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USE OF CAPACITIVE ENERGY STORAGES TO CREATE HIGH-EFFICIENT MULTISTATION WELDING SYSTEMS

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Analysis of structures of multistation sources for arc welding, designed on the base of capacitive energy storages, was carried out. Their prospects for creation of high-efficient welding-technological systems are shown. The structures of centralized power supply systems of welding stations are considered, in which one powerful electric energy storage is used. A decentralized power supply system of the stations is more flexible, when an individual electric energy storage is installed at each workplace. Its advantage consists in the fact that a standard rectifier of VDGM type can be applied. For shipbuilding, a combined power supply system can be used, which implements the positive qualities of both power supply systems and provides a high quality and power efficiency of the welding process. As an example of the use of multistation power sources, a diagram is given, which is based on the method of charge transfer. 13 Ref., 6 Figures.

Keywords: pulsed arc welding, capacitive energy storage, capacitor with double electric layer, charge transfer method, multistation welding systems, step-down converter

It is known that multistation welding systems (MSWS) are widely used in large machine-building enterprises, which is particularly true for shipbuilding. Evolution of these systems followed the path of increase of their energy efficiency. At the first stage these were the studies associated with elimination of ballast rheostats from their design, application of which lowered MSWS efficiency to 40 % in a number of cases. Development of this direction was based, mainly, on designing different types of converters [1, 2], which essentially lowered the power losses and brought the efficiency to 80–85 %.

MSWS application in welding offers a number of advantages to users, such as:

- two-three times lowering of power consumption, compared to welding with single-station welding units [1];
- reduction of no-load losses [3];
- reduction of the expenses for equipment purchasing [1];
- increasing labour safety during welding operations, as power is supplied to the welding station at the voltage of 60–70 V (220 or 380 V at single-station welding) [2]. At the present stage MSWS are implemented by application of semi-conductor step-down converters [3, 4], so that ensuring stable operation of welding stations on maintaining the specified accuracy of technological welding modes under the conditions of external impacts requires a more detailed consideration.

Known is a method of MSWS control, according to which, one welding current source, stabilized by output voltage level, and several unstabilized sources are used to stabilize the voltage level in low-voltage busbars. All the above-mentioned sources are connected to the industrial three-phase current mains (380 V, 50 Hz), their outputs are permanently connected to sections of the low-voltage busbar. The open-circuit voltage in the busbar is created by this summary source, stabilized by output voltage level. At increase of current load in the welding arc the voltage drop in the busbar is compensated by additional connection of unstabilized power sources to the busbar. If current in the common busbar is reduced, switching off of additional unstabilized sources is performed in the reverse order [5, 6]. Thus, voltage stabilization in the common busbar is achieved by increasing the weight and dimensions of welding equipment without maintaining the specified accuracy of the technological welding modes, their programming, as well as in the absence of the possibilities for realization of modulated current welding processes.

More and more attempts to use various electric energy storage devices for stabilization of energy flows in welding processes have been observed recently. In particular, known are devices for conversion of the energy of electrochemical storages into the energy of electric welding arc burning [7, 8] and methods to control the energy flows with the purpose of their stabilization in MSWS, using electrophysical storage devices [9].

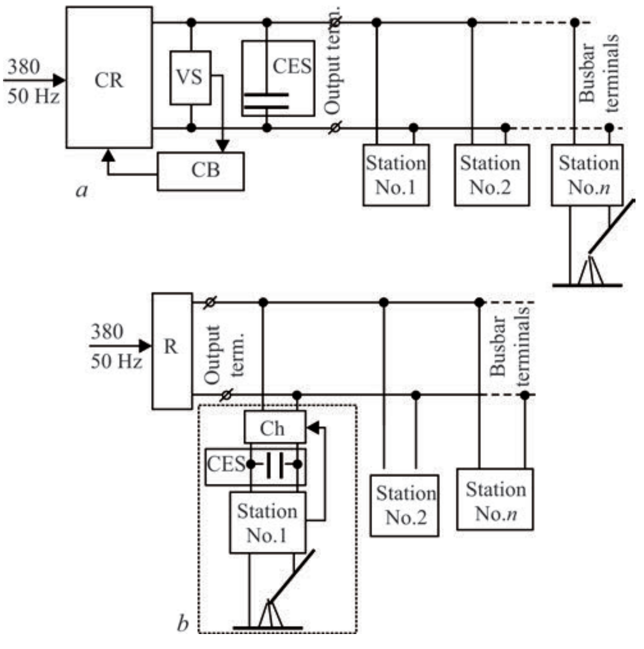

Figure 1. Structures of multistation welding systems with capacitive storages: *a* — centralized; *b* — decentralized

