Conducted Emission of Inverter Power Sources for Resistance Welding

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Abstract - **Investigating electromagnetic emissions of inverter power sources for resistance welding existing special aspects of EMI measurements in the field of resistance welding machines resulting from the power rating and intermittent operation mode of these machines have to be taken into account. The characteristics of the internal switching processes determined by the behavior of the applied power semiconductors, snubber circuits and constructional aspects exert a great influence on the conducted emission of resistance welding inverters.**

Keywords - **Inverter power sources, resistance welding, conducted emission, EMI**

I. INTRODUCTION

Resulting from its effectiveness and versatility resistance welding has become one of the most important joining processes in engineering. It is based on the use of the Joule effect heat, which is generated in the resistances of the parts to be welded due to the electric current flow. As a result of heat input a weld nugget is formed. The resistance weld is produced under a force locally applied by the electrodes. This force is maintained until the weld zone solidifies. Concerning the equipment manually operated machines or welding robots incorporated into highly automated production processes are used. The rated power of applied power sources covers the range from approximately 10 kVA up to several MVA. The control of resistance welding is carried out by means of power electronics and a special process control using various topologies. Besides line controlled single phase a.c. machines and conventional three phase d.c. machines a growing number of medium frequency inverters is applied, Fig. 1.

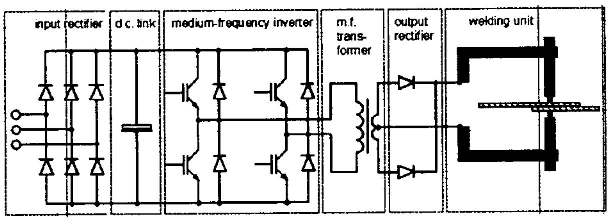

Fig. 1: Block diagram of an inverter power source for resistance welding

Allowing a downsizing of the welding transformer inverters meet the requirements of welding robots concerning the reduction of mass and size of the welding unit in the "hand" of the robot. Furthermore, resulting from their higher dynamic response these electronic power sources offer specific possibilities to influence the welding process and to improve the quality of welded joints. However, it can be assumed that resistance welding inverters feature characteristic electromagnetic noise, resulting from their switched mode operation accompanied by rapid voltage and current slopes. The knowledge of emissions is important for the evaluation of risks occurring by use of electrical machines in their environment. With the background of a growing consciousness regarding electromagnetic emissions [1] and ongoing standardization efforts in Europe including the field of resistance welding equipment [2] we have made investigations concerning the analysis of conducted emission of high-current inverter power sources in the frequency range from 150 kHz to 30 MHz and the evaluation of different methods to mitigate the emission. Considering the total generation of disturbances of devices to be tested generally conducted emissions are regarded as an indicator.

II. MEASUREMENT METHODS

In the field of resistance welding machines a number of specific characteristics has to be considered to choose appropriate EMI measurement methods. Resulting from the power rating and intermittent operation mode of these machines every single welding procedure represents a surge load to the power system. To ensure a sufficient energy supply extremely high short-circuit capacity values of the power system have been laid down in relevant standards concerning resistance welding machines. The insertion of a line impedance stabilization network (LISN) generally used for decoupling of noise voltage leads to an intolerable high input impedance for the resistance welding machines to be tested and reduces their attainable output current. Decoupling of noise voltage with a special voltage probe according to CISPR 16 [3] gives comparable results without decreasing output power of the machine.

Furthermore, emission measurements in the frequency domain using an EMI receiver proved to be especially difficult because of the discontinuous intermittent operation mode of the machines. By synchronizing the measuring cycle of the EMI receiver with a periodically operated resistance welding inverter the complete noise voltage spectrum can be acquired, Fig. 2. In doing so, during one single welding time one frequency range of the disturbance spectrum is evaluated. Consequently, compared to continuous-mode operated devices the total measuring time is considerably higher (up to approximately 2.5 h). Within this total measuring time the inverter has to be operated under fixed conditions.

Another special aspect concerns the different noise voltage level evaluation methods offered by the EMI receiver. The use of the quasi-peak detector recommended by CISPR [4] is important for radio interference phenomena, but can be misleading with the remaining EMI problems [5].

