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Development over the Years

Stud Welding Technology: The Leading Edge in Efficiency and Sustainability

Inverter technology has led to fundamental improvements in stud welding: it enables fast, precise current regulation, is significantly more energy-efficient and the appliances are more compact and lighter than transformer devices with thyristor control. Lower material consumption, less cooling requirement and reduced power consumption contribute to sustainability. Inverter technology offers reliable results even at short welding times – ideal for flexible modern applications.

I well remember a lesson during a seminar at an SLV (Welding Institute in Germeny) in which the lecturer asked us why we need welding machines at all and cannot just take the welding power directly from the mains network. Admittedly, a somewhat provocative question put to future welding engineers, but it helps to clarify some basic facts about welding. There are several answers to this question:

- Everyone who works with electrical energy knows that voltages from a certain magnitude upwards can be dangerous or even lethal for humans. Ohm's law tells us that the voltage U drives a current I through an electric resistance R, I = U/R. The human body also functions as a resistance: all muscles are controlled by small electric currents. Now, if a current flows through the body, the muscles will cramp and the heart, which is also a muscle, may get out of step. For this, Voltages of more than about 50 V are therefore generally considered dangerous.
- But more important, when we just concentrate on welding technology, is the fact that in many welding processes based on the flow of currents, short-circuits occur as part of the process. A short-circuit represents an extremely low resistance leading to correspondingly high currents. Therefore, normal power supply circuits are equipped with fuses which reliably interrupt the circuit in the event of excessive currents. But this is something we cannot tolerate in welding.
- In welding, we need an option to vary the current strength, which, together with the arc voltage, delivers the welding power. This means, we need a source of welding current which is able to transform the mains current as needed.

From transformer to inverter

The simplest type of welding machine is a transformer. The mains voltage of, say, 400 V (primary side) is transformed to less than 100 V (secondary side). The transformer is designed to be so "soft", that the short-circuits on the secondary side have only a very weak effect on the primary side, and so the fuse on the mains power supply side is not triggered in normal operation. Tapping of the power supply provides the welder with different secondary voltages, which generate the corresponding currents.

Today, this type of welding equipment is no longer found in manufacturing or assembly work. The lower the output voltage, the more difficult it becomes to ignite an arc. Moreover, the arc goes out and must be re-ignited with every zero crossing of the current. This cannot be achieved with all types of electrodes; many can only be welded with DC voltage.

So, the next step in development was the use of rectifiers. Direct current can be generated either by a rotating converter or via rectifier cells. Rotating converters have excellent welding properties and can be set precisely, but they are large and expensive. They are also no longer being used in practice. Fixed rectifiers behind a transformer with taps, at first with selenium cells and later with silicon cells, have disappeared from the industry as well.

The introduction of power electronics during the 1980s triggered the triumphant advance of thyristor-controlled welding equipment. A thyristor is a semi-conductor switch, which can be "ignited", i.e. made conductive, at any point in time during the flow of current.

As soon as the flow of current stops, it locks again automatically. It lets alternating current pass in only one direction (rectifier effect). That has made it into a popular actuating unit for controlling the welding current. Several thyristors working together cannot only form a three-phase rectifier, but simultaneously change the average current by "phase gating", i.e. ignition of the thyristor at a certain angle of the phase. At a 0° ignition angle, the full current will flow, and none at all at 180°. In **Fig. 1**, the output current ripple of 300 Hz can be clearly seen (operating frequency for rectification of the three-phase current), which is low at maximum current, but becomes more and more pronounced with weaker currents. A choke to keep the current flow steady during the "breaks" is required to

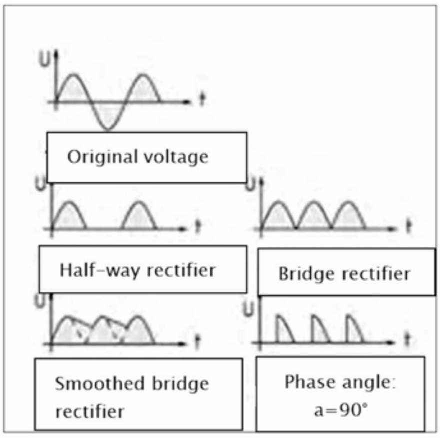

Fig. 1: Rectifier effect in thyristor-controlled welding equipment (© Trillmich)

