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A Simple Arc Starter and Arc Stabilizer Circuit for Inverter Based Arc Welding Power Supply

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Abstract: - This paper presents a new method for arc welding striking and stabilizing in MMA (Manual Metal Arc-welding) power sources. This method uses an auxiliary circuit and a series coupled inductor to adding a spike voltage to output dc voltage. The proposed strategy facilitates arc starting and reduces the weight & size of ferrite core. Simulation and experimental results are presented to show the valuable operation of proposed method in arc starting and stabilizing.

Key-Words: - Arc starter, Arc stabilizer, Switching arc welding power source, Inverter.

1 Introduction

Many researches are developing on welding power sources because of its mother technology. These researches are done to achieve two goals, first: increasing welding quality and second: decreasing weight & size. The voltage supplied by power companies for industrial purpose is too high to use directly in arc welding. Therefore, the first function of arc welding power sources is to reduce the high input or line voltage to an appropriate output voltage range [usually 20 to 80 Volts]. Either a transformer, solid state inverter, or a motor generator can be used to reduce the 120, 240 or 480 V utility power to the rated terminal or open circuit voltage appropriate for arc welding; The same device also provides a high welding current generally ranging from 30 to 1500 (A). An ordinary transformer power source uses a high power transformer & a series inductor the primary contributors to weight & size in any power source are the magnetic parts (main transformer and filter inductor). Several attempts have been made to reduce their weight and size of which the use of an inverter circuit is one. An inverter circuit can produce significant reduction in size and weight of these components as well as decrease their electrical losses; The inverter is a circuit which uses solid state devices to convert DC into high frequency AC, usually in the rang of 10 kHz to 500 kHz, assuming that the conventional welding power sources use transformers operating at the line frequency (50 or 60 Hz). Since transformer size is inversely proportional to applied frequency, reductions up to 75 percent in power source size and weight are possible using inverter circuits; For starting an arc, air must convert into plasma state so that its reduction in its' resistance high current flow through the air gap. The power supply must thus be able to provide both output characteristics (initial high voltage and permanent high current), as shown on the *VI* curve in Fig.1. The arc starting requirements for arc welding depends on developing a sufficient voltage drop between the welding electrode and the work piece to initiate a glow discharge on the electrode. In an ordinary transformer, open circuit voltage is a function of the primary input voltage and the ratio of primary-to-secondary coils, so to decrease voltage when arc starts; a series inductor that results in the increase in weight and size is used. In order to decrease voltage in inverters, TRC with low on-time is employed. Low on-time can result in high power dissipation on inverter transformers and switches, thus increases transformers' weight and size. In this paper we used a simple auxiliary circuit that produces high frequency resonant voltage coupled into output DC voltage by a series coupling transformer and this over-shot voltage can strike the arc more easily. When arc starts and current increases, transformer will be short-circuited and the system will maintain its operation. This simple approach promotes arc starting and stability.