However, it should be noted that MSWS have certain disadvantages related to dependence of welding current on voltage fluctuations and change of the arc gap length; mutual influence of welding stations at their simultaneous operation, absence of the possibility of maintaining the specified accuracy of the technological modes of welding or their programming; as well as absence of the possibility of modulated current welding.

Application of high-frequency converters as welding stations, where technological mode stabilization is performed by PWM-controllers does not completely provide the continuity of welding current and voltage at the device output.

A significant disadvantage of such MSWS built using converters, is deterioration of the parameters of electromagnetic compatibility (EMC). And this leads to considerable power losses in enterprises manufacturing welded structures.

In this connection, the objective of this work is development of new approaches to creation of MSWS built, as will be shown later, using capacitive energy storages (CES). MSWS based on capacitive energy storages (CES), can use circuits corresponding to three topological structures. Figure 1, *a* shows a structure with a centralized CES [9]. A decentralized MSWS structure, where an individual storage device is installed at each station, is given in Figure 1, *b*. And finally, a combined supply diagram for the power stations is shown in Figure 2 [10]. Here, common energy storages are used, and additional storages are installed at each station. Such a structure of MSWS ensures maximum stability of the energy stations, as well as a high quality of welded joint formation.

The centralized power supply system of the stations (Figure 1, *a*) includes a controlled rectifier (CR), voltage control sensor (VS) on the busbar (Figure 1, *a*), to which the capacitive energy storage is connected. The main purpose of the storage is forming a stable supply voltage for the stations. Supply voltage stabilization in this case is performed by control block (CB) which is connected to VS output.

The decentralized structure (Figure 1, *b*) can use a common rectifier (R), without any particularly stringent requirements to output voltage stability. However, you have to pay for it by increasing the complexity of the equipment of the stations, where charge devices (Ch) and station storages (CES/s) are additionally installed. It should be mostly used at development of systems with few stations (2 – 4 stations), for instance, for development of self-sufficient field welding-technological complexes for pipeline welding.

The best is a combined station power supply system (Figure 2), which combines the positive qualities of the above-described multistation welding systems [10]. It has a common storage, with much lower electric capacitance, compared to a centralized power system, and an individual energy storage CES/s is installed at each station, which has the function of additional stabilization of supply voltage. The operation of this MSWS system is described below.

The industrial network voltage (380 V, 50 Hz) is decreased to a safe level by a power step-down transformer included into the controlled rectifier CR. Lower voltage is rectified and converted into charge current of CES storage. Energy level of the storage, which is a capacitor in this case, is controlled by voltage sensor VS (defined as $U = Q/C_s$, where C_s is the storage capacity; U is the voltage level at its terminals; Q is the accumulated charge level). Here, the voltage sensor signal which comes to the input of control block CB, sets such a velocity (current) of the charge, at which the following condition is fulfilled $R_{in}(I_b) \leq R_{tot.imp}(I_b)$, where R_{in} is the inner resistance of controlled rectifier CR, I_b is the busbar current; $R_{tot.imp}$ is the total impedance of the welding stations connected to the busbar.

The busbar voltage is connected, through the power terminals of the station input key InKs, to station charger WSch. Its outputs are connected to the terminals of station storage CES/s (extra high capacity capacitor bank), where the voltage level is controlled by voltage sensor VSs. The inputs of the block of forming the station volt-ampere characteristics BF/VAChs are connected to the terminals of storage CES/s. Welding current required for conducting the specific technological process of welding, is controlled by WCS, the

