

Запропоновано схемне рішення і алгоритм управління зварювального джерела живлення для TIG-AC зварювання з поліпшеними енергетичними характеристиками. Джерело виконане із застосуванням зварювального трансформатора і низьковольтного силового послідовного активного фільтра на силових польових транзисторах з малим опором каналу. Застосовуваний трансформатор може бути з нормальним або підвищеним розсіюванням. Запропоноване джерело характеризується поліпшеними технічними показниками за рахунок можливості формування ВАХ з необхідною жорсткістю без перемикання зварювального трансформатора. Схема управління забезпечує усунення постійної складової зварювального струму при TIG-AC процесі; можливе управління формою зварювального струму. Також забезпечується «м'який» підпал дуги за принципом Lift-Arc, що сприятливо позначається на терміні служби неплавкого електроду. Розроблене джерело відрізняється можливістю роботи в режимі компенсації реактивної потужності. Це дозволяє знизити споживання реактивної потужності електротехнічними комплексами зі зварювальними джерелами живлення і знизити струмове навантаження на розподільчу мережу. Застосування запропонованого принципу побудови джерела для дугового зварювання змінним струмом дозволяє виконувати модернізацію наявних трансформаторних джерел шляхом установки в них блоку активного фільтра. Це дозволить поліпшити споживчі властивості джерел за рахунок поліпшення стабільності горіння зварювальної дуги, плавного регулювання зварювального струму, зниження впливу коливань напруги мережі на якість процесу зварювання. Усувається необхідність в застосуванні баластних резисторів для регулювання зварювального струму, а також блоку конденсаторів для усунення підмагнічування трансформатора при TIG-AC процесі. Запропоноване джерело може бути використане не тільки для реалізації TIG-AC, але і для MMA, MIG, MAG процесів зварювання на змінному струмі

Ключові слова: зварювання неплавким електродом, зварювальне джерело живлення, реактивна потужність, активний фільтр

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IMPROVING ENERGY CHARACTERISTICS OF THE WELDING POWER SOURCES FOR TIG-AC WELDING

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1. Introduction

The static and dynamic characteristics of a power source and its ability to maintain stable arcing exert a great impact on the quality of a welding joint. Therefore, it is a relevant task to construct power sources for welding and related technologies, with improved technical and economic characteristics.

Implementing manual arc welding with a coated electrode (MMA), as well as welding in the environment of inert gas (MIG), including with a non-fusible electrode (TIG), necessitates, first, facilitating the initiation of arc discharge, second, stabilizing the process of arcing. When powered by an AC network, the repeated arc excitation should occur after each transition of the source voltage through zero [1]. In addition, at TIG welding, it is advisable to limit the energy that is released at breakdown of the arc gap, as the increased discharge energy is accompanied by the erosion of a non-fusible electrode, which reduces its service life. Therefore, the relevant tasks are to stabilize arc, to excite the arc with a minimum required discharge energy, and to ensure stable arcing during welding.

2. Literature review and problem statement

The TIG-AC process (Tungsten Inert Gas – Alternating Current) is often used to weld aluminum alloys, in which the AC electric arc burns between a non-fusible tungsten electrode and an aluminum article.

The voltage on a welding arc over one half-period may differ from the voltage over another half-period due to the different emission properties of the electrode and the article's metal. Because of this, a DC current component emerges in the welding circuit, which can be up to 70 – 80 % of the working welding current [2]. This component of the welding current causes the magnetization of the core of the welding transformer, which leads to the growth of the magnetization current and to overheating the transformer.

The DC component of the secondary current of the welding transformer can be eliminated by including a capacitor battery into the welding circuit [3]. The advantage of this technique is the ease of implementation. The drawbacks of the technique: complexity of weldin 23 g current regulation, poor mass-size indicators, impossibility to ensure a quality welding process without the use of expensive equipment, low reliability of equipment (battery of electrolytic capacitors).

Compensators consisting of a resistor, diode and thyristor, connected in parallel, can be used to eliminate the permanent component [4, 5]. Thyristor is used to introduce a pause (in the order of 1 ms) in the main current when it changes to a positive polarity. At the same time, the current of reverse polarity goes through the diode, and to ensure the burning of an arc “on duty” at the closed thyristor, a resistor is used. Such a technique does not completely eliminate the magnetization of the welding transformer, although it brings the constant component to the level of 10–12 % of the main current.

In welding sources that use the inverter-fed welding transformer, a technique can be used to eliminate the magnetization of the welding transformer, which is to indirectly measure its current of magnetization and correct signals to control the inverter [6].

In welding sources based on high-frequency converters [7–9], the problem of transformer magnetization usually does not occur. However, the presence of an output rectifier in such sources limits their use only for DC current welding. To implement the process of alternating current welding, one must use an additional cascade of polarity change [10, 11], which leads to an increase in cost, dimensions, mass of the source and a decrease in its efficiency.

