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Design and Implementation of New Converter Topology for Electrosurgical Units

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Abstract: *Electrosurgery is the process in which high frequency current is applied to human body part for the purpose of surgical operations like cutting, dessication, fulguration etc. While performing electrosurgery, output power from the electrosurgical generator must be kept constant to avoid charring of tissue. This project aims at designing and implementing a converter and controller topology for regulating power by keeping its value within the required power characteristics. The model is designed and initially implemented in MATLAB/SIMULINK by using blocks from Sim Power Systems tool box, then a hardware prototype is built at a frequency of 34kHz.*

Keywords: *Electrosurgery, High frequency inverter,Elecrosurgical unit(ESU), Constant Current mode(CCM), Constant Voltage mode(CVM), Constant power mode(CPM).*

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I. Introduction

Electrosurgery is the process in which high frequency current is applied to human body parts to perform surgical operations like cutting, fulguration, dessication etc. Elecetrosurgical generators are the devices which draw electrical energy from main supply and convert to HF current which is further delivered to tissue through electrode. Ideally, Elecrosurgical generator's (ESG) output is a constant power source. But practically, constant power source limited to a maximum voltage and maximum current as shown in Fig 1.2

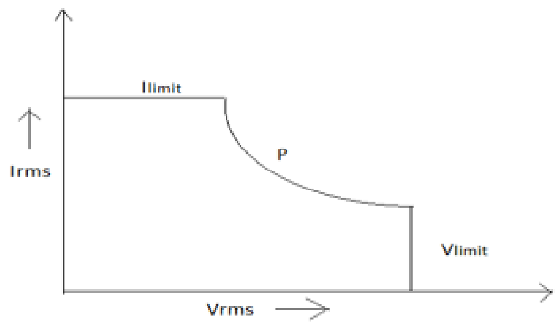

Fig 1 Power characteristics

When a particular amount of power is given to a high impedance tissue, high voltages will be developed resulting in high arching between electrode and tissue. This results in carbonization of tissue. So control of maximum output voltage produced by ESG is needed to achieve desired clinical effects. Also, output power of ESG depend on tissue impedance and ESG circuit topology. Impedance of each tissue will be different from another and also with the increase in depth of cutting impedance also varies. Due to change in tissue impedance and slow response of circuit in ESG to change in impedance causes output power to fluctuate during arching. This results in charring of tissue. Inorder to avoid charring, it is important to develop a new system to regulate output power and peak voltage.

The objective of this project is to develop a new topology which is capable of regulating the output power to avoid undesirable clinical effects. This required innovations in control circuit. The prime target is to measure the skin resistances, instead of randomly selecting the load from the maximum and minimum limits, to improve the accuracy of the project. Another aim is to perform surgery to ensure that charring is avoided.

Controller part is the most important part of the circuit. The system with a proper control strategy is proposed to control the power delivered to the area where surgery is performed. The prototype system is designed and tested at a frequency of 34kHz with primary section consisting of cuck converter and secondary section consisting of High frequency inverter and output transformer.

II. Related Works

Recently various medical devices has been studied and developed with progress of the medical field. Many research and development of electrosurgical device that substitute for a scalpel incision are carried out by the organization every day. All the devices should ensure to avoid power fluctuation for safety as well as clean surgery.

D.J.BeckerandM.S.Klicek [1] designed a system with constant power control circuit and method provide the capability to control the output power of the electrosurgical generator Without having to actually monitor the amplitude of both the output current and output voltage. This allows for a simple constant power control circuit and method Which operate to control the power output Without having to calculate the actual power output of the electro surgical generator. But there was no guaruntee that maximum voltage and current would stay within limits.

R.Thompson [2] suggested a method with voltage and frequency regulated high voltage current mode power supply. They mentioned an effective implementation of a switched current mode power supply as a high voltage power supply in a new and improved electrosurgical generator. Among other things, the switched current mode power supply effectively coordinates the DC output voltage supplied to an RF amplifier and output section to achieve more efficient and effective power control and regulation according to a selected mode of operation and the output power requirements of the electrosurgical generator. But power regulation was not possible with this method.

