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Simplified Strategy to Control Variable DC Power Supply Using Pre-regulator

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Abstract

Efficient power supply is necessary in all the machines to make them work properly with minimal losses. Power supply is used to supply power to electro-chemical machine which is use for machining of metal plate (work piece) with maximum accuracy. Therefore this is application based power supply. This work mainly concentrates on reducing the power losses and get variable value of output voltage and current. Simple control strategy is using to reduce loss and improve the quality of power supply. Control schemes with less complexity and computation has been proposed and developed for enhancing power supply quality and to get variable output quantity value. In this technique rectified voltage is obtained in accordance with the output voltage i.e. output voltage is given to the input side as a feedback and according to the output voltage, input voltage will be adjusted. The proposed power supply is simulated and implemented in hardware. Simulation is done for different reference values and different output values. The hardware is implemented for specific application which has certain range of output voltage and current. Human machine interface is used in hardware to control the system, to get drilling details such as how much deep drilling is required. In this arrangement, auto controlling is done to protect the system if any fault comes or any quantity exceeds its limit.

Keywords: DC power supply; SMPS, pre regulator; PLC; HMI; Electro-chemical machining.

INTRODUCTION

Nowadays most of the systems are very delicate which demands very efficient and accurate power supply for proper functioning [1]. Power supply is basically electronic device which converts one form of energy into another. Its main function is to transmit energy from supply to load connected to it according to the requirement of load [4,5]. Power supply can get energy from any of the source like batteries, fuel cells, renewable energy etc. [6]. Supplies are of many types like switched mode power supply, regulated power supply, Programmable power supply etc. Appropriate power supply should be selected as per application requirement. Many aspects are there which decides which type of power supply should use in particular application like temperature range, voltage and current range require by load, input voltage type i.e. AC or DC and efficiency of the system.

With each and every types of supply there is advantages and limitation which can be overcome by another type of supply or other type of topologies. Initially mostly used power supply was linear power supply which was used widely in industries and for domestic purposes also. It is used when fluctuating supply comes and constant power required by system. It has advantage that it will not produce ripple or noise in the circuit and hence used where noise and ripple is main constraint to take care of[7,8]. Overall performance of this supply is good But problem with this is power losses are very high and efficiency is very low. It will produce very high losses so to reduce these losses new topology came i.e. switched mode power supply [9]. In this type of power supply Rectification done for AC input and converted into DC voltage then switching (ON and OFF) is done at very high frequency [10]. After that transformer have to used for further transfer the energy then rectified into DC output [11]. Capacitors used in this are very small and light weighted as compare used in linear power supply. But this also have drawback. It will produce high ripple value will reduce accuracy in power supply. For this reason linear power supply is still in use in many applications. These two types of supplies are mostly used in real time applications.

There are many other types of supplies like programmable power supply which can use where remote control is needed, this is also having some specific application like x-rays generation, in fabrication and many more but it needs interfacing with system and microcontroller which make it little complex then other types. Many other supplies are available which has their own application areas, advantages and disadvantages. So which supply should use is depends on applications and parameter ranges what it requires with consideration of input range, temperature range, output range and most important efficiency of the system[12].

The main objective is to obtain control over variable DC power supply to a certain range by using pre-regulator for operation of electrochemical machine which is used for machining the metal job with specific dimensions and depth with maximum accuracy and low power losses. By using pre regulator power losses will reduce and by using transformers, rectifiers and voltage regulators will get simple strategy for controlling output voltage and current for particular range. For this particular application voltage range 0-25V and current range 0-100A is required which need to control by developing circuit. In this we have designed a current limiter circuit which will protect the circuit if current exceed certain pre specified range of current. If current exceeds the limit, voltage circuit should get switch off and no voltage should generate in circuit that means supply should get switch off and system should get isolated from supply

In this paper next section is about electrochemical machining and third part is electrochemical machining process used in machining. Forth section tells about pre-regulator concept. Fifth section is basics of power supply and its types. Next section explains about block diagram and basic functionality. Simulation results are explained in seventh section of paper. Implementation and hardware results are shown in next section. Last section is conclusion which is explained in ninth section of paper.