The quality of a welding joint is also affected by the dynamic properties of a power source [12, 13]. Given this, sources for pulse-arc welding are being developed [14]. Since improving the output current change dynamics requires an increase in the switching rate of key elements, sources based on resonance converters are being developed [15, 16]. Moreover, in order to reduce dynamic losses, they use the transfer of active power on the higher harmonics of the output signal of the inverter [17]. A common drawback of the above sources is the need for an additional cascade to ensure operation with alternating welding current.

In addition to providing a quality power supply to the welding process, the development of modern sources should pay attention to their electromagnetic compatibility. In Europe, there are standards such as IEC61000-3-2, IEC61000-3-12, which normalize the emission of higher current harmonics by technical means connected to the 0.4 kV network. In order to meet these standards, the inverter sources must include rectifiers to adjust a power factor [18]. It is also possible to use active filters of higher harmonics [19], or to use special converters powered by a three-phase [20] or a single-phase network [21]. Such technical solutions are more complex and impair the technical-economic characteristics of the welding source.

An increase in the power factor is also possible by applying the modular structure sources with a separate converter in each phase. This approach is only applicable to sources with three-phase power. For example, paper [22] uses three bridge invertors working on a total load – a welding arc. The main drawback of this technical solution is the large number of power keys (12) with appropriate control schemes.

Study [23] implements a similar approach, but with push-pull converters. The number of power components was reduced by 2 times to 6, but this was achieved at the expense of increasing the working voltage, which does not make it possible to call such an approach feasible.

Paper [25] also implements the modular principle of building a source with a high power factor using direct converters; study [25] – with the use of isolated Zeta converters. Both solutions, although distinguished by a small number of

power transistors (3), have serious drawbacks – incomplete use of magnetic circuits of power transformers, large peak currents, and overvoltage on power transistors.

There is a technique to eliminate the permanent component of the secondary current of a welding transformer [26], which is to serially include along with the welding arc the controlled source of EMF (a consistent power active filter). This makes it possible to eliminate the permanent component, to regulate the current of the arc and, maintaining zero balance of the active power of the EMF source, to implement it without an additional power source.

The EMF controlled source is made in the form of a bridge inverter formed by four power keys with a control system. The inverter AC leads are included in the welding chain; the DC link of the inverter includes a large capacity storage capacitor.

The advantages of this technique are: eliminating the permanent component of the secondary current of the welding transformer, improving the mass-size indicators of the power source, improving its reliability, and ensuring smooth regulation of the welding current. The disadvantages of the technique include the inability to control the shape of the welding current and the relatively long transition time at the beginning of welding due to the presence of a phase locked loop (PLL). Since PLL, given its specificity, has a rather long time of synchronization (capture), it would, under actual conditions of welding, lead to the disruption of a welding regime at its beginning (immediately after arc ignition) and worsen the quality of a welding joint.

3. The aim and objectives of the study

The aim of this study is to design a welding power source with improved energy characteristics for TIG-AC welding, which would make it possible to eliminate the permanent component in the welding current, to improve the technical-economic parameters of welding process by improving stability of the welding arc current. To achieve the goals set, the power part of the source is made based on a series active filter.

To accomplish the aim, the following tasks have been set:

- to devise an improved source management method for TIG-AC welding with improved energy characteristics based on a series active filter in order to improve performance speed of the current regulator and to enable control over its shape;

- to investigate the properties of an experimental welding source based on a series active filter and to confirm the stated possibility to control a welding current;

- to justify the benefits of the source with a series active filter for TIG-AC welding in comparison with existing ones.

4. A source for TIG-AC welding with improved energy characteristics based on a series active power filter

To solve the set tasks, we have improved the technique for controlling the welding current of the source with a series active power filter. This improves the quality of welding joints by controlling the shape of the arc current curve, increasing the performance speed of the control system, and improving stability of the welding process.

The proposed solution implies that the arc current is regulated by a series active filter with a feedback on the output

ing values of voltage and the current of the main harmonic. However, the arc current in the practical implementation of the source takes a shape close to the rectangular (it is described below), therefore, the current value of its fundamental harmonic is equal to

$$I_{1RMS} = \frac{4}{\pi\sqrt{2}} I_{ARC}. \quad (3)$$

The RMS value of the fundamental voltage harmonic in case of its sinusoidal shape is related to the average rectified value via

$$U_{1RMS} = \frac{\pi}{2\sqrt{2}} U. \quad (4)$$

Next, we derive the apparent power of the fundamental harmonic:

$$S_1 = U_{1RMS} \cdot I_{1RMS} = \frac{\pi}{2\sqrt{2}} U \cdot \frac{4}{\pi\sqrt{2}} I_{ARC} = U \cdot I_{ARC}. \quad (5)$$

Thus, at a rectangular shape of the arc current and a sinusoidal shape of the utility voltage, the result of calculating the apparent power of the fundamental harmonic based on the average rectified voltage and current is correct.

