SIZING THE PRIMARY POWER SYSTEM FOR RESISTANCE WELDERS

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ABSTRACT
Information on how to select the correct size of substation transformer and 480V bus to power one to one thousand resistance welding machines is presented. Powerline voltage drop, light flicker, power factor correction and harmonic currents are discussed. Strategies to allow more welders to operate on a given power system are explained. Techniques to improve the efficiency of the power system and reliability of the welding process are identified. Consideration is given to selecting the correct sizes and types of fuses. Useful reference material will be available to attendees.

INTRODUCTION
Because resistance welders draw large currents on an intermittent basis, they present special problems to the primary power system in a manufacturing plant. This paper answers the following questions related to these problems.

1. What size does the three-phase power system need to be to support the number of welders I have?
2. How is a welder power bus different from other power buses?
3. What can be done to improve power system efficiency and capacity utilization?
4. What is the proper size and type of fuse to use?

For the purposes of discussion in this paper, spotwelding of steel sheet of thickness between 0.5 and 3 mm. is assumed. The power system supplying the welders is 480VAC, 60 HZ, three-phase. In general, the discussion is centered around standards and practices most commonly used in the North American automobile industry.

I. What size does the three-phase power system need to be to support the number of welders I have?

A typical resistance spotwelder draws between 100,000 and 200,000 watts when welding! To avoid problems of cold welds due to insufficient power, the 480 VAC power system must be capable of supplying this power with less than 10% voltage drop.

Now, 10% voltage drop doesn't sound like much, but consider this: The amount of power available in a circuit is proportional to the voltage squared divided by the resistance. If the voltage drops by 10% (to 0.9 times the original value) the available power drops by 19% (0.9 times 0.9 equals 0.81). A 19% drop in energy to the weld has some serious effects on weld quality!

Most modern resistance welding controls have systems to compensate for powerline voltage drop, but when the powerline voltage drops by more than 10% and the available energy drops by more than 19%, there may not be enough energy left to make the weld, even after the welding control has done all the compensation it can do. For this reason, powerline voltage drops should be limited to 10% or less.

In order to calculate powerline voltage drop, the current draw of the welders and the impedance of the power system must be known. In the absence of actual measurements of powerline draw and voltage drop during weld, the following assumptions can be used:

1. Where there are several single-phase AC spotwelders connected to the same three-phase power bus, the connection of the welders to the power bus is distributed as equally as possible between the three phases so as to make the average power draw equal on all three phases.
2. For a hanging gun welder (single-phase transformer suspended from the ceiling with a kickless cable going to the welding gun), the equivalent three-phase current draw during welding is 400 amperes.
3. For a single-phase AC fixture welding gun or a robotic hip-mounted transformer welder, the equivalent three-phase current draw during welding is 270 amperes.
4. For a single-phase AC integral transformer welding gun, the equivalent three-phase AC current draw during welding is 170 amperes.
5. For a three-phase MFDC welding gun, the equivalent three-phase current draw during weld is 150 amperes.
6. The duty cycle of the welders is 5%.
7. The impedance of the three-phase power system is 7%. That is, When the power system is loaded to its full continuous duty current rating, the voltage will drop by 7%. In other words, if you draw 400 amperes on a 480 V 400 amp bus with a 7% impedance factor, the voltage will drop from 480V (unloaded) to 446V (Fully loaded).

The above assumptions are valid for spotwelders welding sheet steel (galvanized or bare) over the thickness range of 0.5 to 3 mm.

For small numbers of welders (4 or fewer) actuated manually, there is a very high probability that all will be welding simultaneously at least several times a day. Where 4 or fewer welders are involved, the power system should be sized so the voltage doesn't drop by more than 10% when all welders weld simultaneously.

If the power system cannot be sized to handle all the welders welding simultaneously, some sort of interlock can be used to assure that only one welder at a time is allowed to weld. A simple interlock circuit, consisting of only two relays per welder, is shown in Figure 1. For small shop and/or low production requirements, this simple relay circuit works well up to 5 welders. With the use of this interlock circuit, the power system only needs to be sized to handle the current of one welder with no more than 10% voltage drop. So long as the duty cycle of the welders is 5% or less, this interlock circuit slows the production rate by much less than 1%.

