Conversion of a 60 Hz AC Welder to Configurable DC Unit

ENGR 12 Final Project
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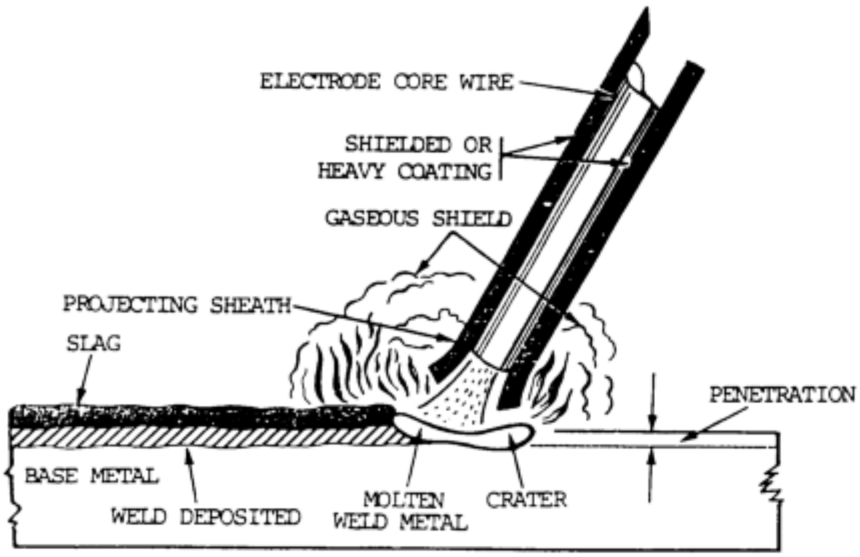
Abstract
This paper explores the design and construction of a direct current shielded arc-welding machine through the use of a full-wave bridge rectifier and smoothing capacitors. Basic electrical circuit design and analysis principles were employed in this project to evaluate the welder's performance.

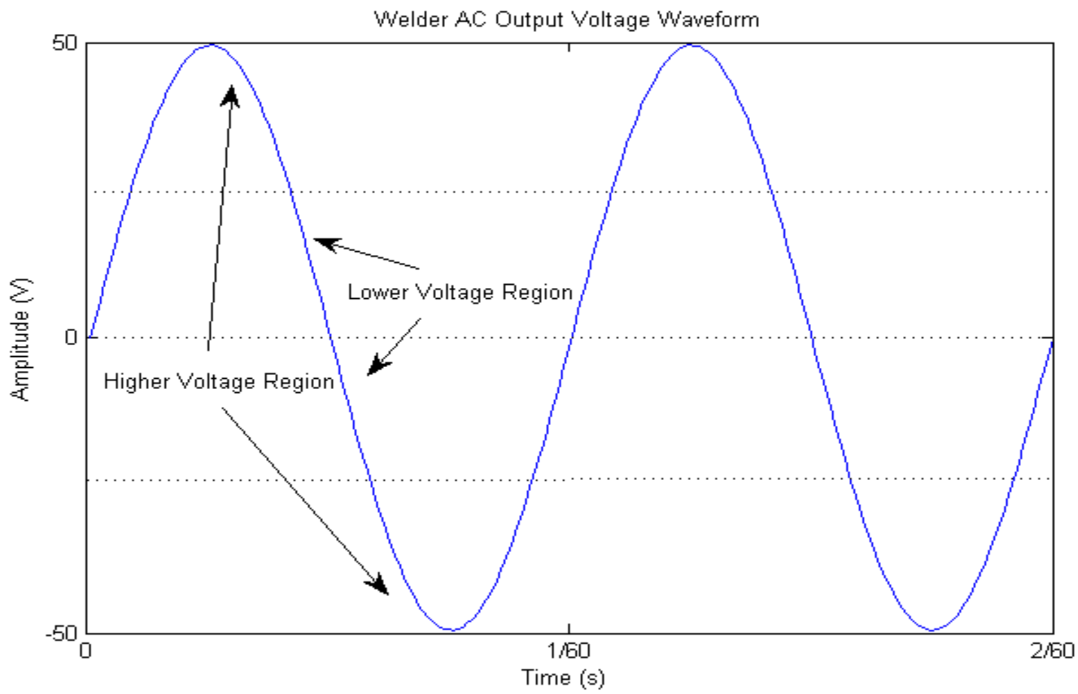
1. Introduction and Theory

A brief overview of the shielded metal arc welding (SMAW) process and vocabulary:



