Novel Pulse Power Supply Operating at High Input Power Factor

Vishnu K Sharma, Kishore Chatterjee, and Vivek Agarwal

Abstract- **Pulse Power Supplies (PPS) are used in several applications like food processing, plasma operation, water sterilization etc. Most of the existing topologies of PPS suffer from drawbacks such as requirement of high voltage DC power supply, series operation of switching devices and use of a pulse transformer. In this paper, an improved PPS configuration, based on the combination of an array of boost converters and an input boost rectifier stage is proposed. Not only does this topology overcomes the above mentioned limitations, but also results in high power factor at the AC mains input and allows independent control of the output pulses' amplitude and duration. Results of computer simulations and laboratory experiments are presented**

I. Introduction

MARX generator [1]-[4] is a conventional topology for PPS, and does not require any pulse transformer, series connection of switches and high voltage DC power supply. But in this topology spark gaps are used as switches, which causes of demerits like low frequency operation, and short life time. The efficiency of system is also low as capacitors are charged through resistors. A boost converter array based PPS [5] is a modification of Marx generator, which overcomes the limitations of conventional Marx generator. In this topology, semiconductor switches and inductors respectively replace spark gaps and resistances of Marx generator. Fig. 1 shows the circuit diagram of this topology. Modified circuit is nothing but the cascaded connection of boost converter and capacitor of previous stage works as a DC input for next stage.

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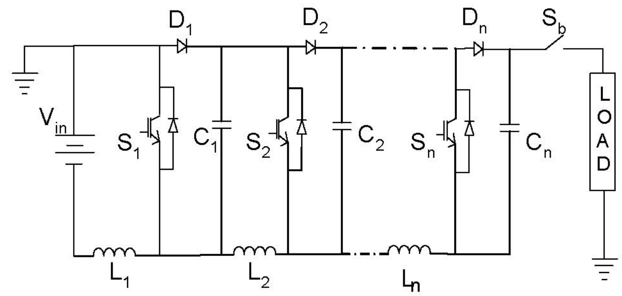

Fig. 1. A boost converter array based PPS.

All switches S_1, S_2,…etc. are turned on simultaneously, and all capacitors come in series with the load during turn on as shown in fig. 2.

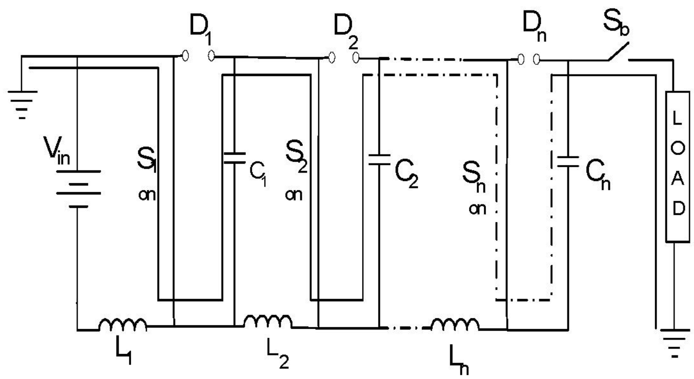

Fig. 2. Equivalent circuit during turn on time.

Magnitude of output voltage pulse is given by:

$$V_0(p) = V_{C1} + V_{C2} + \ldots V_{CN} \qquad (1)$$

The width of the output pulses is determined by the load requirements.

If the current is continuous, the capacitor voltage of n^{th} stage is given by;

$$V_{cn} = V_{cn-1}\frac{1}{1-D},\ D = \frac{T_{on}}{T_s} \qquad (2)$$

where D is the duty ratio, T_{on} is pulse width and T_s is the period of pulse. Therefore, the output voltage of the n^{th} stage is given by;

$$V_{cn} = V_{c1}\frac{1}{(1-D)^n} \qquad (3)$$

where D is the duty ratio, T_{on} is pulse width and T_S is pulse period. If inductor current is discontinuous, capacitor voltage is given by [5];

$$V_{cn} = \left(\frac{T_{on} + T_{\Delta}}{T_{\Delta}}\right) V_{c1} \qquad (4)$$

where T_{Δ} is the time until the current becomes zero after the switch turns off. It is clear from equation 1-4 that the voltage gain of a boost converter depends on its duty cycle. Fig. 3 shows the simulated output voltage pulse for 5% and 10% duty ratio, for a three stage 2.5kHz PPS, keeping input voltage constant. It is clear form fig. 3 that duty ratio and output voltage can't be controlled independently for constant input DC voltage.