M. Gulko and S. Ben-Yaakov [3] suggested a ESG which rely on resonant inverter output stage. Resonant inverters are known to produce an elliptical equilibrium output characteristic, as shown in Fig 2.

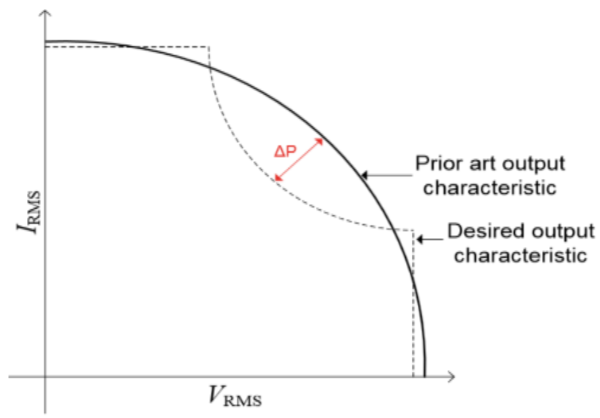

Fig 2 Output characteristics of resonant inverter

The resonant inverter's elliptical output characteristic is a reasonable approximation of the ideal ESG output characteristic, as it tends to exhibit a current source like output at low impedances, and a voltage source like output at high impedances. But at the midranges impedences, ellipse deviate from desired output. But most of the tissue impedences are encountered in this region. This is a major drawback which can be solved using a closed loop control as shown in Fig 3

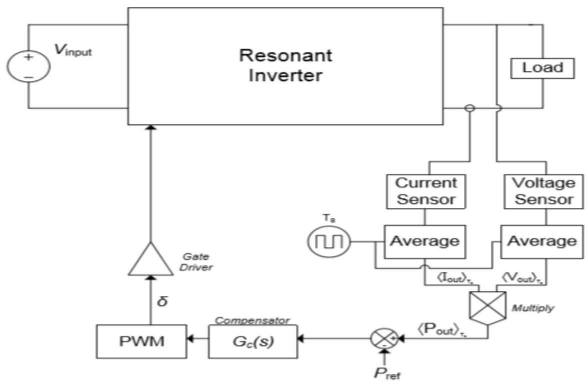

Fig 3 Closed loop control of resonant inverter [3]

Here the average power obtained over entire cycle will be same as that of desired one. But the average power in a single cycle will be greater than that of required one. This will cause undesirable effects like dark patches, called charring, on tissue. Also, excessive power delivery leads to increased thermal spread. So it is important to develop a system using which power fluctuation is avoided.

III. New Egg Topology

The new topology is shown in Fig 4 [4].

