Fig (1.1) Generic structure of feeding lamp

Figure(1.1)shows the generic diagram of feeding a lamp. It consists of an ac source,electromagnetic induction filter,converter,inverter,resonant filter and lamp. 230V ac is applied and is filtered with the help of EMI filter. The output of the filter is fed to converter source where the ac is converted to dc. The dc is then converted to ac through inverter and fed to the load passing through filter Electronic converters used to LED lamps supply typically use a group of power stages connected in cascade. These stages consist of passive and active elements, being the active elements responsible for a significant part of the energy losses of the system. Based on this overview, the application of techniques for reducing the number of active components of the circuit is very attractive.

In search of a simple configuration that can reduce the number of active switches and their respective drive circuits,this paper proposes the use of integration techniques of static converters, A possibility to reduce the power grid consumption refers to the use of lamp dimming control. Systems with dimming capacity can provide high energy savings and an adequate lighting level to the different environments.

This paper is organized as follows: Section II presents the circuit diagram of modified SEPIC Converter for LED lamp driver application. Section III presents the circuit analysis for power factor correction (PFC) and power control. Section IV presents the simulation model and results and finally conclusions are given in Section V

II. CIRCUIT DIAGRAM

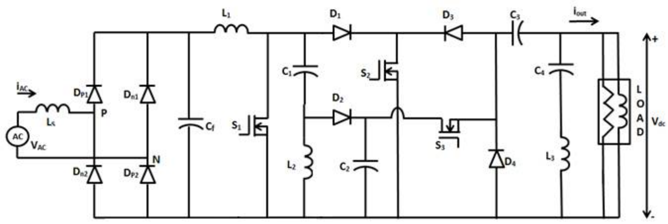

Fig (2.1) Circuit topology

Figure (2.1) is the circuit topology of modified SEPIC Converter for LED drive application. Ac supply of 230V is applied to the rectifier and ac to convert to rectified dc. When switch S1 is closed this voltage appears across the modified SEPIC converter. It is a dc-dc converter. The dc output is given to inverter from where it is converted to ac, filtered and given to the R-L load

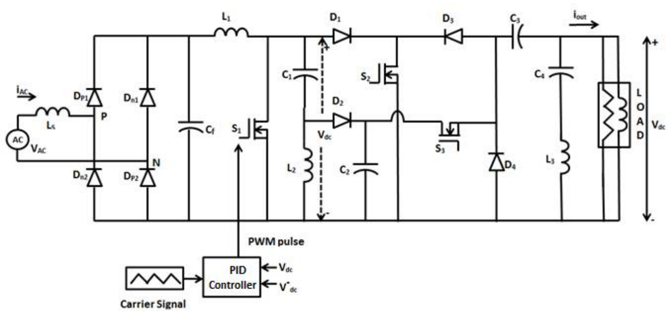

Fig (2.2)Circuit topology with PID controller

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Figure(2.2) is the circuit topology of modified SEPIC Converter for LED drive application with PI Controller. Ac supply of 230V is applied to the rectifier, and ac is converted to rectified dc. When switch S1 is closed this voltage appears across the modified SEPIC converter. If the initialvoltage across the PID is set lower than the actual rectified value, the SEPIC Converter acts as a BUCK converter, the duty cycle reduces and the lamp dims. This dimmed voltage will be appearing across the lamp till the set time. After the set time this dimmed voltage is compared with the final voltage set across the PID. If the final value is greater than dim voltage the SEPIC converter acts as a BOOST Converter, the duty cycle increases and the lamp becomes brighter.

III. CIRCUIT ANALYSIS

Detailed operating principle of proposed circuit is been explained. To reduce the number of MOSFET in the power circuit, Modified SEPIC converter and inverter control is implemented. The proposed model provides high power factor and reduced THD using Modified SEPIC converter with inverter control for LED application.