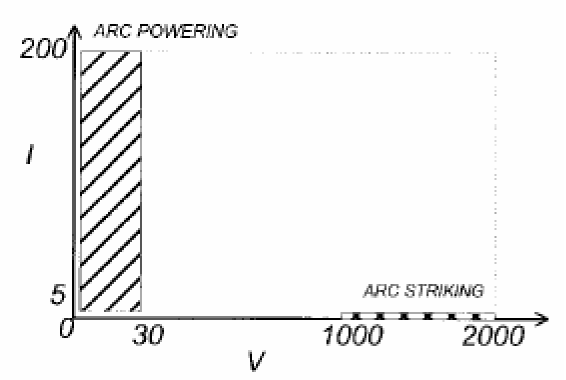


Fig.1. Typical output VI characteristic for arc welding supply

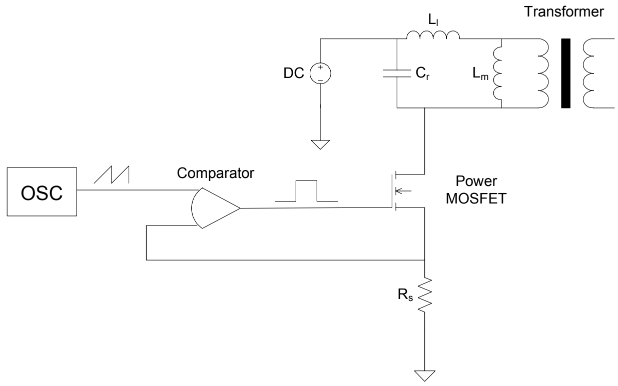


Fig3. A simple resonant circuit

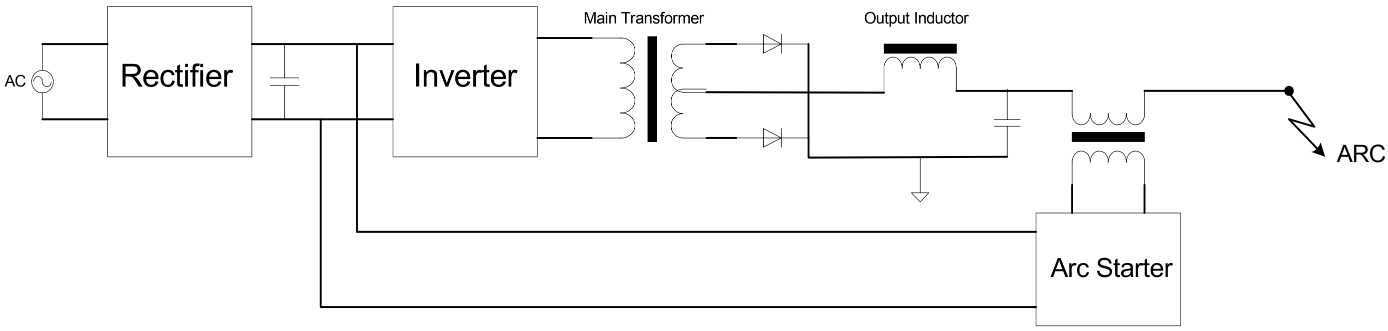


fig 2. A block diagram of the system

2 Circuit Operations

A block diagram of the system is shown in fig 2. The first stage is a rectifier circuit that converts Ac main input voltage to DC within a filter capacitor; second stage is an inverter circuit that converts DC voltage into a high frequency square wave which is applied to a ferrite cored step down transformer in order to reduce and isolate the input voltage. Then a rectifier circuit that benefits from a pair of ultra fast high current diodes converts the square wave to DC voltage and a filter inductor reduces output ripples. The circuit mentioned is the conventional inverter-based arc welding power source. A transformer has been linked series to output voltage that operates as arc starter and a bypass capacitor, C_b , will bypass arc starter circuit's high frequency voltage so it prevents arc starter's high frequency high voltage leakage bake to inverter circuit. the arc starter must operate under two conditions, namely; the open circuit condition when the gas medium around the electrode is being ionized to initiate the arc [Mode 1], and a large secondary current condition when a plasma exists around the electrodes [Mode 2], the arc starter uses a series resonant parallel inductive loaded converter of which the resonant converter circuit is shown in fig 3. The magnetizing inductance (L_m) and the leakage inductance (L_l) of the transformer are used to resonant with Cr, A high secondary voltage is obtained during mode 1 operation by switching the converter. The obtained voltage with resonant frequency:

$$F_r = \frac{1}{2\pi\sqrt{C_r\left(L_m + L_l\right)}}$$

Using the quality factor of the resonant tank will amplify the output voltage. During mode 2 operations, the core is saturated by the high welding current that flows through the secondary of the transformer; therefore the resonant inductance significantly decreases to L_m. The tank energizing current is thereby increased substantially during mode 2 operations. In this case the controlling system does not track the high energizing current, so the tank isn't energized, and arc starter doesn’t inject voltage to output.

The energy needed to charge the capacitor in the resonance circuit is obtained from the DC supply. The switching circuit which is driven by the pulses from PWM controller controls the energy input to the resonance circuit. In order to have appropriate pulse with, the switch current is compared to a ramp wave.

3 TRANSFORMER CONFIGURATION

The analysis of the transformer is complicated due to core saturation and eddy current losses, particularly in the large conductors of the high current secondary winding. The volume, weight and manufacturability of the transformers are also important factors for the assessment and the secondary winding must be able to carry the welding current, which can be from 5 to 200A, and its resistance must be designed accordingly. The following guidelines were used for designing the transformers.

1) Welding cable is used on the secondary winding, and the copper cross-sectional area is, therefore, determined by the output current rating of the welder. The secondary takes up most of the space in the winding window, and the number of secondary turns is determined by the available space.

2) A suitable core size that can handle the integral of the output voltage size is selected. A higher than normal flux density for a given frequency is used and the losses are contained by adjusting the duty cycle of the burst operation.

3) The turn's ratio, as well as the quality factor, determines the output voltage on the secondary during Mode 1 operation. When the number of primary turns is decreased to achieve a higher turn's ratio, the quality factor deteriorates at the same time. Consequently, the output voltage is not as sensitive to the turn's ratio as one would expect. During the investigation, the turns ratio of 1 : 1 was chosen.

4) The Mode 1 resonant inductance and capacitance were selected based on the requirements for frequency and resonant tank characteristic impedance. The air gap is adjusted to achieve a desirable L_l.

Choosing the best transformer configuration is influenced by the specific application. In this experience we use U_52 cored transformer (Fig 4). The advantage of this U-52 cored transformer is a large window area, which makes a high number of turns possible. The disadvantage however is that construction is complicated by the large number of stacked cores.

