Design & Implementation of PWM Based 3-Phase Switch-Mode Power Supply (SMPS)

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***Abstract*—** *This research work is on designing a PWM based SMPS instead of using conventional pulse generating pre-programmed chips. All the topologies of SMPS are studied and their ranges of application are analyzed as well. Two SMPS designs have been proposed. One of them is using analogue switching method by 555 Timer while the other one using microcontroller for PWM generation and feedback control. Firstly, single phase SMPS has been designed using microcontroller and load-end feedback. The single phase layout has been modified to introduce a Three Phase SMPS and the results are observed. Later on The three phase SMPS using microcontroller has been implemented and the difference between the software simulation and practical results have been analysed. The designed Three Phase SMPS gives a value of 5.003V for 5V output, 9.012V for 9V output and 12.677V for the unregulated 12V output.*

Keywords *– SMPS, PWM, 555 timers, Microcontroller, Feedback, Voltage regulation, Power MOSFET, Ripple voltage.*

I. INTRODUCTION

Switch-Mode Power Supplies (SMPSs) are a popular and frequently necessary choice for DC- DC conversion [1]. These circuits are distinctly beneficial compared to other methods of DC-DC power conversion. Many electronic devices require multiple dc voltage level and designers need a way to convert standard power source potentials into voltages dictated by the loads. The voltage conversion process must be versatile, efficient and reliable. Switch-Mode Power Supplies (SMPSs) are often used to get different DC voltage levels which are required for modern applications and are essential for highly efficient, reliable DC-DC power conversion systems. Maximum electronic DC loads are supplied from standard power sources. But voltages from standard power sources may not match with levels required by microprocessors, motors, LEDs or other loads, especially when source voltage is not

Regulated3. Fortunately, the versatility of SMPSs can solve this problem of voltage conversion. Some applications of SMPS include its use in microprocessors, dc motors, and power source for computers. There are many topologies of SMPS and those are classified in fundamental categories like step up, step down, invert or even step up and down. In this case, SMPSs are appreciable because a topology can be selected to fit nearly any output voltage. Though SMPSs have given a solution to DC-DC power conversion but the efficiency of it has become a matter of discussion now.

Day by day the efficiency of SMPSs is required to be increased for having more accuracy in power conversion. Many researches regarding SMPS has been conducted in the recent past. A thesis has been done on the analysis and implementation of SMPS where switching frequency is in the MHz range. Another work has been done on SMPS using PWM concepts. More recently another thesis has been done which focused on reducing volume and improving frequency [2-4].

The objectives of this work are- to have a comparative overview on different SMPS design, to propose a new design to improve efficiency.

II. PROPOSED CIRCUITS

Two Circuits has been designed. In one circuit, the switching action has been obtained using 555timer and it is completely analog design, it has been designed in MULTISIM. The other circuit has been designed using microcontroller and digital switching and feedback control techniques has been used. The digital design has been done in PROTEUS.

A. Proposed SMPS Circuit Generating PWM without Microcontroller

The circuit of Figure1 has been designed in MULTISIM.

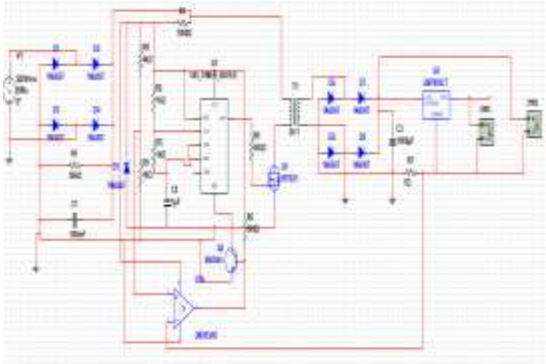


Fig 1: Proposed SMPS Circuit Generating PWM without Microcontroller.

The circuit of Figure 1 has the following components-555 Timer IC, IN4462 Zener diode, IRF821 Power MOSFET, 2N3904 Power Transistor, LM393 AD comparator and LM 7809 positive voltage regulator.

