STATIC AND DYNAMIC BEHAVIOR OF HIGH-CURRENT RECTIFIER DIODES IN RESISTANCE WELDING INVERTER POWER SOURCES

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ABSTRACT - In recent years inverter power sources are more and more used for resistance welding processes. In this paper some results of investigation into the static and dynamic behavior of high-current rectifier diodes used in these inverter power sources will be discussed. By means of digital simulation, losses and efficiency have been determined depending on the power semiconductor parameters.

1. INTRODUCTION

Resistance welding is one of the most important joining processes in large fields of engineering. Among other applications, it is widely used in highly automated manufacturing by robots, for example in automotive industry. The energy required by the welding process is provided and controlled by specific high-current power sources. Power rating covers the range of up to approximately 300 kVA at welding currents to about 100 kA. The weld times are usually in the range of about 20 ms to 500 ms at up to approximately 20 % duty cycle, depending on technological conditions.

Conventional solutions for resistance spot welding robot applications realized in form of a.c. controller-fed single-phase transformer welding guns are limited to the low power range. A stationary three-phase transformer connected with an output rectifier is mostly used for higher performance. Using high-current cables, the welding current is led to the spot welding gun located at the robot arm. Thereby considerable losses and mechanical stresses occur.

In recent years demands of industry regarding shortening the intervals of spot welds in combination with a weight reduction of moving parts of the robot, a more precise control of the energy input to ensure the welding quality and a better utilization of electrical energy led to intensive development activities concerning inverter power sources for resistance welding [1], [2]. The increase of the operating frequency of the high-current transformer up to usually 1 kHz allowed substantially to reduce weight and dimensions of around 70 % compared to a 50/60 Hz-variant. As a result, an especially compact design of high-current transformer and secondary rectifier as an integrated unit became possible. Meanwhile in the low power range industrial resistance welding devices are available with switching frequencies between 2 and 4 kHz and also 20 kHz showing a tendency towards a further frequency increase [3]. Tab. 1 shows the growing number of inverter power sources for resistance welding in the medium and high power range produced in Germany during the last years.

Table 1 Resistance welding inverters produced in Germany

Year	1990	1992	1994	1996	1997
Number	50	200	335	1100	1416

2. INVERTER POWER SOURCES FOR RESISTANCE WELDING

Fig. 1 shows a typical block diagram of the power section of an inverter power source consisting of an uncontrolled input rectifier, a voltage-fed full-bridge inverter with IGBT-modules, a high-current transformer and a center-tapped full-wave output rectifier.

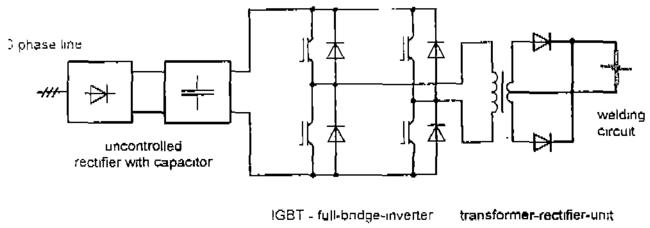

Fig. 1 Inverter power source for resistance spot welding (typical block diagram)

The output rectifier diodes considerably influence the total losses of the high-current power source. Their part of total power dissipation can be up to approximately 25%, Tab. 2. Thus, the diode para-meters essentially determine the highest attainable welding current. With regard to a desired further frequency increase, the analysis of the influence of the characteristics of the rectifier diodes used is of high importance.

Table 2 Power losses of an inverter power source for resistance welding (measured, load resistance: 220 μΩ)

Input power	130,30 kW	100 %
Power losses:		
line rectifier	2,74 kW	2,1 %
inverter	3,14 kW	2,4 %
transformer	38,43 kW	29,5 %
high-current rectifier	30,49 kW	23,4 %
Output power	55,5 kW	42,6 %

Specific diodes with adapted parameters are hardly available at present. Therefore, standard line-frequency diodes are often used. Their switching behavior at higher frequencies is mostly unknown or not specified by the manufacturers. Consequently, a comparison between different diode types is difficult.