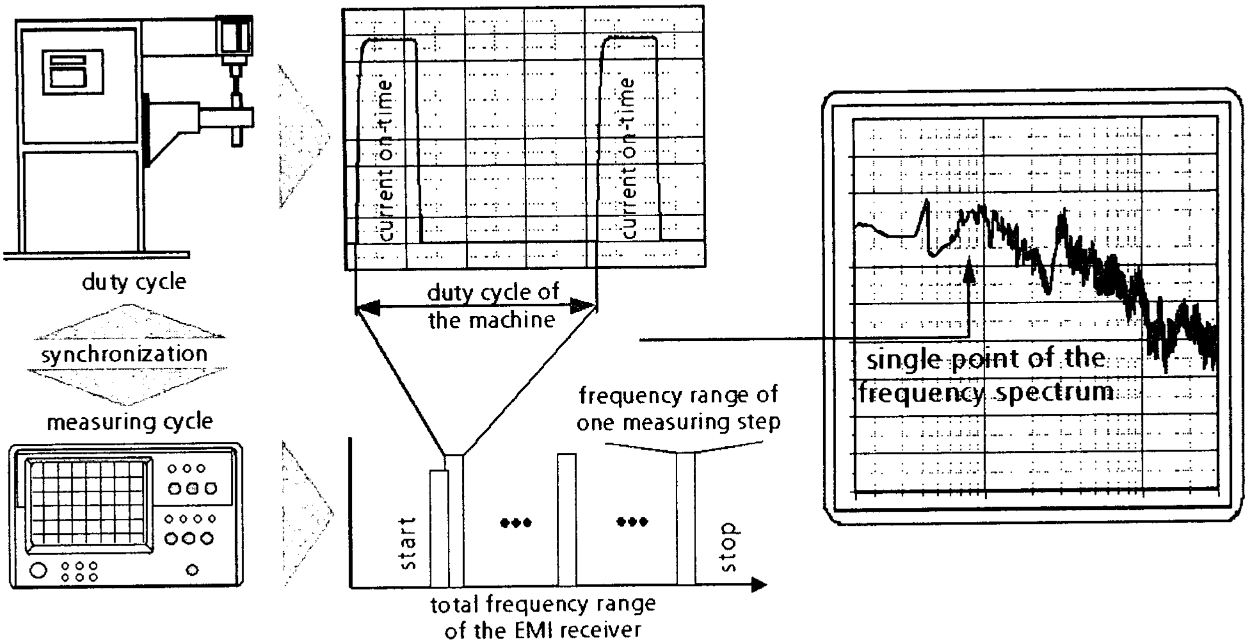

Fig. 2: Measurement procedure of electromagnetic emissions of a resistance welding machine using an EMI receiver

A comparison of these methods resulted in the fact that under the said conditions only the peak evaluation method gives results which are independent from current on-time and duty cycle of the machine, Fig. 3. Furthermore, the peak evaluation is considered to be especially suited to detect disturbances of EMI sources which are impulsive in character and therefore might be harmful to sensitive devices [4].

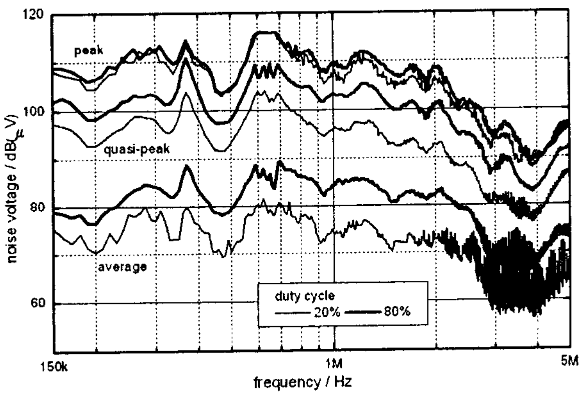

Fig. 3: Comparison of noise levels of a resistance welding inverter at different duty cycle values, output current 3.3 kA

An alternative to the frequency-domain measurement is the acquisition of the decoupled time-domain noise voltage signal, as shown in Fig. 4, followed by a subsequent FFT - analysis. This method is based on the correspondence between noise signal evaluation in the time domain and in the frequency domain [6], [7]. A comparison of both methods yielded a good correspondence up to a frequency of several MHz, Fig. 5. The degree of accuracy of the spectrum calculated from the time-domain noise voltage signal is limited in particular by the sample rate, the storage capacity and the vertical resolution of the digital storage oscilloscope used for the acquisition of the signal.

