ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Special Issue 1, December 2013

One Cycle Control of Bridgeless Buck Converter

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Abstract: Analysis and design of a voltage doubler bridgeless buck converter is performed during the course of project and hardware implementation of a prototype was done during this period. Voltage doubler bridgeless buck converters can be used in switched mode power supplies as rectification as well as power factor correction circuit. Conventional switched mode power supplies contains a bridge rectifier followed by power factor correction circuit and second stage dc to dc converters for generating the required dc voltage.Bridgelesss voltage doubler circuit combines both the rectifier and power factor correction circuit to a single circuit, the output of which is double the voltage produced by a single buck converter [3] used as pfc circuit.

This circuit consists of two buck converters connected in parallel in series out manner. The total output obtained is the sum of voltage across each capacitor of the buck converters which are operating during positive and negative half respectively. MOSFET is used as the switching device of the buck converter Usually pulse width modulation technique is used for switching operation and clamped current mode control is used for controlling the buck converter.

In this paper ,a new control method called One Cycle Control is used for controlling the buck converter during both half of supply voltage. This method is a non linear control technique to control the duty ratio of the switch in real time such that in each half cycle the average value of the chopped waveform is made equal to the reference value. This method provides greater response and rejects input voltage perturbations.Simualation of the circuit employing One Cycle Control is done in MATLAB/SIMULINK .A prototype of voltage doubler buck converter generating a dc voltage of 12V operating at a switching frequency of 65kHz is developed. The gating signals are generated by microcontroller ATMEGA16 and the program is written in C language.PWM switching technique is used here as implementation of One Cycle Control required a better controller. The results obtained are also presented in this paper.

Keywords: Power Factor Correction, Bridgeless voltage Doubler, Buck Converter, One Cycle Control

I. INTRODUCTION

Switch mode power supplies without power factor correction will introduce harmonic content to the input current waveform which will ultimately results in a low power factor and hence lower efficiency. A bridge diode rectifier followed by a power factor correction circuit which is either a buck or boost frontend is commonly used for all switched mode power supplies. Boost converter as a PFC front-end exhibits 1-3% lower efficiency at 100-V line compared to that at 230-V line. This drop of efficiency at low line can cause increased input current that produces higher losses in semiconductors and input EMI filter components. Also it has relatively output voltage, typically in the 380-400-V range. This high voltage leads to switching losses of the primary switches of the downstream dc/dc output stage and the size and efficiency of its isolation transformer.

At lower power levels the drawbacks of the universal-line boost PFC front-end may be overcome by implementing the PFC front-end with the buck topology [7]. Since the output voltage of a buck converter is less, the dc/dc stage can be implemented with lower-voltage-rated semiconductor devices and optimized loss and size of the transformer.

Conventional ac-dc converters has a diode bridge rectifier followed by power factor correction circuit .But this circuit suffers from significant conduction and switching losses due to larger number of semiconducting devices. This problem can be solved by using bridgeless converters to reduce the conduction losses and component count. A bridgeless buck PFC rectifier[3] combines both rectification and power factor correction using a single circuit. This circuit also act as a voltage doubler circuit whose output voltage is greater than a single buck converter. Usually the switching operation is

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controlled by pulse width modulation technique using clamped mode current control of a buck converter .This paper explains a new control method called One Cycle Control [6] which is a non linear control technique and produce faster response than the later one.

II.BRIDGELESS BUCK PFC CONVERTER

Figure shows the PFC circuit formed by two buck dc/dc converters. Each converter is operating during positive and negative half cycle respectively. This PFC rectifier employs two back-to-back connected buck converters that operate in alternative halves of the line-voltage cycle. The buck converter operating during positive half-cycles of line voltage V_{ac} consists of a unidirectional switch comprising of diode D_a in series with switch $S1$ freewheeling diode $D1$, filter inductor $L1$ and output capacitor $C1$. Similarly, the buck converter consisting of the unidirectional switch implemented by diode D_b in series with switch $S2$, freewheeling diode $D2$, filter inductor $L2$, and output capacitor $C2$ operates only during negative half-cycles of line voltage Vac .