3. EXPERIMENTAL INVERTER POWER SOURCE

To investigate different types of high-current rectifier diodes and their influence on power source parameters and behavior an experimental inverter circuit combined with an industrial transformer-rectifier unit has been built up. Four half-bridge IGBT modules of 200A/1200V have been used in a full-bridge inverter topology. The switching frequency is adjustable between 1 and 10 kHz. The rated primary current of the transformer is 800 A. The output current of the power source burdened with a special water-cooled high-current cable of 220 μΩ is up to 30 kA.

In the above described experimental high-current inverter power source for resistance spot welding, different types of diodes have been examined concerning their conduction and switching losses and the transient overvoltage during turn-off.

4. STATIC BEHAVIOR OF RECTIFIER DIODES

The measured on-state characteristics of different high-current diode types differ considerably even at identical voltage classes, Fig. 2.

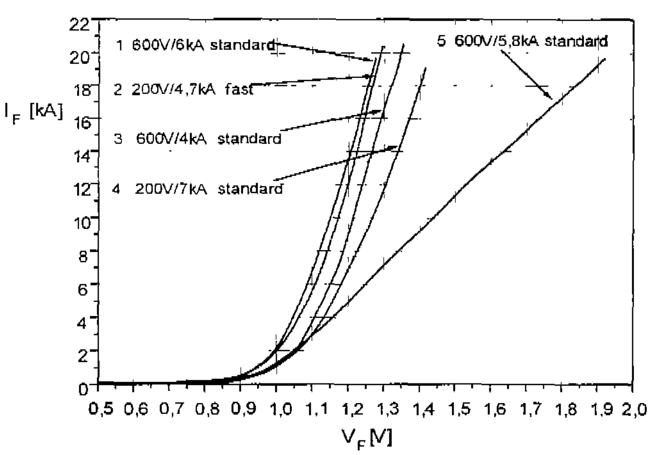

Fig. 2 On-state characteristics of different high-current diodes (measured)

5. DYNAMIC BEHAVIOR OF HIGH-CURRENT RECTIFIER DIODES

The switching behavior of line-frequency tandard rectifier diodes in this application is only ufficiently known in few cases. However, it is of .ecisive importance for the estimation of witching losses and for the choice of the diode 'oltage class because the rectifier is usually ›perated without snubbers for constructive easons. The differences in reverse recovery ›ehavior of the investigated diodes are .onsiderably large, Fig. 3.

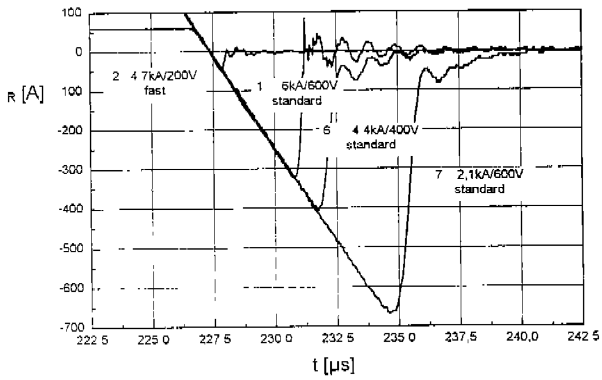

Fig. 3 Turn-off behavior of different diodes (measured)

Here the specific fast diode has the most favourable behavior. However, the turn-off losses at frequencies up to 5 kHz compared to the forward losses are of subordinate importance.

More critically is the snap-off of the reverse current, because this is the reason for high voltage transients which could lead to power source failures and higher electromagnetic interference. Most of the investigated standard line-frequency diodes have such an unsuitable behavior. Only one diode provided sufficient results, fig. 4.

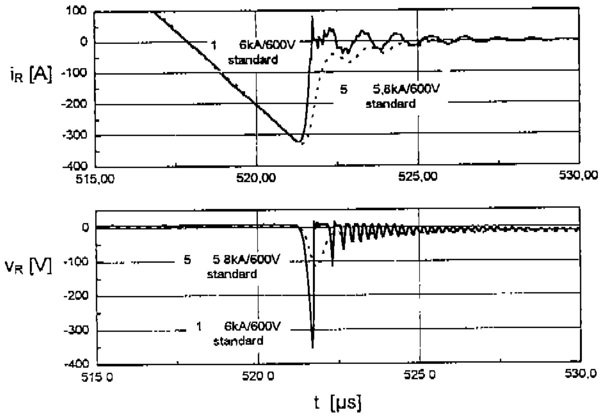

Fig. 4 Turn-off behavior of hard and soft switching standard line-frequency diodes (measured)

6. SIMULATION

Based on the results of measurement, a comprehensive simulation model with the complete high-current inverter power source has been developed using SIMPLORER simulation software [5]. Fig. 5 shows a part of the simulation model concerning the IGBT with the freewheeling diode and the snubber circuit. For the rectifier diodes on the secondary side a behavioral static and dynamic diode model has been used, Fig. 6.