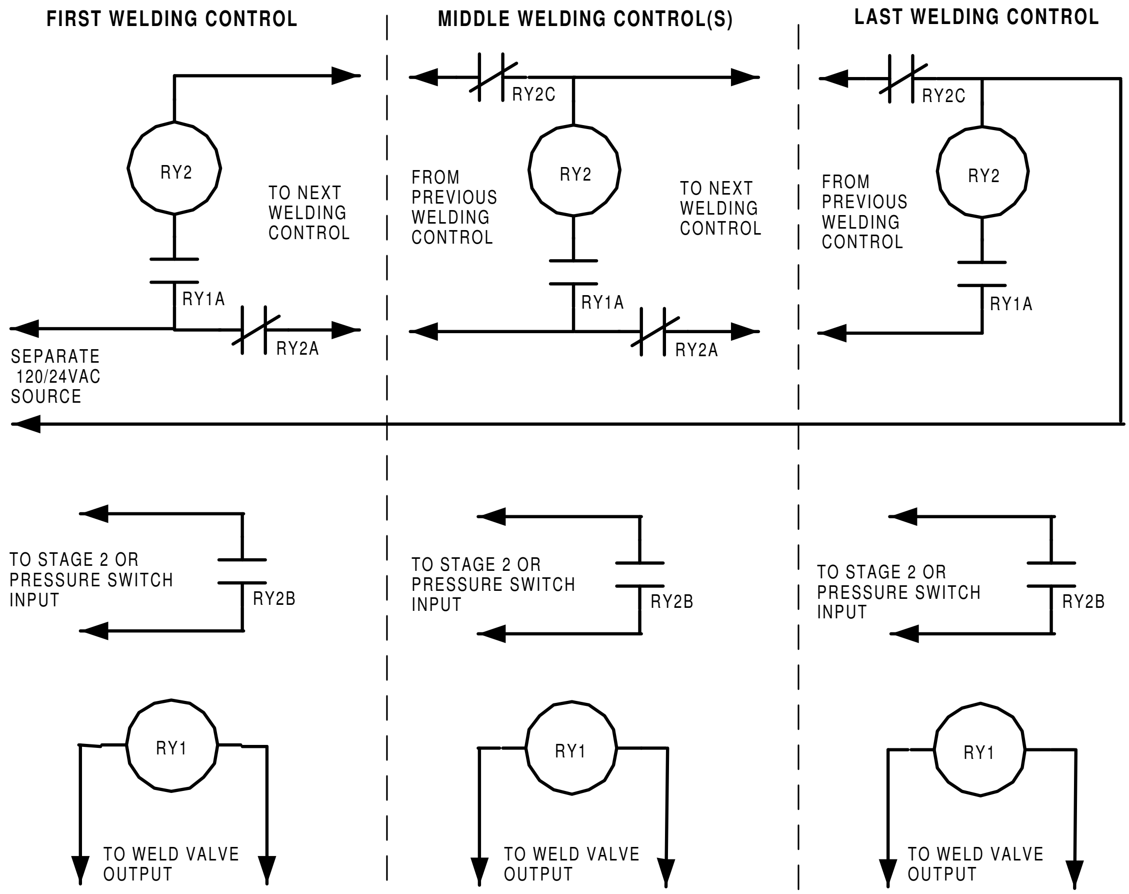


FIGURE 1: Simple interlock circuit for 5 or fewer welders

For 5 or more welders, running at duty cycles of 5%, it becomes very unlikely that all of the welders will weld at the same time, assuming random initiation times by human operators. For 5 or more welders, statistical techniques may be used to estimate the number of welders welding at any instant of time and size the power bus accordingly.

The spreadsheet associated with this paper implements a statistical method to estimate, give a certain number of welders, how often the powerline voltage will dip by more than 10% and how many welds per 1000 will be affected by the voltage drops of greater than 10%.

The data values are entered in column E. These values can be changed as desired for "what if" calculations. For example, with the values already entered, if the average duty cycle is increased from 5% to 10% (a very high value for spotwelding) , it will show that the number of welds likely to have one or more cycles of low line voltage will increase from 2 per 1000 (acceptable for most applications) to 247 per 1000 (good only for making scrap).