Input to the design is 220V ac. The 555 Timer has been used to generate pulses for the switching MOSFET and the Zener diode has been used to protect the 555 timer IC from over voltage. Pulse train produced from 555 timer switches the power MOSFET on and off. When MOSFET is on, current flows in transformer primary and voltage induced in secondary coil supplies the load current. When the switch turns off the induced voltage in the secondary coil reverses. The diode bridge in the secondary coil rectifies the secondary voltage. An output capacitor removes high frequency ripples from the output and produces 12V dc. The regulator provides another output with 9V dc. The comparator has been used to provide protection in case the load draws excess amount of current. In such a case the comparator will turn off transistor Q2 and turn of the 555 timer. This will stop any current from flowing [5-9].

B. Proposed Single Phase SMPS Circuit generating PWM with Microcontroller

The circuit of figure 2 has been designed in Proteus.

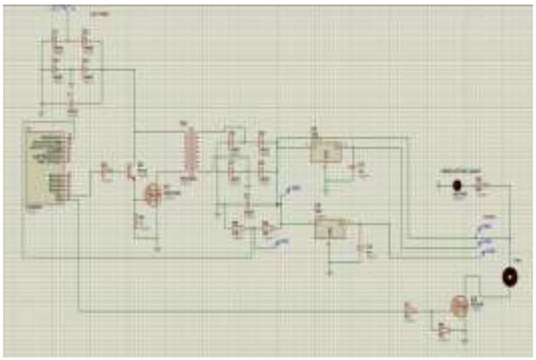


Fig 2: Proposed SMPS Circuit Generating PWM with Microcontroller

The circuit of Figure 2 is a SMPS which uses digital switching and feedback control. The design consists of the following components - PIC16F676 microcontroller, IRFB17N50 power MOSFET, TIP122 transistor, 7805 and 7809 voltage regulators, and a IRFZ44E MOSFET.

The input to the circuit is 220V ac supply. The ac voltage is turned into unregulated dc voltage by using the full bridge diode configuration and the capacitor C1.A program has been loaded in the microcontroller which controls the generation of the switching pulse and also the feedback action of the circuit. When the pulse is high the MOSFET Q1 is switched on and current flows in the transformer primary. A voltage is induced in the transformer secondary and the secondary coil supplies the load current through the full bridge diode configuration in the output side. When the switching pulse is low the current flow in the transformer primary stops and the voltage induced in both primary and secondary is reversed. The secondary coil supplies the load current.

A capacitor C2 has been placed across the output diode bridge and 12V dc is available in the output bus. Using 5V and 9V regulators two extra dc voltage levels are made available as output. The input to the voltage regulators is 12V. They ensure that the voltages of the extra two outputs always remain at 5V and 9V respectively.

Two resistors R2 and R4 has been placed in series across the output bus. Their values are 2.2KΩ and 10KΩ. For 12V output VR2 is 2.16V. The actual VR2 is fed to the microcontroller which compares it with 2.16V. If the actual value is less the microcontroller increases its switching pulse rate to increase the output to 12V.On the other hand if the actual VR2 is greater than 2.16 the pulse rate is decreased to reduce the output to 12V.

There is also short circuit protection available. If a load gets short circuited voltage will become zero. The microcontroller will detect this via the feedback and switch off Q3 and thus eliminate the short circuit situation.[5][6][10-17]

C. Designed Three Phase SMPS Circuit in Proteus

The single Phase SMPS designed in Proteus was modified so that it could work as a Three Phase SMPS.

