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# A Resonant Based Marx Generator

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*Abstract*—**The configuration proposed in this paper aims to generate high voltage for pulsed power applications. The main idea is to charge two groups of capacitors in parallel through an inductor and take the advantage of resonant phenomena in charging each capacitor up to a double input voltage level. In each resonant half a cycle, one of those capacitor groups are charged, and finally the charged capacitors will be connected together in series and the summation of the capacitor voltages can be appeared at the output of the topology. This topology can be considered as a modified Marx generator which works based on the resonant concept. Simulation models of this converter have been investigated in Matlab/SIMULINK platform and the attained results fully satisfy the proper operation of the converter.**

***Keywords-pulsed power supply, Marx Generator, Resonant converter, high voltage.***

## I. INTRODUCTION

Marx modulators are the most popular power supplies amongst all pulsed power technologies. The structure and control simplicity, being more efficient and flexible in supplying a various range of applications make it more applicable in comparison with other methods like Magnetic Pulse Compressors (MPC)[1], Pulse Forming Network (PFN)[2], and Multistage Blumlein Lines (MBL)[3]. However a new topology has been recently proposed based on the positive buck-boost converters which is an efficient and flexible pulsed power supply having merit to supply wide range of loads with high repetitive pulses [4].

A general configuration of the conventional Marx topology is shown in Fig. 1. The initial concept of this topology is charging number of capacitors in parallel up to the input voltage level, and connecting them in series in order to have the summation of capacitors voltages at the output of the power supply. In this way, the aggregation of capacitors voltages which is a high level of voltage will appear across the load.

Recently solid state semiconductor technology has been utilized in Marx configurations instead of magnetic switches which were traditionally in use. This has greatly improved Marx performance in terms of efficiency and flexibility however there are still other technical points can be considered to have more efficient power supply. Although the simplicity of this topology has been known as an advantage for this topology, extra losses caused by using large number of active and passive components through charging and discharging passes can be counted as a weakness for this method. On the other hand, adjusting the output voltage level regarding loads demand is feasible in conventional Marx generator by changing either input voltage level or the switches duty cycle. In this case, an adjustable DC power supply is required at the input to vary the input voltage level. On the other hand, switching while the switches are conducting current increases the switching losses.

Application of power electronics techniques as well as contriving few design arrangements improve the topology in terms of using fewer components and having less conduction and switching losses. This just imposes a little intricacy to control program and modules. In this regard, an inverter is used to supply a new configuration of switches, diodes and capacitors with resonant technique. Resonant phenomenon is considered in power electronics in order to minimize the switching losses. The concept of resonant converters has been developed in this regard based on the resonant specifications. Switching the power switches while the conducted current through switches crosses zero level, keeps the switching losses minimum [5].

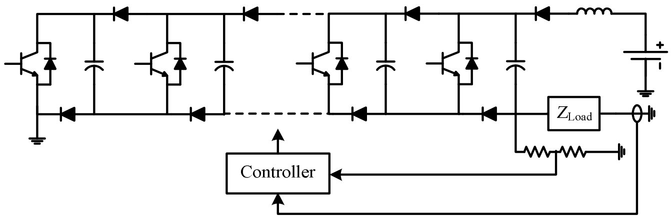


Figure 1. Conventional Marx generator

## II. TOPOLOGY

### A. General Configuration

The Marx modulator proposed in this paper is composed of an inverter supplying a new configuration of diode-capacitor legs through an inductor. This novel configuration consists of a number of diode-capacitor legs arranged in two groups with diodes in opposite directions and several semiconductor switches in between which has the capability of charging the capacitors with opposite polarity and supplying the load through these capacitors. Fig. 2 presents the general schematic