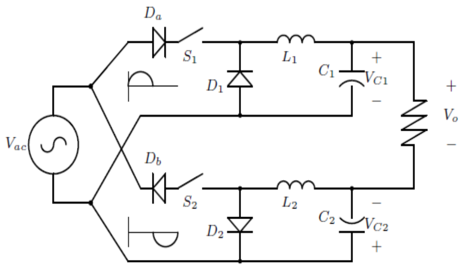

Fig 1.Bridgeless Buck Converter

The input current flows through only one diode during the conduction of a switch, i.e., either D_a or D_b . Efficiency is further improved by eliminating input bridge diodes in which two diodes carry the input current. An additional advantage of the proposed circuit is its inrush current control capability. Since the switches are located between the input and the output capacitors, switches $S1$ and $S2$ can actively control the input inrush current during start-up.
Output voltage V_{ou}t of the PFC rectifier is the sum of the voltages across output capacitors $C1$ and $C2$, is given by $V_{out} = 2DV_{in}$ where d is the duty ratio

III. PWM CONTROL OF SWITCHING CONVERTER

In pulse width modulation (PWM) control, the duty ratio is linearly modulated in a direction so as to reduces the error. Any change in the input voltage must be sensed as an output voltage change and error produced in the output voltage is used to change the duty ratio to keep the output voltage constant. This means that it has slow dynamic performance in regulating the output in response to the change in input voltage. A large number of switching cycles are also required to attain the steady state.
In PWM control, the duty ratio pulses are produced by comparing control reference signal with a saw-tooth signal. As a result the control reference is linearly modulated into the duty ratio signal. If the power supply voltage is changed, for example by a large step up, the duty ratio control does not see the change instantaneously since the error signal must change first. Therefore, the output voltage jumps up and the typical output voltage transient overshoot will be observed at the output voltage. Then the error produced in the output voltage is amplified and compared with the saw tooth signal to control the duty ratio pulses.
A large number of switching cycles is required before the steady-state is reached. The output is always influenced by the input voltage perturbation.
The figure shows a typical buck converter using PWM technique .The voltage output V_o is compared with V_{ref} to generate an error signal and it is amplified.The error signal thus obtainedand saw tooth waveform is given as input to the comparator where it is compared is compared to generate the PWM signal for the switch.Since the error generated is used to vary the duty ratio to keep the voltage constant ,this method produce a slow response

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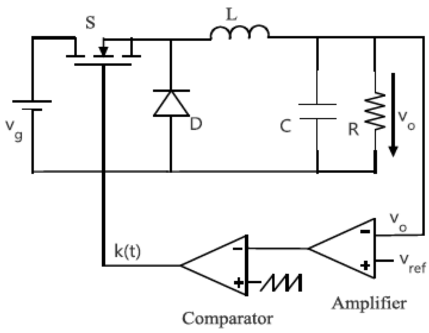

