Pulse Frequency Modulation for Pulsed Power Applications

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Abstract. Pulsed power is a technology in which a great amount of energy is kept for a stretched time and then released in a single burst to achieve high instantaneous power. To put it another way, if a capacitor or inductor stores 1 J of energy and releases that energy in 1 s, the power at that moment will be 1 MW, and the average power will remain the same as 1 W, demonstrating that the law of conversation of energy is in effect. The major goal of this research is to develop or produce pulsed power for applications such as Cancer Cell Treatment and Dielectric Barrier Discharge tubes. By using Pulse Frequency Modulation (PFM), pulsed power is obtained in the range of 0.5 KW to 11 KW with a frequency of 20 kHz and it is noticed that for every rise of 5% of duty cycle there is a rise of 600V of high voltage pulse caused.

Keywords: Pulsed Power · Pulse Frequency Modulation · Pulse Width Modulation

1 Introduction

High pulse power is employed for a varied choice of applications extending from medical field such as cancer treatment to power generation, water treatment and mercury free plasma UV lamps. A strong electric field with a pulse width of a nano second is preferred to disrupt a cancer cell. Hence to ensure this, an electromagnetic wave with high-frequency pulsed power is essential. Which initiates an occurrence of apoptosis in cancer cells.

Apoptosis is vital to treat the cancer cells with an electromagnetic waves of high frequency pulses owing to which apoptosis is easily encouraged in cancer cells [1].

The maximum discharge current in DBD generated by frequency being low with repeated use of uni polar pulses and extended rise or decline duration is nearly a three-fold decrease from those in DBD produced by polarized pulses [2]. The creation of a

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generator of powerful nanosecond pulsed electromagnetic waves that can be used to cure cancer using ultra-short pulsed electric fields [3]. The operation of a solid-state power source intended for medical resources produces bipolar high-voltage pulse bursts at high frequency for resistive loads [4].

For use with parallel reactors, a high-voltage small solid-state pulsed power modulator construction is being investigated. The pulsed modulators current capability has been increased to allow numerous reactors to be driven simultaneously [5].

The fundamental idea is to use many low voltage stacks instead of a single high voltage capacitor to increase the voltage margin of Sic MOSFETs. The stack capacitors are changed in parallel with a rapid charging speed and discharged in series for a high pulse voltage [6].

The resonance of the high voltage transformer leakage inductors shapes the output pulse. To reduce switching loss, all switches are commutated in ZCS mode [7]. For mercury-free plasma UV-lamps-like applications, the use of a pulsed power supply is described in this research. A single-phase AC-DC converter and a fly back converter are used to design High voltage power supplies. The designed system has a 2 s fixed pulse duration, a 25 kHz pulse repetition frequency, and a 2 s pulse amplitude. The output voltage is 5 kilovolts and the current is 2.5 amps [8].

Using a high-temperature superconducting (HTS) based pulsed power transformer as the foundation, a repeating inductive pulsed power supply circuit architecture is developed and simulated to productively enhance charging speed and output pulses of continuous current [9].In water treatment applications, disinfection uses two legs of modular multilevel converter half-bridge sub modules to generate Unipolar or bipolar high voltage pulses. A low-voltage dc input source is used to charge the high bridge-sub module capacitors sequentially from a low-voltage dc input source using a branch that is resistive-inductive and a load switch for reverse-blocking [10]. The proposed work comprises a series of pulse switching modules that produce a high voltage, high power output pulse. For high-power applications, this approach is generally dependable and resilient [11].

2 Pulse Power and Pulse Frequency Modulation

The pulse power supply is a device that produces instant high power at the microsecond or nanosecond level. Pulsed power is the science and technology of accumulating energy over a relatively lengthy period of time and releasing it instantly, thus increasing the instantaneous power.

Pulse frequency is nothing but the number of cycles formed in 1 s. The higher the frequency, finer is the surface finish that can be obtained. With an increase of number of cycles per second, the length of the 'on-time' decreases.

The power supplied to the load is controlled by varying the duty cycle. Where the duty cycle, denoted by "D", is the ratio of the 'ON time to the total period' of the signal, range from 0 to 1, is sometimes expressed as a percentage, i.e., from '0% to 100%'.

