Key Engineering Materials
ISSN: 1662-9795, Vol. 804, pp 41-45
doi:10.4028/www.scientific.net/KEM.804.41

Submitted: 2018-08-31
Revised: 2019-01-09
Accepted: 2019-01-10
Online: 2019-05-29

Simulation of a Self-Excited Power Generation System for Dielectric Elastomer Generation

Takumi Sakano[1,a*], Zhen-Qiang Song[1,b], Kazuhiro Ohyama[1,c], Shijie Zhu[1,d], Mikio Waki[2,e] and Seiki Chiba[3,f]

[1]Fukuoka Institute of Technology, 3-30-1 Wajiro-higashi, Higashi-ku, Fukuoka, 811-0295 Japan

[2]Wits Inc. 880-3, Oshiage, Sakura-shi, Tochigi 329-1334, Japan

[3]Chiba Science Institute Meguro-ku, Tokyo, Japan

[a]mem18106@bene.fit.ac.jp, [b]zqsong33@126.com, [c]ohyama@fit.ac.jp, [d]zhu@fit.ac.jp, [e]waki@hyperdrive-web.com, [f]epam@hyperdrive-web.com

Keywords: Dielectric elastomer generation, Cockcroft-Walton circuit, Ringing choke converter

Abstract. In recent years, global warming is a serious international problem. We focused on dielectric elastomer power generation to solve the problem. The dielectric elastomer generation has characteristics such as compactness and flexibility. The dielectric elastomer generation can harvest electric energy from renewable energy sources such as sea wave, wind, and human motion. However, the dielectric elastomer generation has a weakness dependent on an external power supply. In this paper, we proposed a self-excited dielectric elastomer generation circuit using piezoelectric elements. As a circuit verification method, circuit simulations are performed using MATLAB / Simulink, and the circuit behavior is confirmed from the results. From results, it is considered that dielectric elastomer generation can be performed without using the external power supply.

Introduction

In recent years, global warming caused by carbon dioxide emissions has become a serious problem internationally. As a major cause of carbon dioxide emissions, there is an energy conversion delivered from fossil fuel. Therefore, renewable energy generations that do not emit carbon dioxide are focused as a solution to global warming. The renewable energy power generation is a generation method, which does not emit CO_2 and wreak depletion of resources. The renewable energy power generation includes solar power generation, wind power generation, geothermal power generation, biomass power generation, and the like.

Among various types of renewable energy generation, the Dielectric Elastomer Generation (DEG) is focused and developed [1]. The DEG is a power generation method that converts various mechanical energy into electric energy by using a Dielectric Elastomer (DE). In the previous research of [2], the DEG is used to generate electricity from wave power, hydraulic (Karman vortex), and wind power. The DEG has superior characteristics such as compactness, flexibility, and lightweight. The power generation cost is lower than that of conventional power generations using rotating machines. Therefore, the development as a new type of generator is expected.

The practical application of DEG has various problems. However, an electrical problem of DEG is focused in this paper. The DEG needs an external power supply to charge DE. Additionally, the DEG circuit requires a high DC voltage for charging the DE. In addition to storing the electric energy generated by the DEG, a step-down converter is required to use the generated electric energy as a power supply for other equipment. The Step-Down Converter (SDC) converts a high DC voltage to a low DC voltage. The SDC requires a power supply for controller. As described above, the conventional DEG circuit requires two external power supplies. The additional external power supplies not only complicate the power generation system but also use the electric energy generated by the DEG. As the result, the power generation efficiency of the DEG decreases. In this paper, a self-excited DEG power generation circuit using piezoelectric elements is proposed. Also the proposed circuit is simulated with MATLAB/Simulink, and the circuit operation is verified.

Principle of DEG

This chapter describes the principle of DEG. The DE can be treated as a variable capacitor applied to an electric circuit, and the capacitance is changed due to DE's expansion and contraction caused by mechanical force. The DEG generates electric power by applying the change of capacitance between extended state and contracted state. Figure 1 (a) shows the model of DE in the extended state, and figure 1 (b) shows the model of DE in the contracted state. Assuming that the thickness of DE in the extended state is T_{st} and the area is S_{st}, the electrostatic capacitance C_{st} is described as follows.

$$C_{st} = \varepsilon_0 \varepsilon_{DE} \frac{S_{st}}{T_{st}} \tag{1}$$

Assuming that the thickness of the expanded DE in the contracted state is T_{re}, and the area is S_{re}. The electrostatic capacitance C_{re} is as follows.