4 Simulation Results

ORCAD is used for system simulation to assess the performance of the system. Simulation parameters are as follows:

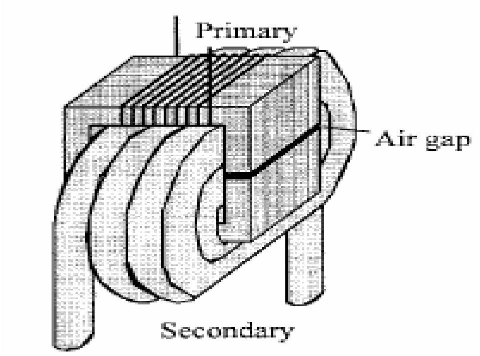


Fig4. U52-cored transformer with 5 pairs of cores, 9 turns on the primary and a 1-1 turn ratio.

V_{in} = 220 V (rms)
Cs = 4400 µF
Inverter MOSFETs = IRFP 460
Main Transformer = EE-65
Ultra-fast Diodes = DSE160-06
Output inductor = 10 µH

Resonant tank parameters:
Cr = 4.7 nF,
L_m=L_l= 2.5 µH
OSC frequency = 100 kHz
Arc starting time = 10µs
Arc stopping time = 70µs

A complete typical cycle of welding process (including arc start, welding and stop) is shown in Fig 5. In fig 6a typical cycle under Mode 1 operation is shown. Peak arc striking voltage isn't required continuously. The cycle is repeated until the arc is struck When Electrode reaches to a sufficient distance from work piece at the instant of 20µs arc starts and during 10µs air resistance diminishes to about 0.1 ohm. The required time for air resistance to lessen is depends on many parameters such as temperature, distance, electrode diameter, gas pressure and etc. but it varies from 1-2 µs to 70 µs. During instants of 30µs to 200µs air has been converted to plasma state. The plasma on the load presents low impedance to the converter and current increase to welding current (100A) (fig.6). The resulting high temperature melts the electrode and work piece. In fig 7 the resonant circuit is not energized and only the arc operating voltage can be seen. If the arc breaks for any reason, what-so-ever leads to increase electrode distance, either by vibration of user's hand or by user decision to finish the welding, air gap resistance increases so high current supplier goes to inhibition therefore current and temperature decrease. Lets assume that this phenomenon takes 70µs of time then the arc starter will automatically return to Mode 1 operation and a high output voltage will once again be applied in order to restarting the arc. Magnifying fig.5 in time axis shows how this transient state occurs (fig 8).

Important parameters of arc welding vary with changes in resonance capacitance. Six various capacitors are applied in simulation to analyze system response. Output RMS voltage versus resonant capacitor alternatives is shown in figures 9. Total arc starter consumptive power versus resonant capacitor alternatives traced in figure 10. Employing the bigger capacitance results in decreases in power consumption thus increases in efficiency. On the other hand, this choice decreases output voltage thus arc starts at closer distance leading to short-circuit or grips. When C_r is the smallest one, output voltage and frequency increase and arc starts in bigger gaps, resulting in easier arc striking and leading to more power consumption and less efficiency. Moreover, RFI problems can cause mystification and entanglement both in design and designer.