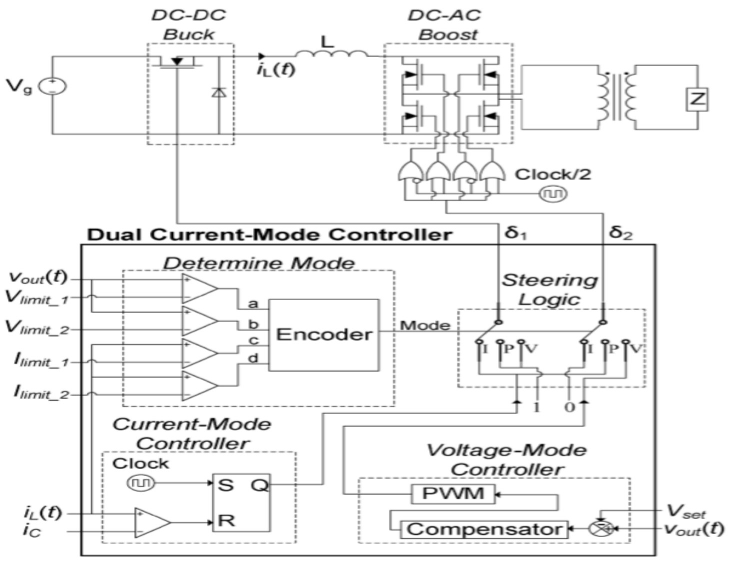

Fig 4 Circuit diagram of proposed converter

The DC voltage can be generated from a ac-dc converter and there must be continuous and constant dc supply. A battery bank can also be used as a dc source. It is given to a buck converter for obtaining fixed conversion ratio. Both inductor and capacitor will function as energy storage unit. Output of buck converter is given to HF inverter and to load through isolation transformer. HF transformer operates in frequency above 60kHz. It provides constant output voltage with high amplitude and power regulation can also be achieved using proper control method. A dual mode controller is used to provide duty ratio to buck and HF inverter where $d_1$is the duty ratio of buck converter and d_2 is the duty ratio of HF inverter. The controller section consist of a voltage mode controller, current mode controller, determine mode and a steering logic. In current mode controller, inductor current of buck converter and reference current are sensed. Hence it is called current programed mode. The error Is fed to R pin of SR flipflop. Clock signal is also given to SR flipflop. Whenever S=1 and R=0, output Q will be in set state. And when R=1 and S=0, output Q will be in reset state. In voltage mode controller, V_{ref} and V_{out} are compared and given to PI compensator to minimize error between them. Output is converter to PWM pulse by comparing with HF carrier. In determine mode, Vout, $I_L$is measured and by comparison to the programmed set points, it directs output to select the mode. There are three modes of operation namely current limiting mode, voltage limiting mode, power mode. Current controller and voltage controller areconnected to steering logic. Depending upon output of encoder, any of the above mentioned mode will be selected. In constant current mode/ current limiting mode is activated [5] whenever i_L is greater than I_{limi1}, I_{limit2} but within V_{limit1}. During this time inverter will be given a fixed duty ratio and d1 will be varied. Constant power region comprises of P_1 and P_2. Whenever i_L is greater than I_{limit2} and output voltage greater than V_{limit2} , constant power mode will get activated. During this time, duty ratio d1 will be kept constant and d2 will be varies. Next is constant voltage mode. When i_L is less than $I_{limi1}$and output voltage greater than V_{limit2} this mode will be activated. During this time, d_1 and d_2 are kept constant.

IV. Simulation Results

Simulink model of both open loop and closed loop was performed in matlab Simulink 2016a. The model implemented in MATLAB/SIMULINK used blocks from Sim Power Systems tool box. Different sections of the whole ESG system are first simulated separately, then combine all of them to get the required result. The output voltage from buck converter is fed to the inverter stage which further feeds load. The specification details are given in Table 1.

Table 1 Parameter specification

SL.NO.	PARAMETER	SPECIFICATION
1	Input voltage	80V
2	Output voltage	40V
3	Output power	60W
4	Switching frequency	50Hz
5	L_{Buck}	1.3mH
6	C_{Buck}	0.187uF
7	Duty ratio	0.45
8	Load resistance	302Ω, 361Ω, 403Ω, 528Ω, 583Ω, 615 Ω
9	Inverter frequency	472kHz
10	V_{limit_1}	134V
10	V_{limit_2}	171V
10	V_{limit_3}	195V
10	I_{limit_1}	0.311A
10	I_{limit_2}	0.35A
10	I_{limit_3}	0.445V

In constant current mode, when R1 = 306 ohm , Output voltage = 134V, Output current= 0.445A and RMS value of output power = 60W. When R2 = 361 ohm, Output voltage = 125V and output power= 55W and output current is maintained to 0.445A as in Fig 6.