$$C_{re} = \varepsilon_0 \varepsilon_{DE} \frac{S_{re}}{T_{re}} \tag{2}$$

From the equations (1) and (2), it can be seen that $C_{st}>C_{re}$. Here, assuming that the charge is constant during the power generation cycle, V_{re} can be represented by C_{st}, C_{re}, V_{st} as follows.

$$V_{re} = \frac{C_{st}}{C_{re}} V_{st} \tag{3}$$

From this equation, it can be seen that V_{re} is larger than V_{st}. The power generation energy E can be expressed as follows.

$$E = \frac{1}{2} C_{st} V_{st}^2 \left(\frac{C_{st}}{C_{re}} - 1 \right) \tag{4}$$

From the above equation, it is clear that the DEG can generate electricity by changing the electrostatic capacity.

In the circuit simulation conducted in this paper, the DE is modeled as a variable capacitor that changes from C_{st} = 1.28 × 10 -8 [F] to C_{re} = 1.28 × 10 -9 [F]. In addition, the cycle in which the electrostatic capacity changes is set to 1/30 [sec].

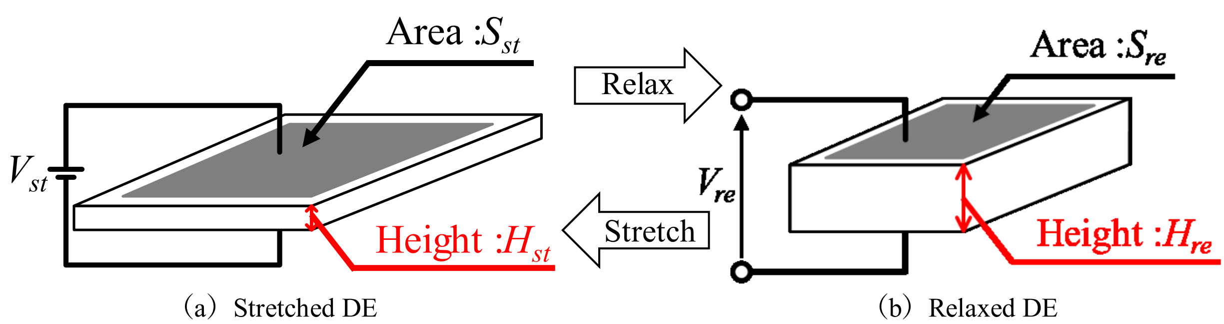


Fig.1 Generation cycle of DEG

Simulation Circuit

In this chapter, the circuit configuration and behavior procedure of the proposed self-excited DEG circuit are explained. Figure 2 shows the proposed circuit, and Table 1 shows the parameters of proposed circuit. The proposed circuit was simulated with MATLAB / Simulink.

《Circuit configuration》

A piezoelectric element and a Cockcroft-Walton circuit (CW circuit) were introduced on the input side of the proposed circuit [3]. A piezoelectric element is an element that converts mechanical vibration into an AC voltage. The CW circuit is a boosting circuit, and it is possible to design a magnification that boosts by the number of diodes and capacitors. In this simulation, the piezoelectric element is made equivalent to an ideal AC power supply (amplitude 200 [V], frequency 30 [Hz]). The CW circuit is designed to boost the voltage of the piezoelectric element by 10 times. Therefore, for the entire input side, the parameter design is performed so that the charging voltage V_{CW} of DE becomes 2000 [V].

A ringing choke converter (RCC) is introduced on the output side of the proposed circuit [4]. The RCC is a DC-DC step-down converter that does not require a power supply used for switching control. During the ON period, the energy is stored in the transformer, and during the OFF period, the voltage is output at the amount of energy stored to the secondary side. In this circuit, since the DE outputs a high voltage, an IGBT with high breakdown voltage is used as a switching element. The switching is started when the generated voltage V_{DE} of DE exceeds a certain value according to the parameters of R_3, R_4, R_5 and C_{12}. In this simulation, the parameters are designed so that switching starts when V_{DE} exceeds 3000 [V]. When the switching is started, the output side voltage V_{o1} is gradually output. V_{o1} is designed to be 100 [V].