Fig 2.Buck converter using PWM technique

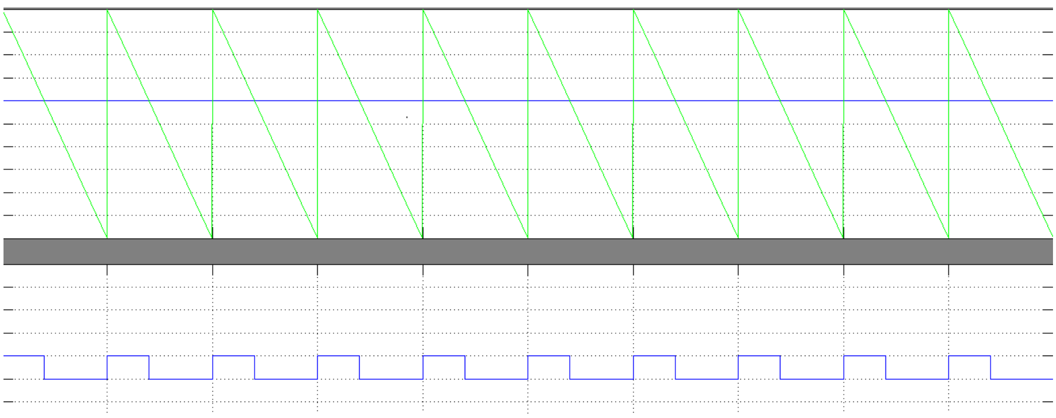

Fig 3.Waveform showing PWM generation

IV.ONE CYCLE CONTROL

One Cycle Control is a new nonlinear control technique implemented to control the duty ratio of the switch in real time such that in each cycle the average value input waveform at the switch rectifier output diode is exactly equal to the control reference. One-Cycle Control method [2] reject input voltage perturbations in only one switching cycle and follow the control reference very quickly. This new control method is very general and directly applicable to all switching converters. Switching converters are pulsed and nonlinear dynamic systems. This technique takes advantage of the pulsed and nonlinear nature of switching converters and achieves instantaneous control of the average value of the chopped voltage or current. This technique provides fast dynamic response and good input-perturbation rejection.

Figure shows a typical buck converter employing One Cycle control. The one-cycle controller is comprised of an integrator with reset, a comparator, a flip-flop, a clock and an adder. The clock triggers the RS flip-flop to turn ON the transistor with a constant frequency. When the switch is turned on by a fixed frequency clock pulse, voltage available across the diode is being integrated. The output of the integrator is compared with the control reference in real time using a comparator.

When the integrated value of the diode-voltage becomes equal to the control reference, the transistor is turned OFF and the integration is immediately reset to zero to prepare for the next cycle. In each cycle, the diode-voltage waveform may be different. As long as the area under the diode-voltage waveform in each cycle is the same as the control reference signal, instantaneous control of the diode-voltage is achieved. Since the switched variable always follows the control reference the output voltage is independent of all input voltage variations.

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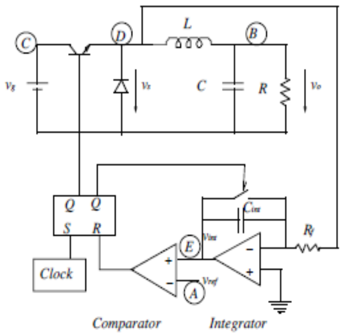

Fig 4.Buck converter using One Cycle Control

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A.*occ controller for bridgeless buck converter*

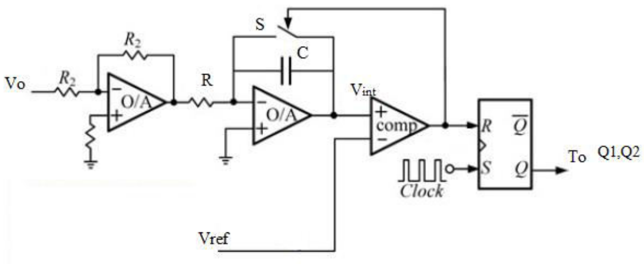

Fig 6.OCC controller for bridgeless buck converter

Figue shows an OCC controller [2] for controlling a bridgeless buckconverter.Here V_o is the output voltage obtained across the two capacitors C1and C2.The output obtained is amplified and is fed to an integrator with reset.At each instant the integral value is being compared with a reference V_{ref} .When integral value V_{int} reaches the control reference,V_{ref} comparator changes its state and turns the switch (transistor) off and the integrator is reset to zero at the same time. Since the reset signal is a pulse with very short width, the reset time is very short, and the integration is activated immediately after the resetting.

Thus, $V_{int} = 1/RC \int kV_o(t)dt$,where k is the gain of the amplifier

The output of comparator is given to a flip flop to give signals to switches Q1 and Q2

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The operation of an OCC controller is explained by means of the following waveforms. Here T_s is the time period of one switching cycle. The operation is explained for positive half cycle during which switch Q1 is operating and Q2 is off ,V_{ref} is the reference voltage .The output voltage is obtained across the capacitor according the ON and OFF of the switch. The integrator is also activated during the start of each switching cycle. When the integral value of V_o reaches the V_{ref} ,the comparator changes its state from low to high which is indicated by a short pulse as shown in the graph. When this condition is reached the switch is turned off till the starting of the next switching cycle and this process repeats for both positive and negative half. By increasing the switching frequency almost constant output voltage can be obtained by this control method. This also eliminates any variation of the input supply voltage and provides a dynamic performance