Indicating an analog signal into digital by two levels 1 and 0's is a class of Pulse-Frequency Modulation (PFM), it is similar to 'Pulse-Width Modulation (PWM)', an analog signal is encoded in magnitude and controlled in time scale in the duty cycle of a square wave.

Contrasting to PWM, in which the breadth of pulses of a square is varied at a constant frequency, PFM fixes the breadth of pulses of a square while changing the frequency.

Further, the frequency of the pulse train is varied in harmony with the instantaneous magnitude of the controlling signal at sampling intervals. The amplitude and width of the pulses are kept constant by the following process:

- By effectively chopping it up into discrete parts, average power delivered by an electric signal gets reduced,
- By spinning the switch between the load on and off at a fast rate, the average value of voltage (and current) fed to the load is controlled.

3 Proposed Circuit

It can be concluded that for pulse power generation the commonly used topology is on the basis of the pulse forming strategy. But it has a drawback of matching range with low impedance, very bad pulsed output shape and output form is load dependent and poor durability. So, the aim is to find a better way to generate pulse power using pulse frequency modulation technique. The objectives of this work to (i) Generate gate pulses with Pulse Frequency Modulation Technique; (ii) Obtain the pulsed power; (iii) Integrate with the Load (for Pulse Power Applications).

Pulsed power is a technique for storing energy over a long period of time and then releasing it as a high-power pulse composed of high voltage and big current, but with moderate low energy, i.e. low time-averaged power, in an incredibly short period of time. When pulsed electric fields are created between them, causing biological effects such as cell membrane electroporation and protein conformational changes.

Manufacturers can offer a solution with excellent efficiency over its full working range by combining the benefits of the PWM design with those of a PFM device in a monolithic “dual-mode” switching converter. The EMI risks associated with PFM are greatly alleviated since the main source of such interference is quick switching at high currents and high voltages, whereas variable-frequency operations only employed in dual-mode devices during low-current and low-voltage operation. The proposed circuit diagram is depicted in Fig. 1 employing PFM and specifications used are given in Table 1.

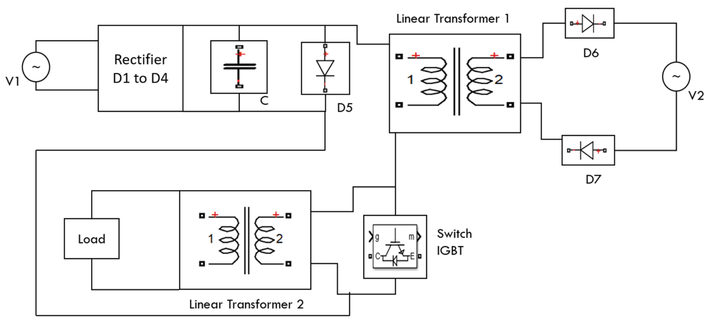

Fig. 1. The circuit diagram for the Pulsed Power Supply

Table 1. Specifications of the Circuit

Parameter	Value
Resistor	100 Ω
Capacitor	10 μF
Linear Transformer	3KVA, 115/230 V
IGBT	1200V, 10A, 20 to 50 kHz
Voltage Sources	110V, 50 Hz
Collector-Emitter Voltage (VCE)	1200V
Collector Current (IC)	30A @25 °C
Minimum Gate threshold voltage (VGE)	4.5V
Maximum Gate threshold voltage (VGE)	8.5V
Gate-Emitter Voltage is (VGE)	± 20V (max)

4 Results and Discussion

In order to obtain the necessary high frequency pulse, different duty cycles are considered with a switching frequency of 20 kHz. The following eight scenarios are being evaluated for high frequency and voltage generation. The corresponding output waveforms are specified from Fig. 2 to Fig. 9 for a duty cycle of 99% separately. The first four Figs. 2, 3, 4 and 5 are the results when the supply voltage is 110V. Next four figures from Figs. 6, 7 , 8 and 9 are the results when the supply voltage is 230V. The following eight scenarios are being evaluated for high frequency and voltage generation for 65%, 70%, 75%, 80%, 90% and 99% duty cycles:

Case1: Source Voltages 110 V with frequency 50 Hz.
Case 2: Source Voltages 110 V with frequency 100 Hz.
Case 3: Source Voltages 110 V with frequency 150 Hz.
Case 4: Source Voltages 110 V with frequency 200 Hz.
Case 5: Source Voltages 230 V with frequency 50 Hz.
Case 6: Source Voltages 230 V with frequency 100 Hz.
Case 7: Source Voltages 230 V with frequency 150 Hz.
Case 8: Source Voltages 230 V with frequency 200 Hz.