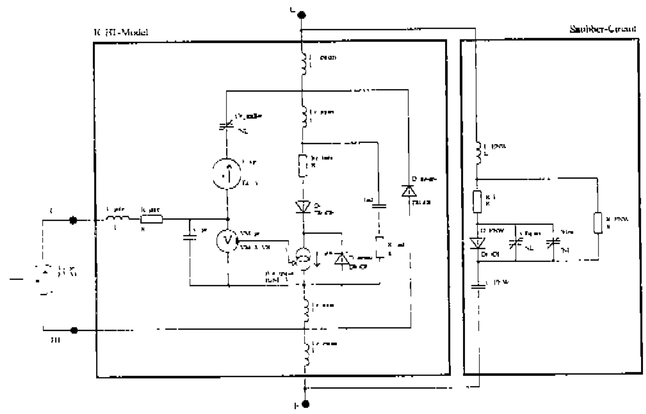

Fig. 5 SIMPLORER simulation model of the inverter power source (one leg of a full-bridge-IGBT-inverter topology)

By means of digital simulation based on the described model the influence of the high-current rectifier diodes upon the power source operation has been investigated [4].

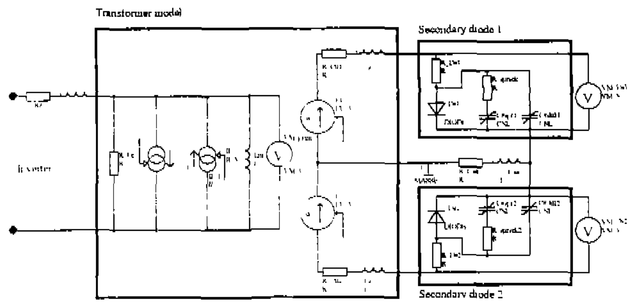

Fig. 6 SIMPLORER simulation model of the inverter power source (MF-transformer. rectifier, load)

The static characteristic of the parametrized exponential static diode model accurately corresponds with the measured values, Fig. 7.

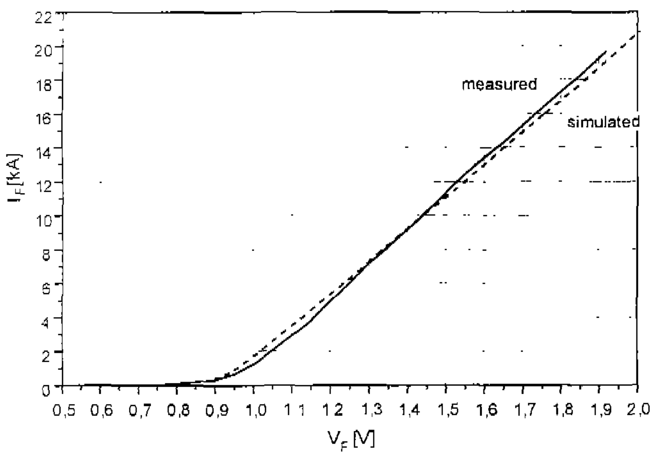

Fig. 7 Measured and simulated on-state behavior of diode 5

Fig. 8 shows the dependency of the output current on the duty ratio of one pair of diagonally arranged IGBTs in case of a switching frequency of 1 kHz considering two types of high-current diodes. Using diodes of type 1 (Fig. 2) inside the output rectifier the attainable output current is 2 kA higher compared to the application of diodes of type 5.

Fig. 9 shows the influence of the different on-state behavior of the rectifier diodes on the average input power and on the rectifier losses. Duty cycle and output current correspond to Fig. 8. By using diodes with an reduced on-state voltage of about 1,3V@20kA the rectifier losses and the input power can be reduced about 15 kW.