ELECTROCHEMICAL MACHINING

It is method in which electrochemical process used to remove metal i.e. reverse electroplating. This can be use to cut metal or to shape metal in specific dimension. It used for hard materials and for very accurate dimensions i.e. geometries can be machined. In this machining will be done without touching metal piece without any spark production in between metal and machine tool. Shown in Fig.1

This can be use for very high removal of Metal without any mechanical or thermal stress. In this process tool act as cathode and work piece as anode. Electrolyte is used between anode and cathode. So as electrons start movement it will start dissolve the metal of work piece. Electrochemical machining can use for many applications like to make multiple hole, drill jet engine turbine blades, die-sinking operation etc.

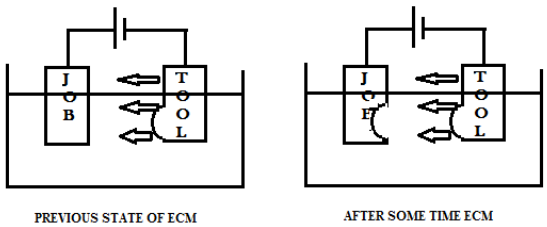

Figure 1: Principle of Electro Chemical Machining (ECM)

ELECTROCHEMICAL PROCESS

In machining, electrodes will go under electrolytic reaction between anode (workpiece) and cathode(tool).for example take workpiece of carbon(ferrous alloy) and salt solution (NaCl) as electrolyte. After getting react, electrolyte will get decompose as potential difference will apply across electrodes. Reaction shown in Fig.2 Equation shown below:-

$$NaCl \rightarrow Na^{+} + Cl^{-} \quad (1)$$

$$H_2O \rightarrow H^{+} + (OH)^{-} \quad (2)$$

As potential difference is applied then positive ions will move towards the tool and negative ions will towards the workpiece. Then electrons will combined with hydrogen ions then reaction will be:

$$2H^{+} + 2e^{-} \rightarrow H_2\uparrow \text{ at cathode}^{-} \quad (3)$$

At anode reaction will be:-

$$Fe \rightarrow Fe^{++} + 2e^{-} \quad (4)$$

Next reaction will

$$Na^{+} + OH^{-} \rightarrow NaOH^{-} \quad (5)$$

For reaction to be taken place potential difference should be between 2V to 30V. Other potential drop will be there like. The activation over potential, ohmic resistance of electrolyte, ohmic potential drop, the electrode potential, Concentration over potential.

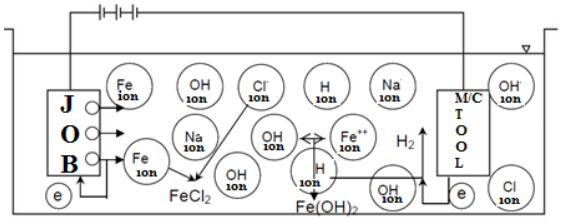

Figure 2: Representation of electrochemical reaction

Machining will take place without any contact so tool can be of any metal that means toughness not need according to work piece toughness. So tool can be of any cheap metal. There is no stress (thermal or mechanical) on tool so there is very less chances of any damage hence tool can use repeatedly. With all these advantages it has few disadvantages like there is chances of corrosion to tool, equipment and metal work piece is much because of acidic electrolyte. One major disadvantage is only electrically conductive materials can be machined and energy consumption is much.

PRE REGULATOR

This is the technique with which will get Rectified voltage in accordance with the output voltage. In project feedback path is connected to input so that output can feed to input side and then further process proceed according to the output value. As feedback is given to input error signal get generated and according to that it will control voltage and current generation and give desire output. Pre regulator is used to reduce power losses and to improve efficiency of the system. For pre-regulation zener is used. This is main part for this topology.