According to Fig. 2; the overall output voltage at the linear transformer is greater than 5000 V at 99% duty cycle, with the output current being very low at a frequency of 20 kHz.; Fig. 3, the overall output voltage at the linear transformer is about 5027 V at 99% duty cycle and the output current is quite low with a frequency of 20 kHz. Fig. 4; the overall output voltage at the linear transformer is about 3906 V at 90% duty cycle and the output current is quite low with a frequency of 20 kHz. Figure 5; the overall output voltage at the linear transformer is about 2620 V at 99% duty cycle and the output current is quite low with a frequency of 20 kHz. According to Fig. 6; the overall output voltage at the linear transformer is about 10,683 V at 99% duty cycle and the output current is quite low with a frequency of 20 kHz. Figure 7; the overall output voltage

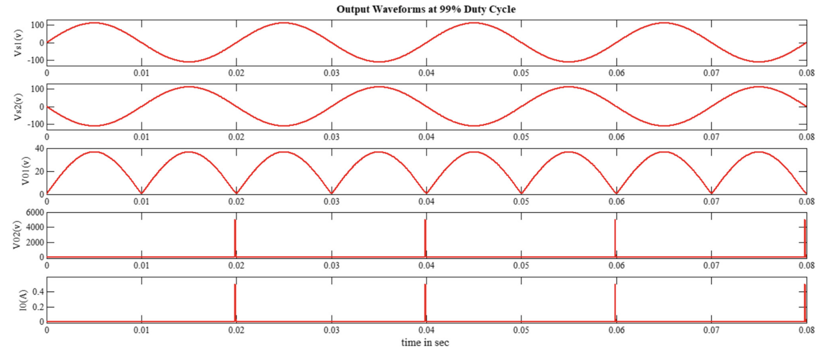

Fig. 2. At a duty cycle of 99% the output waveforms are displayed as source voltage 110 V with a frequency of 50 Hz.

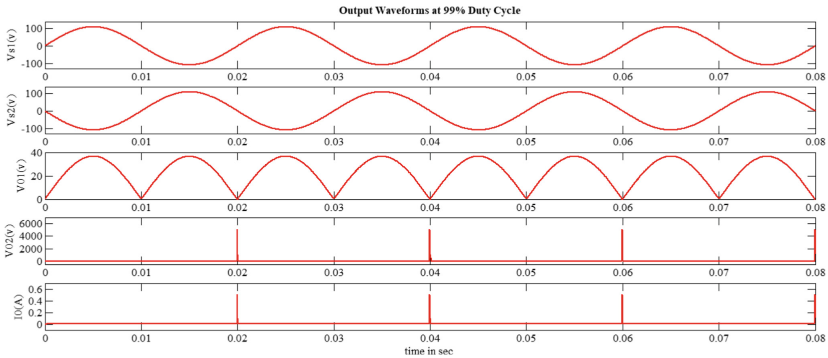

Fig. 3. At a duty cycle of 99%, the output waveforms are displayed as source voltage 110 V with frequency of 100 Hz.

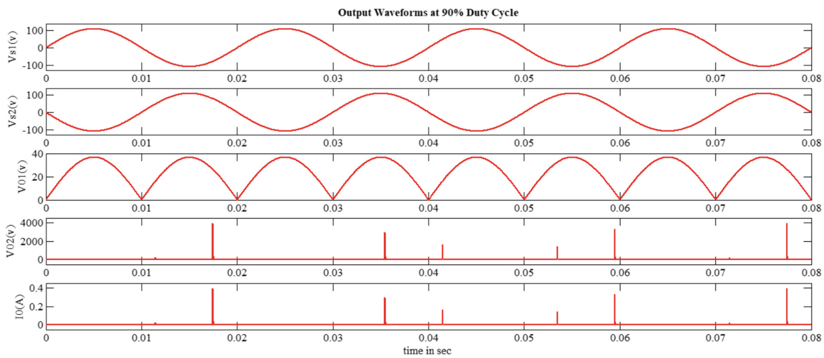

Fig. 4. At a duty cycle of 90% the output waveforms are displayed as source voltage 110 V with a frequency of 150 Hz

