Multi level Electronic Transformer

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Abstract – Serial connection of the rectifiers and parallel connection of the outputs of DCET are presented, providing reduced voltages of the components, as well as to increased battery charging current. Using the carried out investigations and experiments, useful relations are derived for dimensioning the components in the electronic transformer.

Keywords **– AC/DC converter, DC/AC, DCET, battery charging**

I. INTRODUCTION

The reduction of maximum static and dynamic voltage and current values of the converter components is achieved by using of multi-level converters. In [1] a three level converter operating on a common load and supply by a common source is presented. The operating high voltages require high voltage switching components and passive components .

The aim of the paper is introducing, analyzing and dimensioning of a “n” level converter, achieving considerable reduction of the voltages across the included converters. The converters are connected in series and their input and they are connected in parallel in their output (all the converters deliver energy to one and the same load).

II. BLOCK DIAGRAM

The block diagram of a “n” level converter is shown in fig.1. The block diagram includes n similar AC/DC converters, connected in series and “n” DC electronic transformers (DCET). The DCET operate on a common load. The choice of the number of the levels depends on the value of the supplying voltage and output voltage in order to obtain an optimal transformer ratio, n equal to 1 (n=1) [2].

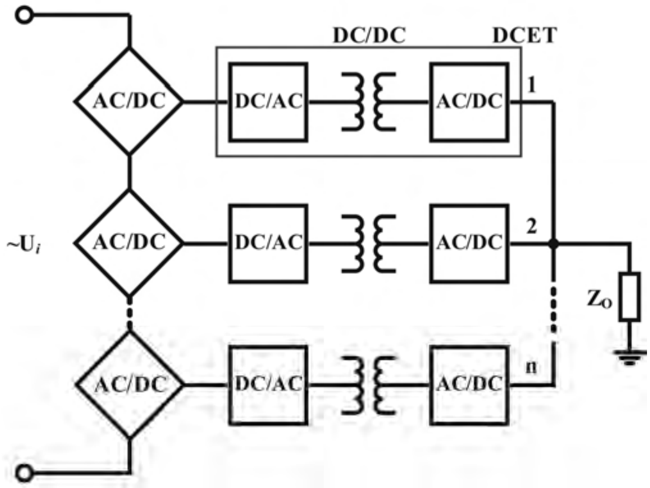

Fig. 1. Block diagram of a multilevel electronic transformer.

The realization of DCET can be achieved whit both one-switch or two-switch converters depending on the output power.

The power stage of one phase three level electronic transformer, suitable for battery charging, is shown in fig.2 Forward converter scheme is used to realize the levels of DCET. The new approach here is that the accumulated energy is transferred to the load by the windings w_m. This is obtainable because the load is almost purely capacitive [3,5,6]. The control of the power switches is realized by PWM controller, which is galvanically isolated in respect to the power stage [4].

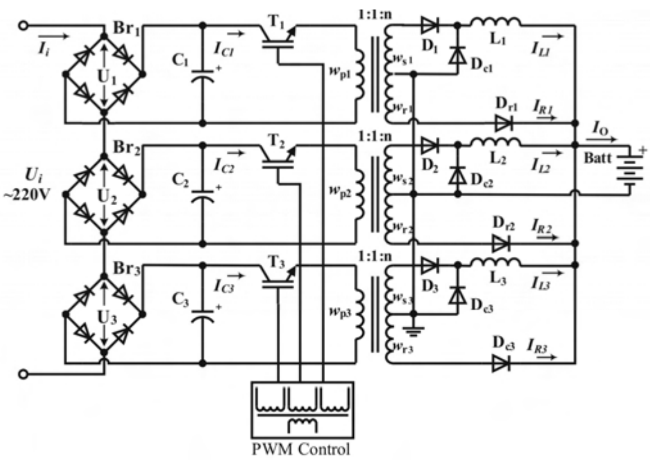

Fig. 2. Principle scheme of the power stage of a three level electronic transformer used for battery charging.

