THYRISTOR DIRECT CONVERTERS FOR SUPPLY OF RESISTANCE WELDING MACHINES

P.M. RUDENKO and **V.S. GAVRISH**
E.O. Paton Electric Welding Institute, NASU
11 Bozhenko Str., 03680, Kiev, Ukraine. E-mail: office@paton.kiev.ua

Machines for resistance and flash-butt welding, power of which can reach several hundreds of kilowatts, are widely used for manufacture of metallic structures and parts. In present time power supply schemes from alternating current main of 50 (60 Hz) frequency, single- and double phase, became the most wide spread for power supply of these machines. Now significant attention is paid to providing of electromagnetic compatibility of energy consumers, especially such powerful as resistance welding machines. This can be provided at uniform loading of three-phase main, including with the help of converters of frequency and number of phases. Aim of the present paper is development and analysis of frequency converters providing uniform loading of three-phase main for existing powerful resistance welding machines, the welding transformers of which are designed for supply from single-phase 50 Hz main. Shown are advantages and disadvantages of the converters operating on 30, 37.5 and 45 Hz frequencies. Pilot specimen of 37.5 Hz converter passed industrial tests during welding of railway rails. 5 Ref., 3 Figures.

Keywords: *resistance welding machines, converters of frequency and number of phases, uniform loading of three-phase main*

Machines for resistance and flash-butt welding are widely used in manufacture of metallic structures and parts. At that, each of them can have different power supply schemes [1–3], the following obtained the highest distribution, i.e.:

• from alternating current main of 50 (60 Hz) frequency, single- and double-phase;

• from converters of frequency and number of phases;

• from sources of rectified voltage of industrial frequency;

• from inverters of increased frequency with further rectifying;

• from condenser type sources.

Variety of power supply schemes is explained by the necessity of setting and working out of different welding cycles providing required quality of welded joints from different metals and alloys. Besides, great attention in present time is paid to electromagnetic compatibility of energy consumers, in particular, such powerful as resistance welding machines (GOST 13109–97). This can be provided at uniform loading of three-phase main, including with the help of converters of frequency and number of phases.

Thus, frequency converters which found application in resistance welding were developed by «Sciaky» company for the first time [1, 2]. However, regardless good technological indices, they did not found wide distribution due to bulky and heavy welding transformer designed for very low frequency (approximately several hertz). A conclusion that required electric and technological characteristics can be obtained at higher frequencies was made based on analysis of frequency characteristics of similar machines, performed by V.K. Lebedev [2].

Converter operating at 30 Hz frequency without valves on secondary circuit of the welding machine and providing uniform loading of three-phase electric main was proposed [2]. The welding machines with such a converter have technological as well as energy advantages in comparison with the single-phase machines. They exceed direct current machines on efficiency and some other characteristics. However, these machines have specific disadvantages, i.e. increased mass and dimensions of the welding transformer in comparison with industrial frequency machines; impossibility of application of such a converter for power supply of existing single-phase resistance machines without reduction of supply voltage since in this situation open-circuit current of the welding transformer rises dramatically (in dozen times) that results in rise of electric losses and failures in operation of automatic regulation systems up to emergency modes.

Aim of the present work is development and analysis of frequency converters providing uniform loading of the three-phase main of existing powerful resistance machines, the welding transformers of which are designed for supply from single-phase 50 Hz main. The authors developed the algorithms for control of converters using 37.5 and 45 Hz at which these drawbacks are eliminated to a considerable extent. Forms of voltage in the output of such converters are given on Figure 1.

The most simple and safe three-phase converter of number of phases can be build on scheme with direct conversion (without intermediate rung of direct current) applying thyristors as control elements which allow multiple current overload. Efficiency of converter operation is evaluated on efficient coefficient K_e, of loading of the main at single and three-phase power supply as well as minimum averaging time of phase (linear) current at uniform phase loading.

At that, the most effective scheme of power source could be a three-phase rectifier. If loading on each phase is similar (that can be assumed with accuracy sufficient for practical evaluation), an average value of each phase current, and respectively, corresponding power, will be constant at averaging time equal half of the period, i.e. 10 ms.

At that, if drop in voltage on the diodes is neglected, efficient voltage in the output of full-wave three-phase bridge (6-pulse scheme of rectification) makes

$$U_e = 0.957U_m,$$

where U_m is an amplitude of linear voltage.