The welding electrode is generally an extruded rod of alloy steel of a diameter determined by the gauges of the ferrous metals to be welded. Except for a brief section on one end, where the electrode clamp makes contact with the metal rod, the electrode is evenly coated with a layer of flux. This material is composed of a variety of metal powders, oxides, salts, and other chemicals such as cellulose. The operator places the electrode in the welding clamp and starts an arc (a jet of hot, ionized gas) between the tip of the electrode and the work piece by quickly touching the electrode to the work piece and then drawing it back slightly to let the arc form. During welding, the flux serves several purposes. The high heat from the plasma arc melts the flux, causing it to both release gases that shield the molten metal of the weld pool (the leading edge of the weld joint) and to flow as a glassy liquid over the molten weld bead, where it continues to shield the cooling weld from oxidation and other contamination from the atmosphere. Additionally, the flux contains releases gases are readily ionized to contribute to arc stability. Finally, some fluxes incorporate other metals such as Magnesium into the weld joint to modify its mechanical properties.

In high school, I built a very simple AC arc welder based off of plans that I found in the internet. The welder circuit consisted of two modified microwave oven transformers, with the primary coils in parallel (to get even input voltage), and the secondaries in series (to attain a high enough voltage to start and maintain the arc). Though this simple welder worked, it did not perform as well as DC welders that I had used in the past. I suspect that the fluctuating voltage impedes the starting of an arc because the welding electrode's voltage is only high enough to start the arc half of the time the operator spends trying to start the arc. As can be seen below, the welding electrode spends equal amounts of time at "low" (below half the peak voltage) voltages as at "high" (above half the peak voltage) voltages:



Though alternating current can be used in SMAW, it is a tradeoff between the two direct current options: direct current electrode negative (DCEN) and direct current electrode positive (DCEP). DCEN is used for welding thinner material because electrons flow from the electrode into the work piece, resulting in a hotter electrode that melts faster and produces shallower welds. DCEP, in which electrons flow from the work piece into the electrode, generally yields deeper weld penetration and is the standard setting used by most SMAW welders. AC is used on a smaller scale because the equipment is cheaper, but the process produces more spattering and a less stable arc.

In order to expand the functionality of my AC welder to include these additional DC capabilities, I decided to construct a full-wave bridge rectifier from individual high-power diodes to convert the input AC into rippled DC and then to pass this across a large smoothing capacitor to reduce fluctuations in the current. After the construction and installation of this circuit, I will subject welds made in the DCEP setting and the AC setting to tensile strength testing to quantify differences in quality between the two types of welds.

2. Procedure

The fist challenge in this AC to DC conversion was to procure electrical components rated to the high currents involved in welding. I took several measurements of current and voltage of the original AC welder under three conditions: open circuit, short circuit, and during welding. The open circuit voltage value is the maximum voltage that the rectifier circuit could experience and the short circuit current is the maximum current the rectifier could experience. Measuring the open circuit voltage between the two electrodes was easily done with a handheld voltmeter (insert make and model here). Short circuit current measurements were taken with a clamp-style AC current probe (make, model) as current was passed through a 10 inch segment of 4 AWG solid copper grounding rod. Voltage drop across the welding electrode and work piece were taken with the same handheld voltmeter and current measurements were taken from the welding electrode lead. These measurements are summarized in the following table:

Input and Output Currents		
Condition	**Current (Amps)**	**Average Current (Amps)**
Input Current During Welding	18-28	23
Output Current During Welding	68-75	71.5
Input Current During Short	44	44
Output Current During Short	138-139	138.5

Open Circuit and Welding Voltages		
Condition	**Voltage (Volts)**	**Average Voltage (Volts)**
Open Circuit Across Electrodes	34.8	34.8
During Welding Across Electrodes	19.8-26	22.9

With these voltages and currents in consideration, with the help of Professor Erik Cheever, I selected diodes (150EBU02) rated to 150 Amps forward current and 200 Volts reverse voltage. Selecting capacitors proved to more difficult as there were more criteria in play: capacitance, maximum current, and maximum voltage. The calculations for determining the capacitance of smoothing capacitor are as follows:

$$I = C\frac{dv}{dt}$$

$$\frac{dv}{dt} = \frac{I}{C}$$

dv is the drop in the capacitor's voltage over time dt as the capacitor discharges

$$\frac{x\ volts\ ripple}{ripple\ duration} = \frac{I}{C}$$

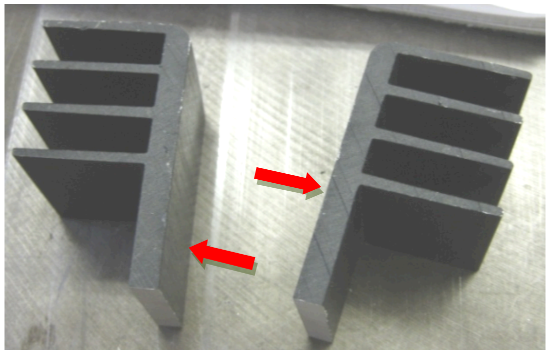
dt is equivalent to half a period: 1/120th of a second

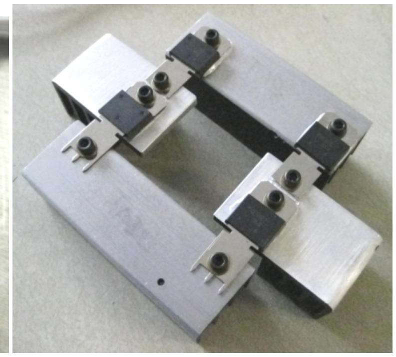
$$C = I\frac{1}{120 * (x\ volts\ ripple)}$$

Capacitance and Ripple Voltage	
Capacitance (Farads)	**Resulting Ripple Voltage (Volts)**
0.186	10% of Peak Voltage = 3.2
0.093	20% of Peak Voltage = 6.4
0.062	30% of Peak Voltage = 9.6
0.047	40% of Peak Voltage = 12.8
0.037	50% of Peak Voltage = 16.0
0.300 (Capacitance used in welder)	6.2% of Peak Voltage = 1.99

To minimize cost, three capacitors of .1F each were used to distribute the high current (an average of 71.5 Amps) between the three capacitors (each rated to 31.43 Amps ripple current).

Circuit construction was not without difficulties. The full-wave rectifier required connections between the diodes that could safely carry an average of 71.5 Amps as well as intermittent currents upwards of 110 Amps during brief short circuits. Heat management was also a chief concern in designing the rectifier. The two problems were solved by making the connections between diodes with sections of Aluminum (with a conductivity of 3.5×10^7 S/m versus Copper's 59.6×10^6 S/m) heat sink with large cross-sections to facilitate low-heat current flow.