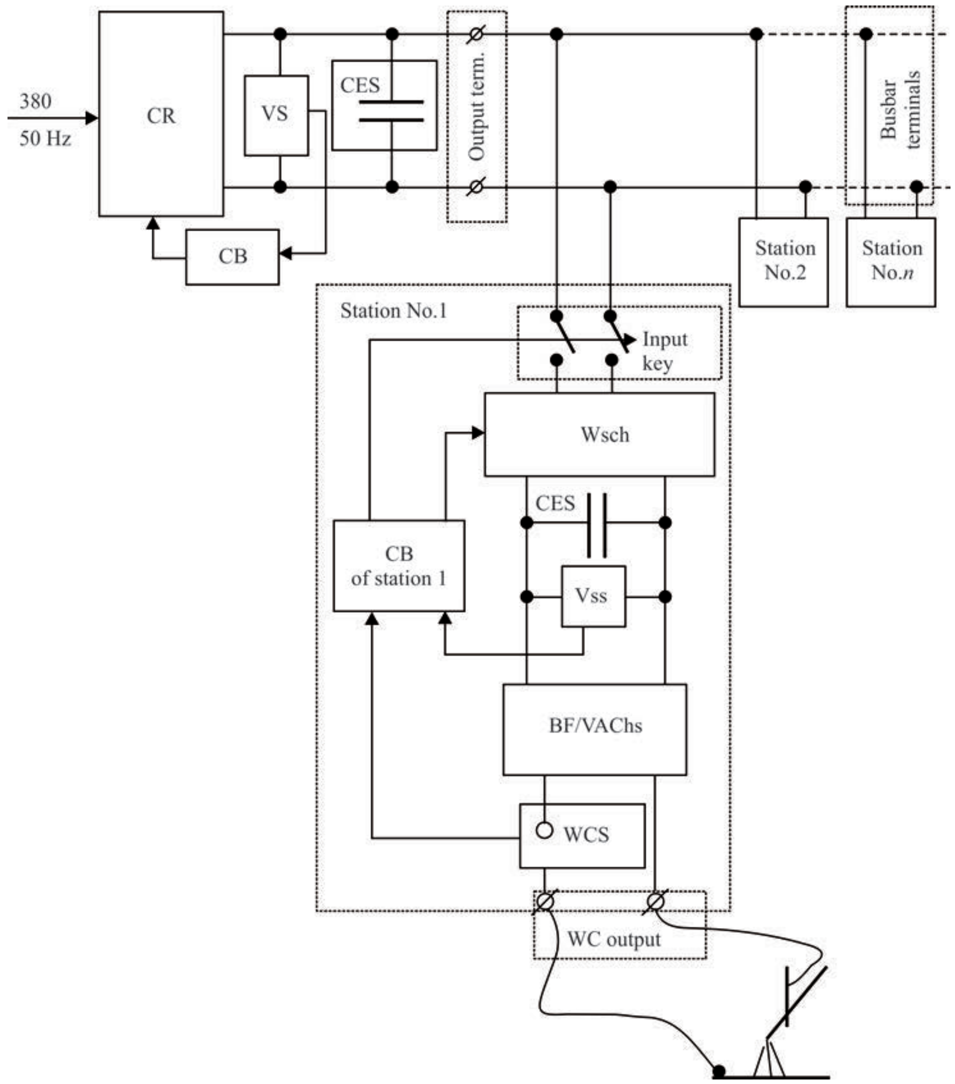

Figure 2. Multistation welding system with a combined diagram of station power supply

signal of which controls the switching frequency of input key InKs to maintain the required level of the charge in storage CES/s, which is necessary to perform a specific technological process of welding.

CES based on capacitors with a double electric layer have significant differences from the classical capacitors, which should be taken into account at their application in MSWS. One of such characteristics of supercapacitors (SC) is Coulomb energy efficiency. Its essence consists in that these devices cannot be discharged to a level below a certain preset specified charge level, because of the electrochemical processes, accompanying their operation. Its value, as a rule, is equal to 25–30 % of the charge maximum level.