The "what if" calculations can also be used to make estimates of the lowest line voltage that will occur with a given number of welders. The value for the "minimum allowable line voltage" (Cell E9) can be decreased until the number of welds per million with one or more cycles of low line voltage reaches 1 per million. This allows the "worst case" voltage drop to be found.

General case estimates for the current draw for different types of resistance spotwelding machines are in cells G2 through G5. These current draw estimates are for the welding of steel (bare or coated) only. If you know the exact value of current draw for the welding machines in your plant, then the known values should be entered here. In general, however, these estimated values should suffice for welding steel in all but the most unusual cases.

The current draws for welding aluminum are about 3 times the assumed values for steel shown in cells G2 through G5. For weld time, use 5 cycles. For duty cycle, use 3%.

The estimates of this spreadsheet are not accurate for a mixture of some machines welding steel and some welding aluminum. If your situation involves a mix of this sort, another analysis method should be used.

Please notice that the calculations are based on the number of welding machines (welding guns), not necessarily the number of welding controls or the number of welding transformers. For example if multiple welding transformers are connected to one welding control or multiple welding guns are connected to a single welding transformer, the number entered in cell E5 should reflect the total number of welding guns or pairs of welding electrodes.

The estimates in this spreadsheet are slightly biased toward "worst case". If you size a welding power bus so that the number of welds with low voltage is about 1 or 2 per thousand, then it is very unlikely you will get cold welds due to low powerline voltage. The statistical assumptions and approximations in this spreadsheet are accurate with 5 or more welders. With more than 250 welders and/or if the welders have a very high duty cycle, you may find that the "Average Bus current" (Cell D29) is larger than the "3-phase power system continuous duty rating" (Cell E11). If this happens, use the higher value in cell D29 to size the power system.

Once the required supply current is calculated by any of the previous methods, the necessary substation transformer KVA is calculated with the following equation:
SUBKVA = CURR*LV*0.001732
where:
SUBKVA is the required substation transformer KVA
CURR is the required supply current
LV is the powerline nominal voltage (480VAC, 390VAC, etc.)

For example, with a required current of 600 amperes and a 480V bus, the necessary size substation transformer would be 498.8 KVA.

II. How is a welder power bus different from other power buses?

Resistance welders are probably the worst loads that can be placed on a three-phase power bus. They draw large amounts of current for short periods on a very intermittent basis. The waveform of the current they draw is almost never a smooth sine wave and it is almost never balanced between the three phases. Harmonic currents, powerline waveform distortion and rapidly changing powerline voltage are the result.

For the above reasons and more, it is not a good idea to put resistance welders on the same power bus as other equipment. A power bus separate from any other in the plant, fed by a separate substation transformer is recommended for powering resistance welding machines.

If a large proportion of the resistance welders in your plant are single-phase, a DELTA connected substation made with three single-phase transformers, rather than a single three-phase transformer is recommended. There are several reasons for this:

1. In a DELTA connected system, the effective impedance presented to a single-phase load is lower.
2. In a DELTA power system, which has no neutral conductor, the imbalance and harmonic currents are forced to flow through the bus, which is sized to handle the current, rather than the neutral conductor which may not be big enough to handle the current.
3. In a DELTA power bus, the three separate single-phase substation transformers rather than a single three-phase transformer reduce the coupling between phases which results in an unloaded phase increasing in voltage when another is loaded down. This reduces voltage fluctuations. This becomes particularly important in a resistance welding power bus where occasional voltage drops reach 15%.

Single-phase AC welders usually have a power factor below 70%; power factors of 50% or less are not unusual. Part of this poor power factor is due to inductance in the secondary loop of the welding machines and part is due to the current waveform distortion caused by the phase control action of the welding control.

Three-phase MFDC welders have a power factor in the 85-95% range. All of the poor power factor is caused by current waveform distortion and none is caused by inductance in the secondary loop of the welding machine.

The usual methods of adding power factor correction capacitors to the bus simply don't work for resistance welders for several reasons:

1. The current draw of resistance welders is extremely intermittent and changes from second to second. Any constant value of power factor correction capacitor will be wrong for the load current almost all the time.
2. Due to the phase control action of the welding controls, there are a lot of harmonic currents generated, primarily 3rd, 5th and 7th order. Due to the intermittent action of resistance welding, the inductance present on the power bus is constantly changing, as some welders start welding and others stop. For any reasonable value of power factor correction capacitors, there will be times when the capacitors and the inductance on the power bus form a tuned circuit, resonant at the 3rd, 5th, or 7th harmonic of the powerline. The resonant action will cause severe waveform distortion on the powerline voltage and

eventually destroy the power factor correction capacitors by exceeding their current rating.