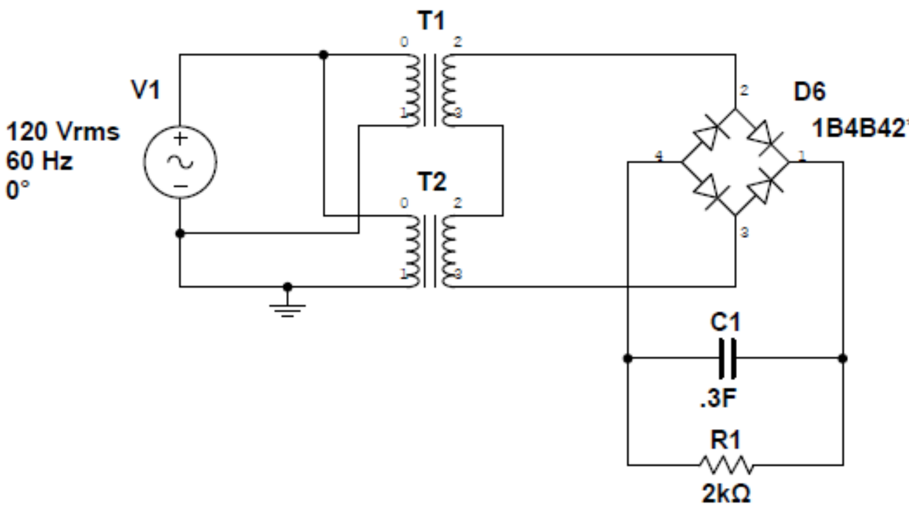




The largest set back was the careless installation of the capacitor bank. After the first the test of the welder, it became apparent that the capacitors had been installed backwards and as a result, the internal electrodes shorted, heated the electrolyte fluid which in turn melted the pressure-venting plug, releasing a jet of electrolyte fluid from each capacitor. Several days later, new capacitors arrived and were installed correctly.

The main safety concern was the charge stored in the capacitors after the welder was disconnected from power. To shorten the time constant, five 1/4W 10 kΩ resistors were connected in parallel across the capacitor bank to yield a time constant of (.3 F)(2 kΩ) = 600 seconds. The capacitors still present a serious safety concern, but do discharge to a safe level of charge over the period of an hour (six time constants). During testing, the capacitors were discharged though a 36o Ohm resistor for convenience (108 second time constant).

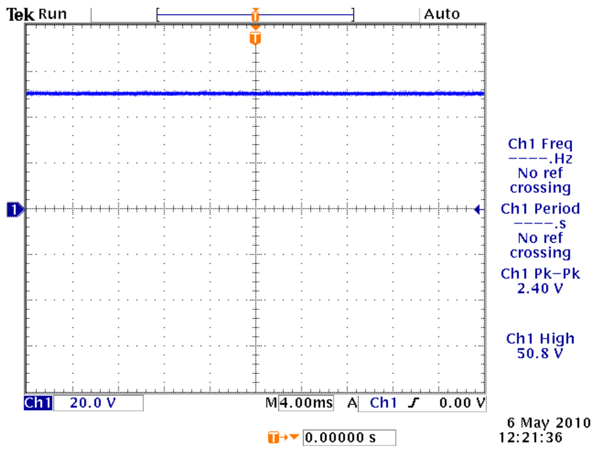
A Multisim model of the welder was created to provide a benchmark for evaluation of the welder's performance. The model's main short coming is the lack of control of current from the voltage source, which results in inaccurate currents in the circuit.