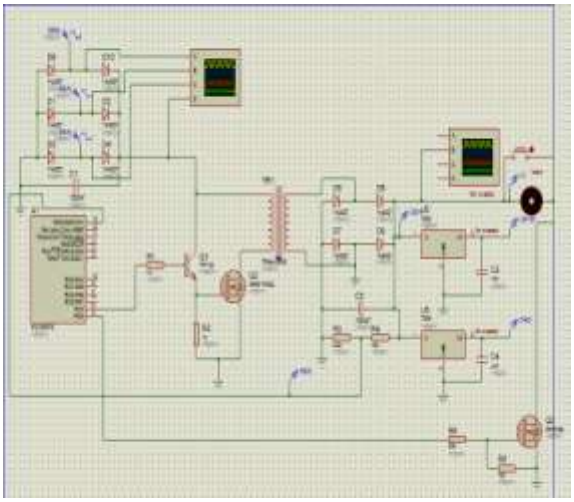


Fig 3: Designed Three Phase SMPS

The overall working principle of the Single Phase SMPS and Three Phase SMPS is same. The circuit design is also similar but there are some differences. The differences are required modifications needed for the change from a Single phase SMPS to Three Phase SMPS

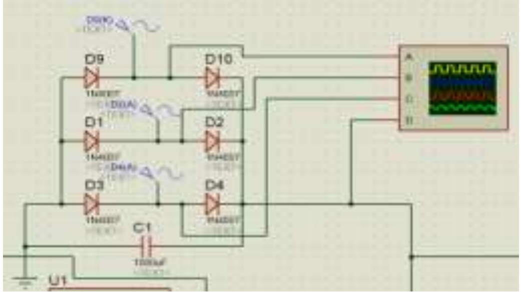


Fig 4: Diode Bridge in Three Phase SMPS

The Three Phase design uses six diodes in the diode bridge. Two diodes conduct at a time. Each diode conducts for 120^o in a full cycle. There are three line voltages present in the three phase supply. The pair of diodes across which the highest line voltage is present at any instant in the forward direction conducts. The Capacitor C1 smooths the rectified voltage.

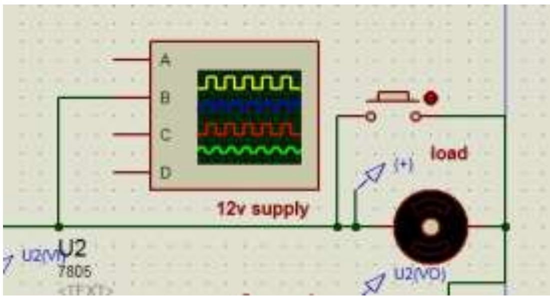


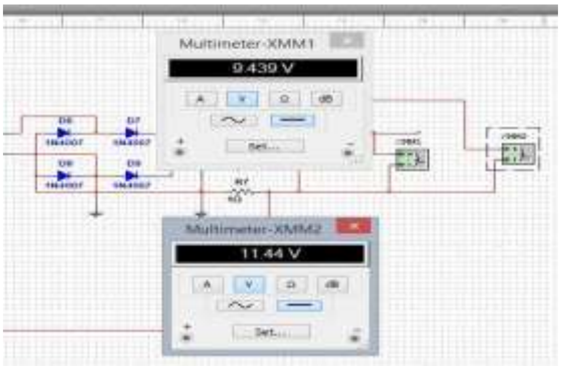
Fig 5: Short Circuit Protection Feature

A switch has been placed across the Dc motor connected to the unregulated 12V output terminal. The switch is closed to short circuit the output terminal. This activates the Short Circuit Feature and the performance of the SMPS under short circuit condition can be observed.

III. SIMULATION AND HARDWARE IMPLEMENTATION RESULTS

The two designed circuits are simulated and the results are shown.

A. *Simulation Result of MULTISIM Design*


Multimeter-XMM1

9.439 V

Multimeter-XMM2

11.44 V

Fig 6: Multi-meter reading of output voltage

In Figure 6 two multi-meters have been used. XMM2 shows the voltage of the output bus, which is 11.44V. XMM1 shows the output voltage of the regulator, which is 9.439V.