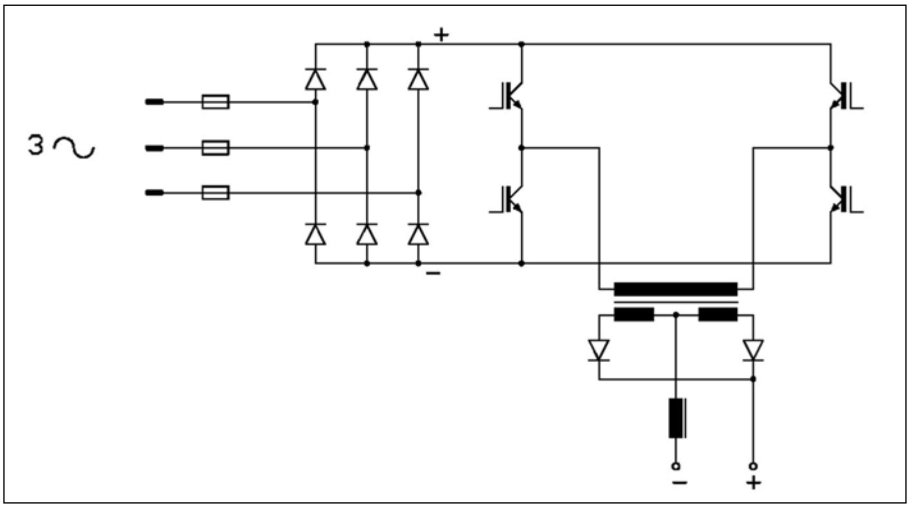

Fig. 2: Basic circuit diagram of an inverter power source with three-phase input, rectifier-DC link and MOSFET semiconductors as fast switches, which send the current in changing directions and with higher frequency through the primary winding of the output transformer; renewed rectification and smoothing behind the secondary winding. (© Trillmich)

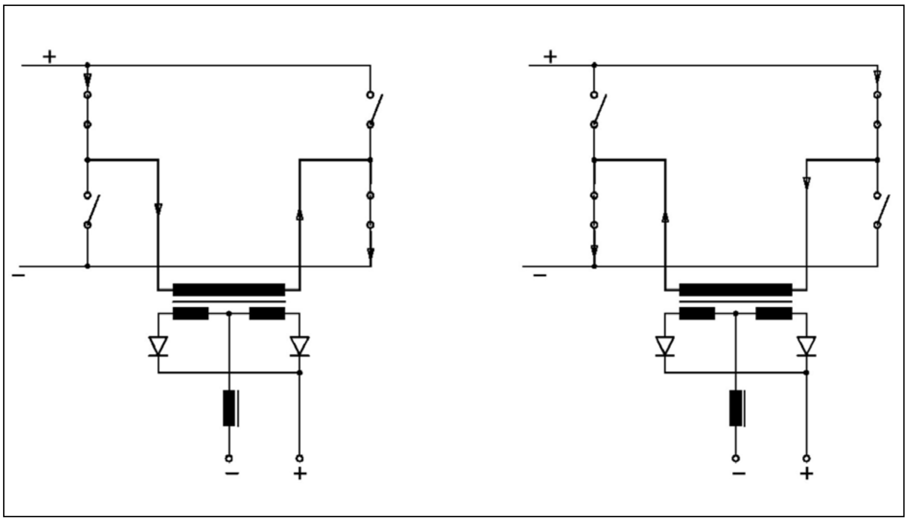

Fig. 3: This diagram shows how, with the fast switches (depicted schematically), an alternating voltage is generated from the DC voltage. On the left picture, the current flows from left to right through the primary coil and on the right picture in the opposite direction. By this alteration of the current flow, a secondary voltage determined by the winding ratio is generated, which can then be rectified by the two diodes and subsequently used for welding. (© Trillmich)

keep the arc reasonably stable. But the current pulsates clearly, especially when welding in the lower output range of such a welding machine model.

High-performance transistors brought about a breakthrough in welding technology. A transistor is a switch which cannot only be turned on at any time but also be locked again whenever required – a classic switch. In mains-powered technology, a transistor would not be of any advantage – its advantages only come into play at higher frequencies.