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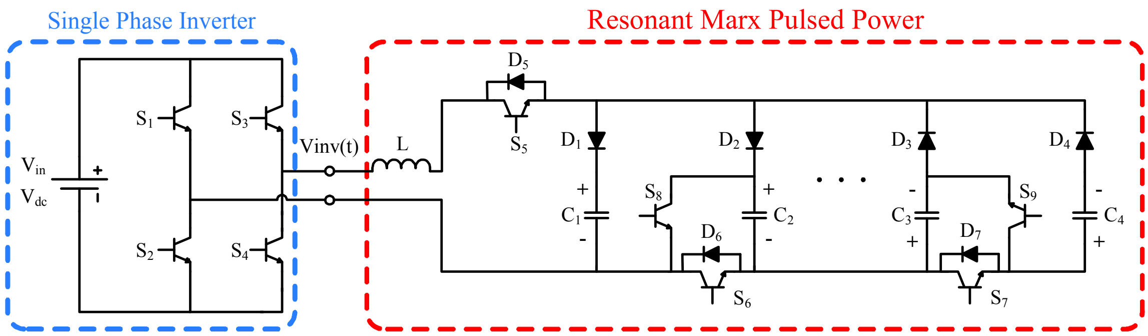


Figure 2. Using resonant concept in Marx topology

of this converter. The front side inverter in this converter provides an alternative voltage supply for the mentioned configuration. In each half a cycle of the inverter voltage, $V_{inv}(t)$, the capacitors in one of those two groups are charged due to the conduction of the related diodes. Each capacitor is charged up to a double input voltage, $V_{in}$, due to the resonant with the inductor. That is why the new configuration is titled "Resonant Marx". In the next step after an entire input supplying cycle, the charged capacitors should be connected together with a proper switching in order to generate a high voltage at the output. With respect to these switching states, three operation modes are considered for this converter in each load supplying cycle.

### *B. Switching Modes*

*1) Positive Charging mode ($S_1$: off, $S_2$: on, $S_3$: on, $S_4$: off, $S_5$: on, $S_6$: off, $S_7$: off, $S_8$: off, $S_9$: off)*

In this operation mode, according to complimentary operation of the inverter's switches, a positive polarity of voltage ($V_{inv}(t)=V_{in}$) is generated across the resonant pulsed power when $S_2$ and $S_3$ are on and $S_1$ and $S_4$ are off. $S_5$ is also turned on, so $D_1$ and $D_2$ and consequently $D_6$ conduct due to imposed of the positive input voltage across them in contrast with $D_3$ and $D_4$ which block the current flow. As a result $C_1$ and $C_2$ are charged in a resonant with the inductor. The trend continues for half a cycle until the capacitors are charged up to

