Jan MUĆKO

Bydgoszcz University of Science and Technology, Institute of Electrical Engineering

Influence of elements parameters on the output characteristics of the voltage multiplier when powered from the inverter in resonance conditions

Abstract. *The article presents the influence of the parameters of the HVdc generator with a multiplier, such as: leakage inductance of the HV transformer, capacitance and the number of multiplier stages on the value of the output voltage, voltage ripple, power and frequency of the supply voltage as a function of the output current. The presented characteristics were obtained under the conditions of synchronization of the output voltage and current of the inverter that powers the multiplier. The presented results will be useful when designing HVdc generators with Cockcroft-Walton multipliers.*

Keywords: voltage multiplier, resonant inwerter, output characteristics, high DC voltage generator.

Introduction

Voltage multipliers have many applications [1]. They are used to generate high DC voltage. They were very popular in CRT TVs and oscilloscopes. Currently, they can be found e.g. in electrostatic spraying systems (powder coating, spraying of plant protection products), electrostatic segregation of materials [2], X-ray tube power supplys [3], systems for obtaining electricity from the electromagnetic field that surrounds us [4, 5]. These are usually low power devices. In the case of designing multipliers with higher power (of the order of hundreds W and kW), it is necessary to analyze the impact of the power supply conditions and the parameters of the used elements on multiplier output characteristics. In the case of powering the multiplier from the inverter, through the HV transformer, resonance phenomena occur. These phenomena were described e.g. in works [6, 7]. In [7] was shown that the most advantageous, due to the stiffness of the output characteristics, is the switching of the inverter transistors with the moments when the current supplying the multiplier changes direction. The voltage and current supplying the multiplier are then synchronized.

This article presents the influence of the values of parameters such as: the leakage inductance of the HV transformer, capacitor capacitance and number of multiplier stages on the value of the output voltage, voltage ripple and frequency of the supply voltage as a function of the output current. The synchronization of the output voltage and current of the inverter will be maintained.

The presented results will be useful in the design of such devices. The motivation to study the impact of the element parameters on the characteristics of the multiplier was the earlier design and construction of two multipliers with rated powers of 60 and 160 W and an output voltage of 40 kV [7], used in sputtering and electrostatic separation devices [2]. The results presented in this article were obtained by means of a computer simulation (in LTSpice). A simplified scheme of voltage multiplier supplied by an inverter with a HV transformer and the inverter output voltage and current are shown in Fig. 1.

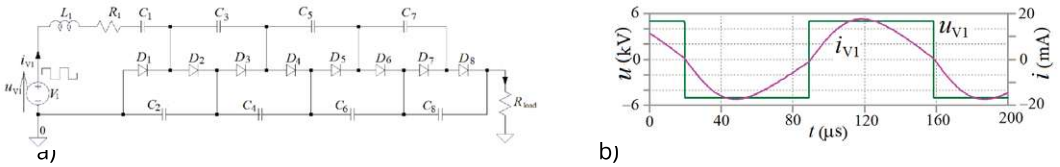
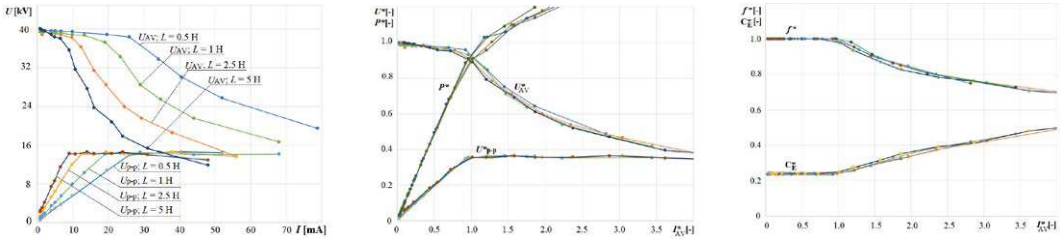


Fig. 1. A simplified scheme of voltage multiplier supplied by an inverter with a HV transformer (referred to the secondary side of the transformer) (a) and the inverter output voltage and current during synchronization (b).

