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Matlab/Simulink Model of High Frequency Converter For Electrosurgical Generators

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Abstract: *.Electrosurgery is a process where high frequency currents are utilized for performing surgical operations like cutting, fulguration, desiccation etc. But due to the change in tissue impedance and slow response of electrosurgical unit to the change in impedance results in output power fluctuation. This leads to charring of tissues. This paper presents a new high frequency converter topology which eliminates these unwanted responses by regulating the power. The simulation is done by using MATLAB/Simulink version 2016a and simulation results are presented.*

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 method in which high frequency currents are applied to human body for the purpose of clinical operations like fulguration, desiccation, cutting etc. When high frequency current is applied to human body, tissue in the exposed area will experience i^2R heating. Depending on the temperature reached, tissue will show different responses. Resistance to the flow of current is present within the body. So we can say that entire exposed region will be a part of the circuit. As the depth of cutting increases resistance also increases. Then higher will be the voltage required to pass [1]. The voltage is provided by a device called electrosurgical unit (ESU). ESU is a device that draws electrical energy from the main supply and convert to a high frequency (HF) current. With the help of an electrode, we pass this current to human tissue.

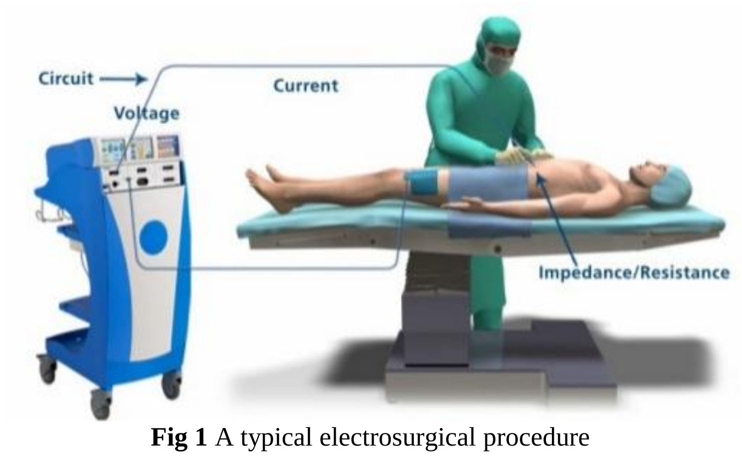

Fig 1 A typical electrosurgical procedure

ESU is considered as a constant power source which has a maximum current and voltage limit [2].Hence the power characteristics will be as shown in Fig 2

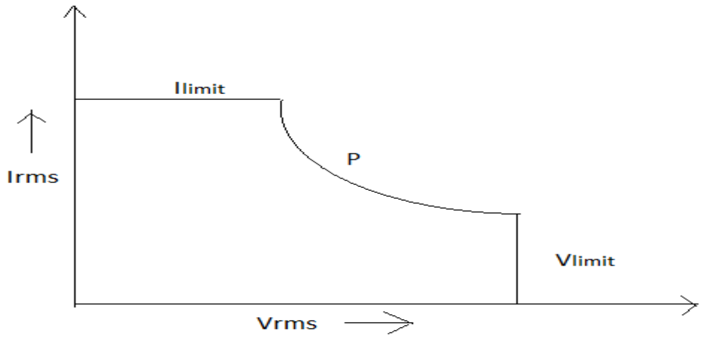

Fig2 Ideal characteristics of ESU

When we provide a particular amount of power to a high impedance tissue, high voltages will be developed and this results in high arching between electrode and tissue. This results in carbonization of tissue. So maximum output voltage must be controlled for obtaining required clinical results. Also the output of the ESU depends on tissue impedance and circuit topology of ESU. Due to the change in tissue impedance and slow response of the circuit used in ESU to change in impedance will cause the output power to fluctuate during arching. This results in charring of tissue. Charring is a type of burn where dark patches appear in the region where cutting is performed. It can be considered as a partial burning which is unwanted. So inorder to avoid charring of the tissue, it is important to develop a new system to regulate the output power and peak voltage.