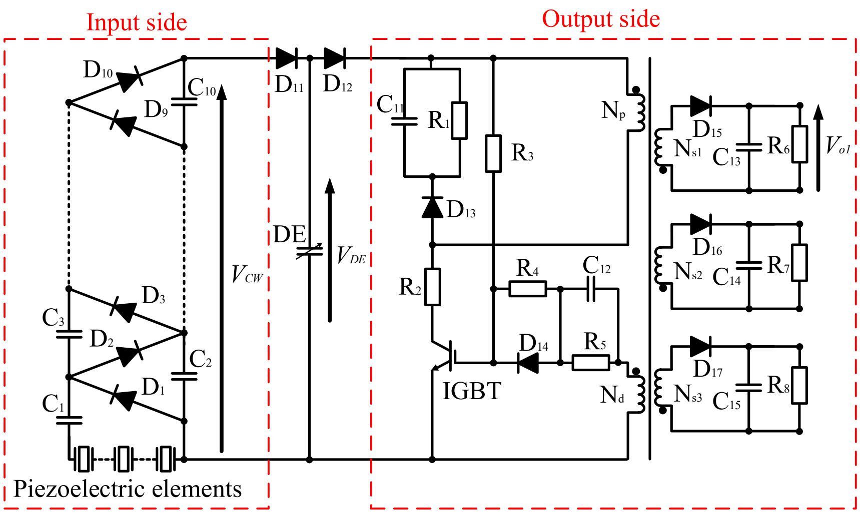


Fig.2 The proposed DEG circuit

Table.1 Parameter of the proposed circuit

Symbol	Set value	Symbol	Set value
C_1~C_{10}	1.3×10^{-4}[F]	R_4	1.0×10^{3}[Ω]
C_{11}	4.7×10^{-6}[F]	R_5	2.0×10^{3}[Ω]
C_{12}	1.0×10^{-4}[F]	R_6~R_8	1.0×10^{5}[Ω]
C_{13}~C_{15}	3.5×10^{-6}[F]	N_p	221
R_1	1.5×10^{3}[Ω]	N_d	2
R_2	1.0×10^{3}[Ω]	N_{s1}~N_{s3}	18
R_3	2.5×10^{6}[Ω]		

C_x: Capacitance, R_x: Resistance,
N_x: Number of turns in a coil (x = 1,2,3.....)

《Circuit behavior》

First, 200 [V] is outputted from the piezoelectric element (modeled as an ideal AC power supply). Thus, the V_{CW} is gradually boosted. As the V_{CW} is boosted, the V_{DE} also rises. When the V_{DE} exceeds 3000 [V], the IGBT is turned on. During switching ON time, the generated electric energy is stored in the transformer. When all the generated energy is stored in the transformer, the IGBT turns off. When the IGBT turns OFF, the V_{o1} is output. The V_{DE} rises again while the IGBT is OFF.

By repeating this operation, the proposed circuit performs DEG without any external power supply. Also, the generated voltage can be taken out. In order to verify that operation of this circuit, the voltage waveforms of V_{CW}, V_{DE} and V_{o1} are estimated by the simulation.

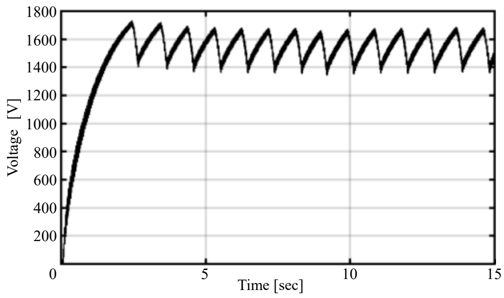
Simulation Results

Figure 3 shows the estimated waveforms of V_{CW}. Figure 4 shows the estimated waveform of V_{DE}. Figure 5 shows the estimated waveform of V_{DE}.

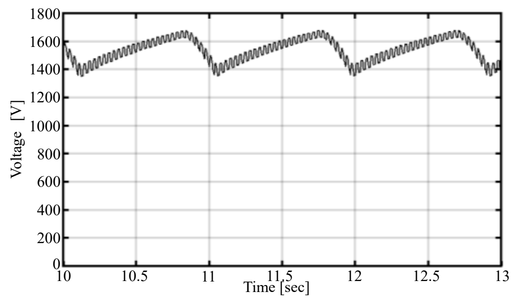
First, boosting operation is carried out from 0 seconds to 2.4 seconds from the result of V_{CW}. When it reaches 1730 [V], it decreases to 1400 [V], and thereafter it repeats rising and descending. And the maximum voltage value decreases to 1650 [V] with time, and becomes substantially constant.