3. A large part of the poor power factor on a resistance welder bus is due to the “chopping” of the AC waveform which is done as part of phase control or by “flat-topping” of the powerline waveform caused by the rectifier input circuits of MFDC welders. Power factor correction capacitors cannot correct poor power factor due nonlinear (switched) current draw.

For the above reasons, DO NOT put power factor correction capacitors on a welder power bus! DO NOT connect anything with power factor capacitors built-in (such as equipment containing motors or lighting circuits) to a welding bus. Except for one special case noted below, power factor correction capacitors on a welder bus are worse than useless.

If power factor correction on a welder bus is necessary it can be done with harmonic filters (tuned to the 3rd and 5th harmonics) and/or active waveform correction devices. However these devices are far more expensive than simple power factor correction capacitors and are often not cost-effective. For smaller installations (50 welders or less) it is usually cheaper to pay the power factor penalty to the utility company. Only in larger installations (100 welders or more) are these devices cost-effective.

There will be cases where installing a separate power bus for the resistance welding equipment simply cannot be done. This often occurs in small manufacturing plants where there are only two or three resistance welders. In this situation, there are several things that can be done to at least mitigate the negative consequences.

1. Use MFDC welding whenever possible. MFDC is much kinder to the three-phase power bus and draws current from all three phases approximately equally.
2. Size the power bus so that even if all the welders weld at the same time, the voltage drop is only 5%. This will reduce light flicker and other undesirable effects on the other devices powered from the same power bus as the resistance welders.
3. Install some sort of system (such as the simple relay circuit mentioned previously) to make sure only one welder can weld at a time.
4. Install one set of very small power factor correction capacitors (1 KVAR maximum) on the power bus as close as possible to the welding machine(s) to help absorb any voltage spikes generated by the switching action of the resistance welders.
5. Put any computers or other electrically sensitive devices (such as telephone equipment) on a UPS (Uninterruptible Power Supply).
6. Get used to light flicker; it WILL happen!

III What can be done to improve power system efficiency and capacity utilization?

Although resistance welders are possibly the worst load that can be placed on a three-phase powerline, there are some things that can be done to make the situation better.

When connecting single-phase welding machines to a three-phase powerline, DO NOT connect all the machines to the same phase of the powerline! Instead, distribute the connections approximately equally between all three phases. For example, if there are 10 welders to be installed, connect three to phase 1, three to phase 2 and four to phase 3. This distributes the average current draw more-or-less equally across all three phases.

If multiple single-phase welders are welding simultaneously, try to run them in groups of three with each welder in the group of three on a different phase. This will present a more balanced load to the three-phase powerline.

In general, try to run the welding transformers on the lowest tap that still gives a satisfactory weld without causing the weld control to give current regulation or voltage regulation faults. This reduces the current draw of the welder and improves its power factor, which results in lower electricity bills.

A load scheduling system that limits the maximum number of welders that can weld at any instant of time can make a big difference in the maximum current draw and can allow more welders to operate on the same size power bus.

The Excel spreadsheet associated with this paper allows a load scheduling system to be simulated and its effect on the production rate estimated. After entering the proper values for your system in cells E2 through E13, the maximum number of welders allowed to weld simultaneously by a load scheduling system is entered in cell E32. When this number is entered, the numbers reflecting the required bus size and the effect on production rate are calculated and displayed in cells C33 and C35. The mathematical approximation used to obtain these values is most accurate in the range of 5-60 seconds per hour of production time lost. Below 5 seconds, the lost production time tends to be overstated (bigger number than it really is) and above 60 seconds per hour, the lost production time tends to be understated (smaller than it really is).

IV. What is the proper size and type of fuse to use?

For an individual welder, the general rule is that the fuse size in the bus disconnect and the wiring from the bus disconnect to the resistance welding control should match the ampere rating of the circuit breaker in the welding control. For example, if there is a 250 ampere circuit breaker in the weld control, then a 250 ampere fuse should be used in the bus disconnect and 250 MCM wire should be used between the bus disconnect and the weld control. The fuse should always be a weld limiter type of fuse which has a very slow-blow characteristic. Use of this rule assures compliance with the National Electrical Code in the USA.