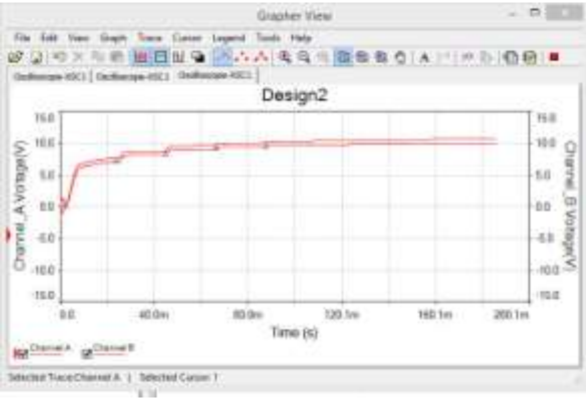


Fig 7: Graphical Representation of Output voltage

Figure 7 shows the two output voltages from the moment the simulation is started. At the beginning, both outputs are at zero voltage. The outputs gradually rise. After a time of about 120 ms the output voltage becomes saturated and stops increasing.

B. Simulation Result of Three Phase SMPS designed in Proteus

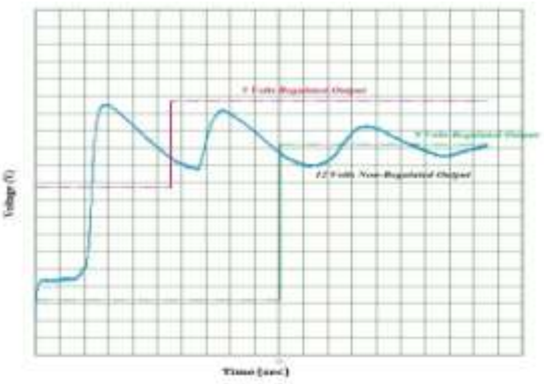


Fig 8: Regulated and Non-regulated Outputs of Three Phase SMPS

Three outputs voltages are shown.5V and 9V are regulated outputs, 12V is the non-regulated output. The pink and green curves are 5V and 9V outputs respectively, and the blue curve is the 12V output. There is much more ripple in the unregulated output. On the other hand, the regulated outputs are much smoother and has almost negligible ripple.

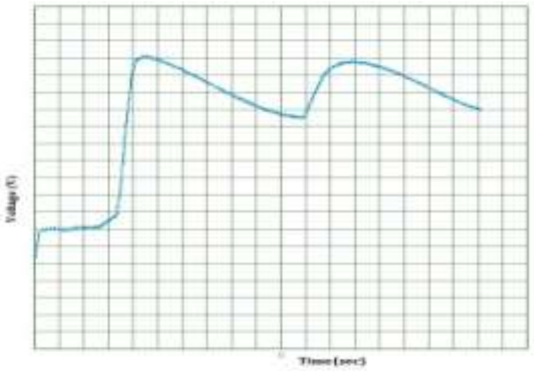


Fig 9: Output voltage curve for capacitive load

A capacitive load of 100µF is connected to the 12V unregulated output terminal. The voltage initially overshoots to 14V and then fluctuates between 11V and 14V.

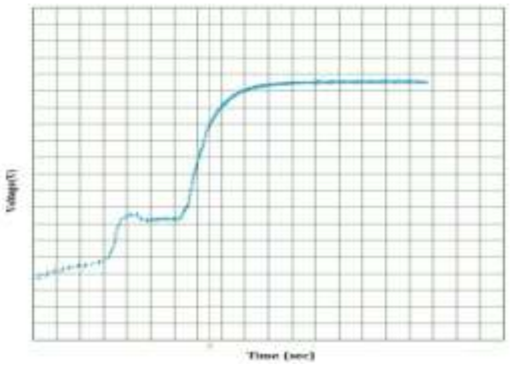


Fig 10: Output Voltage for inductive load

An inductive load of 60mH is connected to the 12V unregulated output terminal. The voltage rise to the 12V mark in case of inductive load was slower.

