The Single-phase AC Regulator on Base of Bidirectional IGBT Switches

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Abstract. **In the work one of the methods for regulation of sinus shape AC voltage for middle-power loads with active-inductive character is observed. Such a regulator keeping output voltage of sinus shape must be fast-reacting and work in closed-loop system. It's shown, that for providing such features Buck and Boost pulse regulators can be applied. The only difference from DC pulse converters is that electronic switches in the system must be with bidirectional conductivity. For this reason an IGBT transistors can be applied with implemented in structure reverse diodes and if such two transistors are connected in series and with contrary conductivity then at activating both one of them will be in on-state. Realization of AC regulators with such switches is described in the work. Results of computer modeling also are given. Output voltage ripples are investigated on subject of their range and efficiency of filtering equipment on LC base. Such regulators can be applied for instance in electrical transport self supply systems.**

Keywords: **bidirectional semiconductor switches, harmonic distortion, insulated gate bipolar transistors, reactive power**

I. Introduction

Ordinary method for regulation and stabilization of AC voltage is based on application of an auto-transformer. But such method is not contact-less and requires a bulk size and expensive transformer. One of possible alternative solutions for regulation and stabilization of AC single-phase voltage can be based on application of pulse regulation methods, using transistor switches, which is ordinary for DC circuits. Applying this method in AC circuits must be solved problem with bi-directional semiconductor switches.

II. Description of the method

Let's discuss essence of step-down or Buck mode AC regulator substituting transistor switches with the ideal contact ones (Fig.1-a). Switch is operating with rather high frequency f and duty ratio

$$\gamma = \frac{t_{ie}}{T}, \qquad (1)$$

where: t_{ie} – time when the switch is attached to terminal "1" (Fig.1-b); T – is switching cycle $T=1/f$; f – frequency. Circuit of load must be clamped and when switch is turned off - position „0", active-inductive load's current can by-pass through clamping circuit.

If time constant of load circuit is much bigger than switching cycle time then load current at fundamental frequency 50 Hz of supply will be smoothed and continuous, i.e., in duration of „0" position bigger as zero.

Averaged value of output voltage in one cycle time of switching is

$$u_{iz(vid)} = \frac{1}{T}\int_0^{t_{ie}} U_m \sin\omega t dt = \gamma U_m \sin\omega t, \qquad (2)$$

where: ω – is angular frequency of the supply voltage, U_m – amplitude of the input voltage. Corresponding RMS value of voltage in one switching cycle time is

$$U_{iz} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} u^2_{iz(vid)} d\omega t} = \gamma U, \qquad (3)$$

where: $U = U_m/\sqrt{2}$. If it is assumed that $\omega L_f << \sqrt{R^2_{sl} + \omega^2 L^2_{sl}}$ and ωL_f – is inductive impedance of filter. At the same time $1/\omega C_f >> \sqrt{R^2_{sl} + \omega^2 L^2_{sl}}$, where $1/\omega C_f$ – capacitive reactance of the filter. Then RMS value of the voltage across the load is:

$$U_{sl} \cong \gamma U = \frac{\gamma U_m}{\sqrt{2}}, \qquad (4)$$

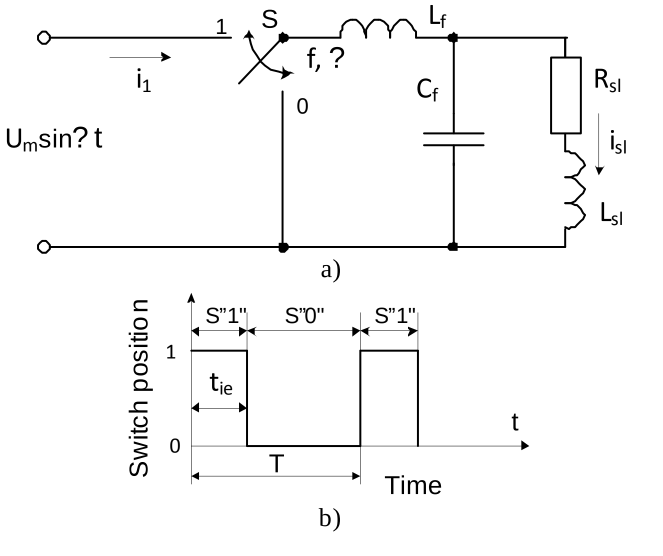

Fig.1. Substitution scheme of the single-phase sinus shape voltage step-down pulse regulator (a), switching diagram of switch S (b).