If the KVA of the welding transformer(s) is known for a particular installation, then all of the 480V wiring, from the bus disconnect to the welding control and from the welding control to the welding transformer can be sized according to the transformer KVA. The basic rule for single-phase welding transformers is that the minimum cable size is 1.7 amps ampacity per transformer KVA. For cable ampacity, the NFPA standard values should be used. For example, a 100KVA transformer requires a wire with an ampacity of 170 amperes, or AWG 2/0 wire. At the bus disconnect, a fuse appropriate to the wire size (200 amperes) is required.

If the transformer KVA is such that the calculated ampacity is more than the rating of the circuit breaker in the resistance welding control, then the wire size and the bus disconnect fuses should be selected according to the circuit breaker rating.

Two or three single-phase AC resistance welding controls can be powered from a single three-phase bus disconnect. When this is done, the following recommendations apply:

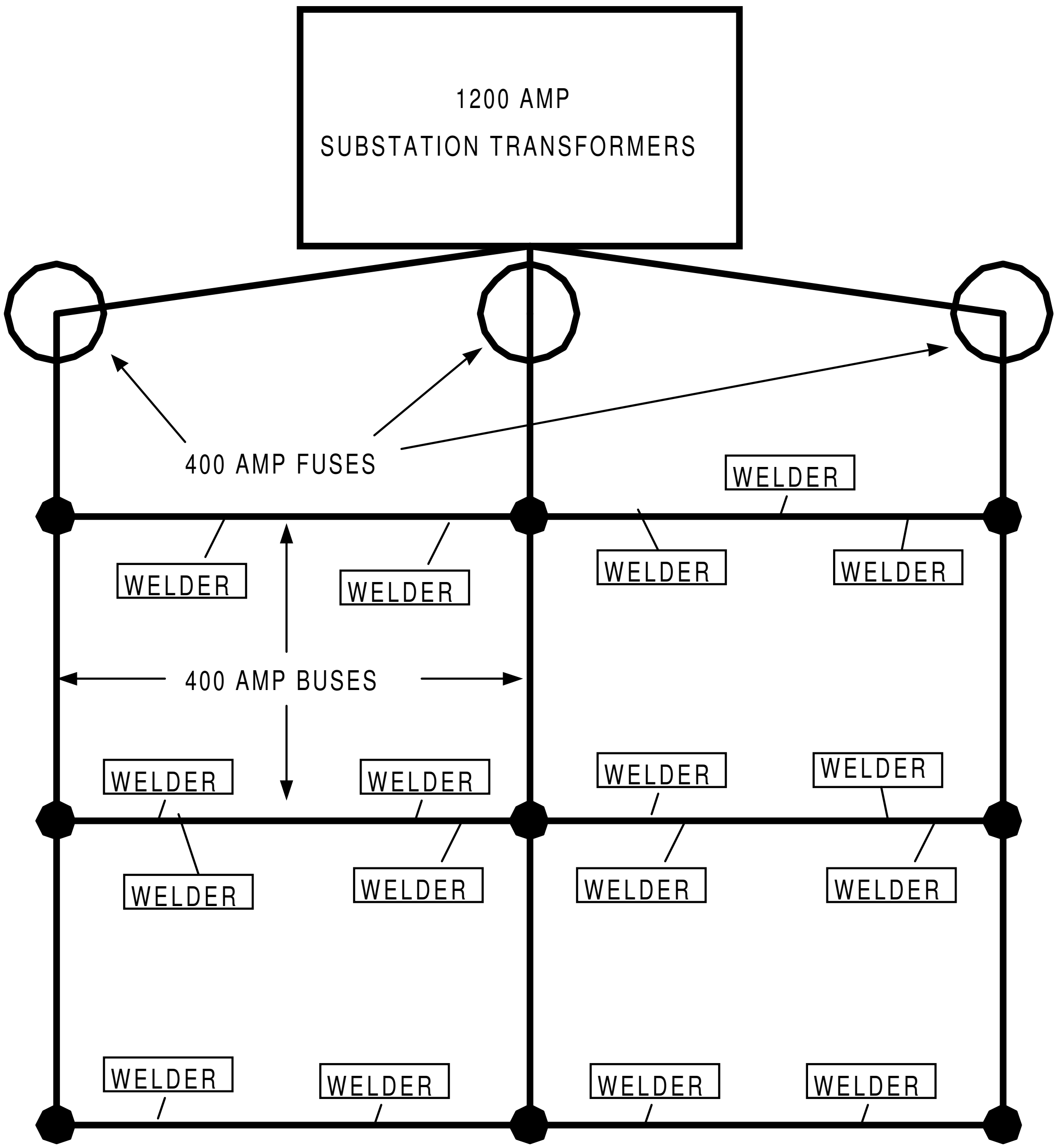
1. All three welding controls should be of the same type and have the same size circuit breakers. For example, it is not advisable to connect a multi-contactor cascade firing control with 6 welding transformers onto the same disconnect as two other single-contactor controls with one welding transformer each.
2. Each of the welding controls is connected to a different phase.
3. The transformers connected to the welding controls should all be the same total KVA.