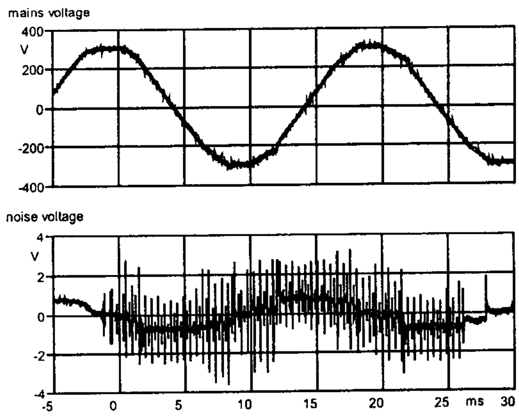

Fig. 4: Decoupled noise voltage

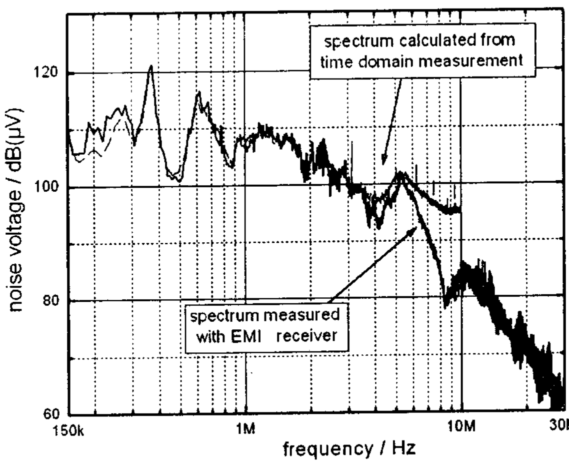

Fig. 5: Comparison of noise spectra measured with EMI receiver and calculated from time domain

As a supposition for investigations concerning further factors influencing the electromagnetic emissions of resistance welding inverters the amount of occurring noise level differences between short circuit load operation and real welding operation of the inverters had to be analyzed. Since the differences proved to be negligible [8], the investigations reported in the following could be carried out using short circuit load operation of the resistance welding equipment.

III. EXPERIMENTAL RESULTS

Modern inverter power sources for resistance welding do not distinguish very much in their topologies and characteristics. Their power module consists of an uncontrolled three-phase rectifier with a bulky d.c. link, a medium-frequency inverter in full-bridge topology with IGBTs and a high-current transformer unit with integrated output rectifier. Differences exist mainly with regard to the rated power, the applied power semiconductors and the switching frequency. The investigations of several industrial inverter power sources as well as own experimental lab power sources in the frequency range from 9 resp. 150 kHz to 30 MHz yielded that the switching operation of the inverter IGBTs represents the dominating noise emission source, Fig. 6.

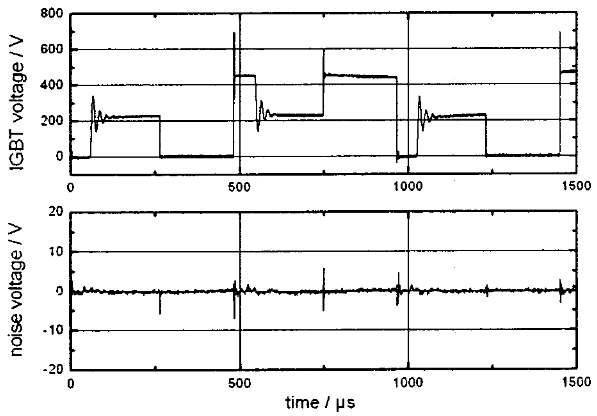

Fig. 6: Comparison of IGBT voltage and decoupled noise voltage

As well as the characteristics of the load circuit including the welding process, the switching operation of the high-current rectifier and the output-current level exert only a small influence. Above 10 MHz inverter machines unlike conventional machines show a relatively high broad-scale noise level. The harmonics of the switching frequency only play a role in the range below 150 kHz and occur as narrow-band noise, Fig. 7.

A more precise consideration of correlations and dependencies was carried out concerning the IGBT, the snubber capacitance and the gate resistance. Using IGBTs of a newer generation with better switching performance higher noise emission values occurred above 20 MHz, Fig. 8.

In the frequency range between 700 kHz and 1.5 MHz the noise level is determined by ringing effects during turn-off of the IGBTs and does not depend directly on switching time.