POWER SUPPLIES

Power supply is necessary part of any electrical system. Nowadays most of the systems are very delicate which demands very efficient and accurate power supply for proper functioning. Power supply is basically electronic device which converts one form of energy into another. Its main function is to transmit energy from supply to load connected to it according to the requirement of load. Power supply can get energy from any of the source like batteries, fuel cells etc. Supplies are of many types like switched mode power supply, regulated power supply, Programmable power supply etc. We have to select appropriate power supply as per application requirement. Many aspects are there which decides which type of power supply should use in particular application like temperature range, voltage and current range require by load, input voltage type i.e. AC or DC and efficiency of the system. Power supplies generate controllable magnitude of DC voltage and current from available input voltage. For making DC voltage IC needed which makes electronic circuit. Power supply must withstand with sudden peaks in voltage and current values. Nowadays power supplies are getting level og very high efficiency which never seen before. Many power supplies are present but these days SMPS is becoming dominating in communication systems, digital computing and networking. In earlier days linear power supply were using , in many places now also use of linear power supply is used but it will give much energy loss and power loss so it has to improve to reduce the losses and make supply efficient. After that industries started switching type power supply which will not give many losses as linear power supply but ripple in the output got increases. But still where ripple is not important factor switching mode power supply is using by industries which will give high efficiency. So according to application we can choose any type of power supply.

A. LINEAR POWER SUPPLY

Overall performance of this supply is good that why it used widely. It is used where noise is main factor to deal with and need good regulation. This supply may not that much efficient as SMPS but for many applications this is most suitable supply for example in audio amplifiers and in electronics equipments etc. Fig.3 and Fig.4 shows the components and the details of the power supply.

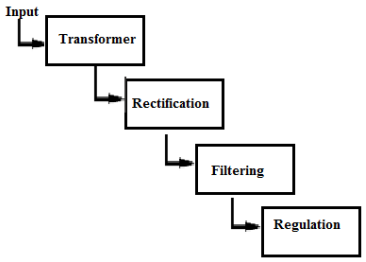

Figure 3: Components of linear power supply

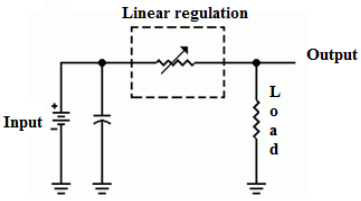

Figure 4: Simplified linear power supply

B. SWITCH MODE POWER SUPPLY

Nowadays mostly used power supply in modern systems is switched mode power supply which has ability to give desire output values efficiently when load is variable. It has many components i.e. active, passive and magnetic components. In this supply linear components (resistors, thyristors) are used very less comparatively and use components which are ideally lossless as switch mode transistors, capacitors etc.

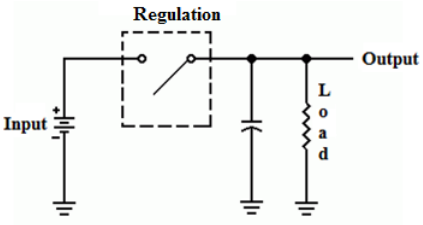

Figure 5: Switched mode power supply

Like all power supply, this supply also use to convert unregulated AC or DC input to regulated and controlled DC output voltages. In this supply input is drawn from mains and then covert it into DC i.e. rectification take place then after that for filtration it will pass through capacitor which filter the rectified output and gives smoother output. Further output value goes under converter i.e. DC to DC converter with high frequency. Frequency of DC to DC converter choose normally high to use of high frequency transformer for isolation and voltage scaling. Advantage of high frequency transformer is, size of the transformer is small and less weight compare to low

frequency transformers used for linear power supply circuit.

SMPS also called DC to DC switching converter because it convert unregulated DC input to regulated DC output voltage using switching(on and off state). Switching will take place at very high frequency. During ON state voltage drop across emitter and collector terminal is negligible and it will operate in saturation mode. On other hand when switch is off it will conduct in cut-off region and current across collector and emitter terminal will is negligible. In case of the linear power supply switch always remains in active region. SMPS use switching devices such as MOSFETs (Metal Oxide Semiconductor Field Effect Transistors) and IGBTs (Insulated Gate Bipolar Transistors). These devices has advantage of high frequency switching ability. These can withstand with high spikes and sudden change in load and power losses are very low in both on and off state. So because off all these advantages supply will be more efficient, light weighted and gives good response i.e. response time is less.

BLOCK DIAGRAM

Block diagram of whole system in which all major blocks are shown in Fig. 6. This chapter explains about all parts and concepts of system and discussed properties, construction and function of each part. This system can be divided into two major part, one is electrical part i.e. power supply and other is mechanical part i.e. machine to which we have provided power supply and used for machining. Electrical part constitutes power supply and controlling parts which used to control input or output voltages of system, current in the system and controlling of it.