This is exactly why the energy, transferred to the load, is provided by partial discharging of the storage. We will use a simple example to explain it.

$$W_{\mathrm{ch}} = \frac{C_{\mathrm{s}} U_{\mathrm{ch}}^2}{2} \text{ and } W_{\mathrm{d}} = \frac{C_{\mathrm{s}} U_{\mathrm{d}}^2}{2}.$$

Energy, which is transferred to load ΔW, is defined as the difference between ΔW_{ch} and ΔW_{d}:

$$\Delta W = \frac{C_{\mathrm{s}}}{2}(U_{\mathrm{ch}}^2 - U_{\mathrm{d}}^2).$$

If we denote $U_{\mathrm{d}} = \Delta U_{\mathrm{s}}$, where α characterizes the voltage level at discharge C_{s}, we will have:

$$\Delta W = \frac{C_{\mathrm{s}} U_{\mathrm{ch}}^2}{2}(1 - \alpha^2).$$

Considering that the storage charge is equal to $Q = C_{\mathrm{s}} U_{\mathrm{ch}}$, the latter expression can be presented as follows:

$$\Delta W = U_{\mathrm{ch}} Q \frac{(1-\alpha^2)}{2} = U_{\mathrm{ch}} Q K_E,$$

where $K_E = \frac{(1-\alpha^2)}{2}$.

If we introduce parameter γ_{ch} (Figure 3), characterizing the effectiveness of storage charge utilization

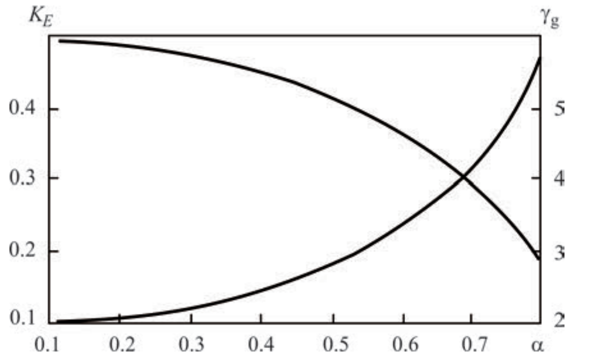

Figure 3. Coulomb energy effectiveness of storages based on capacitors with a double electric layer, depending on α coefficient

and denote it by ratio $\gamma_{ch} = \frac{Q}{\Delta Q}$, as a result we will have:

$$\gamma_{ch} = \frac{1}{K_E} = \frac{2}{1-\alpha^2}.$$

We proposed and experimentally studied the following welding modules as station converters for the above-described MSWS topological structures: a device for powering the nonconsumable welding electrode [11]; a device for transformation of mains alternating voltage of industrial frequency into an alternating voltage of arbitrary frequency [12], or a device for forming welding current pulses of different polarity [13].

Taking the above into account, we will consider in greater detail the realization of the method of charge transfer in station converters.

The topology of the sources, build using converters with charge transfer (CChT) is based on capacitive energy storage (CES), fitted with charger (Ch) with high dynamic parameters and control module (CM). The latter implements the control algorithms in CES charging circuit, as well as the processes of charge transfer in the welding circuit.

We will use the following reasoning, in order to functionally connect the processes, taking place in the sources with charge transfer. As is known, the charge (g_s) in the storage can be determined by the following expression:

$$g_s = C_s U_{ch},$$

where C_s is the storage capacity; U_{Ch} is its charge voltage.

On the other hand, the charge is consumed in the welding circuit:

$$g = I_w t,$$

where I_w is the welding current; t is the welding time.

Then, the following ratio will be the condition for existence of continuous welding current:

$$C_s U_{ch} = I_w t.$$

Assuming that the process of energy flow conversion runs in each period, i.e. $t = 1/f$, i.e. the latter expression can be brought to the following form

$$C_s U_{ch} = I_w / f.$$

Therefore, welding current I_w is defined by the following ratio:

$$I_w = C_s U_{ch} = I_w f.$$

The expression for welding current links all the main parameters of CChT-based sources. It is a base for calculation of all the processes and components of this type of arc welding sources.

Realization of the above-described algorithm of welding source operation is shown in Figure 4.

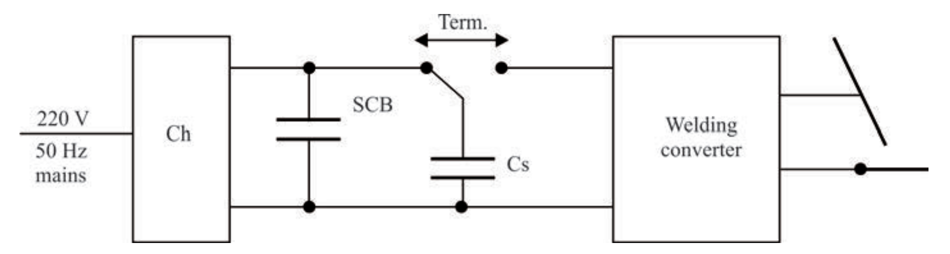

Figure 4. Block diagram of a welding source based on converters with charge transfer