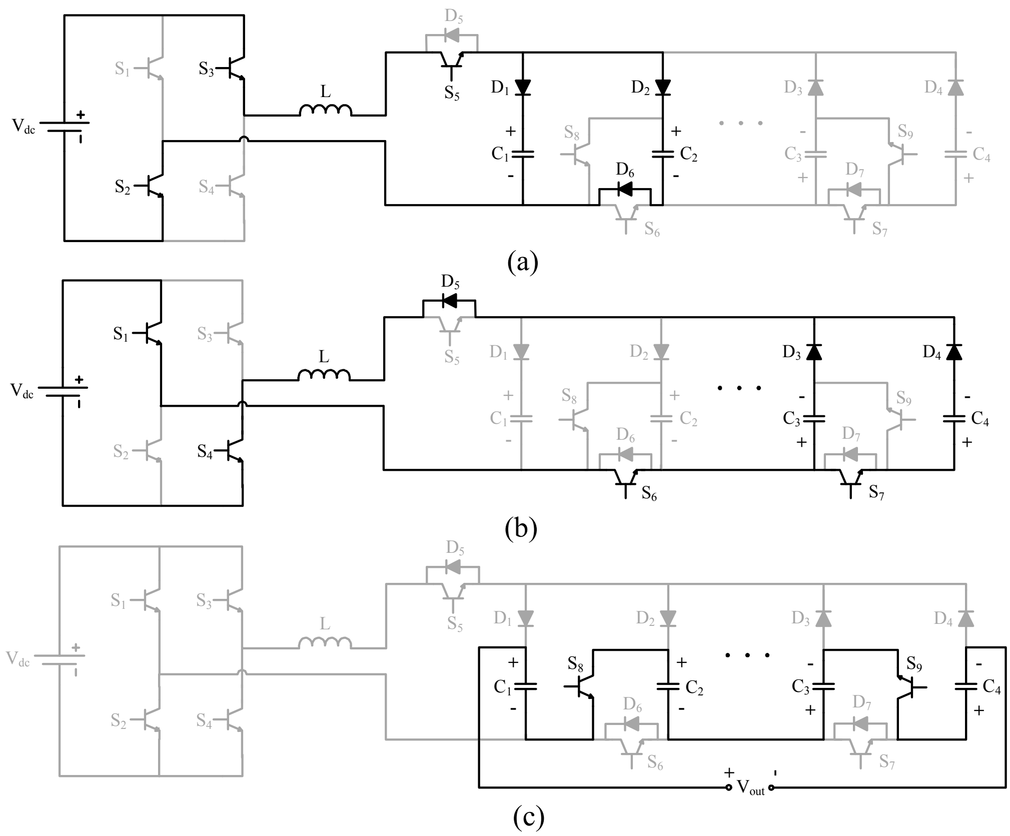


Figure 3. The switching states of proposed topology, (a) Positive charging mode (b) Negative charging mode (c) Discharging mode

double input voltage but the diodes, $D_1$ and $D_2$ cease the reverse current flow and prohibit the next half a cycle of resonant. Therefore the capacitors keep the charge until the load supplying moment. The relevant switching state is shown in Fig. 3(a).

$$C_{eq+} = C_1 + C_2 \quad (1)$$

$$V_C(t) = V_{dc}(1 - \cos\frac{t}{\sqrt{L \cdot C_{eq+}}}) \quad (2)$$

$$I_L(t) = \sqrt{\frac{C_{eq+}}{L}} \cdot V_{dc}(\sin\frac{t}{\sqrt{L \cdot C_{eq+}}}) \quad (3)$$

*2) Negative Charging mode ($S_1$: on, $S_2$: off, $S_3$: off, $S_4$: on, $S_5$: off, $S_6$: on, $S_7$: on, $S_8$: off, $S_9$: off)*

In this mode, demonstrated in Fig. 3(b), $S_6$ and $S_7$ are turned on while on the other hand $S_5$ is switched off. By the conversion of inverter's switching state, turning $S_1$ & $S_4$ on and $S_2$ & $S_3$ off, a negative voltage locates across the inductor, ($V_{inv}(t)$=-$V_{in}$), which forces $D_3$, $D_4$ and accordingly $D_5$ to conduct. $D_1$ and $D_2$ do not conduct in this mode due to lack of positive voltage across them. A scenario similar to the first mode occurs in this stage with contrary power flow through Resonant Marx topology and consequently opposite voltage polarity across $C_3$ and $C_4$.

*3) Load Supplying mode (S1: off, S2: off, S3: off, S4: off, S5: off, S6: off, S7: off, S8: on, S9: on)*

The charged capacitors should be connected together in a correct order to provide the summation of capacitor's voltages at the output of modulator. For this sake, $S_8$ and $S_9$ are switched on simultaneously with turning $S_6$ and $S_7$ off. The diodes do not conduct in this mode neither does $S_5$. Although all inverters switches are disconnected in this mode, to ensure the insulation concerns, the turned off $S_5$ separates high voltage side from the front side inverter in this mode. $S_8$ and $S_9$ are the only power semiconductors conducting and providing supplying loop. The switching state related to this mode is displayed in Fig. 3(c).

These operation modes are in association with bipolar control method of the inverter and the simulation results given in Fig. 4 are according to this modulation technique.

## III. Control Strategies

Based on the control and modulation methods of the inverter, bipolar and unipolar modulations, two sorts of capacitor charging processes are possible which give different feasibilities to this converter. As already discussed, bipolar method provides the configuration with positive and negative levels of input voltage while in the unipolar method; the zero level of voltage would also be available at the output of the inverter. In a case that inverter's switching frequency is more than resonant frequency, the symmetrical adjustment of the