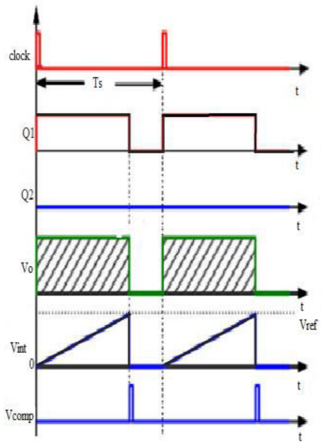

Fig 7.Waveforms showing output of OCC controller

V.SIMULINK MODEL OF BRIDGELESS BUCK CONVERTER AND OCC

The simulation of the proposed controller employed in Bridgeless Buck converter is done in MATLAB SIMULINK.The simulink model of the bridgeless buck converter is shown below. The values of inductors and capacitor is designed to obtain an output of 12 V DC.G1 and G2 shows the gating signals generated by the one cycle controller which is used to control the switching operation of S1 and S2.The simulation is done at a switching frequency of 65kHz.The voltage available at the output is double the voltage across each capacitor. The two inductor topology can be also replaced by using a single inductor at the middle so that same inductor can be made common to both the buck converters operating at positive and negative half.

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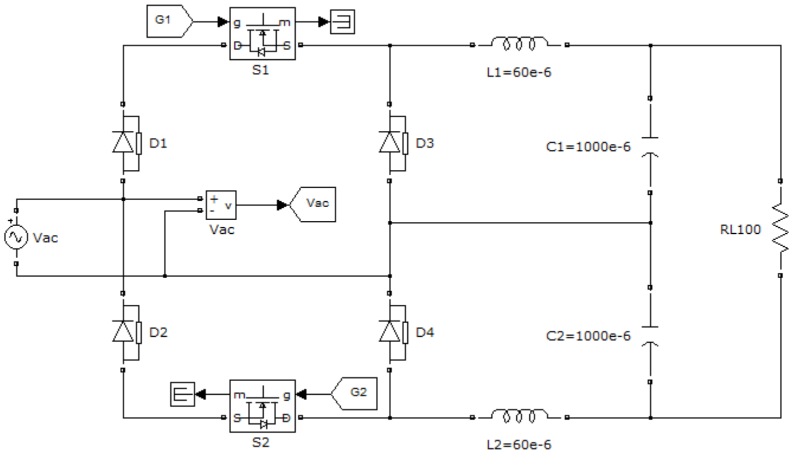

Fig 8.simulink model of bridgeless buck converter

The simulink model of OCC controller is shown below. The output voltage V_0 is fed to the integrator .The output of the integrator is compared with the reference in the comparator and the output of the comparator is used to set and resets the D flip flop. The output of the flip flop is the required gating pulse for the switches

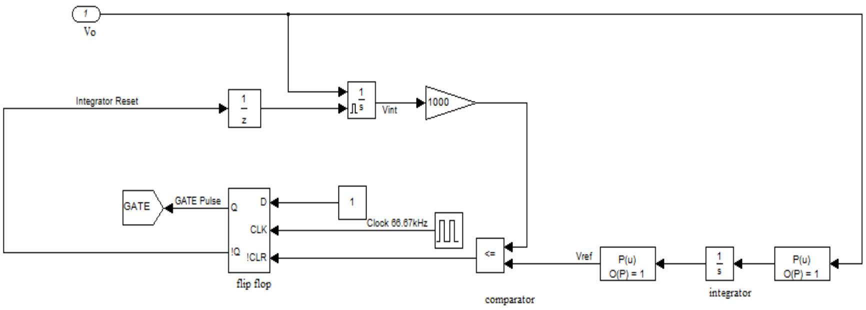

Fig 9 simulink model of occ controller

VI. SIMULATION RESULTS OF ONE CYCLE CONTROLLED BRIDGELESS BUCK CONVERTER

The simulation of the bridgeless buck converter operating at a switching frequency of 65kHz is done using SIMULINK.The buck converter is generating an output voltage of 12V using One Cycle Control method. The gating signals given to the switches during the positive and negative half cycle, input and the output waveforms obtained during the simulation are shown below. When switching pulses are given to one of the switches the other switch will be off. Thus it is important to identify whether the incoming waveform is from the positive half or from the negative half.