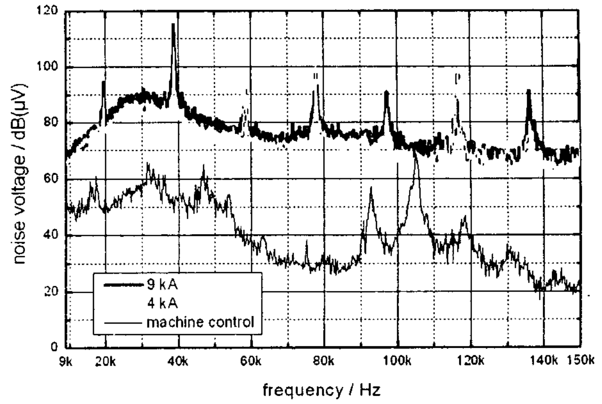

Fig. 7: Noise spectra of a resistance welding inverter in the frequency range from 9 to 150 kHz

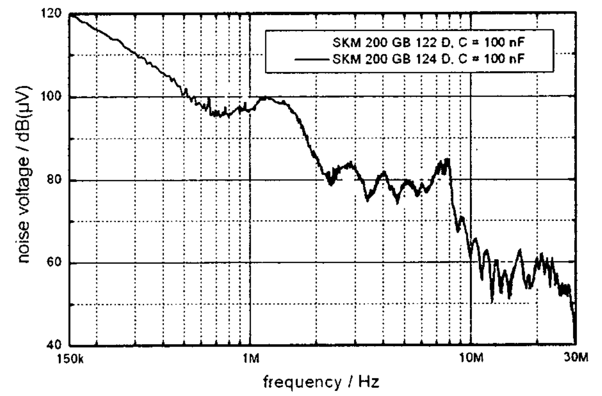

Fig. 8: Comparison of noise spectra of a resistance welding inverter using different IGBTs

The capacitance of a RCD snubber network influences the noise emission in a frequency range around 1 MHz. The gate resistance dimension influences the noise level at frequencies above 1.3 MHz, Fig. 9.

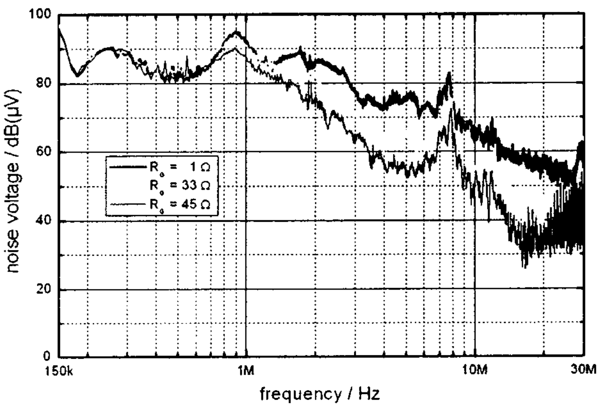

Fig. 9: Influence of IGBT gate resistance on noise spectra of a resistance welding inverter

Higher gate resistance values decrease voltage rise during turn-on. A simultaneous increase of the switching losses can be accepted under certain circumstances because of the relatively low switching frequency.

IV. Noise Reduction

Besides the above described direct noise mitigation measures passive measures have been examined. The insertion of a mains filter into the mains connection represents a common and usually effective method to reduce conducted emissions of a noise generating device. However, in case of resistance welding machines because of the high amounts of rated power, costs and high volume restrict the application of filters for these power sources. Thus, alternatively the application of noise suppression capacitors should be taken into account. Whereas using mains filters a remarkable attenuation of conducted emissions across a wide frequency range can be expected the noise level reducing effect of suppression capacitors is limited to certain frequency bands, Fig. 10. Resulting from undesirable resonances an increase of noise levels may arise elsewhere in frequency. Simulation-aided optimization is restricted here since a correct modeling of parasitic elements is difficult.

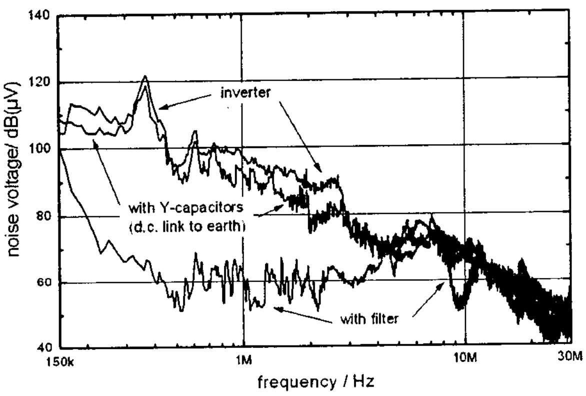

Fig. 10: Effect of suppression capacitors and mains filter on conducted emissions

The application of Y-suppression capacitors attached to the mains connection terminals respectively to the d.c. link of the resistance welding inverter results in predominantly positive modifications of the conducted emission spectra.

V. Conclusion

With the presented results a contribution has been given to the analysis and evaluation of conducted noise emission of inverter power sources for resistance welding which has found attention on the part of industry and the authorities concerned with standardization.

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