Optimization of Harmonics using FPGA

M Smitha
Final Year
Dept. of E & EE
Canara Engg. College

Muhammed Safwan
Final Year
Dept. of E & EE
Canara Engg. College

Shwetha S Pateel
Final Year
Dept. of E & EE
Canara Engg. College

Sujan P K
Final Year
Dept. of E & EE
Canara Engg. College

***Abstract*:- This model aims to mitigate the harmonics in the counter action of an inverter on a Computer UPS in the event of power failure. The humming noise generated by fans, computer speakers etc. while running on inverter can be minimized using this model. By taking an application as an example, this project overcomes the problem of Harmonics produced in the output of a DC-DC Boost Converter by designing the IGBT based transformer-less inverter.**

General Terms:- Harmonics, DC-DC Converter, Total Harmonic Distortion, Transformer-less Inverter.

Keywords:- DC-DC Dual Boost Converter, Switched-Mode Power Supply, IGBT Based Inverter, Single Pulse Width Modulation, L-C-L Filter, Field Programmable Gate Array.

1. INTRODUCTION

Power system harmonics is an area that is receiving a great deal of attention recently. This is primarily due to the fact that non-linear (or harmonic producing) loads are comprising an ever-increasing portion of the total load for a typical Industrial plant.

Harmonics are a mathematical way of describing distortion to a voltage or current waveform. The term harmonic refers to a component of a waveform that occurs at an integer multiple of the fundamental frequency.

Harmonics are caused by non-linear loads, the loads that draw a non-sinusoidal current from a sinusoidal voltage source, such as Switched Mode power Supplies (SMPS) which is used in several electronic devices, ballasts (or chokes) of fluorescent lights, Unlimited power Supply (UPS), inverters, Variable Speed Drives and a whole host of other power Electronic devices. A layperson may observe harmonics in the form of a humming noise emanating from tube light chokes, computer speakers etc.

All Switching DC-DC Converters have been widely used to supply a stable DC output voltage for Industrial products. The conventional open-loop control strategy used for DC-DC Converter with no load and line regulation has several disadvantages compared to closed-loop control of switching converter. Closed control more-over helps in reducing ripple in voltage too.

High levels of harmonic distortion can cause effects as increased transformer, capacitor, motor or generator heating, disoperation of electronic equipment (which relies on voltage zero crossing detection or is sensitive to wave shape), incorrect readings on meters, disoperation of protective relays, interference with telephone circuits, etc.

Harmonics are responsible for increased internal energy losses in loads which cause component failure and result in reduced life span. The ill effects of harmonics on power systems include abnormally high voltages, high currents that cause overheating of generators, transformers, cables, transmission and distribution lines etc.

In order to overcome the problems cited above, it is necessary to improve power quality by reducing the harmonic content in the electricity supply. The need for improvement of power quality is only going to increase with time due to the ever increasing demand for power electronics based appliances.

There are many performance parameters to evaluate the power quality in the presence of harmonics. These include Harmonic Factor, Total Harmonic Distortion, Distortion Factor and Lowest Order Harmonic.[3] The most popular method to estimate the harmonic content in a waveform is Total Harmonic Distortion (THD). It is a measure of the closeness in shape between a waveform and its fundamental component and is given by (1).

$$THD = \frac{1}{V_{o1}} \sum_{n=2,3,....}^{\infty} V_{on}^{2} \qquad (1)$$

2. METHODOLOGY

The simulation of a boost converter based transformer-less inverter was carried out on MATLAB software package. A block diagram based model was developed on Simulink, which is a graphical programming tool by Mathworks.

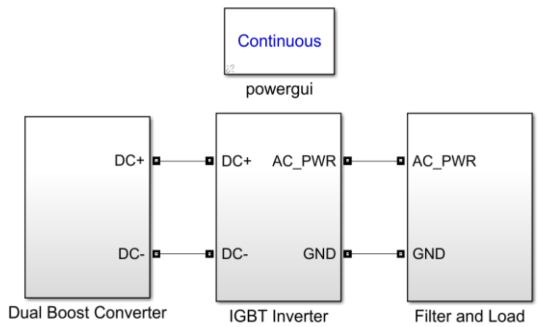

Figure 1. Boost converter based transformer-less inverter.