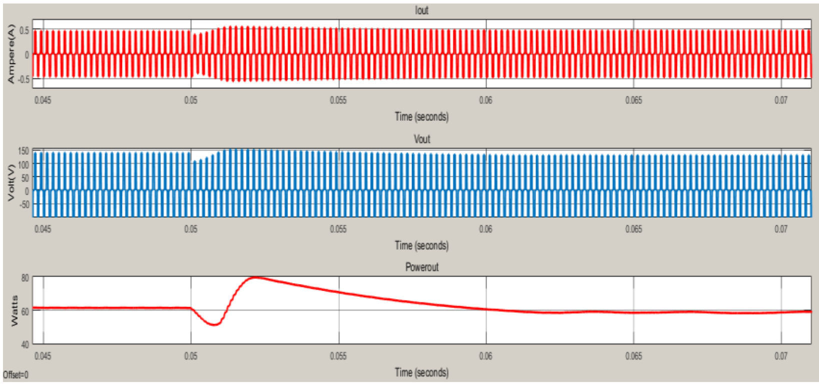

Fig 6 Output in constant current mode

In constant power mode, when R3 = 403 ohm, Output voltage = 166.6V, Output current= 0.36A and RMS value of output power = 60W. When R4 = 528ohm, Output voltage = 187.5V, output current = 0.32A and RMS value of power is maintained to 60W as in Fig 7.

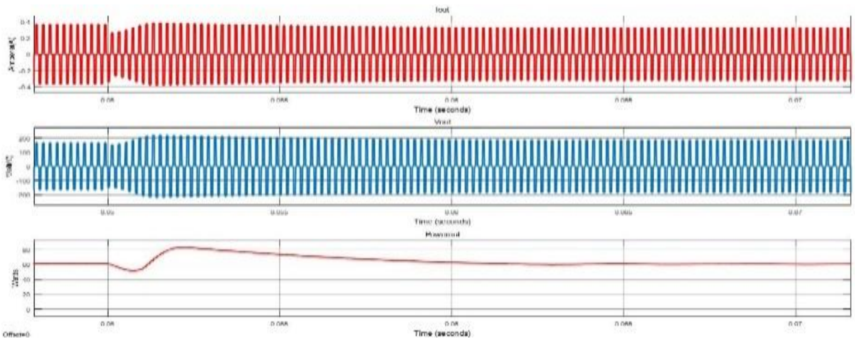

Fig 7 Constant power mode

In constant voltage mode, when R5 = 583 ohm, Output voltage = 193V, Output current= 0.311A and RMS value of output power = 60W. When R6 = 615ohm, Output voltage = 193V and RMS value of power= 54.04W and output current is 0.28A as in Fig 8.

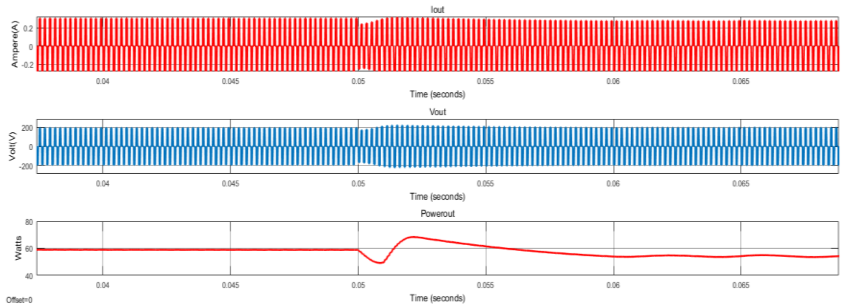

Fig 8 Constant voltage mode

V. Skin Resistance Measurement

Skin resistance measurement is done with conductive fabric which is also called as condutive textile. It is made with metal stands woven into the construction of textile. Hence it can conduct electricity.They are primarily made up of nonconductive substrate like cotton, polyster, nylon etc. and later coated with electrically conductive materials like copper gold or silver. Hence the are used as electrodes.Experimental setup consists of conductive fabric as electrodes, input voltage source of 5V, Arduino board, and arduino software. Inorder to conduct the experiment, conductive fabric was wound between two sections of human arm. First Input voltage of 5V is provided to one of the electrode and output is taken from other electrode. Here human skin will be a part of the circuit and provide resistance.The output voltage obtained depends on this resistance and can be directly mapped into equivalent resistance value with the help of arduino software. The apparatus for skin resistance measurement is as shown in Fig 9