One of the most common topology for high frequency application is resonant converter topology. Different types of resonant converters are available namely class D, class E, Class Ef_2 etc.. Characteristics of resonant inverter is considered as one of the most reasonable approximation of ideal characteristics of ESU. But in midranges, where most of the impedances lies, have a deviation. To solve this disadvantage a closed loop was implemented. This ensures that the average power obtained over entire cycle is desired one. But the average power in a single cycle is much more than the desired value resulting charring of tissue. So the objective of this paper is to develop a new high frequency converter to regulate output power and peak voltage to avoid charring of tissue [2] [3].

In section 2, block diagram of the converter topology is presented.

II. Block Diagram of High Frequency Converter Topology

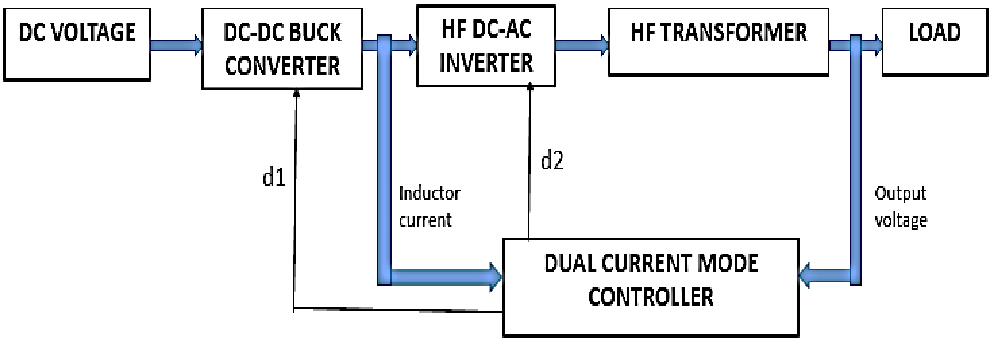

Fig 3 Block diagram of new topology

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 d1 is the duty ratio of buck converter and d2 is the duty ratio of HF inverter.

III. Circuit Diagram of New High Frequency Converter Topology.

The circuit diagram is as shown in Fig. 4.

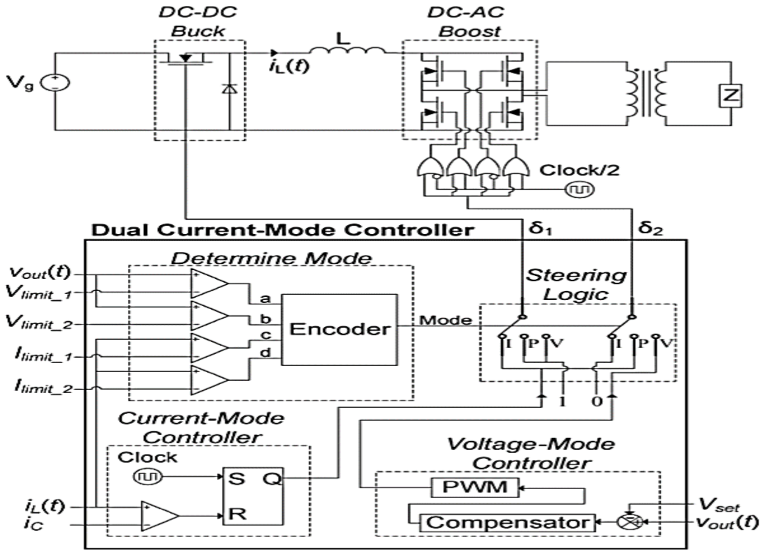

Fig 4 Circuit diagramof new topology [4]

The main components are high frequency inverter and controller.

1.1. HF inverter

High voltage can be generated at the output of the inverter without switching losses across inverter switches. MOSFETS are used as switching device in HF transformer. It provides a three level output. The circuit diagram and switching pattern is as shown in Fig 5 and Fig 6.