2.1 *Dual Boost Converter*

A boost converter is a DC-to-DC power converter as in Figure 2. that steps up voltage while stepping down current from its input to its output. It is a type of switched-mode power supply (SMPS) which contains a diode and a transistor which act as switches and one or more energy storage element, namely a capacitor, inductor, or a combination of the two.

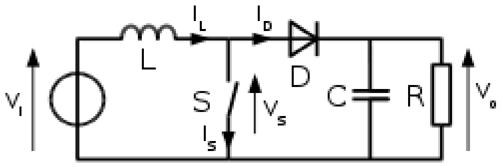

Figure 2. Boost converter

2.2 *IGBT Based Inverter*

A full bridge inverter was designed using four IGBTs which were triggered by various different control strategies. The inverter accepts the DC output of the second stage of the dual boost converter and converts it to AC without any major drop in voltage level. The freewheeling diode connected across each IGBT provides a path for circulating current when the corresponding IGBT is off as in Figure 3. It also helps to mitigate the voltage spikes in the inverter output. IGBTs are preferred instead of MOSFETs for the inverter since IGBT has better turn-on and turn-off characteristics than MOSFET.

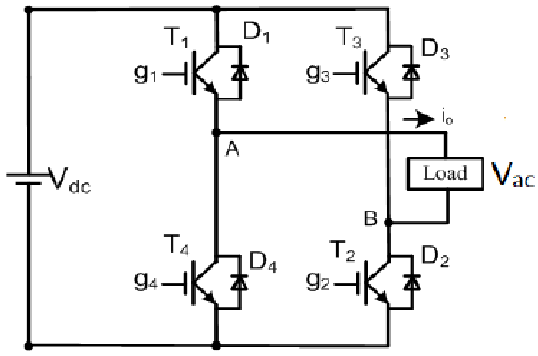

Figure 3. IGBT based Single phase Full Bridge Inverter

The output voltage of a single phase full bridge inverter is determined using Fourier analysis and is given by (2)

$$V_{ac} = \sum_{n=1,3,5....}^{\infty} \frac{4V_{dc}}{n\pi} \sin n\omega t \qquad (2)$$

Where n is the order of the harmonic and $\omega = 2\pi f$ is the frequency of the output voltage in rad/s.

2.3 *Filter and Load*

An LCL low pass filter was used to smoothen the inverter output and obtain a pure sine wave. The filter also helps to reduce the THD. The load is connected at the output of the filter. The model is as shown in Figure 4. Higher values of inductance were found to reduce the amplitude of the output voltage and lower values of inductance were found to result in higher values of THD.

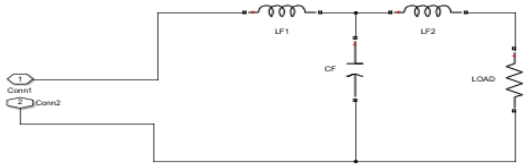

Figure 4. L-C-L Filter and Load

3. CONTROL STRATEGIES FOR BOOST CONVERTER BASED TRANSFORMER-LESS INVERTER

3.1 *Using Two Complementary Square Waves*

Two complementary square waves can be used as gate pulses for an inverter. In this approach, two square waves of 50% duty cycle are used to provide gating pulses to the four IGBTs of the inverter. The first square wave, with a time period of 0.02 seconds (i.e. frequency of 50Hz) and a duty cycle of 50% is used to trigger IGBT1 and IGBT2. The second square wave has the same frequency and duty cycle as the first square wave with a phase delay of 0.01 seconds.The second square wave goes high when the first square wave goes low and thus the two square waves are complementary. The second square wave is used to trigger IGBT3 and IGBT4. The Simulink model of the same is shown in Figure 5.

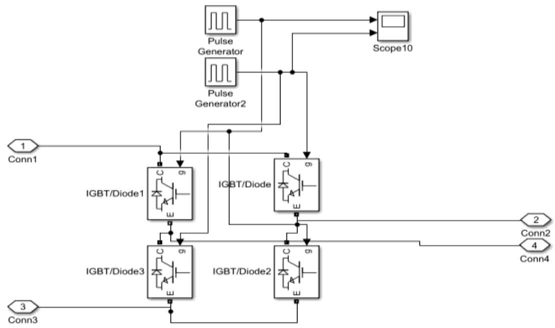

Figure 5. Full Bridge Inverter Using Two Complementary Square Waves

3.2 *Pulse Width Modulation Technique*

With the single phase full-bridge Inverter, it is possible to implement PWM output, as designed below in Figure 6. Pulse Width Modulation or PWM technology is used in Inverters to give a steady output voltage.