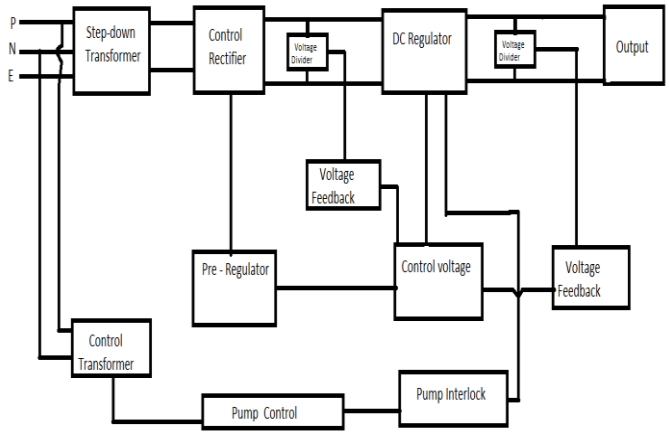

Figure 6: Block diagram of the proposed regulator

From block diagram we can see blocks which are parts of electrical system are listed below

- Step down transformer
- Control rectifier
- DC regulator
- Pre regulator
- Voltage feedback

Mechanical part constitutes all parts of machine which used for drilling or machining of metal work piece. Blocks and parts listed below:-

- Machine
- Pump interlock
- Pump control

SIMULATION

For simulation LTspice is used which is designed by linear technology. Linear Technology provides a variety of custom design simulation tools and device models to allow even novice designers to quickly and easily evaluate circuits using high performance switching regulators, amplifiers, data converters, filters and more.

A. SIMULATION CIRCUIT

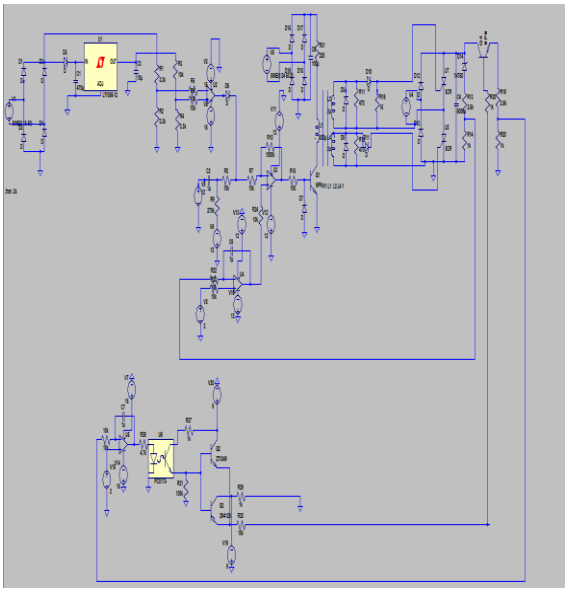

Figure 7: Schematic of power supply

B. SIMULATION RESULTS

Power supply schematic is developed using library in simulink software LTspice shown in a Fig.7

Mains supply is given to the transformer which will step down the value of voltage to 26V and then it gives supply to rectifier. Rectifier is connected with IC LM1458. Input of LM1458 one is AC supply and other is rectified output (pin2 and pin 3) shown in Fig.8 . It will get compare and results in step output (pin1) shown in Fig.9. Again this step output will get compared with charged capacitor waveform using zero crossing phenomenons and after comparison of both signals it results step-ramp wave form shown in Fig.10. Shape of

waveform can be control by preset connected in series with capacitor. Now resultant waveform is compare with feedback value i.e. DC value (these two waveform compare in LM1458 only at pin5 and pin 6) and again it generates square waveform (at pin 7) shown in Fig.11 which controlled by feedback connected through output as input at pin 5 of LM1458 is result of comparison of feedback voltage value and reference value. Controlled square wave will go to pin 4 of 555 timers which work as input for 555 timers. As per input at pin 4 of 555 timer, it gives output (pin4) pulse shown in to the pulse transformer. Pulse given shown is to pulse transformer with results in generating pulses shown in Fig.11 which act as triggering pulse for thyristors of rectifier. This triggering pulse will make on thyristors and rectifies AC input given to it. Triggering pulse are controlled by feedback so system works in closed loop which control output as per requirement. Output of rectifier gives to drain terminal of MOSFET shown in Fig.12. So drain signal what getting for MOSFET is controlled by feedback. And gate pulse given by LM10. So final output will get shown in Fig.13 Input to LM1458 (comparison of sinusoidal and DC waveform)

All waveform about which explained above is shown which is result of system when simulation is performed in LTspice simulation software.

