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# A new DC-DC piezoelectric Converter

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**Abstract**— In this paper a new topology of step down DC-DC converter using a piezoelectric component as storage element is presented. DC-DC conversion process is based on electrical-mechanical-electrical transducer with Zero Voltage Switching (ZVS) for reducing losses. The experimental results in open loop operation are presented and it validates the converter operation principle for 30V to 10V at 2W power conversion.

## I. INTRODUCTION

Today DC-DC converters are widely used in various area of power supply and energy interfaces such as computer power supplies, mobile phones, lightning applications ... etc. In these applications, high efficiency with best integration of converters are very important requirements. Several solutions are proposed in the literature to fulfill these requirements. These solutions include inductor based and switched capacitors based converters. The first converters are most commonly used, however, they are difficult to integrate on silicon. The second converters are easily integrated on silicon but they need high area [1]-[2]. To overcome these drawbacks, a new inductor-less DC-DC converter based on piezoelectric components with high efficiency is proposed in [3]. Piezoelectric components have small sizes, they are easily integrated on silicon. In addition, efficiency of this new converter can be improved from coupling and quality factor of piezoelectric components [4]. These converters are based on electrical-mechanical-electrical transductions. Indeed, during the resonance, piezoelectric component takes energy from the DC source and stored as mechanical deformation. After that, it transmits this stored energy to the DC output as load. A dead-time between each exchange energy phase allows operating in Zero Voltage Switch (ZVS) mode for minimal switching losses. Consequently, a further improvement of efficiency is reached [4]. Moreover, a variable resonant frequency can achieve large amplitude of oscillation.

In this paper, a new topology of DC-DC resonant converter is presented based on the same main process but dedicated for large input/output voltage ratio. This new topology enables to transfer power to the output at each constant voltage phases. Finally, it enables a higher power capability compared to the topology given in [5].

## II. CIRCUIT DISCRIBTION

The topology of DC-DC converter is shown in Fig.1. This converter is composed of one piezoelectric component P, four diodes D<sub>1</sub>, D<sub>2</sub>, D<sub>3</sub>, D<sub>4</sub> and two NMOS FET switches S<sub>1</sub> and S<sub>2</sub>. At the resonant frequency of piezoelectric P, switches S<sub>1</sub> and S<sub>2</sub> are operating in ZVS mode in order to improve the efficiency. Indeed, in steady state resonance mode of piezoelectric P, the conversion is carried out with six phases:

- Phase 1,  $t \in [t_0, t_1]$ : S<sub>1</sub> and D<sub>4</sub> are turned on and S<sub>2</sub> is turned off. During this phase, piezoelectric P is connected between V<sub>in</sub> and V<sub>out</sub>. P takes electrical energy from V<sub>in</sub> and stores it as mechanical deformation. This phase ends by turning off S<sub>1</sub>. The energy acquired by the piezoelectric is controlled by t<sub>1</sub> duration.
- Phase 2,  $t \in [t_1, t_2]$ : All switches are turned off, the piezoelectric P is insulated. Its voltage V<sub>p</sub> decreases from V<sub>in</sub>-V<sub>out</sub> to -V<sub>out</sub> as shown in Fig.2. This phase ends when V<sub>p</sub> is equal to -V<sub>out</sub>.
- Phase 3,  $t \in [t_2, t_3]$ : D<sub>1</sub> and D<sub>4</sub> are turned on, piezoelectric P is connected in reverse voltage to the output voltage to restore part of the mechanically stored energy. In this phase, ZVS mode for S<sub>2</sub> is ensured thanks to diodes operation. The phase ends at half of period.
- Phase 4,  $t \in [t_3, t_4]$ : All switches are turned off, the piezoelectric P is disconnected. During this phase, the voltage V<sub>p</sub> increases from -V<sub>out</sub> to V<sub>out</sub>.
- Phase 5,  $t \in [t_4, t_5]$ : S<sub>2</sub>, D<sub>2</sub> and D<sub>3</sub> are turned on. The piezoelectric is connected to the output voltage to restore a second part its stored energy.
- Phase 6,  $t \in [t_5, t_6]$ : All switches are turned off. Piezoelectric P is insulated. Its voltage V<sub>p</sub> increases from V<sub>out</sub> to V<sub>in</sub>-V<sub>out</sub> (i.e. Fig.2). Time t<sub>5</sub> should be determined to ensure turn on S<sub>1</sub> in ZVS mode when the resonant period ended.

Basically, 1<sup>st</sup>, 3<sup>rd</sup> and 5<sup>th</sup> phases are used for storing and restoring the energy in piezoelectric P. The 2<sup>nd</sup>, 4<sup>th</sup> and 6<sup>th</sup> phases are used to apply the ZVS mode.

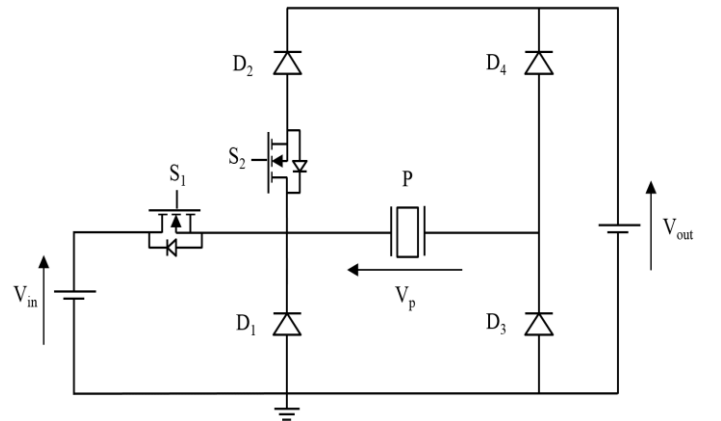


FIGURE 1. PROPOSED TOPOLOGY OF DC-DC CONVERTER

To ensure the proper operating cycle with high efficiency, the operation is governed by the balance equations of electrical charges and energy:

$$Q_{t_1 \rightarrow t_2} + Q_{t_3 \rightarrow t_4} + Q_{t_5 \rightarrow t_6} = 0 \quad (1)$$

$$E_{t_0 \rightarrow t_1} + E_{t_2 \rightarrow t_3} + E_{t_4 \rightarrow t_5} = 0 \quad (2)$$