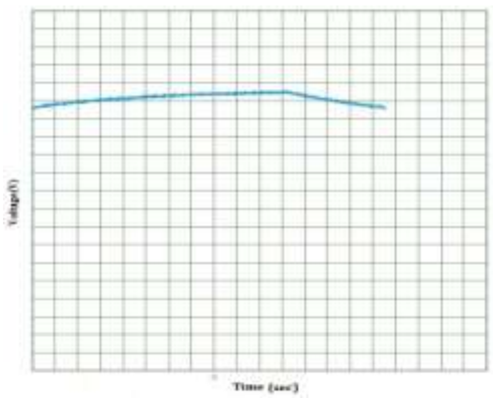


Fig 11: Output Voltage for Resistive Load

A resistive load of 100KΩ is connected to the 12V unregulated load terminal. The voltage initially overshoots to 14V and then fluctuated around 12V and 13V.The ripple for resistive is much lesser compared to inductive and capacitive load.

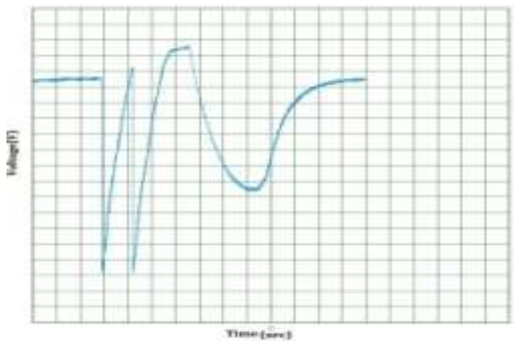


Fig 12: Output voltage when output terminal is instantly short circuited

The behavior of the output voltage when the load is short circuited is shown in above figure. When the short circuit occurs output voltage immediately dropped to zero, because voltage across short circuit is always zero. Short circuit feature activated and interrupts current flow in the short circuited load and voltage again builds up in the output terminal. If the short circuit still exists the voltage build up would not have been possible.

C. Hardware Implementation of Three Phase SMPS Designed in Proteus and Results

The Three Phase SMPS designed in Proteus has been implemented and practical results are taken.

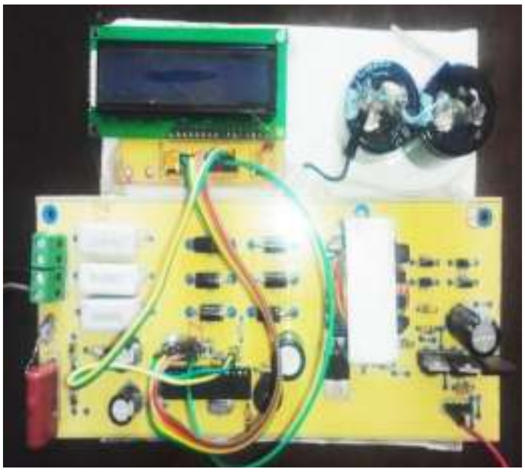


Fig 13: Hardware Implementation of Three Phase SMPS using PIC16F72 microcontroller

The above Figure shows the hardware implementation of the Three Phase SMPS using PIC16F72 microcontroller. The diagram also shows the different components that are used. There are some differences in the components that has been used but the overall working principle remains the same.

The three output voltages are observed using an oscilloscope.

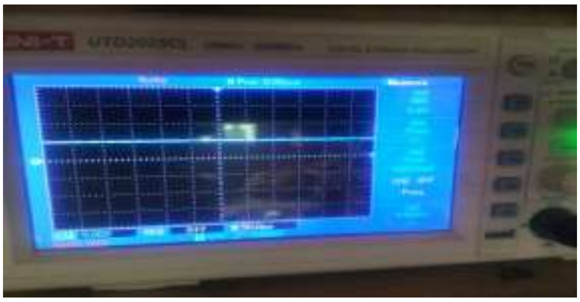


Fig 14: 5V regulated output observed in oscilloscope

The above diagram shows the 5V regulated output which is observed using an oscilloscope. There is very little ripple in the output voltage waveform.