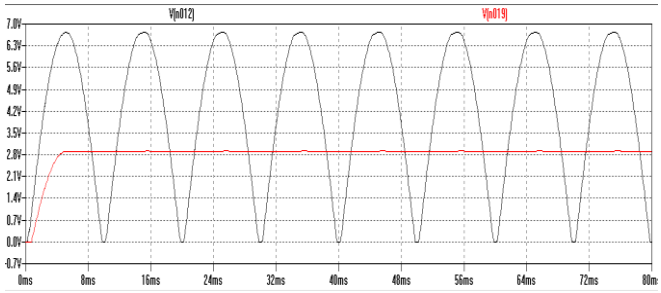

Figure 8: Input of LM1458

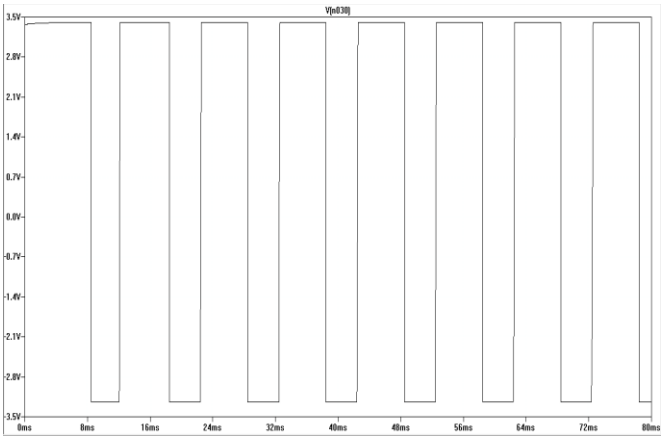

Figure 9: Output of LM1458

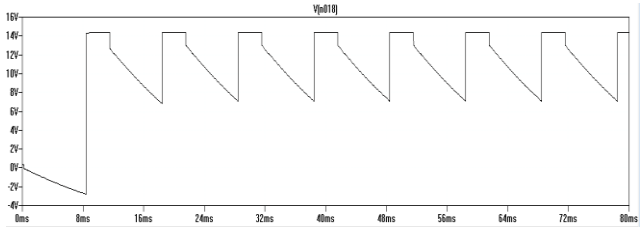

Figure 10: Step-ramp Waveform

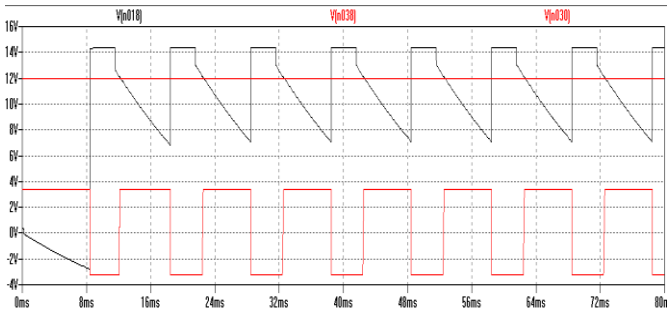

Figure 11: Input of pulse transformer

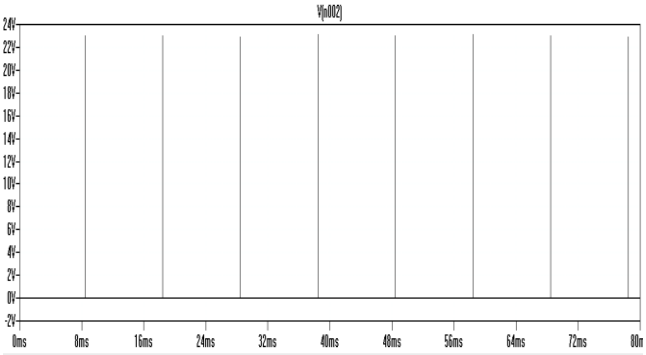

Figure 12: Output pulse of pulse transformer

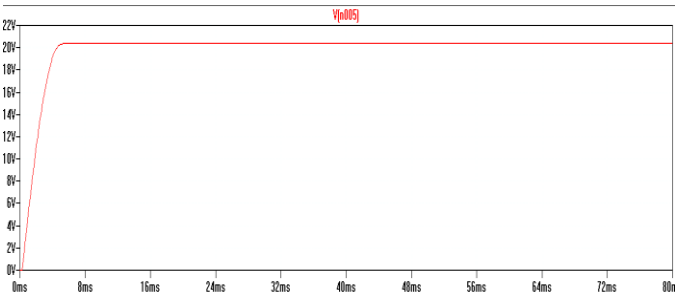

Figure 13: Output voltage waveform

From Fig.13, it is seen that output voltage on input side is 5V more than the output side which is concept of pre regulator and output waveform is smoother than input side output waveform. Hence DC supply of with minute accuracy and less power loss is obtained.

HARDWARE RESULTS

Figure 14: Experimental setup of the proposed scheme

Mains supply is given to the transformer which will step down the value of voltage to 26V and then it gives supply to rectifier. Rectifier is connected with IC LM1458. Input of LM1458 one is AC supply and other is rectified output(pin2 and pin 3) shown in Fig.14. It will get compare and results in step output (pin1) shown in Fig.15. Again this step output will get compared with charged capacitor waveform using zero crossing phenomenon and after comparison of both signals it results step-ramp wave form