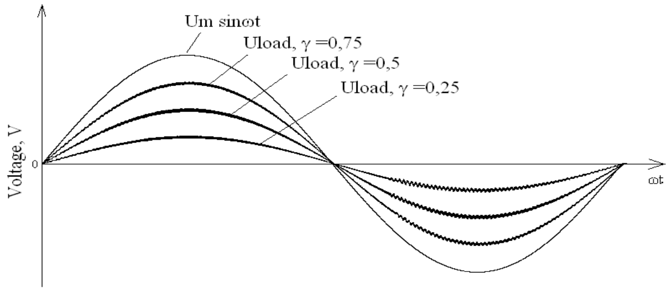

Fig.2. Voltage diagrams for step-down pulse regulator at different values of duty ratio *γ*.

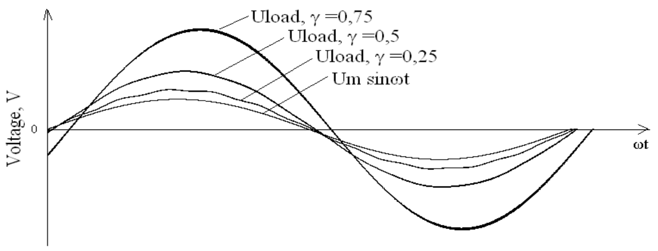

Fig.4. Diagrams of output AC voltage of step-up pulse regulator at different values of duty ratio *γ*.

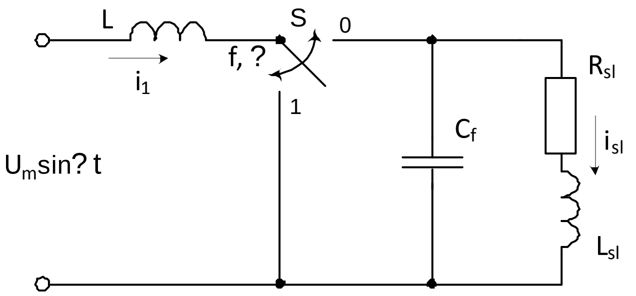

Fig.3. Substitution scheme of step-up pulse converter application for sinus shape AC voltage.

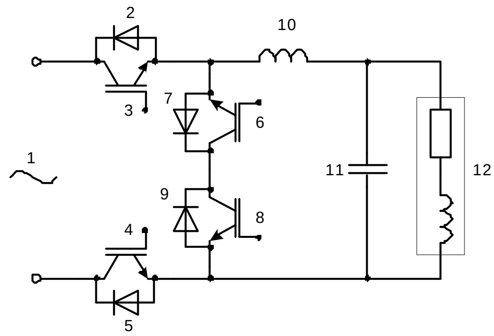

Fig.5. Scheme of single-phase voltage step-down pulse regulator.

The load current then can be calculated as

$$I_{sl} = \frac{\gamma U}{\sqrt{R_{sl}^2 + \omega^2 L_{sl}^2}}, \qquad (5)$$

where R_{sl} – resistance of the load, L_{sl} – its inductance.

Similarly as for DC pulse regulators, there are possible several variants for realization of the duty ratio γ variations. If switching frequency is constant, then γ can be changed increasing or decreasing duty time duration in turned-on position „1" of the switch S. Such realization is nominated as Pulse Width Modulation (PWM). This is most applied regulation method results on using it for sinus shape voltage diagrams at different values of γ are presented in Fig.2.