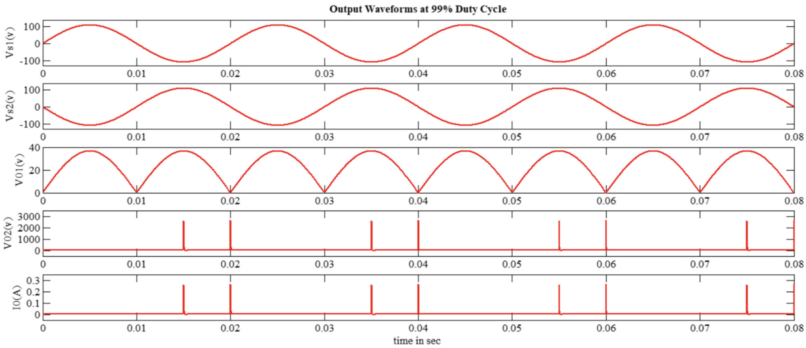

Fig. 5. At a duty cycle of 99% the output waveforms are displayed source voltage 110 V with a frequency of 200 Hz.

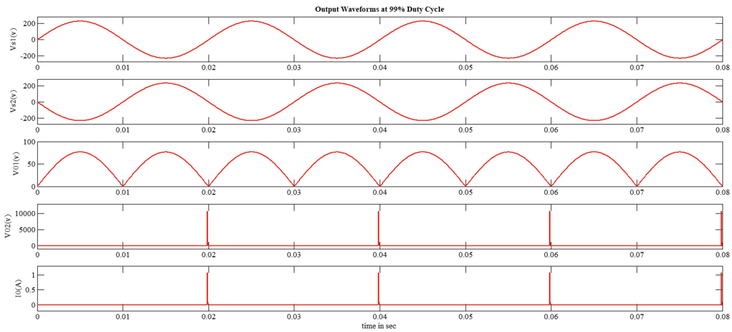

Fig. 6. At a duty cycle of 99% the output waveforms are displayed source voltages 230 V with a frequency 50 Hz

at the linear transformer is about 10,690 V at 99% duty cycle and the output current is quite low with a frequency of 20 kHz. Fig. 8; the overall output voltage at the linear transformer is about 10,690 V at 99% duty cycle and the output current is quite low with a frequency of 20 kHz. Fig. 9; the overall output voltage at the linear transformer is about 5571 V at 99% duty cycle and the output current is quite low with a frequency of 20 kHz.

The detailed analysis for all eight cases mentioned in this work are tabulated from Table 2 to Table 9. From these tables it is observed that minimum value of voltage is 2.2 kV, current 0.22 A and pulse power is 0.5KW for 65% duty cycle with a voltage source of 110 V & 200 Hz frequency respectively. Similarly the maximum value of voltage is 10.69 kV, current 1.06 A and pulse power is 11.42 KW for 99% duty cycle with a voltage source of 230 V & 100 Hz frequency respectively.

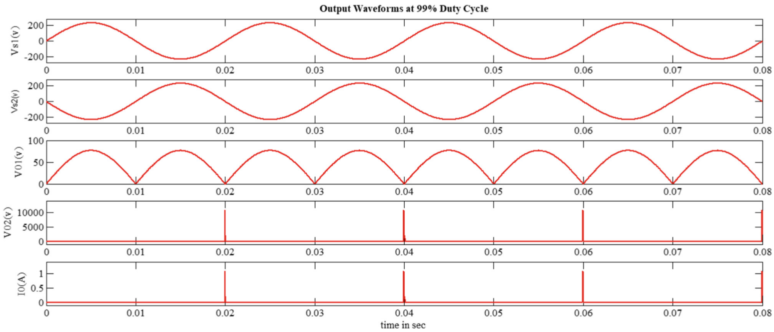

Fig. 7. At a duty cycle 99%,the output waveforms are displayed source voltage 230 V with a frequency 100 Hz