Next, from the result of V_{DE}, the V_{DE} turned out that the first switching started at the moment when the V_{DE} reached 3230 [V] at 2.4 [sec]. It is shown that the maximum voltage drops to 1500 [V] when the IGBT is OFF, and the voltage rises to 3100 [V] during the ON period. The switching operation is performed periodically.

Finally, from the result of V_{o1}, it is shown that the output is started about 2.6 seconds and draw a stair-like waveform. The rise of the voltage also becomes moderate over time.

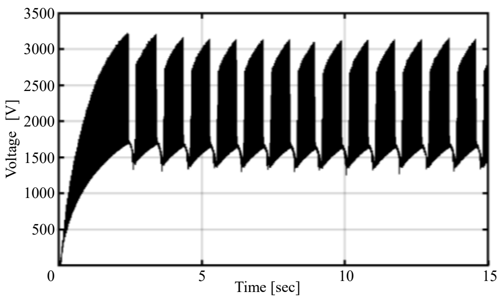


(a) 0 to 15 seconds

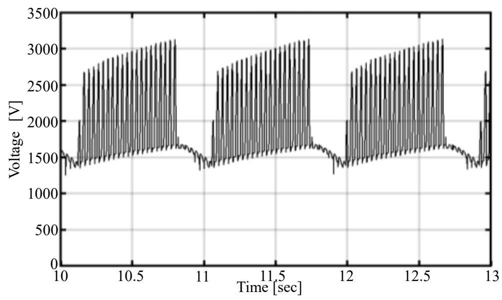


(b) 10 to 13 seconds

Figure 3. Simulations result of V_{CW}.

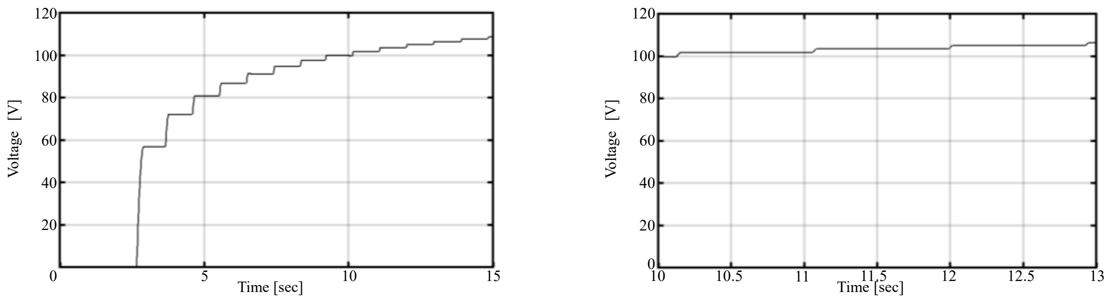


(a) 0 to 15 seconds



(b) 10 to 13 seconds

Figure 4. Simulations result of V_{DE}.



(a) 0 to 15 seconds (b) 10 to 13 seconds

Figure 5. Simulations result of V_{DE}.

Based on the above simulation results, it is confirmed that switching of RCC starts at approximately 2.4 [sec] when the V_{DE} reached 3230 [V], and the V_{o1} is output. It is confirmed that the switching operation is repeated at the switching frequency of 1.01 [Hz]. However, the output voltage does not reach a constant value of 100 [V] which is a desired value. In the future, the circuit parameters will be optimized to solve this problem.

Summary

In this paper, the circuit simulation is performed on the self - excited DEG circuit using the piezoelectric element using MATLAB / Simulink, and circuit operation is verified. From the simulation results, it was found that when V_{DE} reached 3200 [V], switching was performed and V_{o1} was output. This result was close to desired value for the design of the parameter.

References

[1] Seiki C. and Mikio W., Basic Characteristic of Dielectric Elastomer and Their Applications, Journal of Japan Society for Precision Engineering Vol.80. No8., 2014

[2] Jiangshui H. and Samuel S. and Zhigang S. and David R., Maximizing the Energy Density of Dielectric Elastomer Generators Using Equi-Biaxial Loading, Advanced Functional Materials Volume 23, Issue 40 Pages 5056–5061 October 25, 2013

[3] Takao F. and Keiichi S., Operating principle of Cockcroft-Walton circuit to produce high-voltage, The papers of Technical Meeting on Plasma Science and Technology, PST-13-089, IEE Japan, 2013

[4] Tohru K. and Tsutomu O., Loss Reduction and Design Method for Self-Oscillating Flyback Converter, The transactions of the Institute of Electronics and Communication Engineers of Japan. C, 2008.