Characteristics of the voltage multiplier

The characteristics of the multiplier output voltage, the ripple of this voltage (peak - peak), the frequency of the inverter voltage during synchronization and the equivalent capacity of the system as a function of the load current of the voltage multiplier are shown in Fig. 2. These characteristics were obtained for the assumed capacitances C_1=...= C_8=C=1 nF, L = 0.5; 1; 2.5 i 5 H. The simulation also assumed: ideal rectifier diodes, the transformer winding resistance was omitted, a 20 MΩ resistor was connected in parallel to each diode, which in the real system symmetrized the voltages on each capacitors, causing the multiplier to be initially loaded with a resistance of 160 MΩ. Fig. 2a shows the characteristics of the output voltage and the ripple voltage of the system for different values of the transformer leakage inductance. Figures 2b and 2c, on the other hand, show the same characteristics and characteristics of power, synchronization frequency and equivalent capacitance expressed in relative values.

As reference values were adopted: U_{ref} - multiplier output voltage for no-load condition (I_{AV}=0), Z_{ref} = $(L/C)^{1/2}$, f_{ref} - synchronization frequency for I_{AV}=0, I_{ref} = (U_d/Z_{ref})/n, n – multiplication factor, U_d – supply voltage of the inverter, I_{AV} – average multiplier output current U_{AV} – average multiplier output voltage.



a) b) c)

Fig.2. Characteristics of U_{AV} voltage and ripple voltage U_{p-p} (a) and relative values (b) of: output voltage U^*_{AV}, ripple voltage U^*_{p-p}, power P*, synchronization frequency f* and equivalent resonant capacitance C^*_E as a function of relative load current I^*_{AV} for capacitance C =1 nF and leakage inductance L=0.5; 1; 2.5; 5H.

Conclusions

The presented simulation studies show that for the assumed inductance values L=0.5; 1; 2.5; 5 H and constant capacitance C=1nF, practically the same characteristics were obtained in relative values.

Similar simulation studies were carried out for a constant value of inductance L=0.5 H and capacitance C=0.1; 0.25; 0.5; 1 nF. By introducing the previously specified reference values, practically the same characteristics as in Figures 2b and 2c were obtained.

Appropriately selected reference values allow to present the characteristics of the multiplier in relative values, regardless of the parameters of its components.

The conducted research will greatly facilitate the process of designing voltage multipliers in which the inverter output voltage and current are synchronized and resonance phenomena are used.

References

1. Voltage Multipliers Inc, Multiplier Design Guideline http://www.voltagemultipliers.com .
2. Marian Żenkiewicz, Tomasz Żuk, Ewa Markiewicz, Triboelectric series and electrostatic separation of some biopolymers, 2015 Elsevier Ltd. Polymer Testing 42, 192e198, doi.org/10.1016/j. polymertesting.2015.01.009.
3. S. N. Chaudhary, D. Elangavan, "High Gain, Naturally Clamped Dc to Dc Converter for X-ray Application", International Conference on Computation of Power, Energy Information and Communication (ICCPEIC), 2016, pp. 587-592.
4. Filiz Sari, Yunus Uzun, A Comparative Study: Voltage Multipliers for RF Energy Harvesting System, Communications Faculty of Sciences University of Ankara Series A2-A3: Physical Sciences and Engineering, 2019, DOI: 10.33769/aupse.469183.

5. Deepak Kumar Nayak, and Arjuna Muduli, Design of a GSM 900 Energy Harvesting Model for a Remote-Control Device, INTL JOURNAL OF ELECTRONICS AND TELECOMMUNICATIONS, 2022, VOL. 68, NO. 4, PP. 767-773, DOI: 10.24425/ijet.2022.143884.
6. N. A. Samsudin, S. Iqbal, S. Taib, "LLC Resonant High-voltage DC-DC Converter with Voltage Multiplier Rectifier", IEEE International Conference on Control System, Computing and Engineering, 2015, Penang, Malaysia, pp. 508-513.
7. Jan Mucko, The Cockcroft-Walton Voltage Multiplier Fed by an Inverter in Which the Series Resonant Phenomena Were Used, Innovative Materials and Technologies in Electrical Engineering (I-MITEL), Sulecin, 2018, p-ISBN: 978-1-5386-4669-4, IEEE Xplore, DOI: 10.1109/IMITEL.2018.8370479.

***Author**: dr hab. inż. Jan Mućko, profesor at PBS, Bydgoszcz University of Science and Technology (PBS), Bydgoszcz, Kaliskiego 7, 85-796 Bydgoszcz, Poland, e-mail: mucko@pbs.edu.pl*