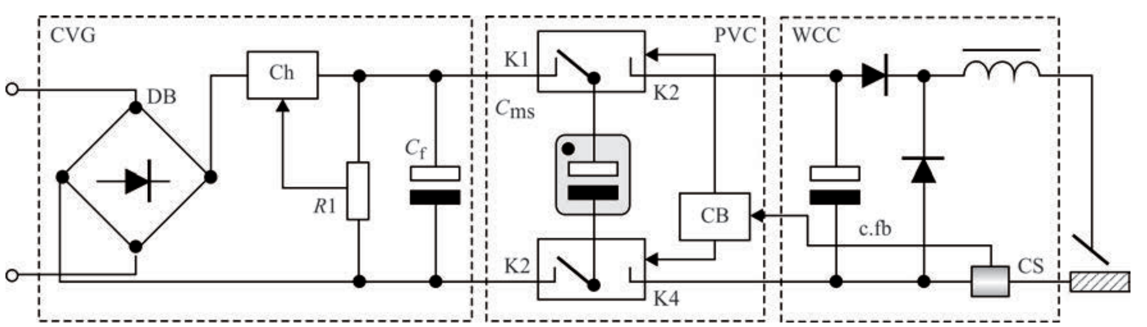

Figure 5. Converter with charge transfer

Its composition includes charger (Ch), supercapacitor bank (SCB), metering energy storage (C_s), which actually powers the welding converter. The device operation frequency is set by the switching device.

As an example of practical application of the above approach, Figure 5 shows the diagram of a welding current source, which has the topology of a step-down converter (SDC). The device consists of three main components: constant voltage generator (CVG), pulse voltage converter (PVC) and welding current converter (WCC). CVG includes a rectifier of diode bridge (DB), charger (Ch), the level of actuation of which is assigned by potentiometer $R1$ and filtering capacitor ($C_{\sim}$). Pulse voltage converter consists of molecular storage C_{MS} and key block K1–K4, the switching algorithm of which is assigned by control block (CB). The operating mode of the latter is determined by feedback signal by welding current c.fb. PVC implements the known mode of a «flying» capacitor, which provides quasi-galvanic decoupling between the input circuit and welding circuit. The operation of WCC block is similar to that of step-down voltage converter, so that we will omit its description. A detailed description of its operation is given in [4]. The method of charge transfer can be implemented similarly in any topologies of the welding current source.

Results of an experimental study of the station converter, made according to the diagram, presented in Figure 5, are shown in Figure 6. Surfacing was performed with electrodes of UONI-13/N1-BK grade, which are usually used for the corrosion-resistant fittings. We used the mode of dynamic arc burning at two fixed frequencies: *a* — 10 and *b* — 100 Hz. In both the cases, the welding currents were equal and corresponded to the value of 120 A, the meander mode being connected.

Conclusions

At the conclusion of this work, it should be noted that application of capacitive storages in the structure of multistation welding systems yields a set of positive results. They include, first of all:

• high energy efficiency, which is due to low inner resistance of the supercapacitors;

• possibility of developing different topological structures of multistation welding systems, depending on technological tasks, which differ by the simplicity and reliability of technical realization;

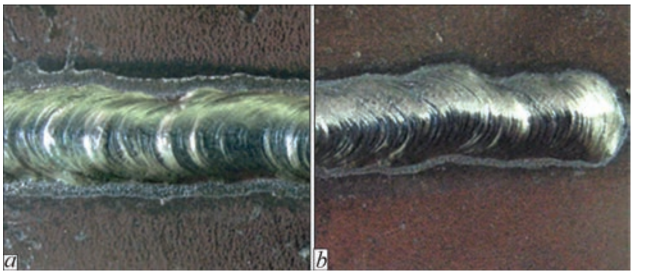

Figure 6. Results of an experimental study of a station converter with charge transfer: *a* — 10; *b* — 100 Hz

• ensuring a high stability of the welding modes due to a quick reaction to destabilizing factors, that is related to a fast response of the station components;

• essentially improved parameters of electromagnetic compatibility, which prevents generation of the high-frequency harmonics into the factory power supply mains.

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