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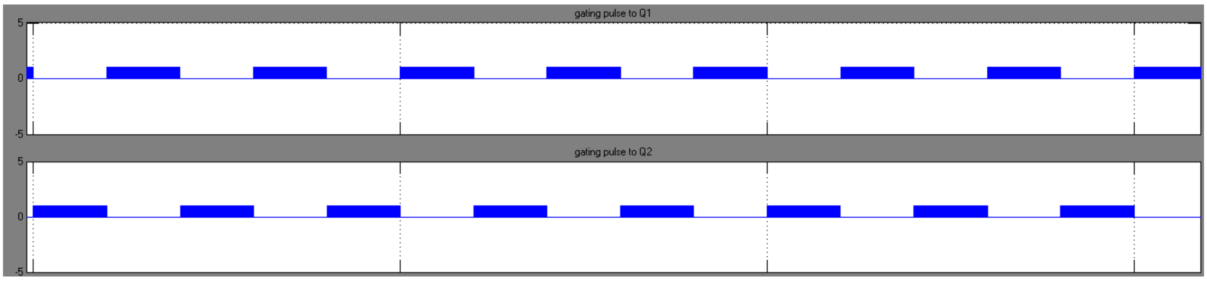

Fig 10.Gating signals to switches S1&S2

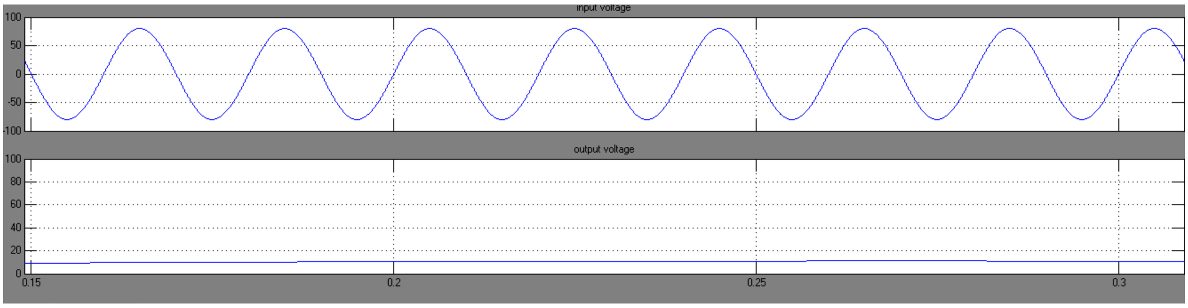

Fig 11.Input & output voltage waveform

VII. HARDWARE IMPLEMENTATION

The hardware setup of the circuit is designed and implemented .Here PWM switching technique is used for varying the duty ratio of the switches and there by controlling the ON and OFF of the switches. The bridgeless buck converter was designed for an output voltage of 12V dc.ATMEGA 16 is the controller used for generating the control signals. The prototype of a typical converter is shown below.IRFP250N power MOSFET is used as the switching device whose switching is controlled by the microcontroller ATMEGA 16L.TLP250 is used as power MOSFET gate driver.BYQ28E is used as the diode rectifier. Two capacitors of 1000µF is used for each set of buck converter which is operating during the positive and negative half cycle. Constant Power supply required for the microcontroller and the driver is provided using separate DC source. Supply required for the operation of other semiconductor devices is being supplied by the power supply unit being implemented within the circuit.

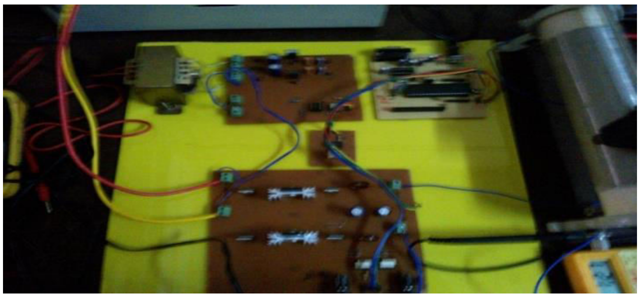

Fig 12.Hardware setup of bridgeless buck converter

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VIII.EXPERIMENTAL RESULTS

The results obtained during the hardware implementation are presented below. The input voltage and current waveforms, gating signals and the output obtained are shown.