shown in Fig.16. Shape of waveform can be control by preset connected in series with capacitor. Now resultant waveform is compare with feedback value i.e. DC value (these two waveform compare in LM1458 only at pin5 and pin 6) and again it generates square waveform (at pin 7) shown in Fig.17 which controlled by feedback connected through output as input at pin 5 of LM1458 is result of comparison of feedback voltage value and reference value. Controlled square wave will go to pin 4 of 555 timer which work as input for 555 timer. As per input at pin 4 of 555 timer, it gives output (pin4) pulse shown in Fig.18 to the pulse transformer. Pulse given shown in Fig.19 is to pulse transformer with results in generating pulses which act as triggering pulse for thyristor of rectifier. This triggering pulse will make on thyristors and rectifies AC input given to it. Triggering pulse are controlled by feedback so system works in closed loop which control output as per requirement. Output of rectifier gives to drain terminal of mosfet. So drain signal what getting for mosfet is controlled by feedback. And gate pulse given by LM10. So final output will get shown in Fig. 20 and Fig.21

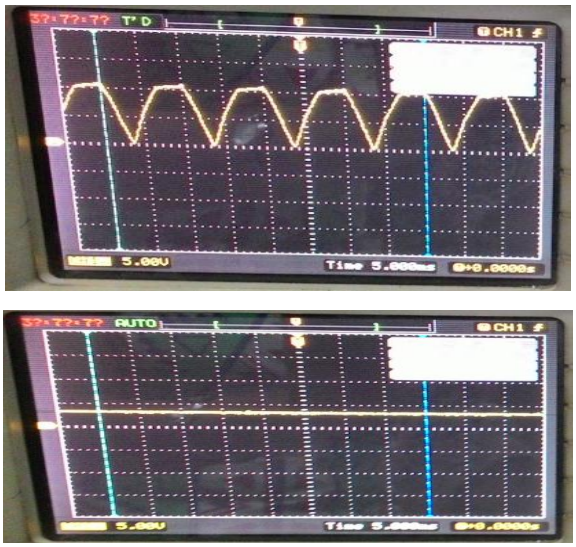

Figure 15: Input waveforms for LM1458 (comparision of two waveforms)