As it is known, efficient voltage of double-phase power main is $U_e = 0.707U_m$. Further, it is assumed for simplification of evaluation that modulus of total resistance of load circuit which depends on frequency of feed voltage, Z will change insignificantly as for considered forms of output voltage. Then full-wave three-phase bridge will have the following value of coefficient of main load efficiency, i.e. specific power at its output in comparison with maximum possible consumption of power only from two phases

$$K_e = (0.957U_m/0.707U_m)^2 = 1.832.$$

Such a system also has technological advantages since amplitude coefficient representing itself relation of amplitude voltage value to its effective value $K_a = U_a/U_e$ equals 1.045, whereas that for alternating current makes $K_a = 1.41$ [1].

It should be noted that power supply system is symmetric and balanced, if sum of instantaneous powers on each phase at any moment of time is constant. The efficiency coefficient makes $K_e = 3$ at such power consumption.

Efficiency of the rectifier power circuit reduces due to necessity of rectifier being set into the secondary circuit of power transformer. At that, drop of voltage on the diodes is comparable

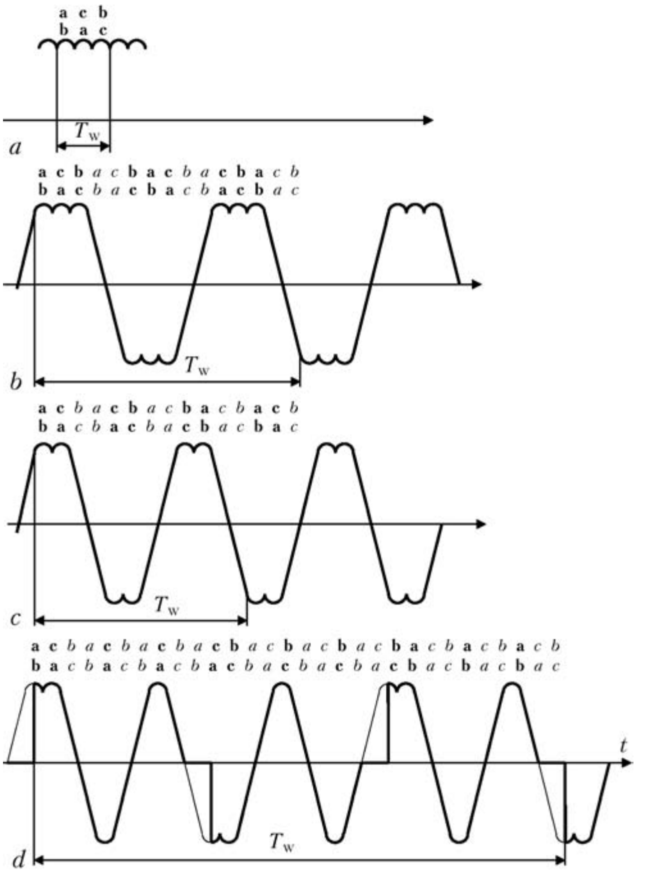

Figure 1. Forms of voltage in the output of 6-pulse rectifier (*a*), frequency converter 30 (*b*), 37.5 (*c*) and 45 (*d*) Hz. Bold type letters are linear voltages at which rectifier is switched on

with voltage in the output of rectifier and significant part of the power is lost on the rectifier.

If converter which supply primary circuit of the power transformer with voltage in form of pulses of quasi-direct current is used, than losses on controlled rectifiers will be insignificant. However, if polarity of voltage pulses at the transformer output is switched, it is necessary to pass switching as minimum in two subsequent series of linear voltages. Because of this duration of each semi-period increases for 6.6 ms and, respectively, averaging time rises at which phase currents are rectified and output power of supply scheme, consequently, drops.

Thus, with frequency of output voltage 30 Hz

$$K_e = 1.314,\ T_w = 50\ \text{ms},\ K_a = 1.23,$$

and with 37.5 Hz

$$K_e = 1.195,\ T_w = 40\ \text{ms},\ K_a = 1.29.$$

Specially designed transformers are to be used for work with indicated frequencies. Simple transformers set on double-phase welding machines for alternating current of 50 Hz frequency are difficult to be used due to their high open-circuit current at frequencies lower 50 Hz, for example, 37.5 Hz.