If switch is connected in parallel to source through inductance L, which is applied as energy storage device, then it's possible to obtain voltage step-up pulse regulator (Fig.3).

Using RMS values of AC voltage at neglecting of losses in pulse regulator, load voltage can be calculated as

$$U_{sl} = \frac{U}{1-\gamma}. \qquad (6)$$

In the case similarly as for step-down regulator, effect can be obtained at variations of duty time duration of position „1" of switch S in switching cycle and voltage diagrams at different γ will be in accordance with presented in Fig.4.

Because each source has itself an active resistance and inductance then source voltage $U_m \times \sin \omega t$ really begins decrease and voltage of load cannot increase to endless value.

Then the load voltage can be found as

$$\dot{U}_{sl} = \dot{U}_0 - \left(\frac{\dot{I}_{sl} Z_1}{1-\gamma} \right), \qquad (7)$$

where Z_1 is complex impedance of source, U_0 – no-load voltage. It is possible to conclude that

$$\frac{\dot{U}_{sl}}{\dot{U}_0} = \frac{1-\gamma-k}{(1-\gamma)^2}, \qquad (8)$$

where $k = \dot{I}_{sl} Z_1 / \dot{U}_0$. Based on this equation the maximum of voltage can be estimated.

Generally sinus shape voltages in Fig.4 are mutually shifted by phase as it can be seen from above given expressions (7, 8) with complex numbers.

III. Realization of AC pulse regulators

For practical realization of pulse regulator must be applied IGBT transistors with freewheeling diodes.

Pulse regulation is obtained so, that in AC circuit are inserted two transistors in series but with opposite direction of conductivity, but in parallel to load also are inserted same configuration of transistors. Control power of transistors is small and therefore best way is activate both counter-connected transistors with common for the both control pulse (Fig.5). Load circuit is operating from L-C filter.

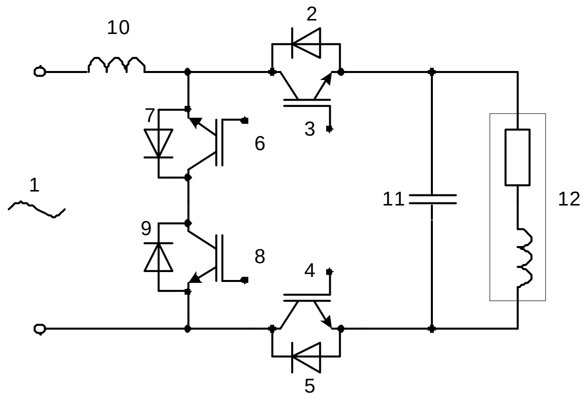

Fig.6. Scheme of the single-phase voltage step-up pulse regulator.

Contrary conducting transistors 3, 4 are inserted in series in AC circuit, each of them are clamped with reverse diodes respectively 2 and 5. In the common circuit of mentioned transistors and load 12 a reactor 10 is inserted, but in parallel to the load – capacitor 11, forming with the reactor an L-C output filter. In parallel to circuit of the reactor and capacitor two more contrary conducting transistors 6 and 8 with reverse diodes respectively 7 and 9 are introduced.

Regulator is working in such way, that when voltage of source is bigger than rated one, control pulse generation junction is sending alternately high frequency pulses to the transistors 3, 4 and to 8, 6. When pulses are applied to transistors 3, 4, then not dependent on polarity of AC voltage the filter circuit is connected to the supply source and current in circuit by absolute meaning is rising. If current is passing through transistor 3, then simultaneously diode 5 is also conducting; if in other half cycle current is passing through transistor 4, then diode 2 is also conducting.

When control pulses are disconnected from transistors 3, 4, transistors 6, 8 are activated simultaneously, providing not dependently on direction of current clamping way for reactor 10 current. If reactor's current is passing on capacitor, then current is passing through transistor 6 and diode 9; if direction of reactor's current is opposite then transistor 8 and diode 7.