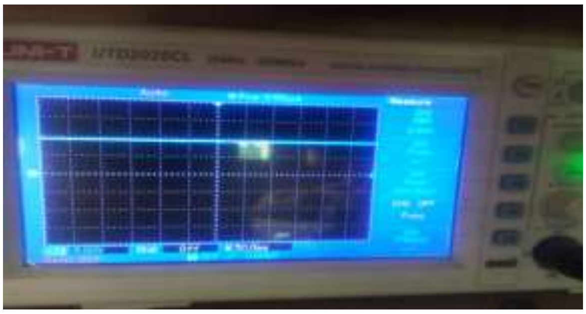


Fig 15: 9V regulated output observed in oscilloscope

Figure 15 shows the 9V regulated output waveform. There is very little fluctuation in the output voltage.

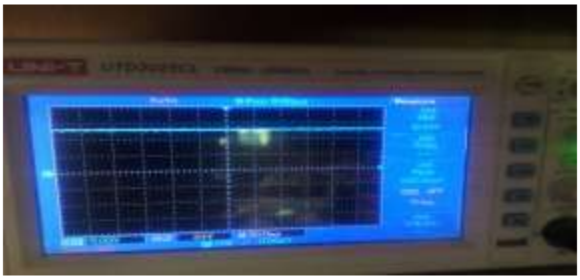


Fig 16: 12V unregulated output observed in oscilloscope without load

In the above figure the 12V unregulated output voltage without load is shown using an oscilloscope. The output has more ripple compared to the previous ones, this is mainly because it is unregulated.

Fig 17: 12V unregulated voltage with load

Figure 17 shows the 12V unregulated voltage with load that is observed in the oscilloscope is shown. There is much more ripple than Figure 18 which shows the unloaded voltage

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D. *Comparative Overview*

This section provides a comparative overview between the designed SMPS and conventional SMPS designs.

TABLE I

Comparison between Conventional and Designed Single Phase SMPS

Criteria	Conventional Single Phase SMPS	Designed Single Phase SMPS in Multisim	Designed Single Phase SMPS in Proteus
Output Voltage	Unregulated 12V and regulated 5V	Unregulated 12V and regulated 9V	Unregulated 12V,regulated 5V and 9V
Output Current	1A	3A	1A
Switching Method	VIPer22A primary switcher is used	555 timer IC is used	PIC16F676 microcontroller is used

Feedback system	12V unregulated voltage is feedback by using opto-coupler to adjust switching pulse	No feedback system	The 12V unregulated output is feedback by using a voltage divider network
Output Voltage Control	Unregulated 12V is fed to a 5V regulator	Unregulated 12V is fed to a 9V regulator	Unregulated 12V is fed to a 9V and 5V regulator
Short Circuit Protection	There is no such protection	Short circuit protection is present	Short circuit protection is given

TABLE II

Comparison between Conventional and Designed Three Phase SMPS

Criteria	Commercial Three Phase SMPS	Designed Three Phase SMPS
Input Voltage Range	200 to 400 Vac	180 to 420 Vac
Output Voltage	5V and 3.3V	Unregulated 12V,Regulated 5V and 9V
Output Current	10mA for 5V, 100mA for 3.3V	1A for each of the regulated outputs
Switching Method	VIPer12AS is used for switching	PIC16F676 microcontroller is used to generate switching pulse
Output Voltage Control	5V output voltage is controlled by a feedback controlled network .The 5V output is fed to a regulator to produce 3.3V	12V unregulated output is controlled by a voltage divider feedback network. The unregulated output is fed to regulators to produce 5V and 9V
Short Circuit Protection	None	Short circuit protection feature is present to provide protection in case load is short circuited

IV. DISCUSSION

The output voltage of the SMPS without regulator should be 12V and the output after the voltage regulator should be 9V.But the actual voltages are 11.44V and 9.493V as shown in Figure 3.The graphical representation shows a value of 11.632V and 10.223V.