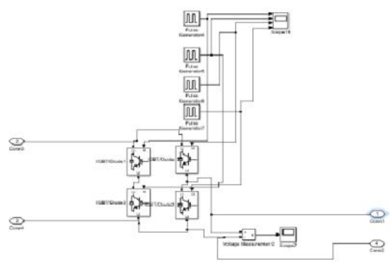

Figure 6. PWM Inverter

The timing sequence of the static switching elements of the full bridge to achieve the PWM voltage waveform is as in Figure 7.

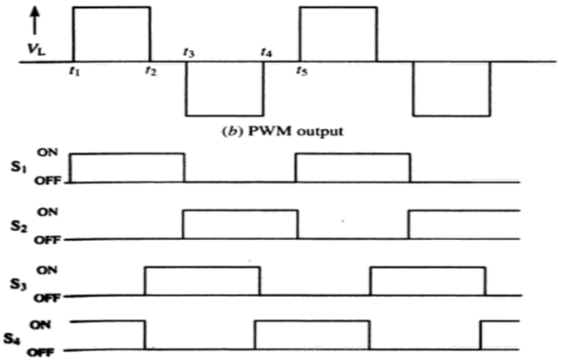

Figure 7. Switching Strategy to Implement PWM

3.3 Sinusoidal Pulse Width Modulation

The PWM pulses used to trigger the IGBTs were generated by comparing a triangular wave of frequency 200Hz with two Sine waves of frequency 50Hz as shown in Figure 8. The four square waves thereby generated were given as gate pulses to the four IGBTs as in Figure 9.

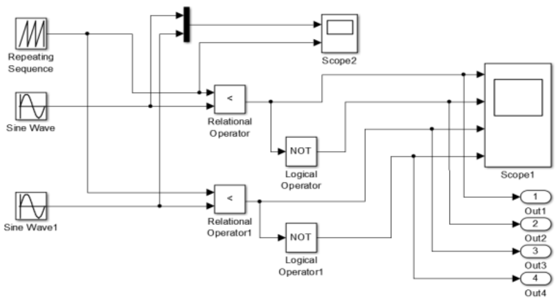

Figure 8.Gating Pulse Generator

The gating pulses for the four IGBT's is as shown in Figure 9.

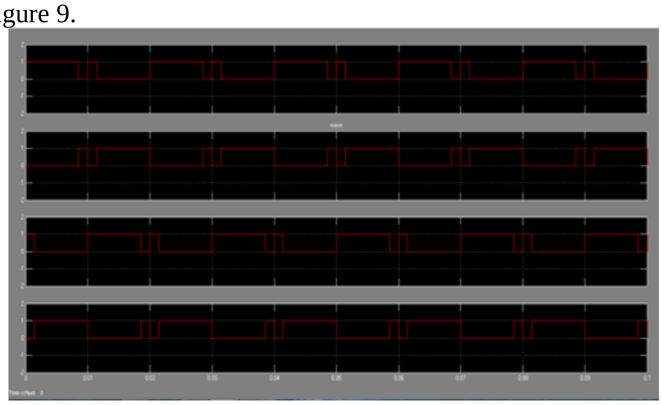

Figure 9.Gating Pulses

4. SIMULATION RESULTS

A standalone Dual boost converter is modelled on Simulink as shown in Figure 10. as per the design. The desired output voltage of the inverter is 230 Volts (RMS). This is equivalent to a peak or maximum voltage of 325.26 Volts. Hence, the boost converter is designed to give a DC output voltage of 325.26 Volts from a DC input voltage of 24 Volts. This voltage is achieved in two steps since a very high duty cycle (very close to 100%) is required to step up the DC voltage from 24 Volts to 325.26 Volts. Such a high duty cycle will make the system unstable.

A switching frequency of 20KHz was assumed for the MOSFET switches in both the stages. The output voltage ripple was designed to be about 1% in both stages by using suitably high value of capacitance. The first stage boost converter is designed to step up a DC voltage of 24 Volts to around 96 Volts. The second stage in turn steps us the voltage from 96 Volts to 325.26 Volts.

