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HOW TO DISTRIBUTE POWER TO RESISTANCE WELDERS

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INTRODUCTION

This publication outlines the basic principles for proper design of industrial power systems which must furnish power to resistance welders. The intermittent character of resistance welding loads introduces special problems not associated with

power supply for most other types of load. The nature of these problems and methods for their solution are presented. Sufficient information is included to permit selection of suitable types and ratings of power supply equipment for the majority of applications.

RESISTANCE WELDER LOADS

Resistance Welding

Resistance welding is a process in which metal pieces are firmly held together while a high electric current is caused to flow between them. The resistance in the path of the current generates sufficient heat to weld the pieces. The welding current usually ranges from 3000 to 30,000 amperes or more. This current is ordinarily provided by a welding transformer which is a part of the welding machine. Fig. 1 is a schematic diagram of a typical resistance welding machine.

The welding transformer of Fig. 1 has a transformer with a single-turn secondary, which connects to the electrode holders through a flexible lead. The flexible lead permits some vertical movement of the upper electrode, so that the pieces to be welded may be inserted between the electrodes. The pressure mechanism of the machine puts a substantial force between the pieces by pressing down on the upper electrode. This force assures good electrical contact and enough pressure at the joint for welding. Current is controlled by a contactor in the transformer primary. The contactor is usually an electronic device mounted on the machine and employing ignitron tubes. The current flows for only the very short time required to complete the weld.

Nature of Load

The intermittent nature of resistance welding loads introduces special problems not associated with power supply for other types of load. For each installation it is desirable to have estimates of the expected number and location of welders and the amount and character of their inputs. Approximate data are usually sufficient for system design purposes. Ample allowances should be made for possible future increases in the welding load.

The kva rating of a welder is the input kva which the welder transformer can accept without overheating, when (and if) current flows 50 percent of the time during any minute of operation.

The actual input to a resistance welder cannot be determined directly from its rating. It is necessary to estimate the input to each machine as affected by its type, and the operating conditions.

Such information can usually best be obtained from the welder manufacturer, but test data may be

used if the machine is already installed. In many cases, only rough estimates are needed, and these can be made from information provided in this bulletin, for the type and rating of each welder. The most important aspects of resistance welder input are kva demand, duty cycle, power factor, welds per minute, and whether the welder is single-phase or three-phase. Most welders are single-phase.

The kva demand is the maximum input during welding. It may be from 30 kva for a small machine to 1000 kva for a large welder. The duty cycle is the ratio of weld time to total time for a weld. The weld time is usually from one to thirty cycles. The total time is determined by the number of welds per minute, which may vary from a few welds to several hundred.

Measurement of Input

The current, voltage, and power input of a welder can seldom be measured accurately by conventional instruments because of the short weld time. For weld times of 10 cycles or more, pointer-stop instruments may be used. A pointer-stop instrument has an adjustable rest for the pointer - so that the pointer may be held near the expected reading before current flows. This avoids the delay usually associated with movement of the pointer to the indicating position. The stop for a pointer-stop voltmeter should hold the pointer down instead of up scale, so that it will be near the value to which the voltage may be expected to drop. Several trials

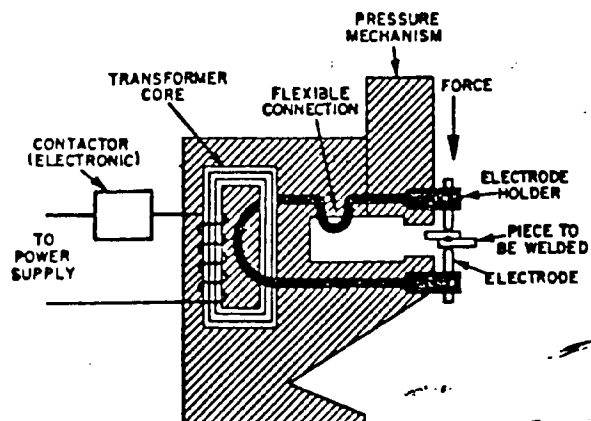


Fig. 1 Schematic diagram for resistance welder (1093803)