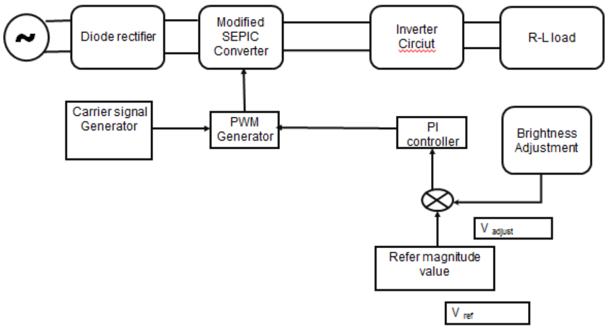

Fig (3.1) Block Diagram of Proposed Topology

The block diagram of proposed topology is shown in Figure (3.1).To design low cost small size and high power factor circuit for LEDs, the design objective is to reduce the THD, improve power factor thus improving system performances.

A. MODIFIED SEPIC CONVERTER

The single ended primary inductor converter SEPIC is a type of dc-dc converter allowing the electrical potential (voltage) at its output to be greater than, less than or equal to that at its input. The output of SEPIC is controlled by the duty cycle of the controlled transistor.

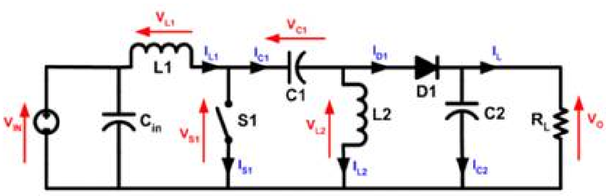

Fig (3.2): SEPIC Converter Model

Figure (3.2) shows the model of SEPIC Converter. Circuits run best with a steady and specific input. Controlling the input to specific sub circuit is crucial for fulfilling design requirements. AC-AC conversion can be easily done with a transformer; however DC-DC conversion is not as simple. Diodes and voltage bridges are useful for reducing voltage by a set amount, but can be inefficient. Voltage regulators can be used to provide a reference voltage.Additionally, battery voltage decreases as batteries discharge which can cause many problems if there is no voltage control. Most efficient method of regulating voltage through a circuit is with a DC-DC converter.

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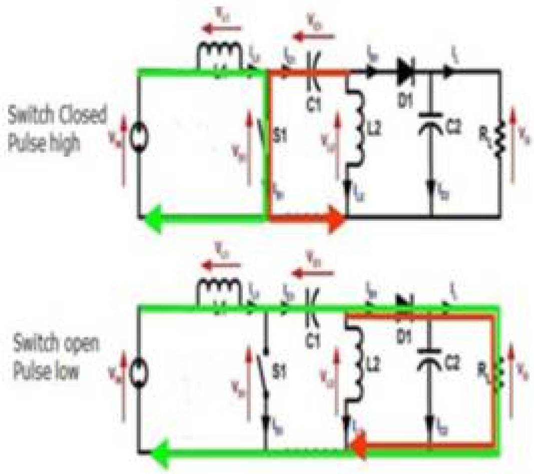
All DC-DC converters operate by rapidly turning ON and OFF of MOSFET, generally with high frequency pulse. For the SEPIC when the pulse is high the MOSFET is ON, inductor 1 is charged by the input voltage and inductor 2 is charged by capacitor 1.The diode is OFF and the output is maintained by capacitor 2. When the pulse is low the MOSFET is OFF, the inductors output through the diode to the load and the capacitors are charged. The greater percentage of time(duty cycle)the pulse is low ,the greater the will be. This is because the longer the inductor charge , The greater the voltage will be. However the pulse last too long the capacitors will not be able to charge and the converter will fail as shown in Figure3.3



Fig(3.3)Switch position of SEPIC Converter operation

B.INVERTER CONTROL

The inverter stage employs a single input inductor (Lin) current source resonant inverter that consists of resonant inductor (Lr) and a parallel capacitor (Cr) to form the corner frequency. The parallel inductor (Lp) is the staring inductor that provides sufficient high voltage to ignite the LED. It also helps to reduce the circulating current in the resonant tank by providing more current to flow to the lamp at desired switching frequency.