For the Single Phase circuit that has designed in Proteus the output voltages are 5.00545V, 9.00305V and 12.2896V. These voltage values are much closer to the respective desired values when compared with the Proteus Simulation result. The voltage fluctuation is also very little. So the effect of the use of digital feedback control techniques using microcontroller is quite evident when the results of the two simulations are compared. The output voltages of the three phase SMPS always remain above the normal output voltage under no load condition. The regulated output voltages show better performance than the unregulated output voltage. Under no load condition the unregulated output always fluctuates between 11V and 12V after an initial overshoot to 14V.In case of inductive load the fluctuation in the unregulated output voltage is much greater. When the unregulated output terminal is connected to inductive and capacitive load the behaviour of the output voltage changed. The output voltage goes through transition periods before settling. When it settles it shows more ripples compared to the normal loaded condition .The short circuit feature always activates when the load terminal is short circuited. The transition from the Single Phase SMPS to the Three Phase SMPS is simple. A modification in the input diode bridge is all that is required for the transition. So the design is versatile and simple as well. The single phase is well suited for low power applications but for higher power applications the three phase design would be more suitable. The SMPS using microcontroller has better dynamic characteristics and shows better performance.

A hardware implementation of the three phase design has been done. There is some differences in the components used. A Zener Diode (2.3V) has been used to maintain a steady voltage drop across the network.20MHz crystal has been used to provide clock pulse for microcontroller operation. In practical application, two 220uF 400V electrolytic capacitors have been used to keep the output voltage steady. Power MOSFET IRF740 has been used for switching. An LCD has been used to display the output data. The different component that has been used in the hardware implementation is to make the circuit more stable. There is no difference in the overall working principle of the two designs. Changes are simply made to compensate for the differences in the theoretical and practical working behavior of the three phase SMPS.

There is little difference in the outputs between the three phase software and practical design. For the practical design the 5V and 9V regulated outputs showed smooth dc outputs with almost negligible ripple. The 12V unregulated output has a bit more ripple than the regulated outputs, but when the 12V unregulated output in the presence of a load is measured considerable amount of ripple is present in the output. The increased ripple is because of the presence of the load.

V. CONCLUSION

A SMPS power supply which converters input ac supply into a regulated dc voltage output has been designed. Three designs have been constructed so far. An analogue design has been chalked in Multisim and two designs using PWM switching and feedback control by microcontroller has been made in Proteus. One SMPS has been designed for Single Phase and another has been designed for three phase operation.

The proposed design shows better software simulation performance than the conventional design. Output voltage is stable and has very good regulation. When the hardware implementation of the designed three phase SMPS is done some adjustments has to be made in the components used for stable performance. Overall, practical results of the design are satisfactory. The designed three phase SMPS is suitable for high voltage applications up to 420V.

REFERENCES

[1] SMPS (Switched Mode Power Supply), [online], Available: http://www.engineersgarage.com/articles/smps-switched-mode-power-supply

[2] Abdul Majid ," Analysis and Implementation of Switch Mode Power Supplies in MHz Frequency Region", Electronics Design Division, Mid Sweden University,2012

[3] Sarika Tripathi," Design and Implementation of Switched Mode Power Supply using PWM", Department of Electronics and Communication Engineering, National Institute of Technology Rourkela, May 2010

[4] S M Ahsanuzzaman ," Interactive Flexible Switch Mode Power Supplies For Reducing Volume And Improving Efficiency",Graduate Department of Electrical and Computer Engineering, University of Toronto,2012

[5] PowerSemiconductorApplications,PhilipsSemiconductors[Online]Available:http://www.nxp.com/documents/application_note/APPCHP2.pdf

[6] Module 3 DC to DC converters. [Online] Available: http://www.nptel.ac.in/courses/.../PDF/L23(DP)(PE)%20((EE)NPTEL).pdf

[7] NE555 Datasheet, STMicroelectronics

[8] LM393 Datasheet, STMicroelectronics

[9] LM7809 Datasheet, FAIRCHILD Semiconductor

[10] PIC16F630/676 Data Sheet, MICROCHIP

[11] MICROCHIP[Online]Available:http://www.microchip.com/wwwproducts/Dvices.aspx?product=PIC16F676

[12] Power MOSFET Avalanche Design Guidelines,VISHAYSILICONIX [Online], Available:http:// www.vishay.com/docs/90160/an1005.pdf