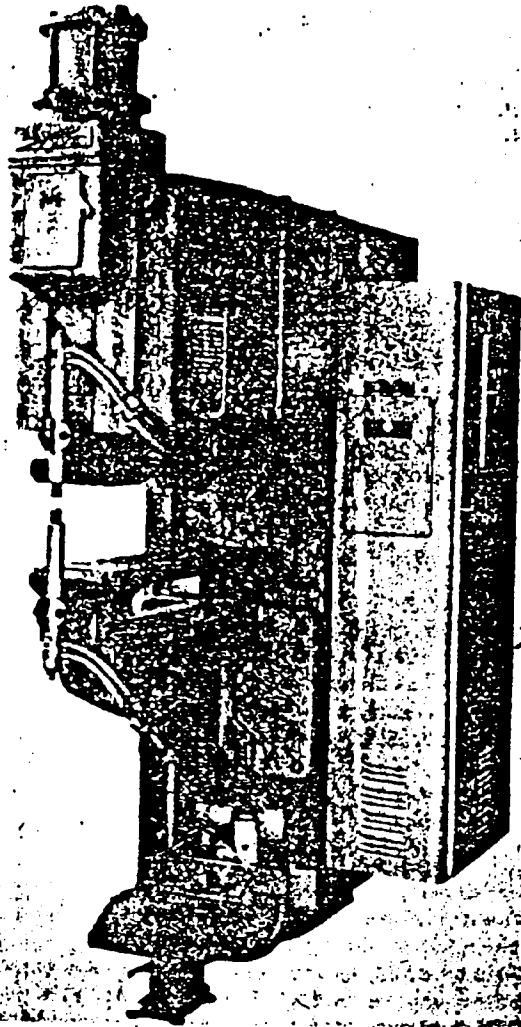


Fig. 2 Typical resistance welder for spot or projection welding (1027403)

may be required to obtain a satisfactory initial setting of the stop. For weld times of less than 10 cycles it is usually advisable to use an oscillograph if measured data is required.

Spot or Projection Welders

Fig. 2 shows a typical welder for making spot welds or projection welds. Spot welds are made between the two vertical electrodes at the front of the machine. Projection welds are made by placing the pieces to be welded between the two horizontal flat plates, called platens, behind these electrodes. Welds are then formed where small projections on one of the pieces press against the other piece.

Fig. 3 shows the input current to a typical single-phase spot or projection welder. In this case the weld time is four cycles and the total time from the start of one weld to the start of the next is 40 cycles. Hence, the duty cycle is 10 percent. Depending upon operating conditions, the duty cycle of spot or pro-

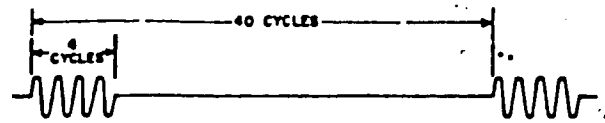


Fig. 3 Spot or projection welder (1093804)

jection welders may range from one to twenty percent.

Occasionally several impulses are used for each weld, when employing a practice called pulsation welding, or when preheating or post-heating are required.

The kva demand is the product of the line voltage and the RMS current during the weld time. For a spot or projection welder, the demand may be two or three times the rated kva of the machine. Often, however, welders are operated at less than their maximum welding outputs, depending upon the material or parts being welded.

The power factor of conventional spot and projection welders is usually from 30 to 50 percent. Portable spot welders, called gun welders, however, may have power factors as high as 90 percent. This high power factor results from the resistance of the long cables used between the welding transformer secondary and the portable "gun" which holds the electrodes.

If electronic heat control is used with a welder, the power factor is proportionately reduced as the heat setting is lowered. However, maximum voltage drop occurs at 100 percent heat setting.

Seam Welders

The electrodes of a seam welder are two wheels. The current flows from one wheel through the weld to the other wheel. A series of welds called a seam is made as the welding wheels rotate, causing the welded pieces to move horizontally between them.

Fig. 4 shows the input current to a typical seam welder. The duty cycle of such a welder is high, usually about 50 percent. The maximum demand is commonly close to the rated kva of the machine. The power factor is ordinarily about 30 to 50 percent.

Butt Welders

A butt welder welds two pieces end to end by forcing the ends together as the welding current flows between them. The input is similar to that of a spot welder.

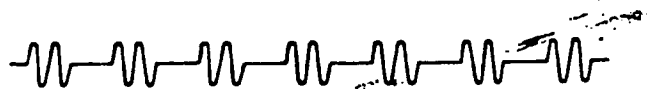


Fig. 4 Seam welder (1093805)

Flash Welders

A flash welder is a special form of butt welder which heats the pieces by establishing an arc between them for a period, called the flashing time, before butting them together so that they weld during the remaining conduction period, called the upset time.

A flash weld has a characteristic load pattern. During the flashing period, which may be several seconds, the input current is at a power factor near 80 percent. During the upset period, which may last only a few cycles, the current is several times the flashing value, and the power factor is reduced to about 50 percent.

Multiple Welders

Sometimes several electrodes are mounted on a common movable frame which applies welding pres-

sure for a number of welds at the same time. The machine includes separate welding transformers for each weld or pair of welds. The control for such a multiple welder may cause all welds to occur at once, but for a small additional cost, welds can be made to occur in a sequence of one or a few at a time. This greatly reduces the maximum demand of the welder. The increase in time required to complete a group of welds is usually negligible, and the cost of power supply equipment may often be substantially lessened.

Frequently it is advantageous to make three welds at a time or multiples of three and connect the corresponding welding transformers in the machine to different phases so that the load is three-phase.

The power factor of multiple welders is usually high, 75 percent being a typical value.