The signal ϕ is sent to the phase locked loop (PLL) whose function is to form a curve of the predefined shape with a network frequency and the required phase shift. The PLL output signal amplitude is scaled to reflect the voltage on the load and the shape of the required V-I characteristic of the welding source. The resulting signal is a reference signal for the current regulator.

Measurements of average voltages, currents, and powers are synchronized with the transition of utility voltage through zero. Therefore, the system's response time to transition processes is 20–40 ms.

The optimal shape of welding current for TIG aluminum welding is a squarewave without a DC component, similar to that formed by the source TIR-300D. First, the squarewave has a unity crest factor. This reduces the maximum temperature of a non-fusible tungsten electrode. In the case of a sinusoidal shape, when the current passes through the extremes the temperature of the electrode has time to increase due to its low heat capacity, which leads to a decrease in the service life of the latter. Second, the high speed of the squarewave transition through zero increases the stability of arcing, as it reduces the likelihood of deionization of the arc gap [1, 2].

A total harmonic distortion (THD) coefficient of the current consumed by the source under an operating mode close to the rectangular shape of arc current is about 30%. To reduce THD, one should use a sinusoidal arc current shape or current in the form of a sum of the sinusoidal and rectangular signals (to ensure a high speed of transition through zero and reduce the probability of deionization of the arc gap).

It should also be noted that when the polarity changes, the electrode receives the sum of voltages of the secondary winding of the transformer and the output voltage of the series filter, which facilitates the process of maintaining the arc.

If the described source is used for MIG welding, the optimal current shape may be different from the square wave. Thus, it is possible to implement modes with the imposition

of current pulses to detach the droplets of an electrode's metal in the sources with forced transfer.

5. Results of studying an experimental welding source executed with a series active filter

The physical appearance of a series active power filter is shown in Fig. 3. Fig. 4 shows the physical appearance of its control board.

The power switches used are the field effect transistors IRFP4110 (two in parallel) for a welding current of up to 120 A. A DC link capacitor has a capacity of about 20,000 μF and a maximum working voltage of 126 V. The inverter control scheme is made using the specialized IR2110S drivers and a STM32F100C86B microcontroller operating at 24 MHz.

The device includes a liquid crystal text indicator of 16 \times 2 symbols with illumination. In the course of work, it displays information about the source parameters (messages about readiness and errors, voltage and current of the arc, etc.).

Fig. 5 shows a welding current oscillogram during operation of the described source.

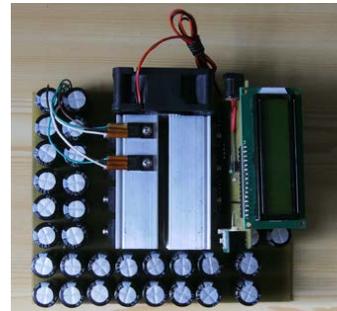


Fig. 3. Physical appearance of a power active filter for TIG welding

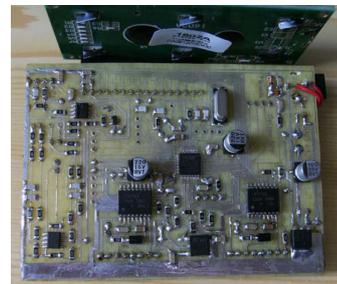


Fig. 4. Physical appearance of control board for a series active filter

The balance of active power to maintain constant voltage in the DC link is provided by shifting the welding current phase relative to the utility voltage. It should be noted that it is possible to work with a lead phase shift of the current relative to the utility voltage, that is the source in this case is a generator of reactive power. Fig. 6 shows a combined oscillogram of voltage and current of the source under this mode.

Conditions for reigniting the arc when polarity changes in this case are somewhat worse than those under the mode of reactive power consumption; however, it is possible to ensure stable arcing due to the high speed of current change.

It makes sense to use the reactive power generation mode during operation within a complex with the reactive power consumers.