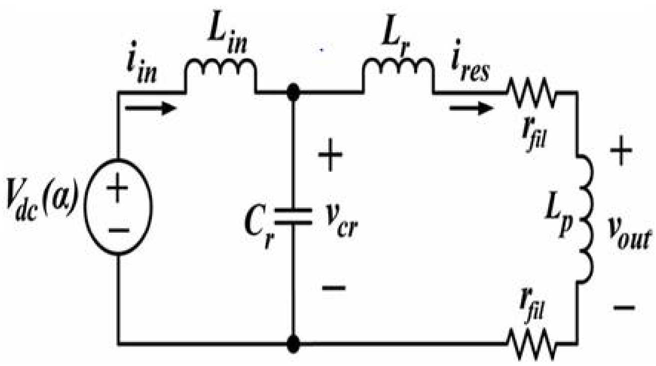


Fig (3.4)Equivalent Circuit Inverter Control Model

Figure (3.4) shows the equivalent circuit of resonant inverter with R-lamp representing the steady state lamp resistances and Rf representing the resistances of filament. The Q- factor of the proposed resonant circuit can be determined. By selecting high enough Q value the resonance circuit, close to sinusoidal waveforms are achieved at the output and fundamental approximation can be applied. The characteristic impedances of the resonance circuit is defined to relate the quality factor and lamp resistances.

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C.PI CONTROLLER

PI controller will eliminate forced oscillations and steady state error resulting in operation of ON/OFF controller and P-controller respectively. However introducingintegral mode has an negative effect on speed of the response and overall stability of the system. Thus PI controller will not increase the speed of response it can be expected since PI controller does not have means to predict what will happen with the error in near future. This problem can be solved by introducing derivative mode which has ability to predict what will happen with the error in near future and does to decrease a reaction time of the controller. I controller are very often used in industry especially when speed of response is not initial.

In control engineering PI controller is a feedback controller which drives the plant to be controlled by a weighted some of the error (differences between the output and the desired set point) and integral of that value. It is the special case of PID controller in which the derivative (D) part of the error is not used. PI controller is mathematically represented as shown in Figure (3.5)

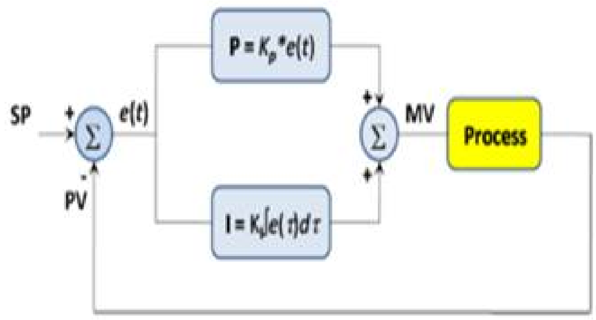

Fig (3.5) PI Controller

Integral control action added to the proportional controller converts the original system into high order.Hence the control system may become unstable for a large value of Kp. Since roots of the characteristic equation may have positive real part. In this control, proportional control action tends to stabilize the system, while the integral control action tends to eliminate or reduce steady state error in response to various inputs.As the value of Tp is increased, in the early history of automatic process control the PI controller was implemented as the mechanical switch.

Most modern PI controllers in industry are implemented in programmable logic controls (PLC) are as a panel mounted digital controller. Software implementations as the advantage that they are relatively cheap and are flexible with respect to implementation.

D. LC FILTER

A inductor-capacitor (LC) circuit is an electric circuit composed of inductors and capacitors.LC circuits are either used for generating signals at a particular frequency or picking out a signal at a particular frequency from a more complex signal. They are key components in many electronic devices. An LC circuit is an idealised model since it assumes there is no dissipation of energy due to resistance. Any practical implementation of the LC circuit will always include loss resulting from small but non zero resistance within the components and connecting wires.

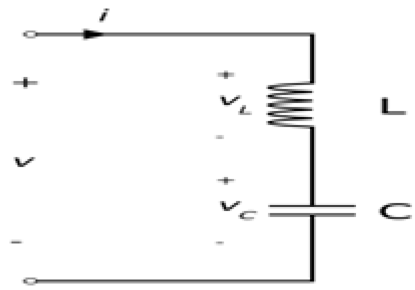

Fig (3.7) LC Circuit

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LC circuit is shown in Figure (3.7).The purpose of an LC circuit is usually to oscillate with minimal damping so that the resistance is made as low as possible.