But how can we generate a much higher frequency from the mains voltage of 50 Hz and the DC current we need for welding as well? **Fig. 2** shows the principle. First, the mains voltage is changed into DC current by a reversed rectifier, which converts 400 V input voltage into a DC voltage of about 560 V. But that voltage cannot be used for welding; here we need substantially lower values. Yet it is not possible to transform DC voltage with an iron/copper transformer. So, we turn the DC voltage back into alternating voltage, but thanks to the fast transistors (known as IGBTs – Insulated-Gate Bipolar Transistors) with a much higher frequency. In drawn-arc welding technology, frequencies in the double-digit kHz range are normal.

Fig. 3 shows the transistors as switches, the direction of the current changes from the left to the right of the diagram and vice versa. We then transform this alternating current of, say, 20 kHz frequency to the required low welding voltage. It is well known that the size of a transformer sinks drastically with the frequency, so inverter welding machines are much smaller and lighter than the old thyristor machines.

To alter the amperage of the welding current, the principle of phase angle control is applied here once more. Now, the ripples and gaps are virtually no longer noticeable at low currents, but in drawn arc welding technology and in resistance welding, too, inverter technology is clearly dominant due to its advantageous properties – with negligible limitations.

The leading edge in stud welding

Let's now turn to stud welding technology. Here, inverters came onto the market considerably later than in MIG/MAG-, TIG- or manual arc stud welding. Why was this so? For stud welding, significantly higher currents are required than for the processes just mentioned; at the beginning, suitable fast transistors were not available. But this has definitely changed over the last few years. Right up to the highest performance class, welding of size 25 shear connectors, users now have inverter stud welding equipment at their disposal.

Why does the inverter clearly have the leading edge particularly in stud welding? There are many reasons, some of which become clear in a process sequence, such as is shown by comparing a thyristor machine (**Fig. 4**) with an inverter model (**Fig. 5**). With the short-pre-set welding time of 100 ms, the thyristor power source takes about half the welding time to reach the target value of the current. The shorter the set welding time, the more the effective current deviates from the preset current.

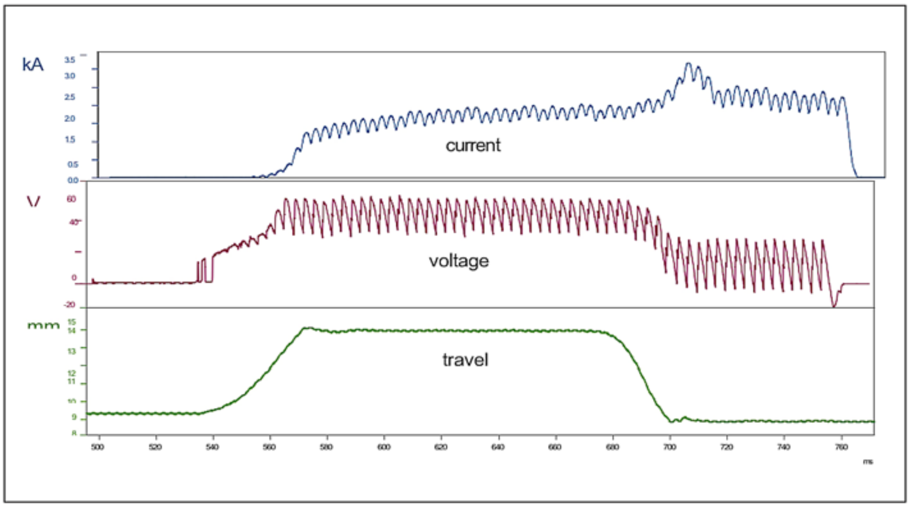

Fig. 4: Stud welding with a thyristor power source: during a welding time of 100 ms, the power source takes about half of that welding time to reach the target current value of 1,920 A. (© Trillmich)