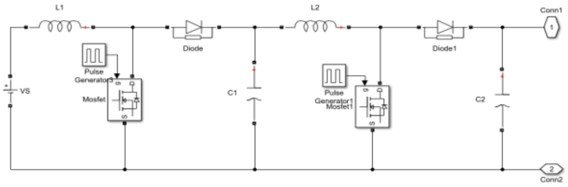

Figure 10. Dual Boost Converter

The results obtained after the simulation of DC-DC Boost Converter with the load is as shown in Figure 11.

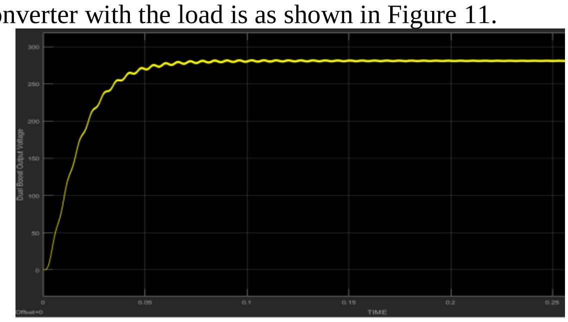

Figure 11. DC-DC Boost Converter Output Voltage With Load

4.1 Full Bridge Inverter Using Two Complementary Square Waves

The circuit for the conversion of the DC-AC is done by choosing an IGBT based Inverter as in Figure 12.

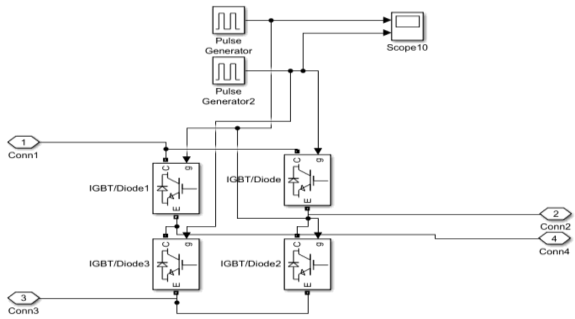

Figure 12. Full Bridge Inverter Using Two Complementary Square Waves

The results obtained for the inverter output is as shown in Figure 13.

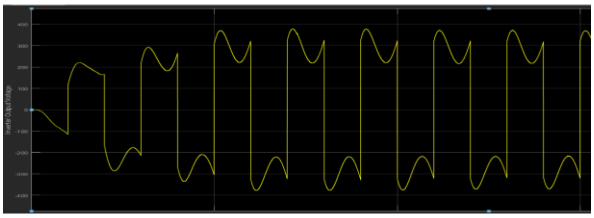

Figure 13. Inverter Output Voltage

In order to smoothen the output of the IGBT based Inverter an LCL Filter is designed as shown in Figure 14.

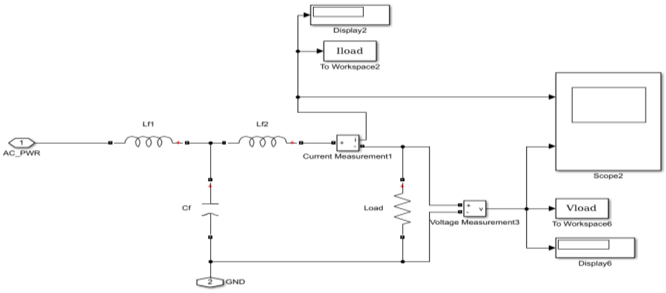

Figure 14. Filter and Load

The output at the terminal of the filter as shown in Figure 15.

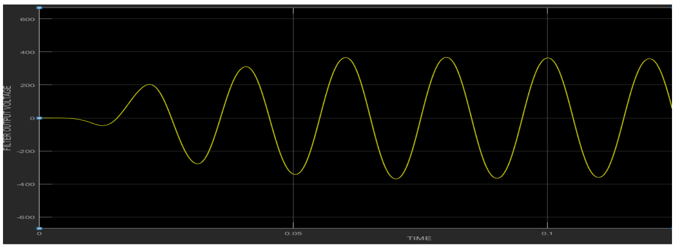

Figure 15. Filter Output Voltage

The output voltage across the load was found to be in excellent agreement with the desired value.