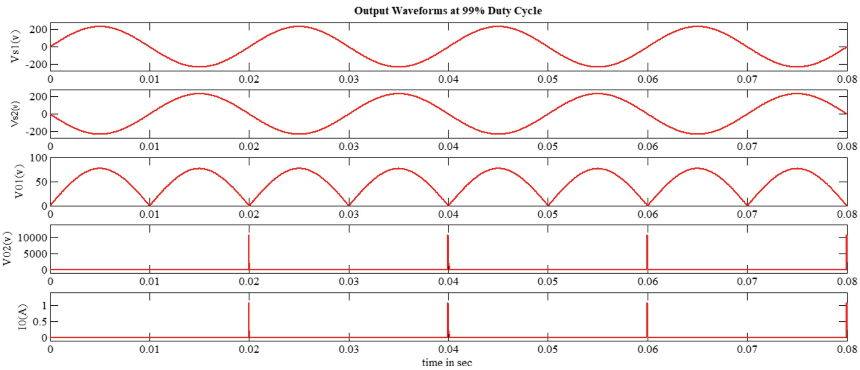

Fig. 8. At a duty cycle of 99%,the output waveforms are displayed source voltage 230 V with a frequency of 150 Hz

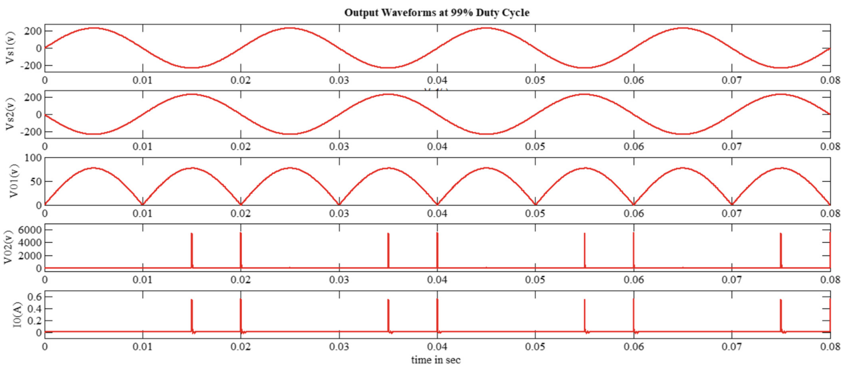

Fig. 9. At a duty cycle of 99%,the output waveforms are displayed source voltage 230 V with a frequency of 200 Hz

Table 2. Table of Voltage, current and Power for different duty cycles for 110 V & 50 Hz

Duty Cycle	T_{on}(msec)	T_{off}(msec)	Avg Voltage(V)	Avg Current(A)	Avg Power(W)	Pulse Width (kHz)
65	13.05	6.95	1102	0.1102	121.45	20
70	14.05	5.95	1840	0.184	338.56	20
75	15.05	4.95	2646	0.2646	700.13	20
80	16.05	3.95	3440	0.344	1183.36	20
90	18.05	1.95	4668	0.4668	2179.02	20
99	19.85	0.15	5032	0.5032	2532.10	20

Table 3. Table of Voltage, current and Power for different duty cycles for 110 V & 100 Hz

Duty Cycle	T_{on}(msec)	T_{off}(msec)	Avg Voltage(V)	Avg Current(A)	Avg Power(W)	Pulse Width (kHz)
65	13.05	6.95	3805	0.3805	1447.81	20
70	14.05	5.95	4137	0.4137	1711.47	20
75	15.05	4.95	4427	0.4427	1959.83	20
80	16.05	3.95	4667	0.4667	2178.08	20
90	18.05	1.95	4973	0.4973	2473.07	20
99	19.85	0.15	5027	0.5027	2527.07	20

Table 4. Table of Voltage, current and Power for different duty cycles for 110 V & 150 Hz