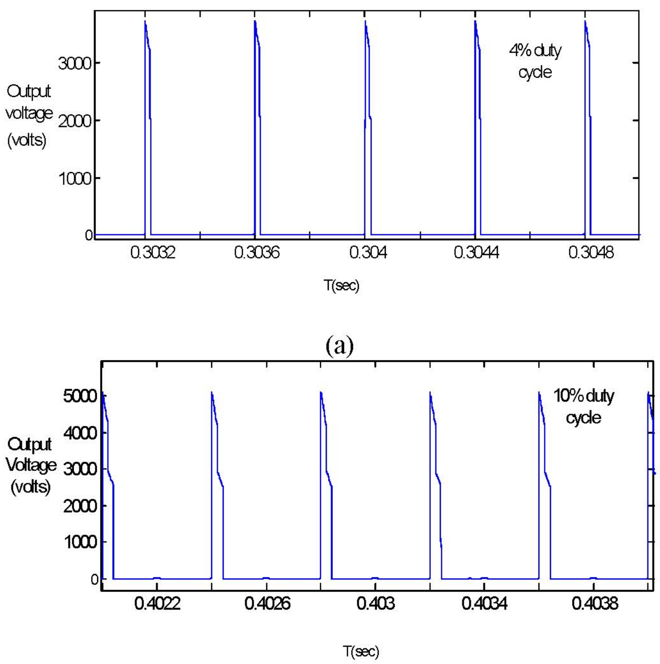

Fig. 3. Output voltage pulse (a) for 5% duty ratio (b) for 10% duty ratio.

This paper proposes a new PPS configuration, which allows independent control of output pulse width and amplitude of voltage simultaneously. Moreover, it also operates at near unity power factor.

II. PROPOSED PPS

Fig. 4 shows the circuit diagram of the proposed PPS. In proposed PPS, Constant DC supply is replaced by boost rectifier. Boost rectifier provides variable DC input to boost converter array for regulating the output voltage. There are two switching pulses in the circuit, one for boost rectifier and another for remaining switches of boost converter array.

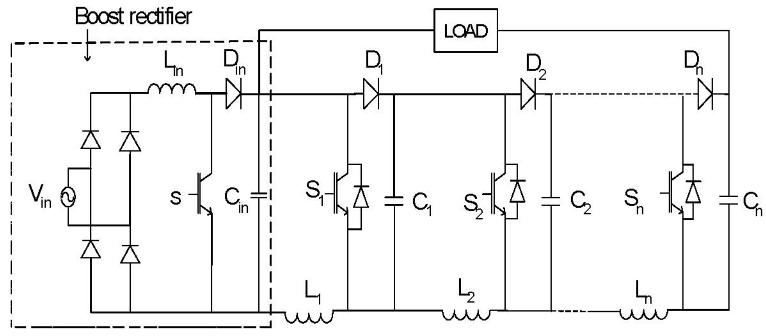

Fig . 4. Circuit diagram of the proposed PPS.

Control scheme of proposed PPS is shown in fig. 5.

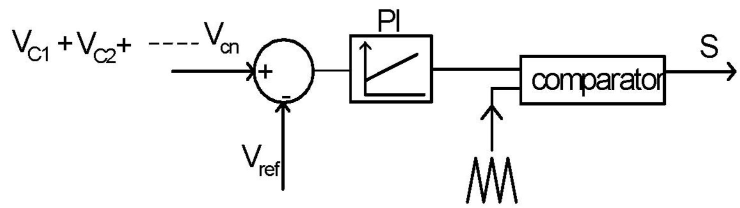

Fig. 5. Output voltage control scheme.

As amplitude of output pulse $V_0(p)$ is sum of voltages of C_1, $C_2 \ldots C_n$, capacitors of boost converter array, it is compared with a reference voltage, which is processed through the PI controller to generate the control command for the converter to reduce the error. For variable duty ratio, PI scheme automatically control the output voltage. Thus proposed topology allows independent control of duty ratio and output voltage.

Figs. 6 and 7 show the simulation results of a three stage 10kV PPS. Fig.4 shows the output voltage waveform, while individual filter capacitor's voltages have been shown in Fig.5. All the Converters are operated in DCM.