The harmonic content in the load voltage is analyzed using powergui FFT Analysis Tool as shown in Figure 16.

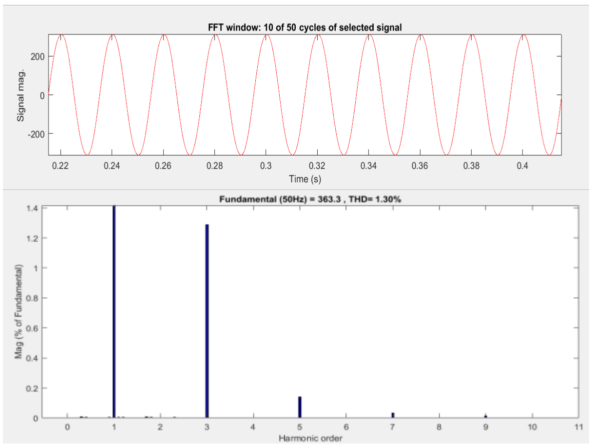

Figure 16. Steady State THD with filter

The results obtained from this plot of Magnitude vs Harmonic Order, it can be inferred that the steady state Total Harmonic Distortion (THD) with filter is about 1.30%.The harmonic content in the system is of the order 1, 3, 5 along with the negligible higher order.

4.2 Pulse Width Modulation Technique

The circuit for the conversion of the DC-AC is done by choosing an IGBT based Inverter as in Figure 17.

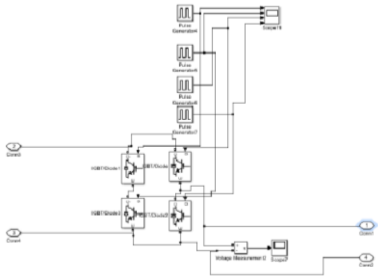

Figure 17.Single Phase Inverter by PWM Technique

The results obtained for the inverter output is as shown in Figure 18.

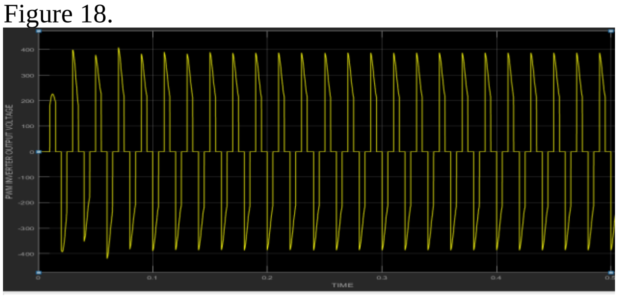

Figure 18.PWM Inverter Output Voltage

The harmonic content in the load voltage is analyzed using powergui FFT Analysis Tool as shown in Figure 19.

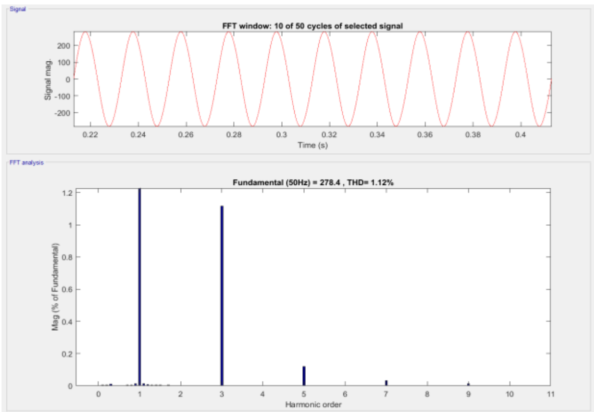

Figure 19. Steady State THD with PWM Inverter and Filter

The results obtained from this plot of Magnitude vs Harmonic Order, it can be inferred that the steady state Total Harmonic Distortion (THD) with filter is about 1.12%.The harmonic content in the system is of the order 1, 3, 5 along with the negligible higher order.

The magnitude (% of fundamentals orders) of Harmonic Distortion is less when the PWM technique is used as a control strategy for Inverter compared with the complementary square waves as the gate pulses for the inverter circuit.

4.3 Sinusoidal Pulse Width Modulation

The inverter output voltage without filter was found to be square wave with 3 levels and a peak steady state output voltage of around 400 Volts. The inverter output voltage without an output filter is shown in Figure 20.