When two or three welding controls are powered from one three-phase bus disconnect, the disconnect and the fuses in it should be sized 1.5 times bigger than what would be required for a single control. For example, it is acceptable to connect three resistance welding controls with 250 ampere circuit breakers to a single 400 amp three-phase disconnect.

For three-phase MFDC resistance welding controls, the bus disconnect fuses and the wiring between the bus disconnect and control should always be sized according to the circuit breaker size in the welding control. The wire used to connect the welding control to the welding transformer should have an ampacity equal to 1/3rd of the rated current of the inverter at 10% duty cycle. For example, a 600 amp MFDC welding control equipped with a 150 amp circuit breaker should be installed with 150 amp bus fuses, AWG 0 wire between the bus disconnect and the circuit breaker and with AWG 3/0 wire (200 amps) between the welding control and the welding transformer. The bus disconnect fuses should be weld limiter (slow blow) type fuses.

The main power bus fuses feeding the welder bus should be sized according to the rated capacity of the power bus or the substation transformers, whichever is less. If the layout of the plant permits, it is advantageous to install the welder bus in a loop configuration with the beginning and end of the loop near the substation transformers. Power is fed from the substation transformers into both ends of the power bus. This both lowers the effective bus impedance by providing dual current paths to any load and it doubles the capacity of the bus. For example, if a 1200 amp welder bus is required, the requirement can be met with a looped 600 amp bus. A looped bus is particularly effective where there are a large number of welders, distributed more-or-less equally along the bus. Depending on the installation, this may save considerable amounts of money.

Other bus configurations, such as the ladder configuration shown in Figure 2 can also be used. In Figure 2, the need for a 1200 amp welder bus is met with interconnected 400 amp buses.



= BUSES CONNECTED TOGETHER AT THESE POINTS

FIGURE 2: **Bus "H" configuration to obtain higher currents**

In order to meet local electrical code requirements, it may be necessary to add auxiliary fuses at the points where the power buses are interconnected. It is always good practice to have a proposed bus design reviewed by the local electrical code enforcement agency.

SUMMARY AND CONCLUSIONS

The guidelines presented in this paper are directed toward resistance spotwelding equipment in an environment like an automobile body assembly line. The guidelines in this paper are not designed for resistance seam welders, very large welders (such as used to weld automobile rims or aircraft landing struts), three-phase DC welders, or to any welders with a 500 KVA or larger welding power supply. The guidelines of this paper assume that either steel or aluminum, but not a mix of the two, is being welded.

For all but the most unusual installations of resistance welding equipment, the information presented in this paper should be sufficient to properly size the three-phase power bus so the welders can operate reliably.

In addition to the information given in this paper, a number of articles and other material about powerlines for resistance welders are included in the appendix. This material was the basis of this paper.

Because of size (over 100 pages with the appendix) this paper was distributed in electronic form (on a CDROM). If you are reading a paper copy of this paper, the electronic form, with all the appendices can be downloaded from the Welding Technology Corp. web site (www.weldtechcorp.com) or can be obtained by contacting Jack Farrow at 248 477-3900 or jfarrow@weldtechcorp.com .