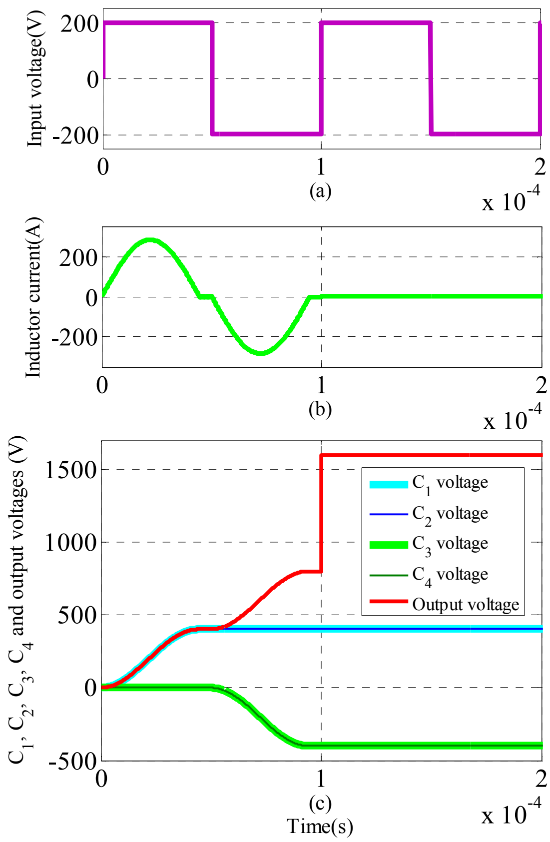


Figure 4. Simulation results of proposed topology with bipolar control: (a) Input voltage, (b) Inductor current, (c) capacitors and output voltages

voltage levels in the capacitors is not possible in bipolar method. This shortage has been removed with controlling the inverter through the unipolar method. In unipolar method, the alternate zero levels of voltage between the positive and negative levels make the identical voltage charges possible for all the capacitors [6]. The switching modes shown in Fig. 5 are the inverter's extra switching states which provide zero level of voltage for the configuration.

Gates switching signals and the voltage and current waveforms of Resonant Marx topology are shown in Fig. 6. In this case, the inverter controlled with unipolar modulation method supplies the Marx topology.

## IV. Simulation Results and Analyses

The simulation results are provided in this section to verify the validity of proposed topology. The waveforms in Fig. 7 and Fig. 8 belong to a modulator working under bipolar and unipolar control methods respectively. The Specifications of simulated model are provided in Table I. The adjustment skill of the proposed topology over generated voltage level is investigated in these simulations.

TABLE I. Specifications of the Modeled Circuit

| $V_{in}$ | L | $C_{1,2,3,4}$ | $f_{inv}$ | $f_r$ |
|---|---|---|---|---|
| 200 V | 10 uH | 10 uF | 10 kHz | 11.2 kHz |

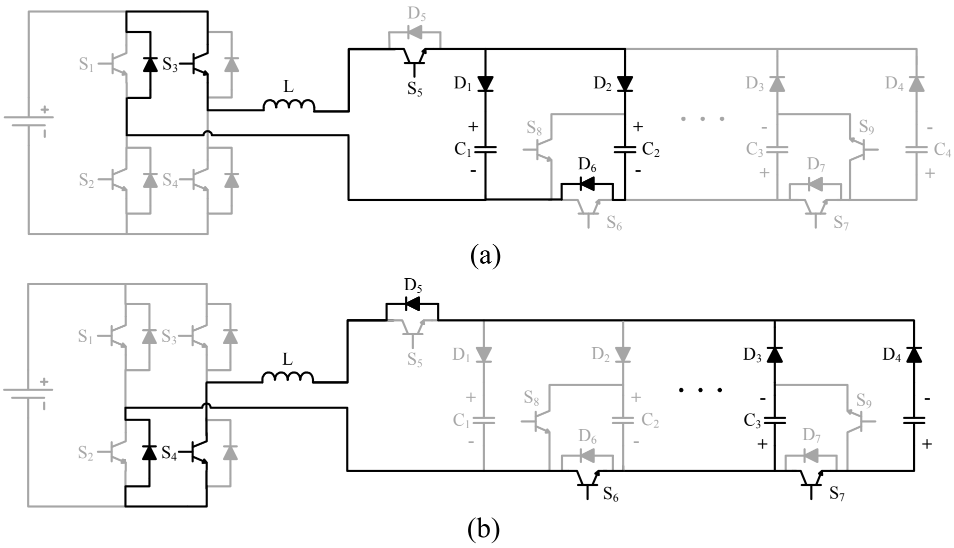


Figure 5. Extra switching states of proposed topology with unipolar control modulation