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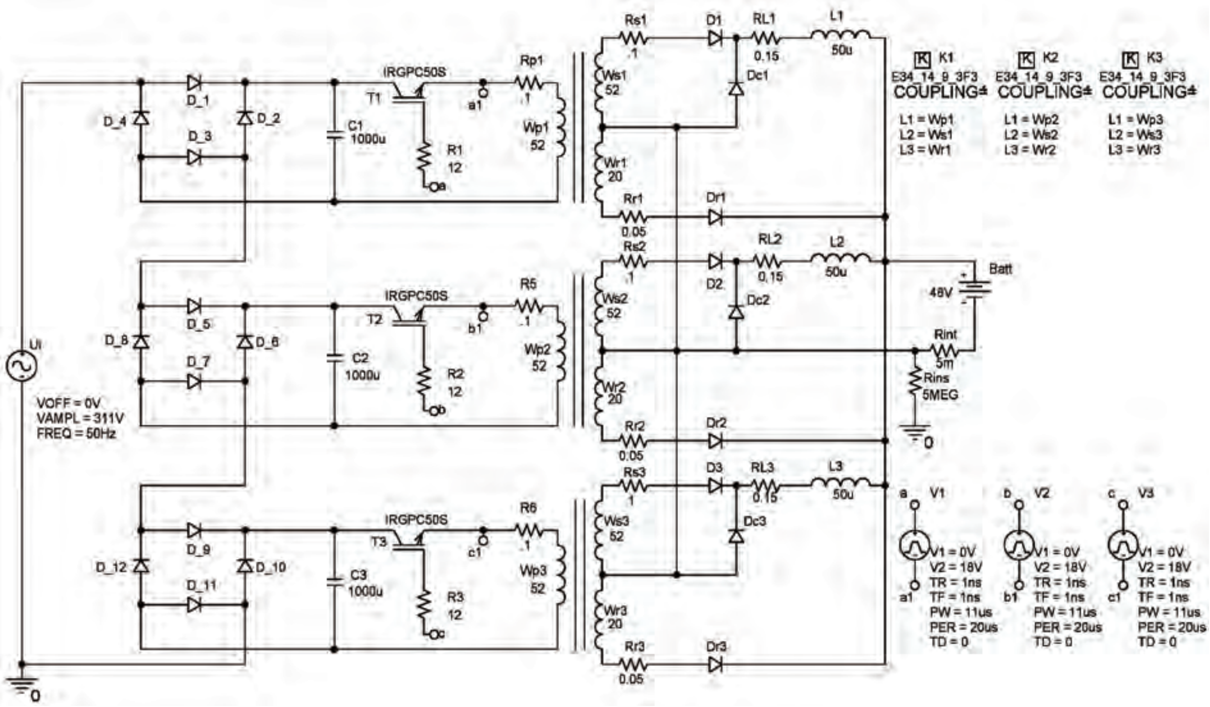

Fig. 3. PSpice model of the investigated three level electronic DCET for battery charging

A specific feature of the scheme is that the voltage across the diodes in the rectifier bridges Is three time less then the power supply voltage, and the battery charging current is three times higher then the power transistor current. This advantage can be taken in account in investigation and dimensioning of the scheme.

In fig. 3 is shown the PSpice equivalent model of the circuit. Transformers of each of the levels are designed for P_O=1000W. A magnetic core model of PHILIPS is used with parameters A_C=1,78cm^2, saturation induction B_{sat}=4900Gauss and μ_i=3000 [3]. For the designed power, inductors with L1=L2=L3=50µH are used.

In the equivalent model, the pulse-width modulator (PWM) is replaced by pulse generators V1, V2 and V3, which work synchronous without phase difference. The resistors Rp1÷Rp3, Rs1÷Rs3, Rr1÷Rr3 и RL1÷RL3 in the circuit represents the active resistance of the conductors of the windings. The resistor Rins represents the isolation resistance of the transformers, and Rint the internal resistance of the battery.

In fig. 4 and fig. 5 are given the waveforms from PSpice simulations, showing the functionality of the chosen circuit.