IV. SIMULATION DIAGRAMAND RESULTS:

SIMULATION DIAGRAM:

OPENLOOP:

The simulation diagramof open loop system is shown in the Figure 4.1.The main purpose of this simulation diagram is to determine total harmonic distortion in terms of harmonic order and frequency

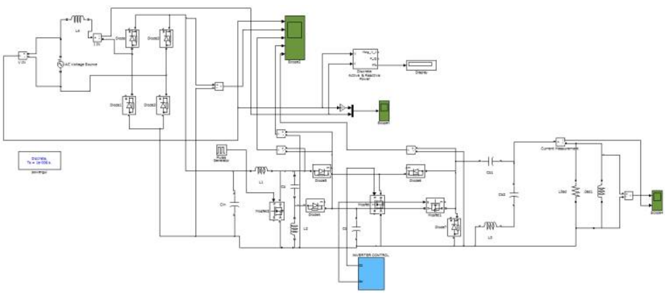

Fig (4.1) Simulation Diagram of Open Loop System

CLOSED LOOP:

The simulation diagram of closed loop system with modified SEPIC topology for LED load developed with subsystem as well as filter circuit, rectifier, inverter and SEPIC topology integrating with switches is shown in figure (4.2).The main merit of closed loop system is duty cycle can be altered without altering the design of the system.

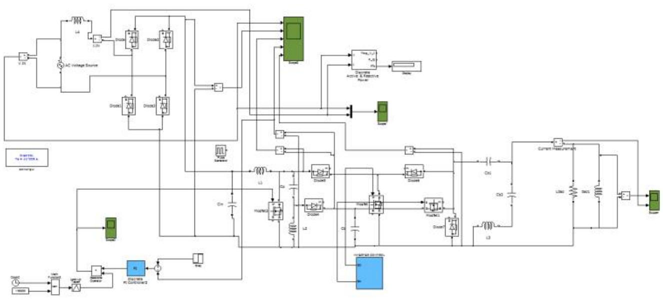

Fig (4.2) Simulation Diagram Of Closed Loop System

SIMULATION RESULT:

The result obtained after performing the simulation is shown in below figures. All the waveforms obtained are studied well. The ouput voltage and current waveforms obtained are found to be as required for the latter operation of the lamp.The results are obtained for different time range.

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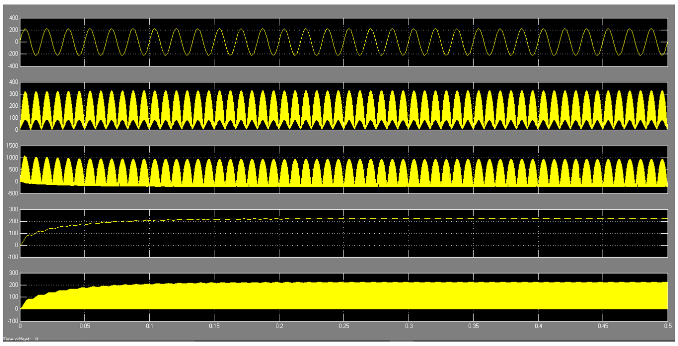

Fig (4.3) Simulation graph of open loop system input/controlled/before and after converter/inverter voltage

In figure (4.3) various voltage parameters of Open Loop System have been plotted like input voltage,output voltage of rectifier,input and output voltage of modified SEPIC converter and output voltage of inverter circuit