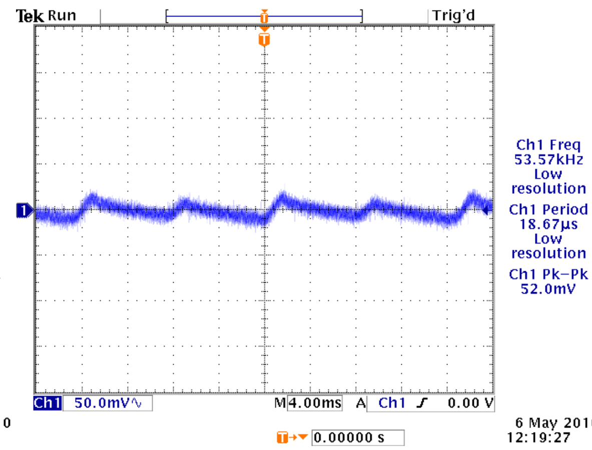


3. Results and Discussion

Welding performance in the DCEP setting was very poor. The first step in SMAW welding is striking the arc, which involves making brief but direct contact between the work piece and the electrode, which results in a short that when broken starts the arc. In this case, the short reduces the time constant of the capacitors' discharge from 200 seconds to a value near .12 seconds (a welding electrode at room temperature has a resistance of .4 Ohms). This sudden discharge causes a loud, powerful, and brief arc that gouges out a small crater in the work piece. Following this initial contact, the arc behaved poorly: it pulsed and sputtered and demonstrated no stability or endurance.

However, the rectifier and smoothing circuit performed correctly under a test load of a 100W light bulb (a test suggested by Prof. Cheever). The welder's leads were connected to the terminals of the bulb and a Tektronix digital oscilloscope was used to measure the AC and DC voltages across the light bulb.



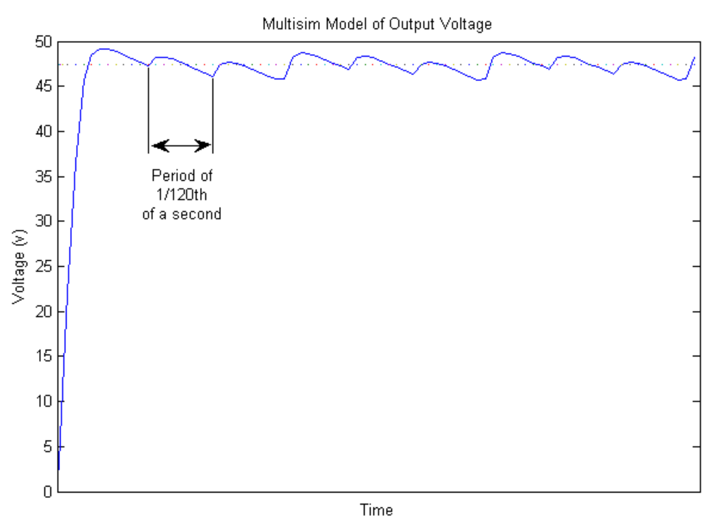


The Multisim model behaved largely as expected and produced an output that largely resembled predicted behavior, except for a pattern of three decreasing pulses, which is likely due to circuit rendering difficulties within the Multisim software. The signal has an average value of 47.4 V and a pulse period of 1/120th of a second, which is consistent with predictions. However, the observed amplitude of the AC component of the welder output is only 26 mV instead of roughly 2 V predicted by calculations or the ~1.5 V of the model. I'm not entirely sure why this is. Given that the welder performance data was taken across a 100W bulb whose resistance under load is roughly 144 Ohms (this is a value I looked up—I did not measure the resistance of the bulb I used), the combined time constant of the light bulb and the 2 k$\boldsymbol{\Omega}$ is about 40 seconds, so the drop observed over 1/120th of a second (from peak to peak) should be

$$V_{Pk-Pk} = V_{in}e^{-\frac{t_0}{\tau}} - V_{in}e^{-\frac{t_1}{\tau}}$$

$$V_{Pk-Pk} = 50.8 * e^{-\frac{0}{40.3}} - 50.8 * e^{-\frac{.00833}{40.3}} = 0.010499 = 10.5\ mV$$

This is a fifth of what was observed. The larger peak to peak voltage indicates a faster time constant, which is likely due to a lower than expected resistance in the light bulb.



4. Conclusion and Future Work

The full-wave rectifier and smoothing capacitors formed an effective circuit for converting the high alternating current output of the transformers to low-ripple DC, though the practicalities of welding limit the circuit's intended application. One potential improvement to the circuit to achieve actual welding functionality is to add a series inductor to one of the electrode lines to prevent the instantaneous discharge of the capacitors upon contact with the welder.