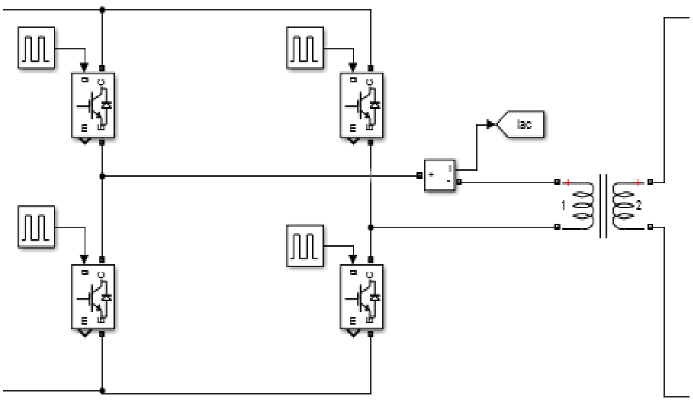

Fig 5 High frequency inverter

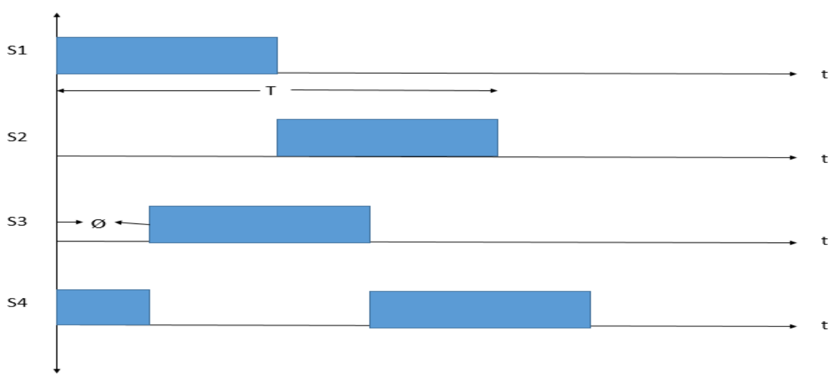

Fig 6 Switching pattern of HF inverter

It consist of four modes. In mode 1, S_1 and S_4 will conduct. So the output voltage developed will be positive. In mode 2, S_1 will be on but S_4 will be turned off and S_3 will conduct 90 degree after S_1 starts conducting. Then the output will be zero. Mode 3 will begin when S_1 get turned off. S_3 and S_2 will conduct during this instant and output will be negative. In mode 4, S_2 and S_4 will be on and output will be zero. After mode 4 the same cycle will be again repeated. The output voltage waveform is as shown in Fig 7.

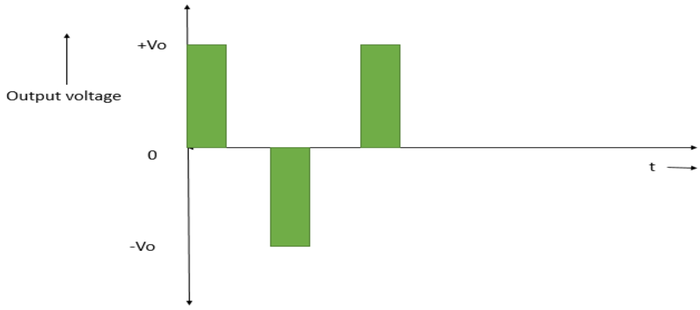

Fig 7 Output voltage waveform of HF inverter

3.2 Control unit

Here a dual mode current controller is used using which voltage and current can be controlled(Fig 8)

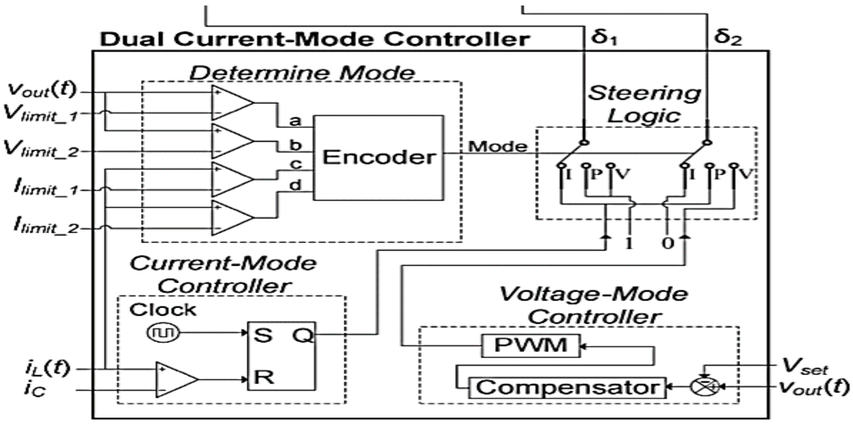

Fig 8 Controller [4]

It 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=o, 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, V_{out}, 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 which will be discussed in next section. Current controller and voltage controller re connected to steering logic [4]. Depending upon output of encoder, any of the above mentioned mode will be selected as shown in Table I.