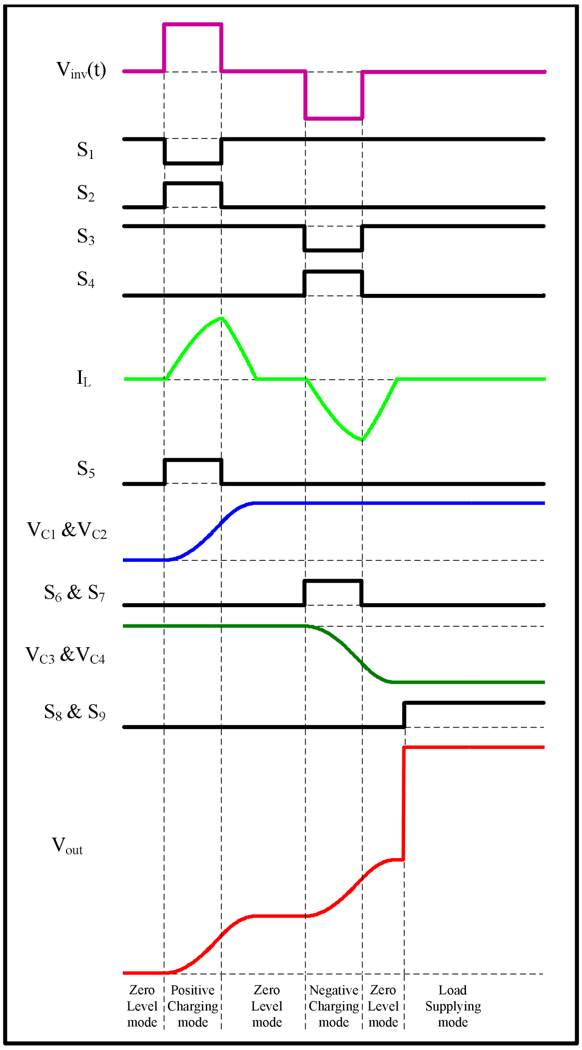


Figure 6. Current and voltage waveforms accompanied by relevant switching signals pattern, (Unipolar control method is applied).

To control the voltage level in bipolar method, the inverter's switching frequency is increased while the duty cycle of inverter switches are changed in unipolar method. The input voltage and the inductor current waveforms are demonstrated in Fig. 7 & 8 (a) and (b) respectively. The capacitors and the output voltages are depicted in Fig. 7 & 8 (c). As apparent in this figure, $C_1$ and $C_2$ are charged during first half a cycle of input voltage while $C_3$ and $C_4$ are charged in the next half cycle; both due to the resonant phenomena between the capacitors and the inductor. As can be inferred by comparing these figures, the symmetrical adjustment of output voltage is not possible through bipolar switching despite of unipolar method. Ultimately, according to the supplying mode of the converter, the aggregation of capacitors voltages which is also depicted in Fig. 7 & 8 (c) appears at the modulator output.

## V. Structure and Performance Comparison

In comparison with the conventional Marx generator, suppose that a voltage up to eight times the input voltage is expected to be generated at the output. To satisfy this aim, an eight-stage conventional Marx generator is required while a four-stage Resonant Marx can give a similar level of voltage at the output. In this case, the number of components in each topology is listed below:

- ✓ Conventional Marx Generator (8 times $V_{in}$): 8 Switches, 8 Capacitors, 16 Diodes
- ✓ Resonant Marx Generator (8 times $V_{in}$): 9 Switches, 4 Capacitors, 4 Diodes

As can be seen in the above comparison, the number of capacitors and diodes considerably reduced in this configuration while an extra switch has been added. The additional switch is $S_5$ which insulated the input source from the rest of circuit at discharging mode. It can be eliminated if either all inverter switches are turned off during supplying mode or the zero switching state of unipolar method is applied to the resonant pulsed power configuration. Even with keeping