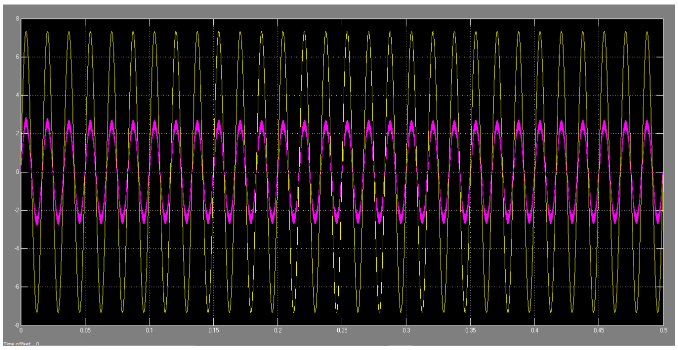

Fig (4.4) Simulation graph of input voltage and current magnitude in Open Loop System

Figure (4.4) shows the parameters of open loop system plotted against input voltage and current magnitude .Input voltage and current magnitude are in phase with each other giving unity power factor.

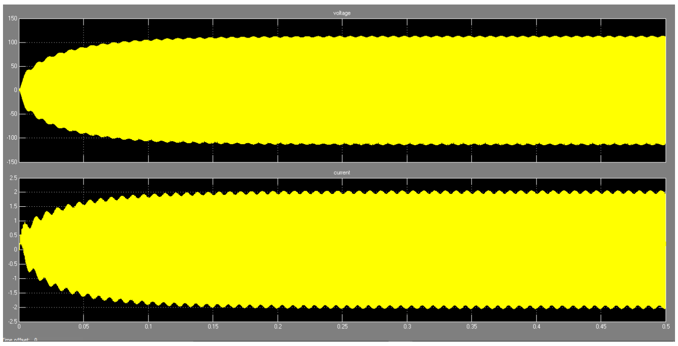

Fig (4.5) Simulation graph of output voltage and current magnitude in Open Loop System

Figure (4.5) shows the parameters of Open Loop System plotted against Output Voltage and Current magnitude.

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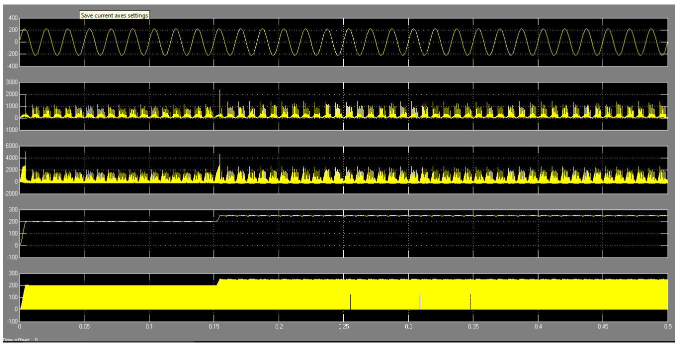

Fig (4.6) Simulation graph of closed loop system input/controlled/before and after converter/inverter voltage

In figure (4.6) various voltage parameters of Closed Loop System have been plotted like input voltage, output voltage of rectifier, input and output voltage of modified SEPIC converter and output voltage of inverter circuit

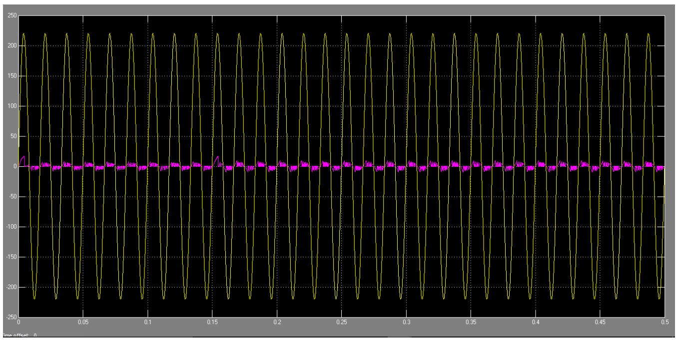

Fig (4.7)Simulation graph of closed loop system with Input Voltage and Current magnitude.

Figure (4.7) shows the parameters of open loop system plotted against input voltage and current magnitude .Input voltage and current magnitude are in phase with each other giving unity power factor.