Duty Cycle	T_{on}(msec)	T_{off}(msec)	Avg Voltage(V)	Avg Current(A)	Avg Power(W)	Pulse Width (kHz)
65	13.05	6.95	2888	0.2888	834.05	20
70	14.05	5.95	3116	0.3116	970.94	20
75	15.05	4.95	3333	0.3333	1110.89	20
80	16.05	3.95	3539	0.3539	1252.45	20
90	18.05	1.95	3906	0.3906	1525.68	20
99	19.85	0.15	4195	0.4195	1759.8	20

Table 5. Table of Voltage, current and Power for different duty cycles for 110 V & 200 Hz

Duty Cycle	T_{on}(msec)	T_{off}(msec)	Avg Voltage(V)	Avg Current(A)	Avg Power(W)	Pulse Width (kHz)
65	13.05	6.95	2242	0.2242	502.65	20
70	14.05	5.95	2333	0.2333	544.28	20
75	15.05	4.95	2409	0.2409	580.33	20
80	16.05	3.95	2469	0.2469	609.60	20
90	18.05	1.95	2540	0.2540	645.16	20
99	19.85	0.15	2620	0.2620	686.44	20

Table 6. Table of Voltage, current and Power for different duty cycles for 230 V & 50 Hz

Duty Cycle	T_{on}(msec)	T_{off}(msec)	Avg Voltage(V)	Avg Current(A)	Avg Power(W)	Pulse Width (kHz)
65	13.05	6.95	8071	0.8071	6514.10	20
70	14.05	5.95	8775.1	0.8775	7700.23	20
75	15.05	4.95	9390	0.9390	8817.21	20
80	16.05	3.95	9900	0.9900	9801	20
90	18.05	1.95	10555	1.0555	11140.88	20
99	19.85	0.15	10683	1.0683	11412.6	20

Table 7. Table of Voltage, current and Power for different duty cycles for 230 V & 100 Hz

Duty Cycle	T_{on}(msec)	T_{off}(msec)	Avg Voltage(V)	Avg Current(A)	Avg Power(W)	Pulse Width (kHz)
65	13.05	6.95	2357	0.2357	555.544	20
70	14.05	5.95	3916	0.3916	1533.505	20
75	15.05	4.95	5621	0.5621	3159.56	20
80	16.05	3.95	7298	0.7298	5326.08	20
90	18.05	1.95	9900	0.9900	9801.00	20
99	19.85	0.15	10690	1.0690	11427.61	20

Table 8. Table of Voltage, current and Power for different duty cycles for 230 V & 150 Hz

Duty Cycle	T_{on}(msec)	T_{off}(msec)	Avg Voltage(V)	Avg Current(A)	Avg Power(W)	Pulse Width (kHz)
65	13.05	6.95	6110	0.6110	3733.21	20
70	14.05	5.95	6591	0.6591	4344.13	20
75	15.05	4.95	7051	0.7051	4971.66	20
80	16.05	3.95	7487	0.7487	5605.51	20
90	18.05	1.95	8265	0.8265	6831.022	20
99	19.85	0.15	8679	0.8679	7532.504	20

Table 9. Table of Voltage, current and Power for different duty cycles for 230 V & 200 Hz

Duty Cycle	T_{on}(msec)	T_{off}(msec)	Avg Voltage(V)	Avg Current(A)	Avg Power(W)	Pulse Width (kHz)
65	13.05	6.95	4746	0.4746	2252.45	20
70	14.05	5.95	4942	0.4942	2442.33	20
75	15.05	4.95	5105	0.5105	2606.10	20
80	16.05	3.95	5236	0.5236	2741.57	20
90	18.05	1.95	5393	0.5393	2908.45	20

5 Conclusion

It is observed that a 660V rise in high magnitude of voltage pulse is obtained with every rise in 5% of a duty cycle. This work achieved by using the concept of pulse frequency modulation. By increasing the source voltage, we have seen a rise in the voltage spike. By looking at the various waveforms we have decided to use the concept of pulsed power, the width of a pulse width duty cycle is 50 microseconds and hence the frequency is 20 kHz.In pulsed power supplies, this idea can be revealed to produce a pulse with a change of frequency inevitably. Which can be achieved with the help of specific equipment using power converters with a desired output voltage or current. So that a high pulse power is achievable in particle accelerator of nuclear reactors; high current is achievable in arc stroking where high current maintains the arc throughout the plasma.

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