Figure 16: Output of LM1458

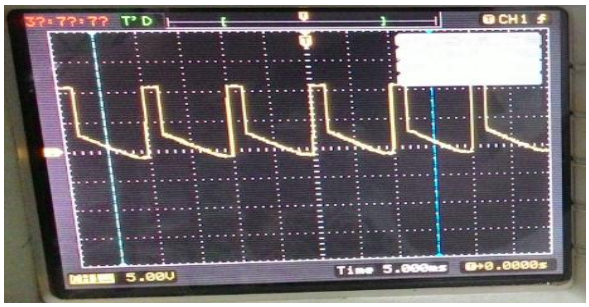

Figure 17: Generation of step-ramp wave for (after capacitor charging discharging)

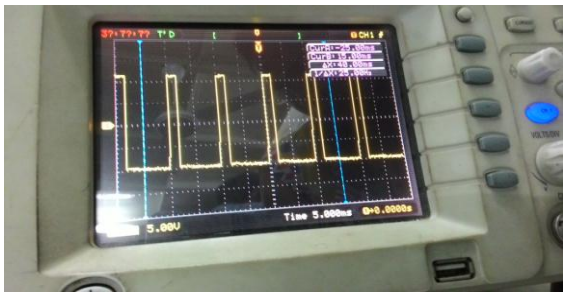

Figure 18: Input to the pulse transformer

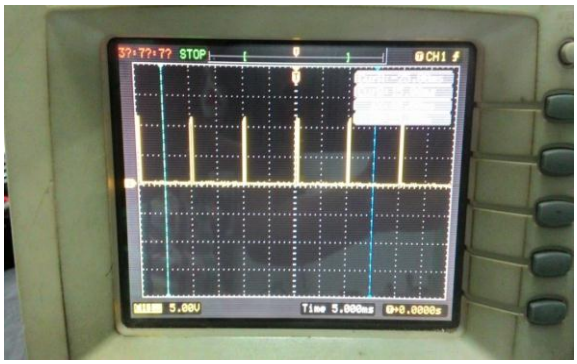

Figure 19: Output of the pulse transformer

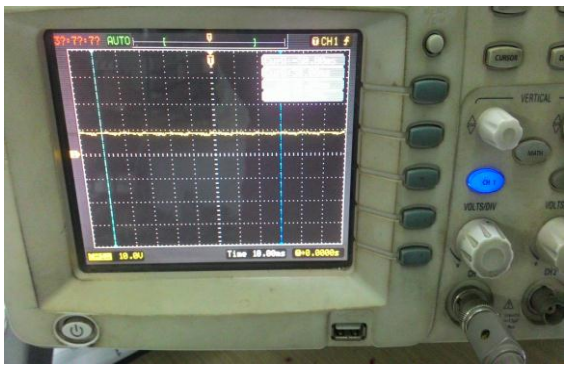

Figure 20: Output waveforms (Input side)

Figure 21: Output waveforms (Output side)

CONCLUSION

This paper was to develop control strategy for variable DC power supply using pre-regulator. In this paper pre-regulation used which results in low power losses with accuracy in output parameters i.e. voltage and current. The main purpose of the developing this strategy is to reduce power loss with accuracy in output parameters. In one topology there is problem of getting high ripple but less power loss and in other topology problem is to get high power loss but very low ripple and noise. So to overcome from all drawbacks and to get efficient power supply with fewer ripples we have developed this topology of controlling variable DC power supply using pre-regulator. So in new topology two feedback paths is connected. Current value variation depends on load and distance between metal plate and drilling terminal which also controlled by developed strategy. Current limiting circuit is also developed so that if any problem comes or current exceed its limit then power supply will get off suddenly which protect system to get harm and does not allow excess current through circuit. Using HMI we can feed voltage and current values and time for how much duration needed power supply for system which controlled by PLC. It also shows how much distance covered by drilling machine needle. All controlling is automatic and safe. This strategy is not only simple but also it is reliable and easy to use in real time applications. Easy to use because all controlling can be done through HMI and all values can be observed easily as we discussed before.

In this design suitable components is used and tested for required performance as per application. Performance was verified on developed circuit with all selected components for different value of output voltage and current within a specified range demanded for particular application. Design developed on simulation using LTspice was successfully completed and tested with desire output. Same design was implemented on hardware and tested successfully with desire output values. Hence design and implementation of control strategy of variable DC power supply was successfully completed. We can design supply for more real time application and other topologies which are present in market.

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