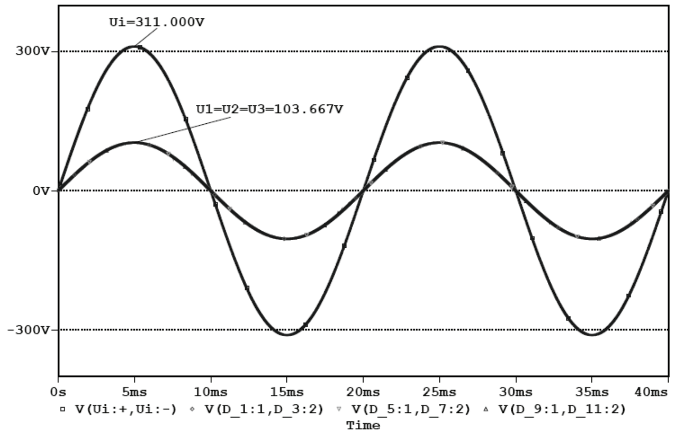

Fig. 4. Simulation waveforms of DCET

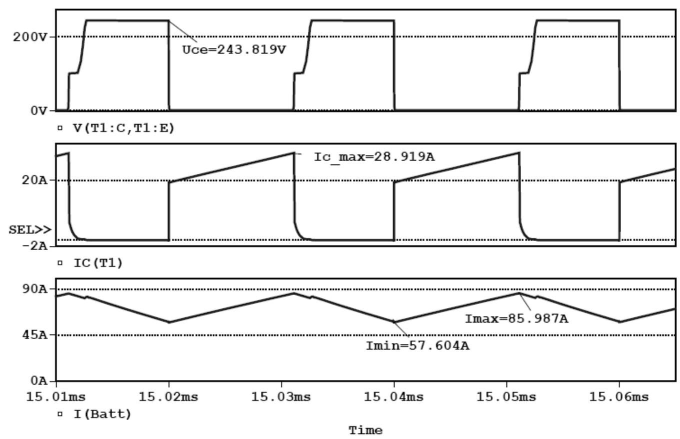

Fig. 5. Simulation waveforms of DCET, voltage and current of a power transistor and charge current of the battery

It can be noticed that:

- The input voltage of each stage (U_1, U_2, and U_3) are equal, and three times less, than the input voltage (U_i)
- The voltage across transistors is in the admissible range (U_{CE1}=2.4U_1)
- The current through the transistors has small AC component and no real peak values.
- The charge current of the battery is three times more, than the current in each level, at transformation coefficient k = 1.

It is necessary to investigate the possibility of stabilization of the charge current, when the supply voltage and the battery voltage change. In fig. 6 is shown the control characteristics of the device under test, when the supply voltage changes. One can see that the current can be regulated in the range of 20 ÷ 60A when the supply voltage changes with ΔUi= ± 20%.

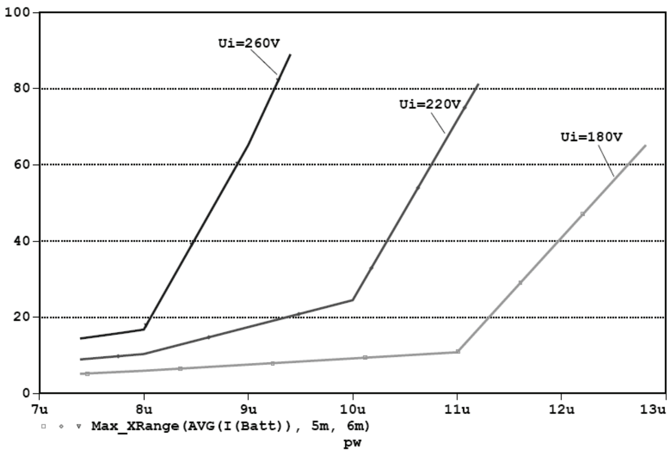

Fig. 6. Control characteristics of the circuit, when supply voltage changes

In fig.7 is shown the dependence of the charge current, on different values of the battery - U(Batt)= 44, 48 и 54V.