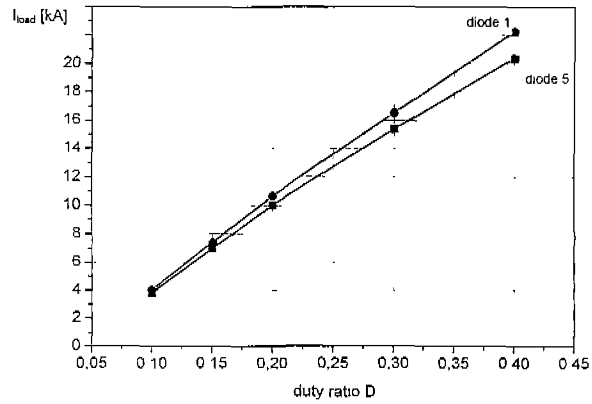

Fig. 8 Influence of diode type and duty ratio on load current (simulated) (load resistance: 220 μΩ)

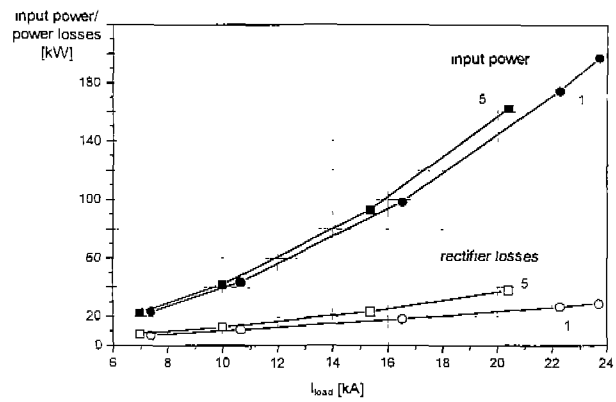

Fig. 9 Influence of diode type and load current on input power and rectifier losses (simulated) (load resistance: 220 μΩ)

Further simulations have been carried out to study the influence of snubber circuits. Even with soft switching standard diodes the reverse voltage peak without snubbers can easely reach more than 100 V. With hard switching diodes more than 400V depending on the leakage inductance of the transformer and the parasitic inductance between transformer and rectifier are possible. With a conventional RC-snubber the maximum reverse voltage can easely be reduced, Fig. 10. Power losses due to the snubbers can be neglected. However, snubber circuits are still unusual in this application because of constructive problems.

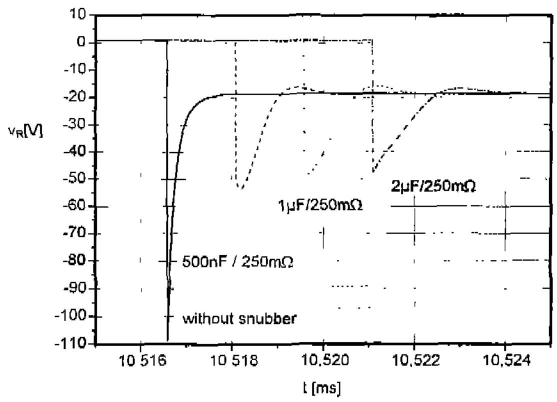

Fig. 10 Influence of the snubber parameters on the maximum reverse voltage at turn-off (simulated)

7. CONCLUSION

The static behavior of the high-current rectifier diodes essentially determines the highest attainable welding current, the input power and the efficiency of a resistance welding power source. The investigated diodes of various manufacturers are characterized by relatively great differences in the voltage drop at higher currents even for those diodes with the same voltage class. By choosing an optimal diode type, the output current of a given configuration was about 10%, 2 kA higher than before. Diodes with a lower voltage class of 200 V can only be used, if their turn-off behavior is very soft, or combined with snubbers. As the investigation showed, some manufacturers offer standard line-diodes with a soft turn-off characteristic, but unfortunatly mostly there is no specification of the dynamic behavior of these diodes. The demand of a higher switching frequency for the power sources discussed is only of interest at the lower power range for mobile devices. At the power range of about 100 kVA and above the maximum attainable switching frequency is more determined by the MF-transformer with its specific losses, its leakage inductance and commutation interval times than by the diode parameters.

As a result of the investigation some suggestions can be made to manufacturers of resistance welding equipment concerning the optimization of a high-current inverter power source and the selection of suitable power semiconductors, in particular of the rectifier diodes.

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