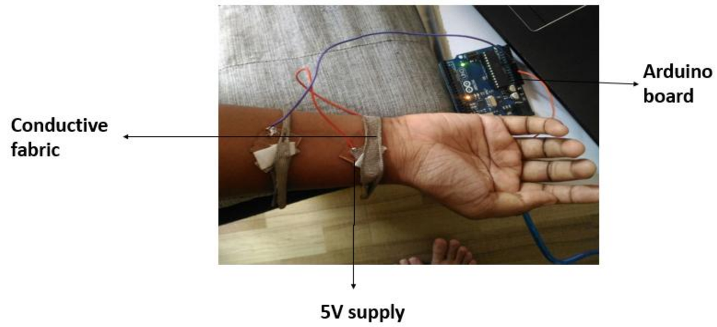

Fig 9 Experimental setup of skin resistance measurement

Skin resistances of six people of age group within 20-25 are measured for various instances of time as shown in Table 2. All the values are in ohm.

Table 2 Measured skin resistances at various instances.

NAME	After 5s	After 30s	After 1m	After 1.20m	After 1.45m	After 2m
Aswathi S	996	900	806	650	592	520
Nimitha Gopinath	923	891	802	711	670	590
Akhila Jose	980	915	823	711	691	620
Karthik V S	899	854	756	646	511	499
Emmanual H	892	822	787	622	567	501
Vijay Purushothaman	903	820	776	623	599	511
Aswathy N	1023	987	820	716	587	456
Aishwarya Rajan	1001	845	766	623	512	489

From the above table we can infer that with the increase of time resistance is getting reduced. This is due to the fact that as time elapses, skin condition is changing from dry state to wed state. Summer season makes the skin wet within a short span of time. Hence inorder to estimate the output load average of all the values are taken and shown in Table 3.

Table 3 Estimated skin resistances

SL.NO.	NAMES	SKIN RESISTANCES
1	Aswathi S	770
2	Nimitha Gopinath	801
3	Akhila Jose	673
4	Karthik V S	302
5	Emmanual H	361
7	Vijay Purushothaman	470
8	Aswathy N	940
9	Aishwarya Rajan	560

VI. Hardware Implementation

The control algorithm of the system is developed using the controller ATmega328. Hardware implementation consists of implementing buck stage, inverter stage and controller stage. The schematic diagram is shown in Fig 7 and over all implementation diagram is shown in Fig 8. In buck circuit, only one switch is used. So the problem of shorting does not arises. Hence only low side of driver IC is used and boot strap capacitor is avoided. Main components used in inverter stage are four IRFP460 power MOSFET's and two FAN7382N driver ICs. In driver IC both low side and high sides are used.

Hardware implementation consists of implementing buck stage, inverter stage and controller stage. The schematic diagramis shown in Fig 10 and over all implementation diagram is shown in Fig 11. In buck circuit, only one switch is used. So the problem of shorting does not arises. Hence only low side of driver IC is used and boot strap capacitor is avoided. Main components used in inverter stage are four IRFP460 power MOSFET's and two FAN7382N driver ICs. As IRFP460 can operate at a frequency upto500kHz, it is suitable for inverter circuit. In driver IC both low side and high sides are used. A boot strap capacitor is connected between two switches in same arm. This isolates one of them. Hence shorting is avoided. High side work only if low side is connected.'