And by the ZVS mode equations:

$$t = t_3 \quad \text{then} \quad V_p = -V_{out} \quad (3)$$

$$t = t_6 \quad \text{then} \quad V_p = V_{in} - V_{out} \quad (4)$$

$$V_{in} \geq 2 * V_{out} \quad (5)$$

Where  $E_{t_0 \rightarrow t_1}$  is the stored energy in the piezoelectric material during the 1<sup>st</sup> phase,  $E_{t_2 \rightarrow t_3}$  and  $E_{t_4 \rightarrow t_5}$  are the restored energy during the 3<sup>rd</sup> and the 5<sup>th</sup> phases respectively.  $Q_{t_1 \rightarrow t_2}$  is the accumulated algebraic charges in piezoelectric during the 1<sup>st</sup> phase.  $Q_{t_3 \rightarrow t_4}$  and  $Q_{t_5 \rightarrow t_6}$  are the transferred charges to  $V_{out}$  during the 4<sup>th</sup> and 6<sup>th</sup> phases respectively. Using these equations and the equivalent electrical model of the piezoelectric material (see Fig. 3) enable to determine the closing duty cycle of  $S_1$  and  $S_2$ . The electrical model is described in [4]-[5].

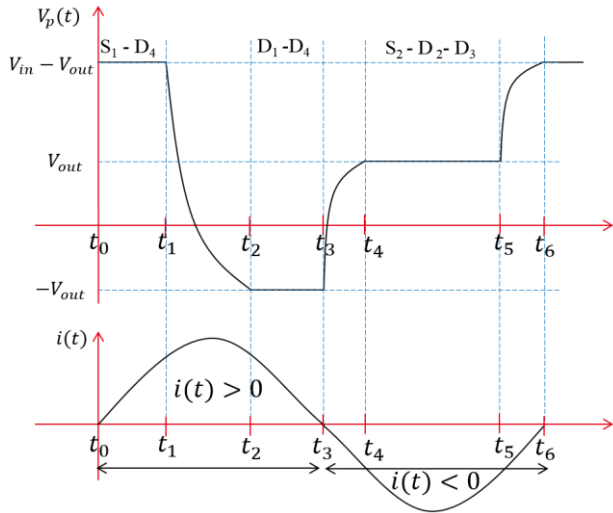


FIGURE 2. VOLTAGE AND INTERNAL CURRENT OF PIEZOELECTRIC

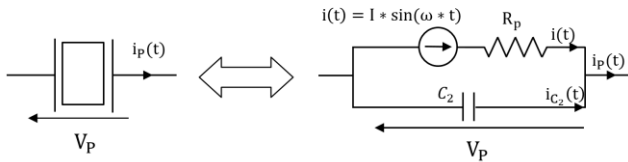


FIGURE 3. ELECTRICAL MODEL OF PIEZOELECTRIC

### III. EXPERIMENTALE VALIDATION

A DC-DC converter circuit was designed and fabricated for experimental validation. The characteristics of used

piezoelectric are given in [5]. The output load is represented by a bulk capacitor of  $10\mu F$  in parallel with one resistance of  $50\Omega$ . These components are chosen in order to get 100mV of oscillation voltage and an electric power of 2W under 10V. For this operating point, the resonance frequency is 99.4 kHz.

Figure 4 presents the experimental results in open loop operation. The experimental waveforms match with the theoretical waveforms. The green curve in figure 4 represents the input current.

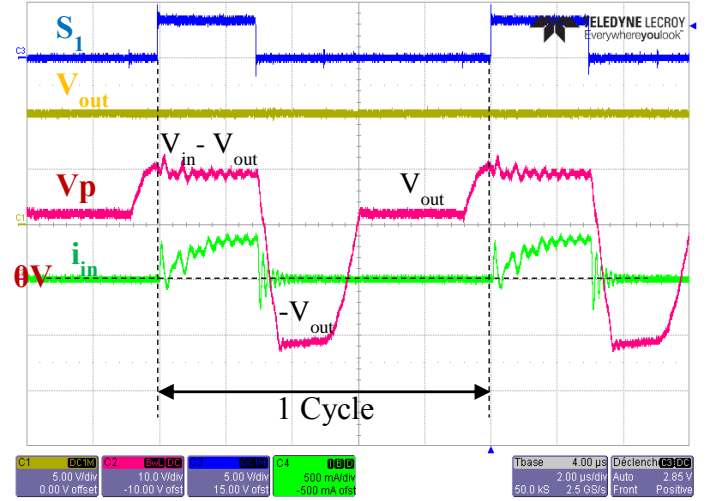


FIGURE 4. EXPERIMENTAL WAVES FORMES OF DC-DC CONVERTER

### IV. CONCLUSION

This paper presents a new topology of DC-DC converter using piezoelectric device as storage element and maximizing the output current in the case of a high ratio between the input and output voltages. An experimental test in open loop validates the converter process for a 30V to 10V at 2W power conversion. This converter will be modeled and simulated in Matlab Simulink software to analyze the performances in closed loop at transient and steady state. Results will be presented in the final paper.

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