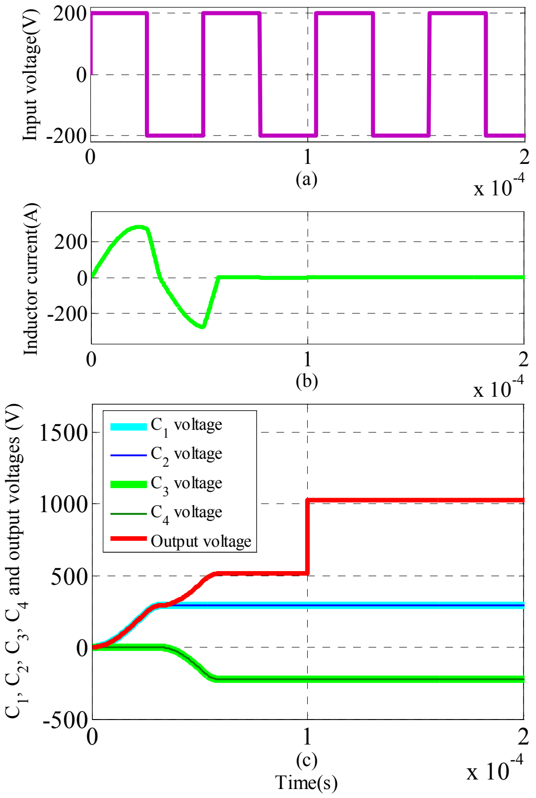


Figure 7 Simulation results of proposed topology with bipolar control $f_{inv}>f_r$: (a) Input voltage, (b) Inductor current, (c) capacitors and output voltages

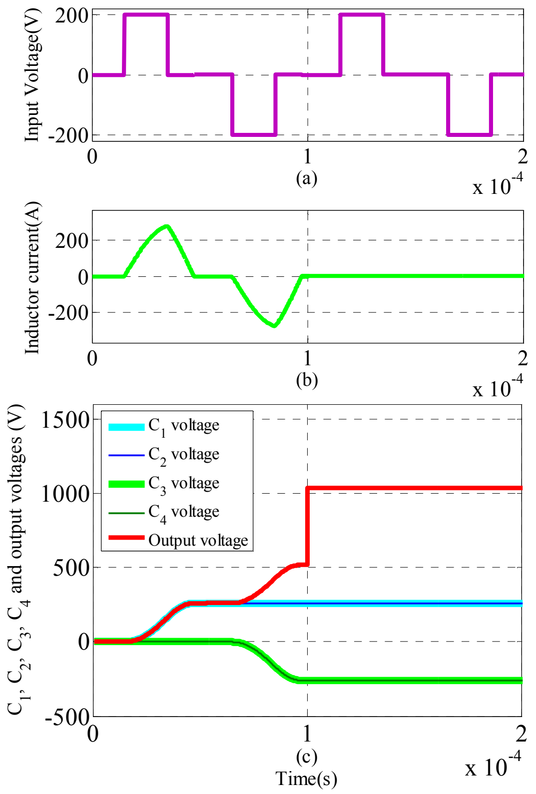


Figure 8 Simulation results of proposed topology with unipolar control: (a) Input voltage, (b) Inductor current, (c) capacitors and output voltages

this configuration structure unvaried, the number of switches will also be decreased for higher voltage generations. Take this point to the account that the Resonant Marx configuration in this structure is comprised of four solid state switches indeed and the other four switches are the inverter's switches. Considering the components voltage ratings, it is worth to know that currently components with different voltage ratings can be found in the market with the same price.

On the other hand, the proposed configuration can effectively reduce the conduction and switching losses in comparison with former modulator. Less number of diodes and power switches naturally results in less conduction losses. The switching losses are also at the lowest level because the switches are turned on and off in the absence of flowing current which is due to the resonant phenomena. On the other hand by controlling the inverter with unipolar method, the adjustment of generated voltage will be possible with less switching losses. Switchings in this condition mostly occur while no current flows through the switches, and as a result these transitions accompany with minimum losses.

## VI. CONCLUSION

A new Marx modulator topology has been proposed in this paper base on the resonant phenomena in order to generate high voltage for pulsed power applications. The converter is composed of a single phase inverter and a resonant pulsed power configuration. Diode-capacitor legs and semiconductor switches are used in this configuration with a novel structure which markedly reduces the number of components in comparison with the conventional Marx generator. Many simulations have been carried out in order to validate the modulator's ability in providing high voltage for pulsed power applications.

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