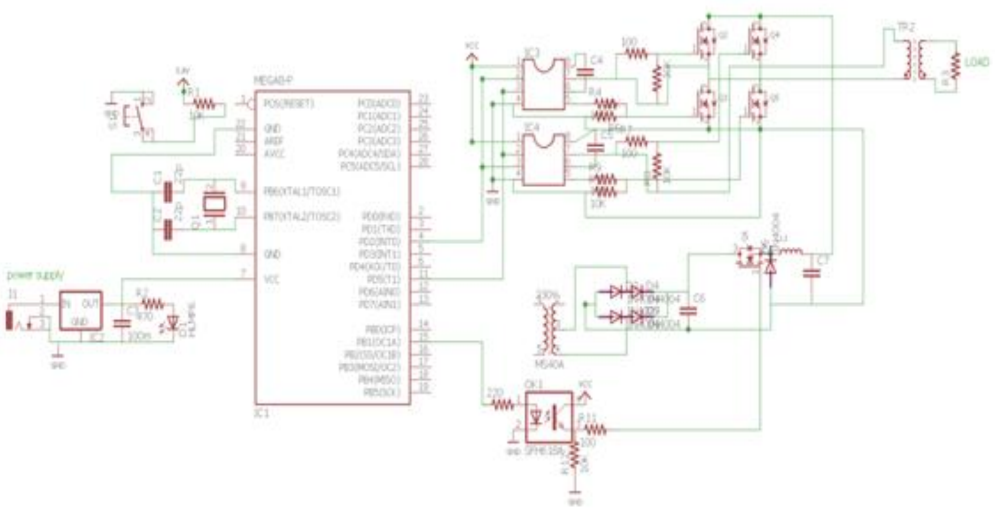

Fig 10 Schematic diagram

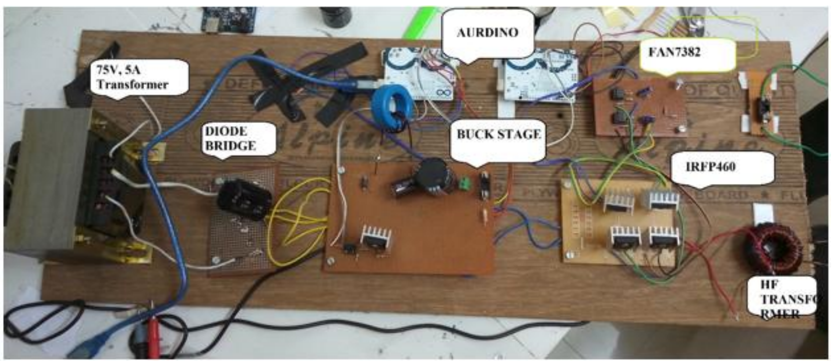

Fig 11 Hardware implementation diagram

In buck section, driver IC provide necessary Vgs to Power MOSFET. PWM pulsed are provided to switch and with the variation of pulse width output voltage can be varied. Input voltage is given as 80V and output is obtained as 40V. Inverter section operates at a frequency of 34kHz. Output voltage waveform obtained is as shown in Fig 7.11.