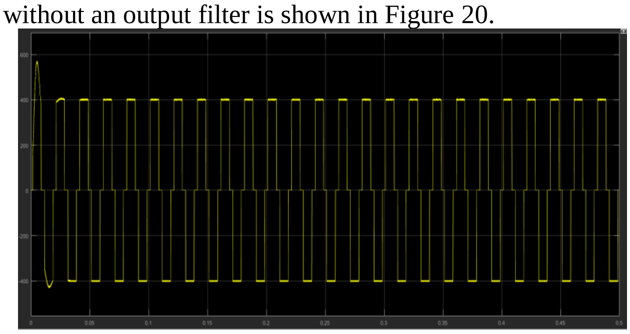

Figure 20. Inverter output voltage without output filter

The Total Harmonic Distortion of a signal can be determined using the Powergui FFT Analysis tool in Simulink. This waveform was found to have a THD of 28.84% over the first 10 cycles. The THD was found to decrease if more cycles were considered for analysis. The harmonic content decreased with time and it was found that the early switching transients contributed a lot to the THD value.

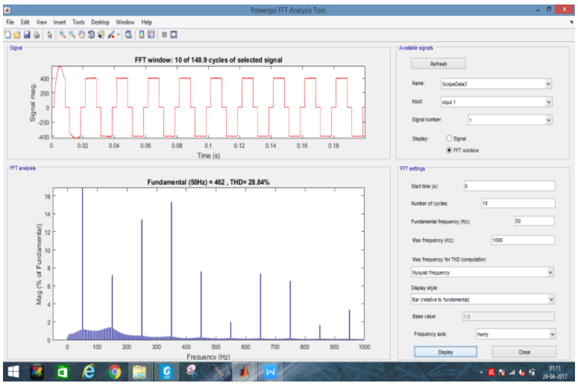

Figure 21.THD without output filter

An LCL filter used to smoothen the inverter output and obtain a pure sine wave also helped to reduce the Total Harmonic Distortion to 14.51%. The output voltage of the filter was found to be around 313 Volts (peak) i.e. an rms value of around 221 Volts. The voltage across the load was found to be sinusoidal.