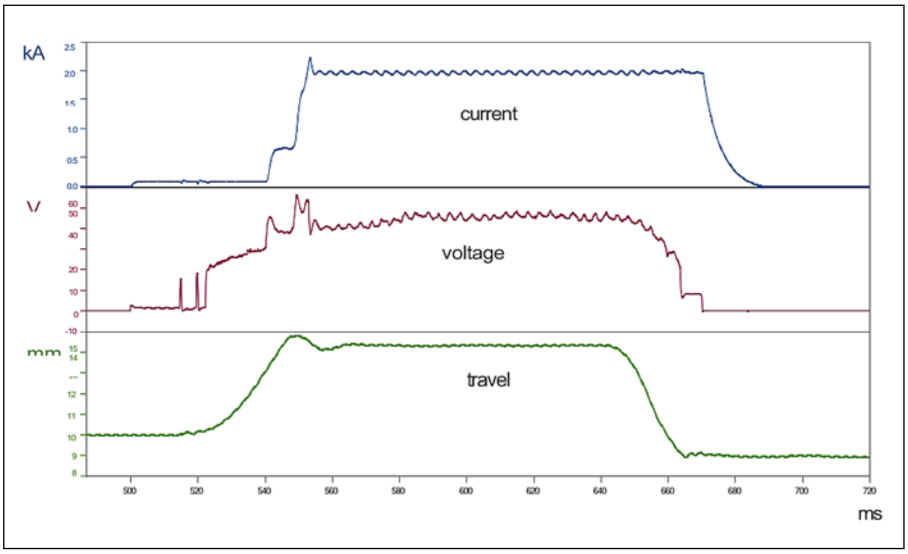

Fig. 5: Stud welding with an inverter power source: The inverter already reaches the target current of 1,950 A after about 10 ms. (© Trillmich)

By contrast, the inverter already reaches the target value after about 10 ms. This is why especially short cycle welding of small-diameter studs on thin metal sheets can be accomplished without much trial and error. A large inverter stud welding appliance is ideally suited for all process variants of draw-arc stud welding and all diameters from 3 to 25 mm. As is shown in **Figs. 6 and 7**, both current and voltage come with significantly lower ripples.

Comparison of transistor and thyristor technologies

Table 1 compares the attributes of transistor and thyristor technologies. Let us take a look at the details:

- An inverter appliance is easy to transport, in most cases inside a station wagon, and it can often be loaded and unloaded by hand. For a thyristor model, at least a delivery van is required. Loading and unloading it can only be done with a forklift or crane.
- A thyristor appliance contains many valuable raw materials such as copper and transformer sheets, which make up most of its mass. Its ecological footprint is considerably larger than that of an inverter. The Eco Design Regulation of the EU (2019/1784) requires from welding systems a high degree of efficiency, which cannot be achieved with transformers. Currently, stud welding appliances are still excluded from this rule, but for how much longer will that be the case?
- For welding size 25 shear connectors, an inverter can also be operated with a small welding sequence from a 63 A power connection. A thyristor machine cannot: it requires at least 80 A, which means a 125 A socket. Large companies do have 63 A sockets, but 125 A sockets are rare and expensive. Therefore, a thyristor appliance can hardly be used at changing workplaces.
- Inverter appliances convert considerably more of the input energy into welding output than thyristor machines. The losses are caused by the large, heavy transformer.
- Since thyristor appliances can only adjust the current step by step in line with the mains frequency, they either fail to reach the target value during short welding times (current regulation “from below”), or they “overshoot” it (current regulation “from above”). Welding of small studs in relation to the maximum performance is very difficult, and welding of relatively thick studs on thin metal sheets as well. But these are tasks which an inverter can handle without any trouble.
- Today, especially the operating expenses for an appliance are an important factor. The transformer of a large stud welding appliance already has a power loss of more than 1 kVA just in idling, the equally strong inverter only about 0.2 kVA.
- Inverters are able to run an electric program parallel to the welding process, such as making a low current flow for a selectable time to clean slightly contaminated surfaces. A reduction of current at the end of the welding process is also possible, or other variations according to the user’s requirements.
- An inverter does not cause any noise apart from the ventilator, which is mostly thermostat-controlled. By contrast, a large mains power transformer significantly contributes to noise pollution. Its sheet metal housing may amplify its 50-Hz humming noise rather unpleasantly.
- Every welding machine needs a cooling system. A transformer needs more than an inverter, the air from the ventilator flows directly round the transformer coils, dirt accumulates and may

Table 1: At a glance: comparison between transistor and thyristor technology (© Trillmich)

Attributes (for 2600 A maximum output current)	20-kHz technology (transistor)	50-Hz technology (thyristor)
Total mass	102 kg ( )	316 kg ( )
Material input	low	high
Load on the power network	medium	high
Idle power approx.	0.2 kVA	1.1 kVA
Regulation speed	high	low
Suitability for welding on thin sheets	high	medium to low
Current programming possible	yes	no
Noise generated by transformer	none	audible
Pollution due to cooling	low	high
Operation with different mains voltages	wide range of voltages	limited, fixed transformer winding required
Example: shear connectors 19 mm Ø, 1600 A.0,8 s, welding performance including cable losses 64 kVA		
Grid output	90 kVA	121 kVA
Efficiency	71 %	53 %
Energy requirements for 1000 welds	20 kWh	27 kWh

lead to destruction of the insulation. In inverters, the switching components are mounted on cooling elements, only those are exposed to the air flow.