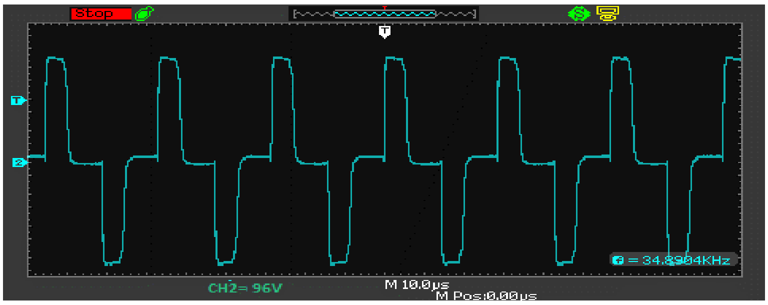

Fig 28 Output across load for R1= 470ohm

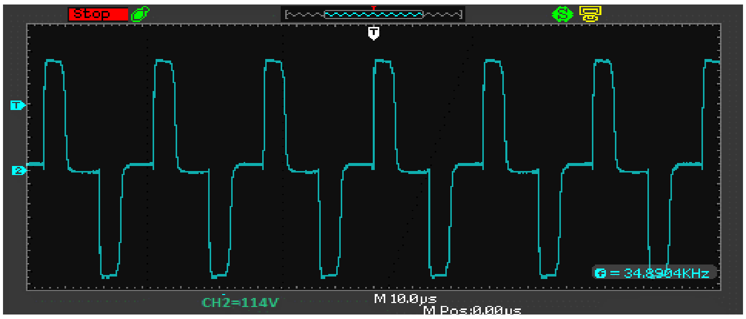

Fig 28 Output across load for R2= 560ohm

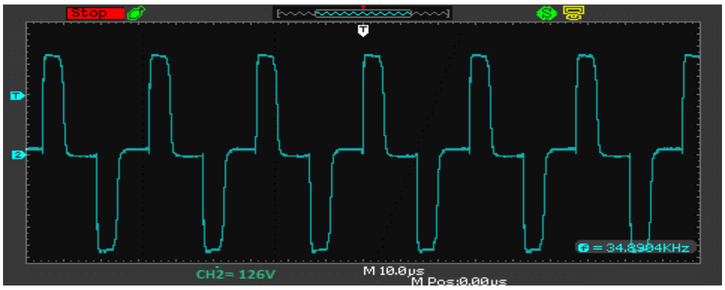

Fig 28 Output across load for R3= 673ohm

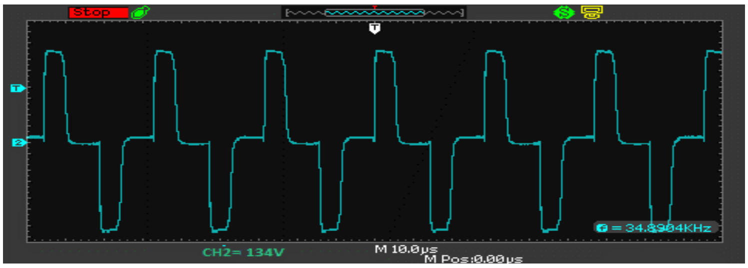

Fig 28 Output across load for R4= 770ohm

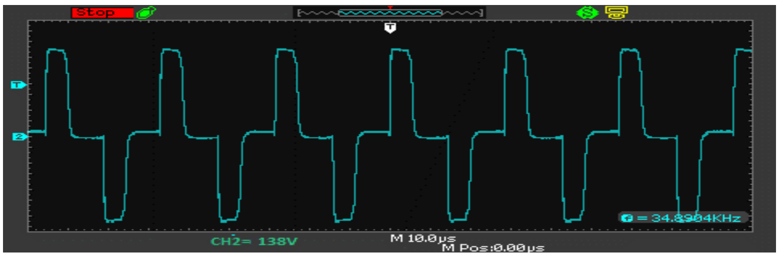

Fig 28 Output across load for R5= 800ohm

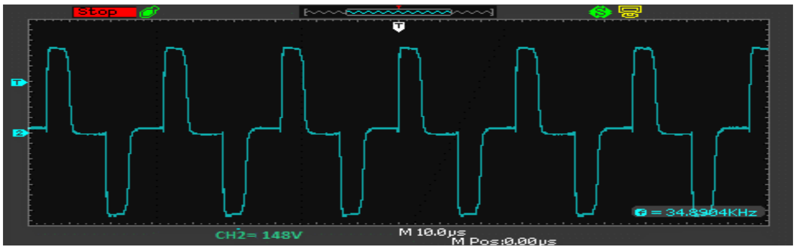

Fig 28 Output across load for R6= 940ohm

VII. Conclusion and Future Scope

Medical technologies used in hospitals has improved all over the world since a couple of years. The basic purpose of these devises are patient safety. In particular, the use of electrosurgical devices is often associated with hazards that may seriously influence the outcome of the procedure. This project presents a converter topology comprising a high frequency inverter and controller for obtaining regulated power output for electrosurgery. With the increase of resistance automatic transition between various modes will ensure that voltage and current are maintained within the limits. It also ensures that power fluctuation due to the change in impedance and slow response of the circuit topology to change in impedance is avoided. As a result of which charring of tissues can be eliminated and clinical operations can be made more efficient. Simulink model of the system was developed in MATLAB 2016a and the results are verified for a frequency of 472kHz. Hardware prototype was developed at 34kHz and control algorithm of the system is developed using ATmega328. Required output is obtained from the system.

The completion of this prototype suggests that output power of the system can be made constant irrespective of load using a two level output waveform. An improved ESG can be developed with the benefits of producing arbitrary pulse patters, thus not only replicating the currently used electrosurgical waveforms butalso unlocking the potential for exploring new clinical effects.

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