If voltage across a load is not sufficiently high then longer pulses are applied to transistors in source circuit 3, 4, but to 6, 8 – shorter. If voltage across load is too large then pulse duration for transistors 3, 4 is shortened, but for 6, 8 – increased. In such way stabilization of load voltage level is provided.

If transistors are switched with much higher frequency than rated frequency of supply source then because of filter operation voltage of its capacitor 11 is practically of sinus shape.

If supply voltage is smaller than rated value of load voltage then control pulses are applied alternatively to transistors 6, 8 and 3, 4 (Fig.6). Independently from polarity of source voltage reactor 10 through transistor 8, diode 7 or transistor 6, diode 9 is connected to the source terminals and electromagnetic energy is stored in the reactor. When control of transistors 6, 8 is deactivated control of transistors 3, 4 is activated and independently on polarity of current in reactor 10 the later is inserted in series with load. As result voltage of capacitor 11 is increasing as also load voltage. If load voltage is smaller than longer transistors 6, 8 are activated in switching cycle but shorter time duration – transistors 3, 4. If load voltage is rising above preset value then transistors 3, 4 are activate longer, but 6, 8 – shorter. In such way load voltage is stabilized.

IV. Computer simulation of the scheme

Computer simulation is provided using simulation package PSIM which allow provide simplified simulations. As it is seen from diagrams Fig.8 and Fig.9 ripples of output voltage are bigger at smaller parameters (capacitance and inductance) of output filter.

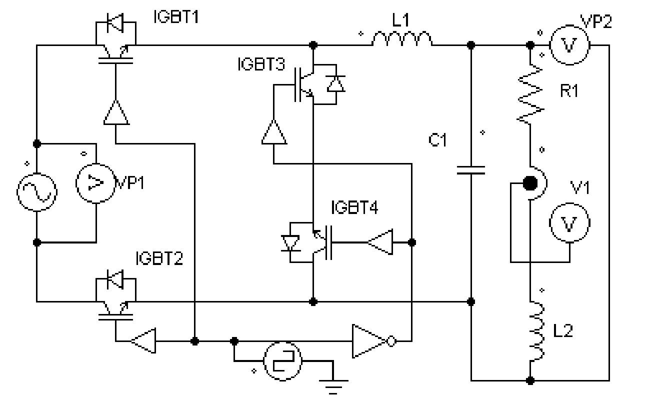

Fig.7. Scheme of computer simulation of step-down pulse converter at $\cos\varphi$ = 0,8 and active power of load P= 1,5 kW, keeping duty ratio γ=0,5, $U_{baroš}$=220V, switching frequency = 50kHz.

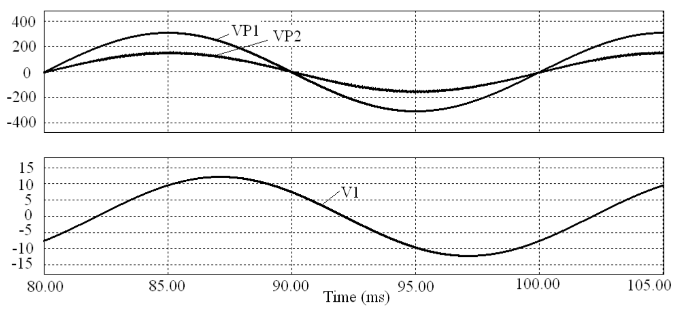

Fig.8. Modeling of step-down pulse regulator at parameters of filter L1=1mH and C1=0,5μF.

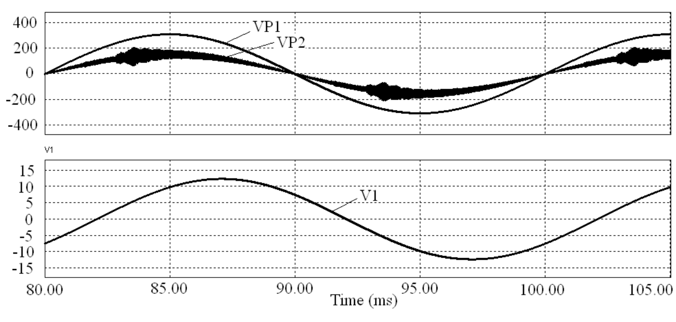

Fig.9. Diagrams of voltages and currents for step-down pulse regulator at parameters of filter L1=0,2mH and C1=0,5μF.