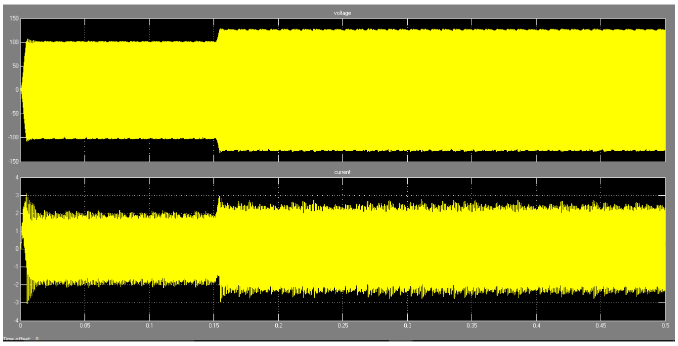

Fig (4.8) Simulation graph of closed loop system with output voltage and current magnitude.

Figure (4.8) shows the parameters of Closed Loop System plotted against Output Voltage and Current magnitude.

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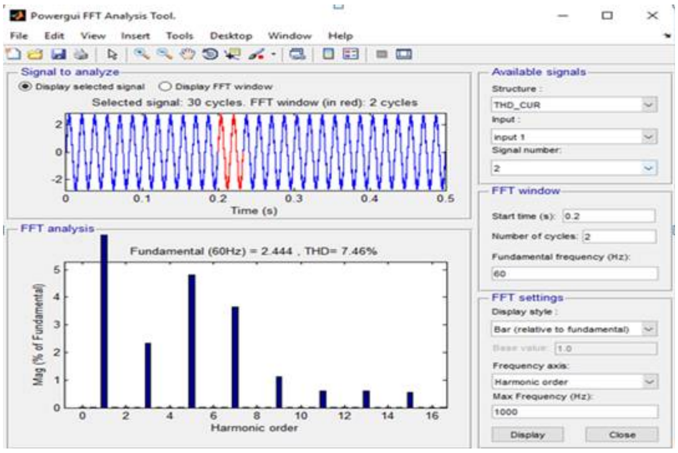

Fig (4.9) Total harmonic distortion of input current in terms of harmonic order

The graph when plotted against current magnitude (%fundamental) and harmonic order in Figure (4.9),Total Harmonic Distortion was reduced to 7.46%

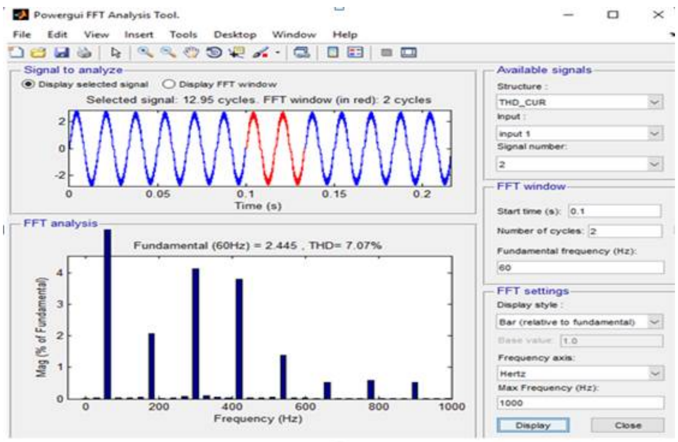

Fig (4.10)Total harmonic distortion of input current in terms of frequency

The graph when plotted against current magnitude (%fundamental) and frequency is shown in Figure (4.10), Total Harmonic Distortion was reduced to 7.07%

V. CONCLUSION

High frequency LED lamp using Modified SEPIC integrated inverter circuit topology was developed. A modified SEPIC power factor corrector is used in integrated topology. Modified SEPIC converter can be operated as a power factor pre regulator. The integration of the power factor correction and power correction stages reduced the system component count. The simulation shows input power factor 0.99 from 20% to 80% duty cycle.Total Harmonic Distortion in terms of harmonic order was determined as 7.46% and in terms of frequency is 7.07%.The input current waveform varies in sinusoidal manner thus increasing the efficiency of the system. This ensures better performance of the LED Lamp. High power factor corrector inverter control switched electronic LED Lamp can be introduced in many applications. The switching and conduction losses are reduced to a great extend thus reducing the complexity of the circuit.

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