Table I: ENCODER BLOCK

a	b	c	d	Mode
0	0	1	1	I
1	0	1	0	P
1	1	0	0	V

2. MODES OF OPERATION

Three different modes of operation can be explained using the characteristics given in Fig 9 where ideal characteristics are divides into different region. It consist of current limits I_{limi1}, I_{limit2}, I_{limit3} and voltage limits V_{limit1}, V_{limit2}, V_{limit3} where V_{limit3} and I_{limit3} are maximum permissible values.

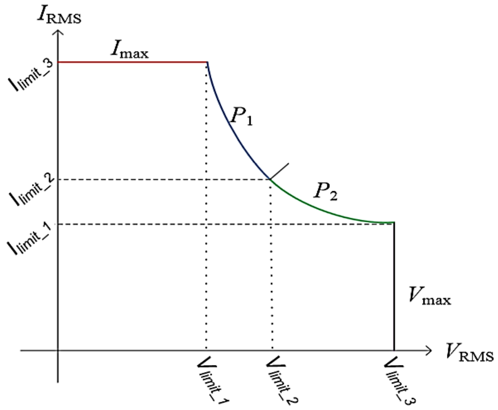

Fig 9 Various sections in ideal characteristics [2]

In constant current mode/ current limiting mode is activated whenever iL 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. Tabular representation of various modes are given in Table II.

Table II: Summary of output modes

Mode	Buck duty cycle	Boost duty cycle
Constant current	variable	0%
Constant power	D1max	Variable
Constant voltage	D1max	D2max

As the load impedance increases, the increasing output voltage triggers the Current Power Voltage transitions, while decreasing impedance (increasing current) triggers mode transitions in the opposite direction.

IV. Simulation Results

A Simulink model of the mentioned converter topology was developed in matlab Simulink version 2016a. The three modes of operation was evaluated by considering the voltage and current limits are shown here. Simulation diagram is shown in Fig 10.The output wave forms of constant current mode, constant power mode and constant voltage mode are shown in Fig 11, Fig 12, Fig 13

Vlimit1 = 150V
Vlimit2 = 270V
Ilimit1 = 10A
I limit2 = 25A

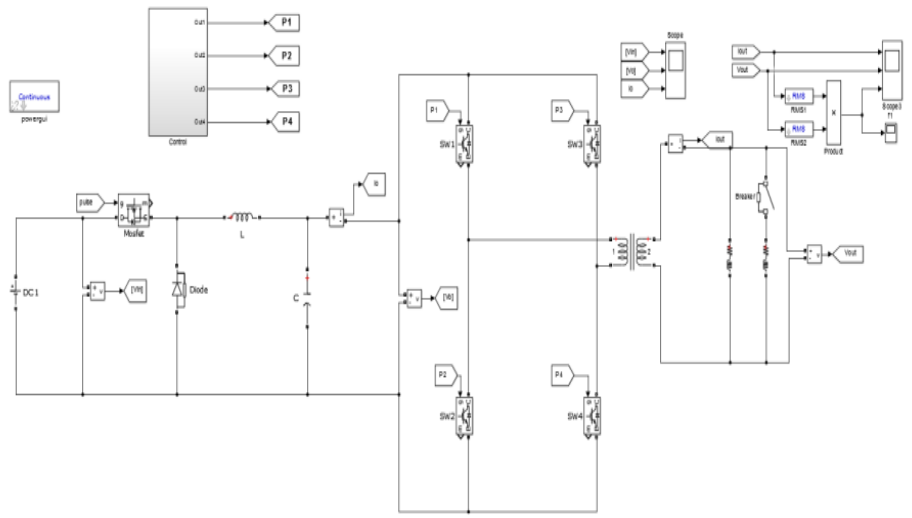

Fig 10 Simulation diagram in closed loop control.