- Inverters manufactured by Bolte are equipped with a wide-range power supply unit with input voltages ranging from 320 to 495 V. With thyristor appliances, only specific voltage levels via transformer tapping are possible.
- Several small Bolte inverters can be combined with each other into a large power source (a power package).
- The inverter burdens the source of energy considerably less than a thyristor machine. With generator operation (on building sites), a smaller size is often sufficient for the inverter.

All in all, there is no reason for considering obsolete thyristor technology when purchasing a new stud welding appliance. You can see this for yourself in a live demonstration or, alternatively, by an extended test series with a Bolte inverter on the premises of your own company. ■

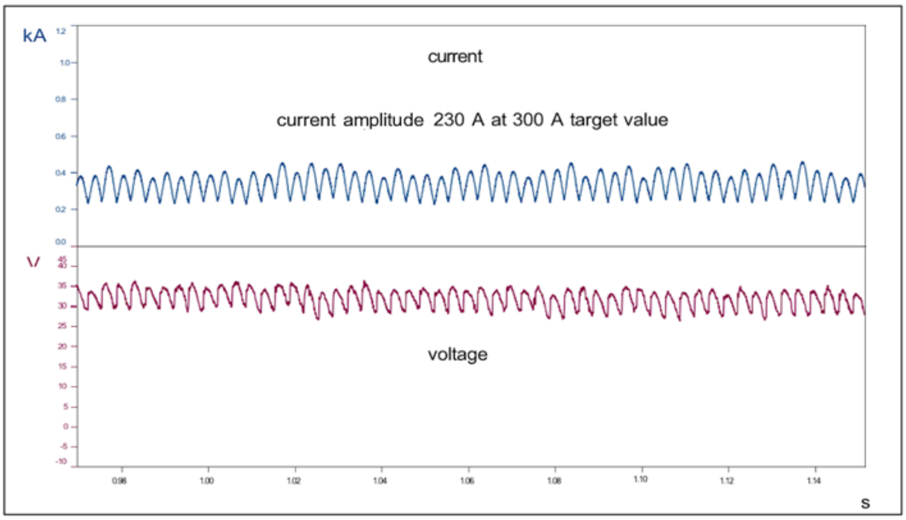

Fig. 6: Stud welding with a thyristor power source: with a target value of 300 A, the oscillation amplitude is about 230 A. (© Trillmich)

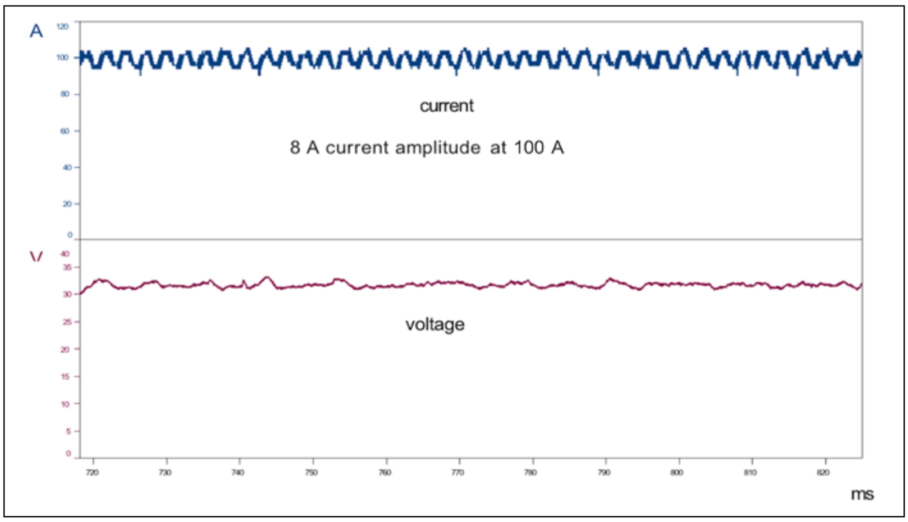

Fig. 7: Stud welding with an inverter power source: at 100 A target value, the oscillation amplitude is about 8 A. (© Trillmich)

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