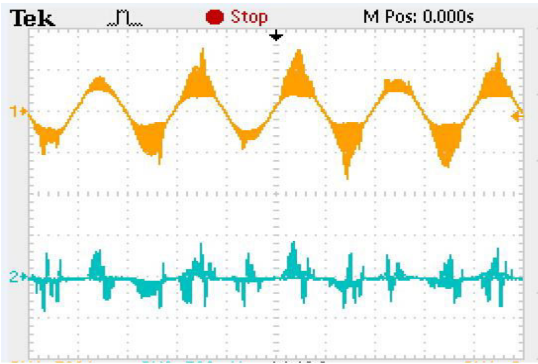

Fig 13.Input voltage & current

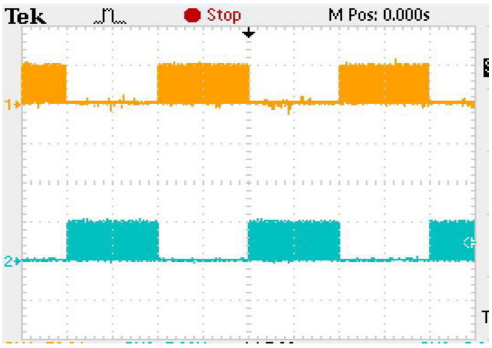

Fig 14.gating signals to switches

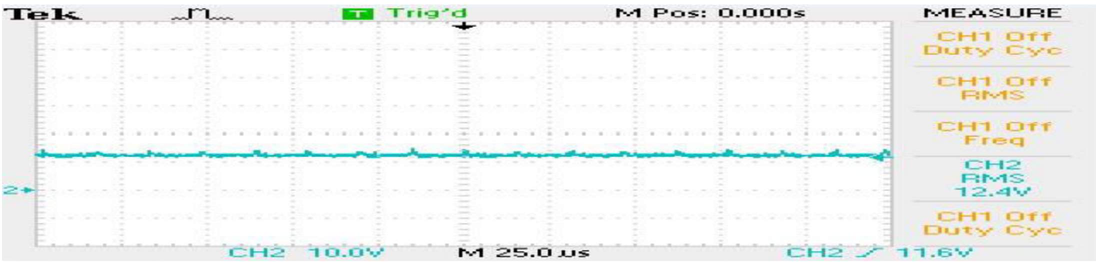

Fig 15.Output voltage waveform

VIII.CONCLUSION

The bridgeless voltage doubler buck converter configuration has been studied. This circuit generates the output voltage which is double than a conventional buck converter since it is having two buck converters operating in a complete cycle. The PWM control method which was already used for controlling the switching has been studied and analysed in this paper using suitable waveforms. A new control method called One Cycle Control has been implemented to the bridgeless buck converter in order to get dynamic response and to eliminate the input voltage perturbations. Since the output voltage always follows the switched variable the output remains constant at the reference value .This method also eliminates the use of various control loops thus reducing the complexity of the conventional cicuit.The simulation of bridgeless buck voltage doubler circuit using One Cycle Control was done in Matlab simulink and the waveforms obtained at the time of simulation is presented here. The hardware implementation for the prototype is made for 12V dc and PWM technique is used as the switching technique. Microcontroller ATMEGA 16 is used as the controller. As a future work the hardware circuit should be implemented using one cycle control.

ACKNOWLEDGMENT

First and foremost, I would like to thank God Almighty for his assuring presence and blessings as it was only through his grace I was able to complete my project successfully.

I extend my deep sense of gratitude and hearty thanks to **Prof. K Radhakrishnan** (HOD, Electrical and Electronics Engineering Department) for his inspiration and support to do the project internally. I would like to thank my internal guide **Prof. Leena Thomas**, Professor, EEE Department, MACE for her valuable guidance, support and timely advice

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Vol. 2, Special Issue 1, December 2013

given to me during the course of the project. I also render my sincere thanks to all the professors of electrical and electronics department of MACE for their valuable suggestions given to me during the completion of my thesis work Last but not the least I sincerely thank my parents and husband for all their support and encouragement and for the sacrifices they have made, that helped me to complete the project successfully.

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