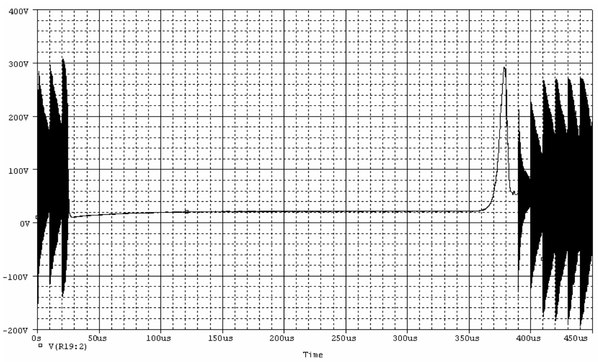


Fig.5. Out put voltage in complete assumptive cycle

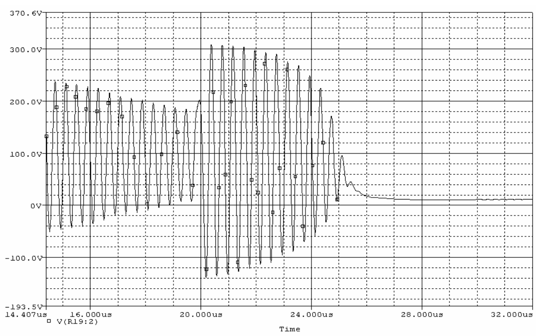


Fig.6. Output voltage at mode I and II

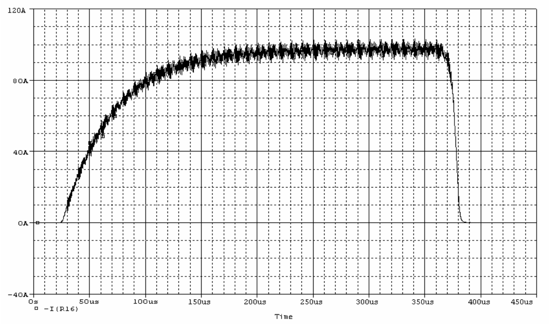


Fig.7. Output current with I_{ref}=100A

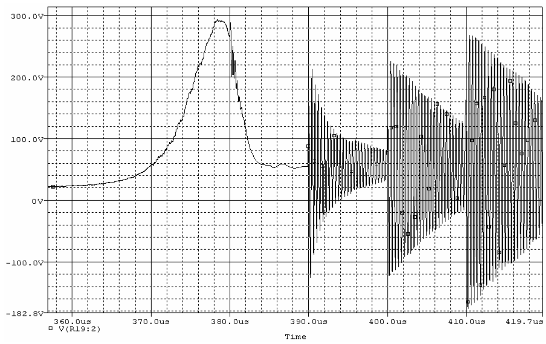


Fig.8.Transient voltage in mode II to mode I

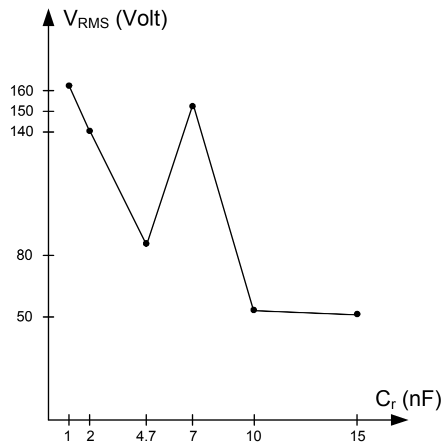


Fig.9. Output voltage versus resonant capacitor alternatives

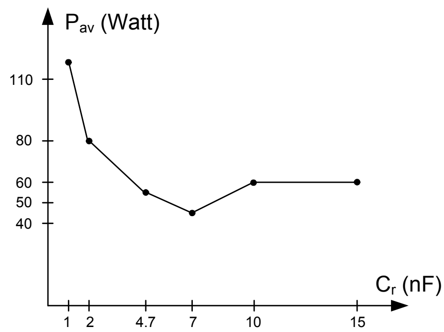


Fig.10. Output voltage versus resonant capacitor alternatives

5 Experimental Results

An experimental circuit shown in fig.11 was built to verify the simulated results. The high-current converter is an inverter. The current on the inductor is measured, rectified, and then compared to a reference current in the control circuit. The current amplitude increases and, when the reference voltage exceeds, the converter is switched off for a period. During the plasma condition, the low impedance of the load helps output current to reach the turnoff reference current and a time-out circuit activates the dead interval. In Fig 13 single end MOSFET drain voltage is registered. In a very short on time switch energizes the resonant tank, then switch's current reaches a sufficient magnitude that control system (contain a simple UC3844) turns the switch off and resonant tank begins to resonate so that a large amplitude voltage is injected to the electrode thus an amateur user can start welding easier than in ordinary systems.

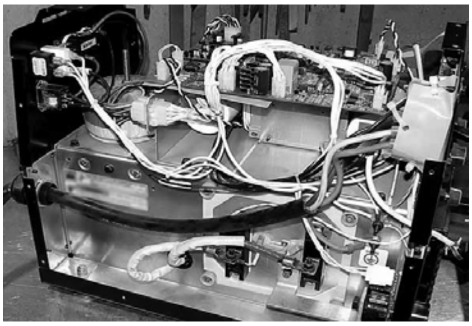
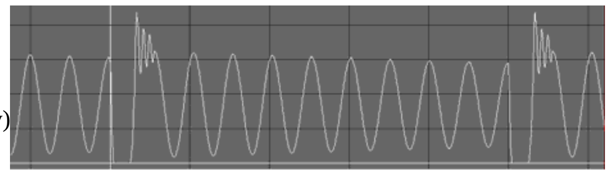


Fig 12. Purposed experience circuit

$V_o t$
(100v/Div)



Time (2μs/Div)
Fig.13. Drain voltage in mode I

7 Conclusions

A new and simple arc starter/arc stabilizer circuit is proposed to facilitate the arc welding process and prevention of griping of electrode. The simulation and experimental results verifies the considerable performance of proposed circuit. The simulation and experimental results are close to each other that show the modeling of arc and circuit operation has been acceptable. The power consumption of proposed circuit is low because it is basically a resonant circuit. Using the proposed circuit has resulted in reduction of copper losses of power transformer so the overall efficiency of system has increased.

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