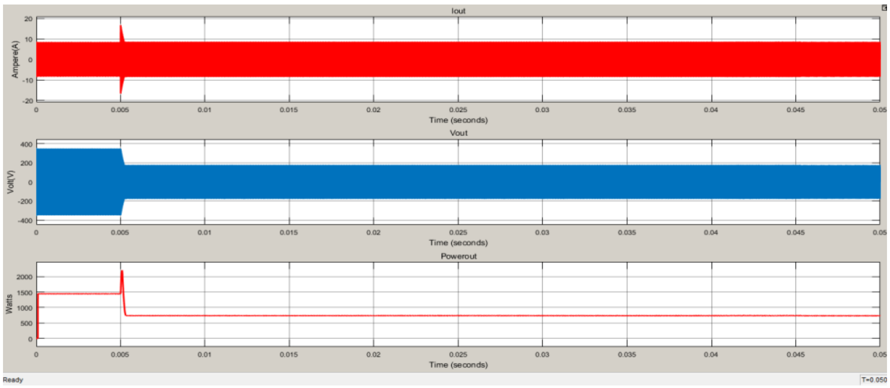

Fig 11 Constant current mode

In Constant current mode, when R1 = 41.6ohm ohm, Output voltage = 350V, Output current= 9.8A and RMS value of output power = 1500W. When R2 = 83.2ohm, Output voltage = 200V and RMS value of power= 600W and output current is maintained to 9.8A.

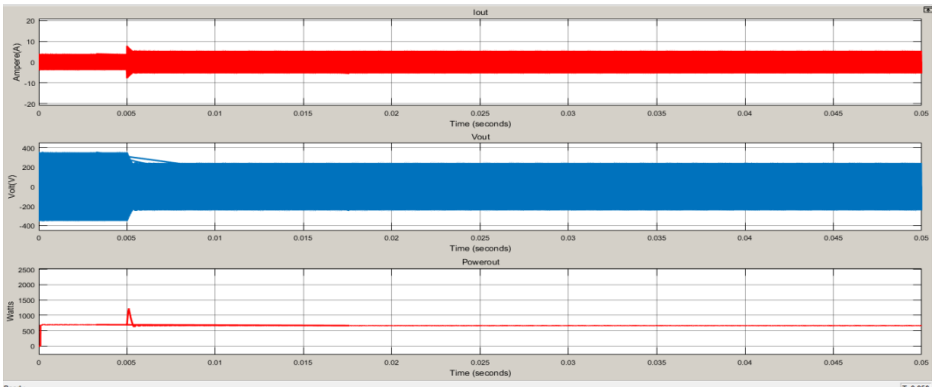

Fig 12 Constant power mode

In Constant power mode when R3 = 90 ohm, Output voltage = 350V, Output current= 5A and RMS value of output power = 750W. When R4 = 180ohm, Output voltage = 250V, output current = 8A and RMS value of power is maintained to 750W

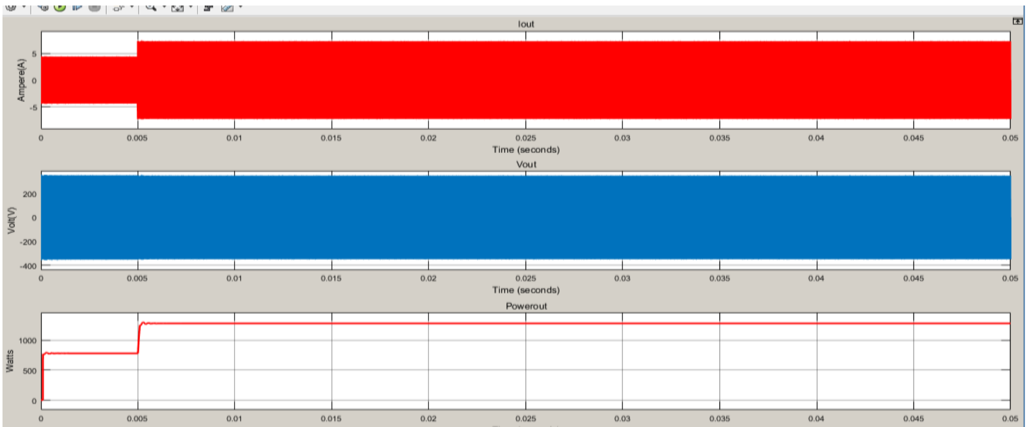

Fig 13 Constant voltage mode

In Constant voltage mode when R5 = 190 ohm, Output voltage = 350V, Output current= 5A and RMS value of output power = 800W. When R6 = 270ohm, Output voltage = 350V and RMS value of power= 1300W and output current is 7A.

V. Conclusion

This paper 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.

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