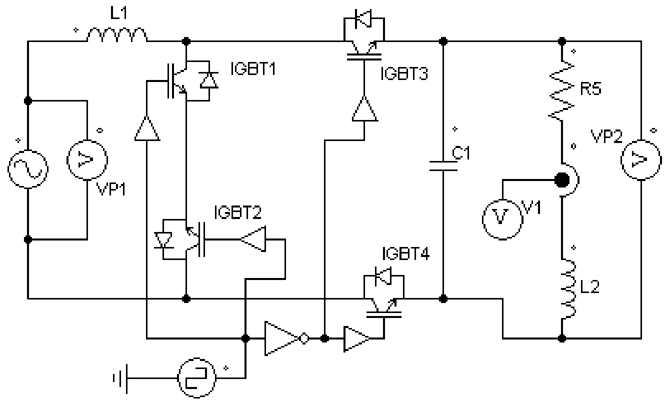

Fig.10. Computer modeling scheme for step-up pulse regulator at load's $\cos\varphi = 0{,}8$ and its active power P= 2,5 kW, duty ration γ=0,5, $U_{baroš}$=110V.

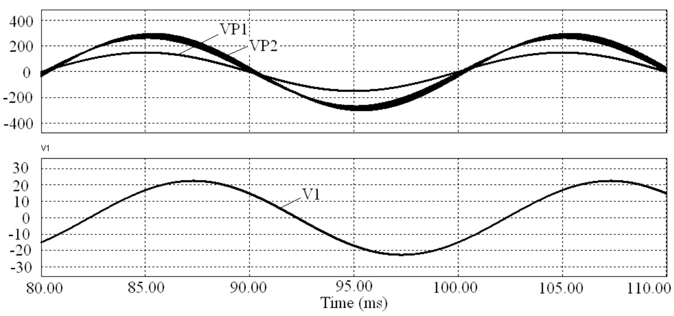

Fig.11. Simulation diagrams for step-up pulse regulator at capacitance C1=5μF.

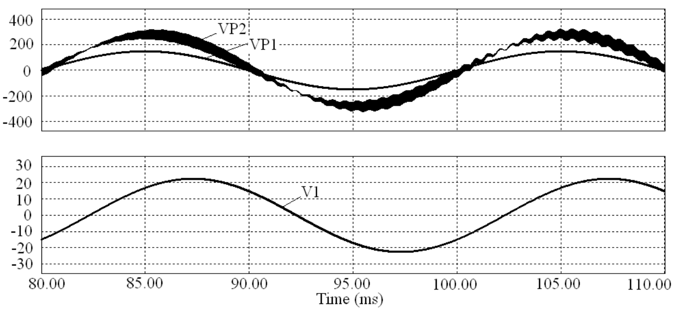

Fig.12. Simulation diagrams for step-up pulse regulator at capacitance C1=2,5μF.

V. CONCLUSIONS

1. Schemes for step-down and step-up pulse regulators of the AC sinus shape voltage are elaborated using as base switches an IGBT transistors connected in contrary conduction direction and controlled by simplified algorithm.

2. Computer simulation of elaborated high-frequency schemes approved possibility to construct an industrial pulse regulators on its base for supply of middle-power loads.

3. Synthesizing stabilizer on base of created schemes output of converter must be supported by filter which must be constructed taking into account quality of output voltage for accepted load at all deviations of input AC voltage values.

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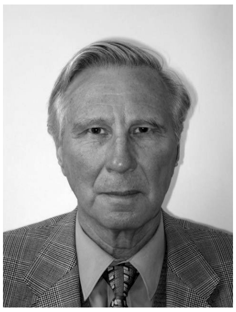

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