Having done a good amount of research on welder circuits and implementations, I am considering constructing a lighter weight, more efficient inverter-type SMAW welder. This type of welder uses both a rectifier and an inverter to reduce the power supply transformer's size and weight by up to 75% (M. Haque and A. Atashi). These welders first rectify the AC input and then pass it through a high-frequency inverter, whose output is then passed through a transformer to bring the power to welding current. The decrease in transformer weight and size are proportional to the increase of input frequency (A. M. and A. A.).

A second interesting improvement to my current design would be to include a dynamic arc adjustment system that bases adjustments to arc current and voltage on spectrographic information obtained though monitoring the arc's emission spectrum. This is likely far beyond my current capabilities, but spectral analysis of the arc would yield very interesting and potentially useful information about the weld joint.

5. Acknowledgements

Special thanks to Professors Cheever and Molter for their help in troubleshooting and design, to Smitty for letting me use the weld shop, to Ed Jaoudi for troubleshooting, hardware and components, and to Tom Snyder for use of the scene shop and tools.

6. References

http://upload.wikimedia.org/wikipedia/commons/f/f8/SMAW_weld_area.PNG
http://en.wikipedia.org/wiki/Shielded_metal_arc_welding
http://www.thefabricator.com/article/arcwelding/smaw-revisited-you-can-never-know-too-much **http://www.thefabricator.com/article/arcwelding/smaw-basics-how-much-do-you-knowr**
http://en.wikipedia.org/wiki/Electrical_conductivity
http://en.wikipedia.org/wiki/Incandescent_light_bulb

7. Appendices

Matlab code used to generate graphs:

```
%% AC waveform

x = linspace(0,1/30,200);
plot(35*sqrt(2)*sin(120*pi*x));
% axis([0 1/30 -130 130]);
title('AC Voltage Waveform');
xlabel('Time');
ylabel('Amplitude (V)');

%% rectifier circuit behavior (MATLAB simulation)
figure;
x = linspace(0,1/30,200);
plot(abs(120*sin(120*pi*x))); %rectifier output

%% capacitor discharge behavior
x = linspace(0,.025,800);
x2 = linspace(0,.01645,800);
cap = 32*exp(-x2/6);
rectOut = 32*cos(120*pi*x + 1/120);
figure;
set(gca,'ylim',[30 33]);
plot(x2,cap,x,rectOut);
title('Rectified AC and Capacitor Smoothing');
xlabel('Time');
ylabel('Amplitude (V)');
%% Multisim Performance vs. Actual Performance
msdata = importdata('msdata.scp', '\t');
mt = msdata(:,1);
mv = msdata(:,2);
steadyState = mv(50:450);
mt = mt(1:91);
% mt = mt*(.767730);
```

```
mv = mv(1:91);
y = mean(steadyState)
std
plot(mt,mv,mt,y);
title('Multisim Model of Output Voltage');
xlabel('Time (s)');
ylabel('Voltage (v)');

dcdata = importdata('DCdata.txt', ',');
dct = dcdata(:,1);
dcv = dcdata(:,2);

% plot(dct, dcv);
acdata = importdata('ACdata.txt', ',');
act = acdata(:,1);
acv = acdata(:,2);
% plot(act,acv);

% mt = mt';
% mv = mv';
% mt = mt(1,500);
% mv = mv(1,500);
% mt = mt';
% mv = mv';


%% Header from MS Data

% Oscilloscope data: SCP
%
% Time base: 0.767730 seconds per division
% Time offset: 0.000000 seconds
% Channel A sensitivity : 20.000000 volts per division
% Channel A offset: 0.000000 volts
% Channel A color: 13126600
% Channel B sensitivity : 5.000000 volts per division
% Channel B offset: 0.000000 volts
% Channel B color: 6604900
% Channel A connected: yes
% Channel B connected: no
%
% Column 1  Time (S)
% Column 2  Channel_A Voltage(V)
% Column 3  Channel_B Voltage(V)
%
% Time                  Channel A
% -------------------------------
```