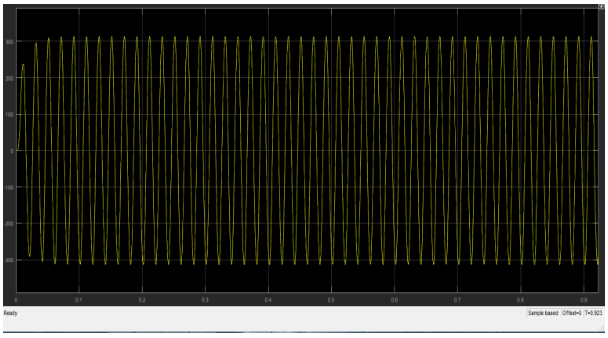

Figure 22. Output Voltage of LCL filter

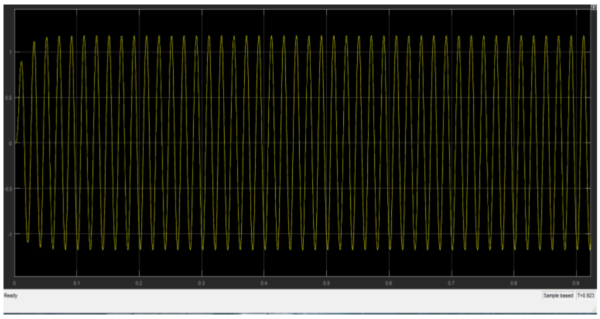

Fig.23.Output Current of LCL filter

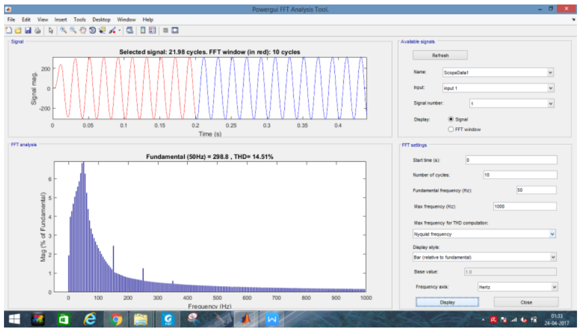

Fig.24. THD with LCL filter

5. FPGA BOARD

Field Programmable Gate Array or FPGA for short is an Integrated Circuit designed to be configured by a customer or a designer after manufacturing. FPGAs can be programmed using Hardware Description Languages such as Verilog or VHDL. FPGAs contain an array of programmable logic blocks and a hierarchy of reconfigurable interconnects that allow the blocks to be wired together. Logic blocks can be configured to perform simple as well as complex logical operations. In most FPGAs, logic blocks also include memory elements, which may be simple flip-flops or more complete blocks of memory. Spartan-3 is the chosen FPGA board for this project as in Figure 25. It has 633 Input/Output pins and is Input/Output centric.[5] It has a higher ratio of Input/Output pins to gates. It has 1872KB of total block RAM and 520KB of total distributed RAM. The board has dedicated 18 x 18 Multipliers and comes with four Digital Clock Managers. Data transfer takes place at a speed of more than 622 MB/second.

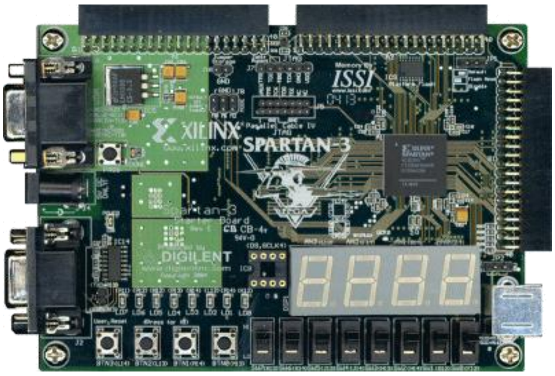

Figure 25. Spartan-3 FPGA Board by Xilinx

A Field Programmable Gate Array (FPGA) based real time implementation of a closed loop controller for regulating the load voltage under line and load disturbances by generating Digital Pulse Width Modulation (DPWM) is developed. Digital Proportional Integral (DPI) controller is designed to generate the DPWM.

6. CONCLUSION

The harmonic content needs to be further mitigated in the inverter circuit by using different control strategies.

The dependency of the load on output voltage need to be reduced by varying the duty cycle of the switching circuit using FPGA.

7. ACKNOWLEDGEMENT

First and foremost, we would like to extend our heartfelt thanks to our parents for their encouragement and blessing.

We would like to express our special thanks of gratitude to our mentor and Project Guide, Mrs. Ashwini K G , Asst.Professor and our project coordinators, Mr. Divyesh Divakar , Mr. Ananth Krishna Kamath , Asst. Professors, E&E Department, for their keen interest at every stage of our Paper.Their prompt inspirations, timely guidance with kindness and valuable advice throughout this work has always helped us.It is a genuine pleasure to express our deep sense of thanks and gratitude to Dr. Rajalakshmi Samaga B L, Head of The Electrical and Electronics Department, for her moral support and encouragement. We are indebted to our college for providing an environment with all the facilities that helped us in various ways for our ongoing Project. We would like to take this opportunity to express our deep sense of gratitude towards all those who have helped us in various ways for preparing this paper.

8. REFERENCES

[1] D. W. Hart, Power Electronics, McGraw-Hill, 2011.

[2] M. H. Rashid, Power Electronics,Circuits,Devices and Application,3rd Edition, Pearson Education,Inc, 2004.

[3] M. S. K. Reddy, “A Small Signal Analysis of DC-DC Boost Converter,” *Indian Journal of Science and Technology,* vol. 8(S2), pp. 1-6, January 2015.

[4] K. G. Georgakas, “Harmonic Reduction Method for a Single Phase DC-AC Converter Without an Output Filter,” *IEEE Transactions on Power Electronics,* vol. 29, pp. 1-9, September -2014.

[5] D. A. M. ,. D. D. Kanchan Chaturvedi, “Active Power Filter Techniques for Harmonics Supression in Non-Linear Loads,” *International Journal of Scientific Engimeering and Technology,* vol. 1, no. 2, pp. 123-127.

[6] J. A. Prathap, “Implementation of FPGA based DPWM-Digital PI Closed Loop Controller for Voltage Regulation,” *Indian Journal of Science and Technology,* vol. 9(38), October -2016.