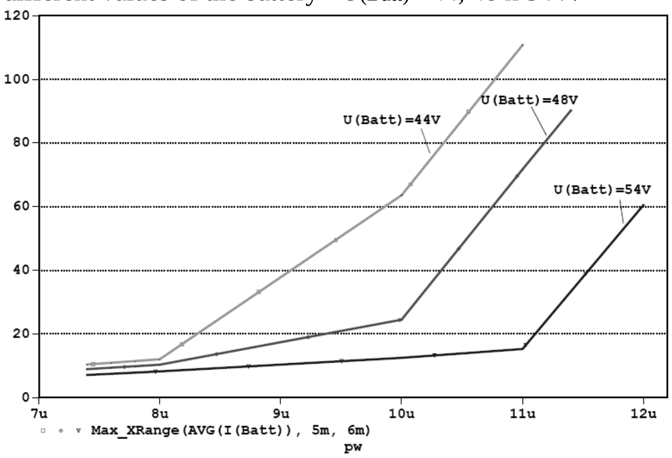

Fig. 7.Control characteristics of the circuit, when battery voltage changes

Two sections are clearly distinguished in fig.6 and fig. 7 are visible, characterized with different slopes. This is due to the discontinuous and continuous working mode of the converters. The discontinuous mode of the current through the inductance is achieved at low values of duty ratio δ and the charge current depend less on δ.

The dependence of the maximum voltage across the power transistors upon the charge current with battery voltage changing (U(Batt)= 44, 48 and 54V) is shown on fig. 8

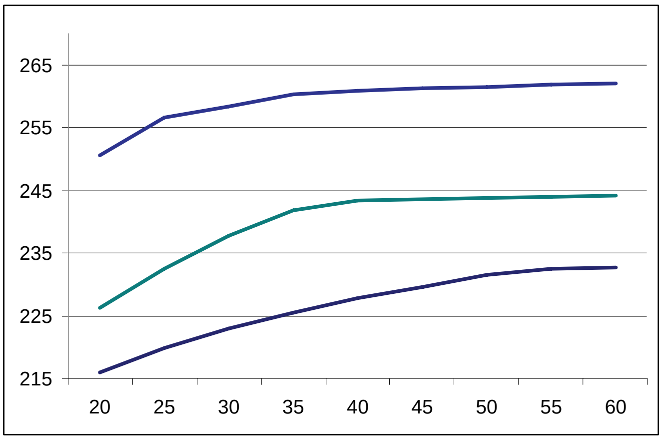

Fig. 8. Voltage across the power transistors versus the charge current

When the charge current changes according to the specifications (20A ÷ 60A), and the battery voltage is in the range U_{batt}=(44÷54)V, the voltage across the power transistors does not change a lot U_{CE}=(2.2 ÷ 2.6)U', where U'=U_1=U_2=U_3 is the supply voltage of each stage.

On the basis of the obtain waveforms and the dependences for the voltage and current of its components, several formulas can be derived to help dimensioning these components. The average value of the current through the power transistor is:

$$I_C = \frac{1}{T}\int_0^{t_И} k.\frac{I_O}{n}dt = \frac{k.\delta.I_O}{n}, \qquad (1)$$

where $k = \frac{w_s}{w_p}$ is the transformation coefficient of the power transformers;

n is number of levels (stages) of DCET.

The maximum value of the voltage across the transistors is:

$$U_{CE} = \frac{\gamma.U_{im}}{n}, \qquad (2)$$

where γ=(2.2÷3) is a coefficient giving voltage loading of the transistor.

The required value of the inductance in each level is determined by the admissible pulsations of the charge current:

$$L_n = \frac{n.U_0.(1-\delta)}{a.f.I_0}, \qquad (3)$$

where:

L_n is the inductance in each level;

a is the pulsations coefficient and $a \in [1.5 \div 3]$;

U_O is the output voltage;

f is the working frequency of the converters.

The choice of the number of levels depends on the supply voltage and the output voltage. In this way optimal structure of the transformer can be obtained with transformation coefficient k=1[4].

CONCLUSION

Serial connection of the rectifiers and parallel connection of the outputs of DCET leads to reducing the working voltages of the transistors and the reactive elements, as well as to increasing the charging current of the battery.

When the supply voltage changes and/or battery voltage vary (according to the specifications), a constant value of the charging current is obtained by controlling the duty ratio δ.

Using the carried out investigations and experiments, useful relations are derived for dimensioning the components in the electronic transformer.

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