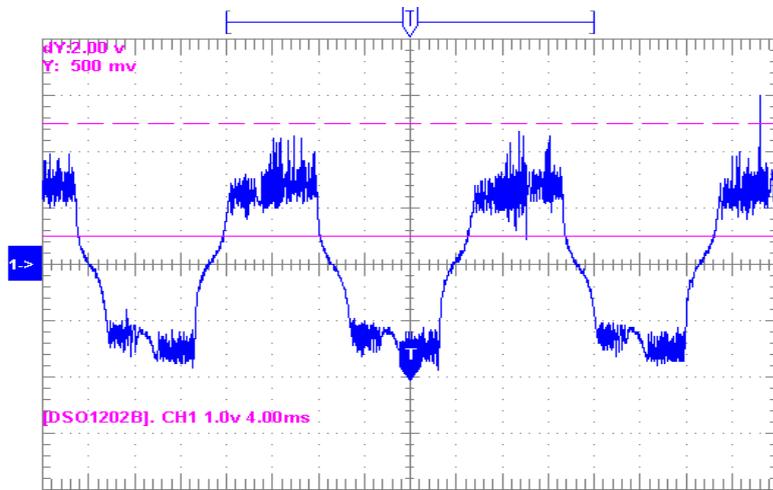


Fig. 5. Welding current during operation of the source with a series power active filter

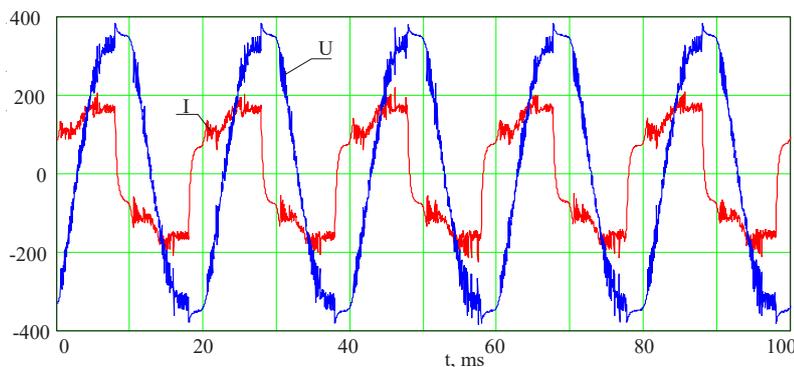


Fig. 6. Oscillogram of voltage and current from the source with a series power active filter under a reactive power generation mode

6. Discussion of results of studying the designed power source for TIG-AC welding

Control over the shape of a welding current has made it possible to significantly improve (stabilize) the character of progress of the welding process and to prolong the service life of tungsten electrodes. In addition, a source with a series active power filter demonstrates a much less sensitivity to utility voltage fluctuations and makes it possible to smoothly regulate a welding current without resorting to switching the windings of the transformer.

Compared to the sources of rectangular current based on thyristor converters (such as TIR-300D) [2, 3], the source with a series active filter has the following advantages:

1) significantly better mass-size parameters, because the energy storage uses capacitors rather than an inductor. This reduces the volume taken by an energy storage by at least 3 times;

2) lower energy losses in semiconductor elements through the use of field effect transistors instead of thyristors. A voltage drop on the conducting thyristor is 1.3–1.8 V, while on the field effect transistor it is easy to achieve a voltage drop of less than 0.2 V under a working welding current [3]. Accordingly, the dissipated thermal power is also reduced;

3) a possibility to control the output resistance of the source and form V-I characteristic with the required stiff-

ness without switching the welding transformer. In conventional sources, the stiffness of V-I characteristic is determined by the leakage inductance of the welding transformer; changing it employs magnetizing a magnetic wire or installing a magnetic shunt. In the proposed source, the formation of V-I characteristic is carried out via software (Fig. 2) and does not require any manipulation with the transformer. Moreover, it is advisable to use transformers with small leakage, which are distinguished by lower power losses and by the better ratio of power to mass.

In addition, a possibility to work in a mode of reactive power generation (the oscillogram in Fig. 6) would make it possible to reduce the current load on a power network when such sources are operated in a combination with other electric receivers-consumers of reactive power. Known welding sources [2, 3] are the consumers of reactive power and cannot operate under a mode of its generation.

7. Conclusions

1. Application of the proposed principle of building a source for the AC arc welding could eliminate the DC component in a welding current, improve the technical-economic parameters of welding process by improving stability of the welding arc current. One should note a significant improvement in the mass-size characteristics of the source that implements the proposed topology of the circuit compared to the source that includes capacitors in the secondary circuit. This is achieved owing to that the volume taken by the unit of a series active power filter is at least 3 times less than the volume occupied by capacitors.

2. The proposed technical solution also reduces the consumption of reactive power by electrotechnical systems consisting of welding power sources. This is achieved by transferring the designed source into a reactive power generation mode, which makes it possible to partially compensate for the reactive power consumed by other electric receivers included in the electrotechnical complex.

3. It is also possible to modernize existing AC welding sources with low-frequency transformers by installing the designed power series active filter into them. That would make it possible to use them for implementing the TIG, MIG, MMA alternating current welding processes.

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