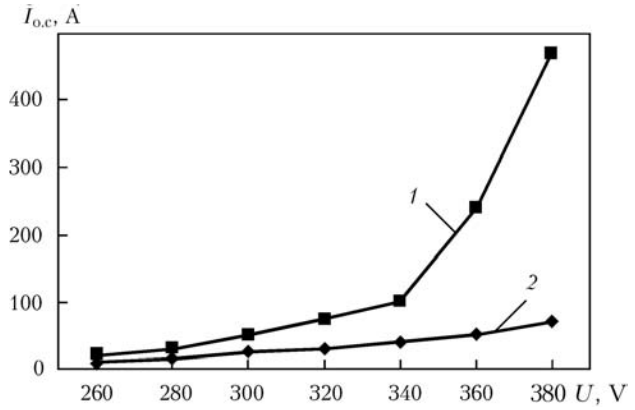

Figure 2. Dependence of open-circuit current on input voltage for welding transformers of K-190 (*2*) and K-1000 (*1*) machines at supply from 37.5 Hz frequency converter

Thus, experimental investigations of power transformer for resistance machine K-1000 showed 10 time increase of open-circuit current at supply from alternating current main of above 360 V voltage and frequency 37.5 Hz in comparison with supply of 50 Hz frequency voltage at the same effective voltage (Figure 2). Open-circuit current for machine K-190 makes 20A and for machine K-1000 is 35 A at supply from alternating current main of 50 Hz frequency, voltage U = 380 V. It is obvious that operation of the transformers would be more complicated at 30 Hz voltage frequency.

Special measures should be taken, if the converter is supposed to be used for 50 (60) Hz transformers. At that, the main index, i.e. equal phase loading, should be preserved.

The most simple method for frequency increase is «insert» of multiple number of periods of voltage with 50 Hz frequency in a form of 37.5 Hz voltage after each voltage pulse of similar polarity in that linear voltage at which pulse ends [4]. In this case

$$K_e = [(2n + 1)/(2n + 1.333)]^2,$$

$$T_w = 40 + 60n,\ K_a = 1.41(2n + 1.133)/(2n + 1).$$

In particular, frequency of voltage makes 45 Hz at $n = 1$ [5]

$$K_e = 0.81,\ T_w = 100 \text{ ms},\ K_a = 1.56.$$

Indexes of efficiency on power and coefficient of amplitude approach to data for double-phase power since power is virtually carried out by series of 50 Hz pulses. At that, open-circuit current of welding transformer significantly reduces and three-phase selection of electric power allows obtaining uniform main load at 0.1 s averaging time.

Therefore, all considered algorithms have advantages as well as disadvantages. The algorithm using voltage of 37.5 Hz frequency is the most optimum for already existing welding machines.

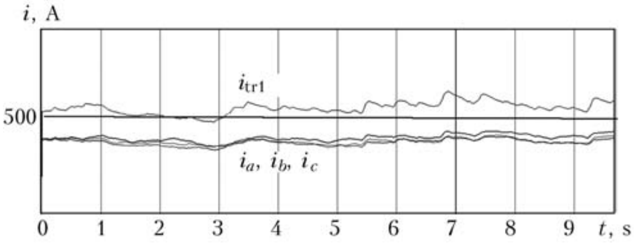

Figure 3. Oscillograms of currents i_a, i_b, i_c in A, B, C phases in the input of converter and current in the primary circuit of welding transformer i_{tr1} in welding of rails on K-1000 machine using converter of frequency and number of phases

Power source with 37.5 Hz voltage frequency passed industrial tests during resistance welding of large section parts. It was used in fusion welding more that two years on rail welding train (technological tests of the power source were guided by staff researcher of the E.O. Paton Electric Welding Institute A.V. Didkovsky). Welding of strings set in main rail track was carried at final stage of testing. In the first as well as second cases the quality of welded parts met the technical requirements for these parts.

Oscilography of phase currents in the input of converter of frequency and number of phases in welding (Figure 3) showed that they are equal between each other and reduces per 20 % in comparison with current in load (source output).

Conclusions

1. Frequency converters with control algorithms on 37.5 and 45 Hz frequencies have electric advantages over power sources for resistance welding machines of industrial frequency due to consumption of electric energy from three phases.

2. Pilot tests of frequency converter on 37.5 Hz showed possibility and appropriateness of its application for flash-butt welding, in particular, of railways rails. At that, uniform load of three-phase electric main is provided.

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