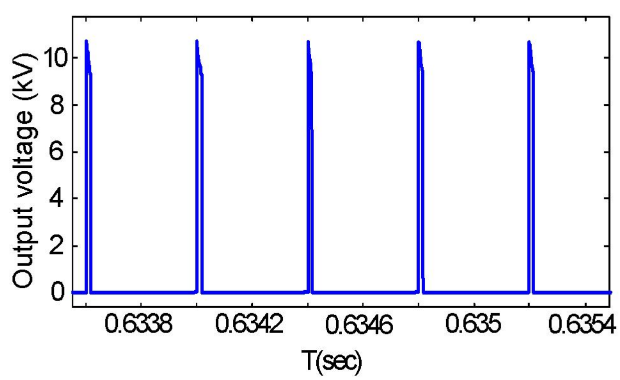

Fig. 6. Output voltage.

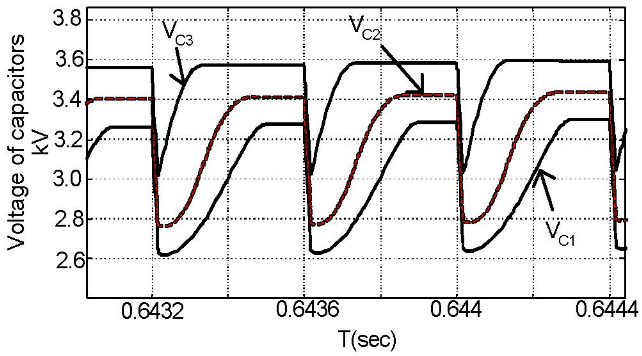

Fig. 7. Voltage of capacitors.

III. DESIGN CONSIDERATIONS

The designing of circuit is based on characteristics of output pulse, which are described by following parameters

1. The pulse width of output voltage
2. The energy transferred in each pulse duration
3. The magnitude of pulse voltage
4. The frequency of the voltage pulse

The capacitor's value of boost converter array is given by [5]

$$C_{1.....n} = \frac{\tau \times V_{out}}{\Delta V \times R_{load}} \qquad (5)$$

where τ is the pulse width and ΔV is voltage drop during pulse. ΔV is decided by energy packets, which are to be transferred in each pulse duration. Energy transferred into a single pulse is given as follows;

$$E = \frac{1}{2} C_{eq} (V_1^2 - V_2^2) \qquad (6)$$

where V_1 and V_2 is the output voltage at the initial and final instant during the pulse and C_{eq} is the equivalent capacitance, when all capacitance of boost converters are in series during switching.

Inductors of boost converter array are preferably operated in discontinuous current mode for reducing reverse recovery problem of diodes, so inductor value is given by [5];

$$L \le \frac{T_s V_{out}}{2 I_{out}} D(1-D)^2 \qquad (7)$$

Filter capacitor and inductor of boost rectifier should satisfy following inequality; [6]

$$C_{in} \ge \frac{2 I_0}{V_{r1}} \left| f(t) \right|_{peak} \qquad (8)$$

where V_{r1} is the voltage ripples across the capacitor C_{in}. $f(t)$ is a function of time, and is given as follows

$$f(t) = \{ \frac{\pi}{\omega \lambda} \int_0^{\omega t} \frac{\sin^2 \omega t}{a - \sin \omega t} d\omega t - t \} \qquad (9)$$

where

$$a = \frac{V_{Cin}}{V_m} \qquad (10)$$

where V_{Cin}, V_m are the capacitor voltage across C_{in} and peak value of AC side voltage of boost rectifier. The inductor in the rectifier circuit is designed by following inequality.

And $L_{in} \le \frac{V_m}{I_P} D_m T_S$ (11)

IV. CONCLUSION AND FUTURE SCOPE

A boost converter array topology has been proposed. A 10kV, 20A, 5 kHz PPS has been designed and simulated. Prototype hardware is implemented in open loop with 500V, 4.5 kHz, $40\mu s$ output pulse. For controlling the voltage of output pulse, boost rectifier is used as a DC input for boost converter array. Proposed PPS can be used in applications such as food processing and water sterilization. Most of the problems of conventional topologies like high DC input voltage, high voltage pulse transformer, series operation of switching devices are absent in proposed topology.

The prototype hardware, that is implemented is a crude model, and has some possibilities of improvements. The capacitors, which are discharged in load periodically, have some parasitic inductance, which distort the shape of output pulse, due to rise time and fall time. This phenomenon comes in picture more significantly at high voltage, and high frequency. The stray impedance of connecting wires also affects the voltage swing in switching period. The load is modeled in simulation and experimental work. A sophisticated model with least connecting wires and stray impedance of capacitors has to be made with actual load.

V. REFRENCES

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