SPECIAL WELDERS

Several special types of welders have been developed which have lower kva demands than the conventional welders required for a given weld. These machines have a higher initial cost but the extra cost may be offset by savings in the distribution system. However, when there are a substantial number of welders to be supplied from one substation, it is usually most economical to use a substation adequate for conventional machines, with the possible exception of a few unusually large welders, which may be special machines.

Series Capacitor Welders

One method of reducing the demand of a welder is to use a single-phase machine with series capacitors. The capacitors are selected to change the power factor to 100 percent at full heat. The maximum welding kva is usually 30 to 50 percent of that for a machine without capacitors and is proportional to the power factor of the machine before application of capacitors. Electronic heat control is used, and this reduces the power factor below unity at reduced heat settings. The maximum line voltage drop usually occurs at about 90 percent current, and the power factor at this setting is 90 percent.

Metallic Rectifier Welders

Some welders use a metallic rectifier to convert three-phase a-c power to d-c for welding. The kva demand is usually 35 to 60 percent of that for a comparable conventional machine, and moreover, it is a balanced three-phase load. A small amount of harmonics, about five percent, is introduced into

the a-c line current by the rectification process. The power factor is high.

Frequency-changer Welders

These machines convert three-phase power to single-phase at a low frequency, usually four to twelve cycles per second, for welding. The kva demand is usually 35 to 60 percent of that for a comparable single-phase welder. The input is three-phase at a high power factor. Harmonics comprise about 20 percent of the RMS line current. Voltage drop, however, is primarily due to the remaining 60 cycle component of current. The power factor of this component is called the vector power factor and a typical value is 85 percent. Voltage drop may be calculated in the same manner as for a balanced three-phase load at this power factor. The line current fluctuates somewhat at twice the welder output frequency, and this fluctuation may be slightly more objectionable from the standpoint of light flicker in some cases than the same voltage drop by a welder which does not have this fluctuation.

Stored-energy Welders

Several types of welders employ energy storage between welds to reduce input demand. These include capacitor discharge welders, electromagnetic stored energy welders, d-c battery welders, and welders with motor-generator sets. Such equipment greatly reduces demand, but the initial cost is relatively high. The first two types mentioned were widely used in the aircraft industry in World War II but they are now being supplanted by other methods which do not store energy.

VOLTAGE DROP

Limits for Voltage Drop

To check the suitability of a power system for resistance welders it is advisable to be able to estimate expected voltage drops. These should not be too great too often for good welding results; also they should not cause objectionable light flicker or impair performance of other loads.

Calculation of Drops

With any given three-phase power system, a line-to-line single-phase load will cause twice as much drop as a three-phase load of the same kva and power factor.

Improvement of power factor reduces the drop for a given load kva, and power factor improvement is usually accompanied by a reduction in demand as well.

For single-phase welders, with power factors of about 50 percent or less, the percent voltage drop on a single-phase supply nearly equals the percent system impedance times the ratio of load kva to the base kva used for determining the system impedance.

Transformers

For example, a 100 kva single-phase welding demand on a 1000 kva single-phase transformer with

ten percent impedance will cause about one percent drop through the transformer. If the same single-phase load were applied to a 1000 kva three-phase transformer with the same percent impedance it would cause a two percent drop.

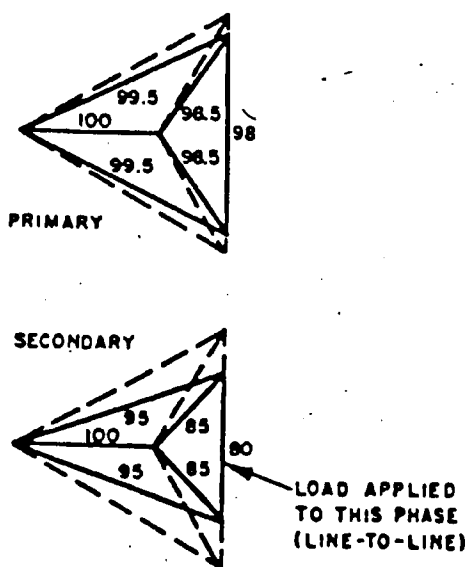
Lines, Cables and Busways

The impedances of lines, cables, or busways may be expressed in percent on the transformer kva rating and added to the transformer percent impedance to obtain the total impedance. Impedance data for lines, cables, and busways are available in articles devoted to short-circuit calculations.

Usually it is practicable to design low-voltage feeder circuits so that their impedances are about one or two percent on the substation kva rating, but long runs of small current ratings may have considerably higher impedances.

Primary Supply System

The impedance of a substation primary supply system may be approximately determined from the calculated short-circuit kva. For example, if a 1000 kva three-phase substation is supplied by a system with 200,000 short-circuit kva, the percent impedance of the system is one-half percent on the substation rating. ($1000/200,000 = 0.005$)



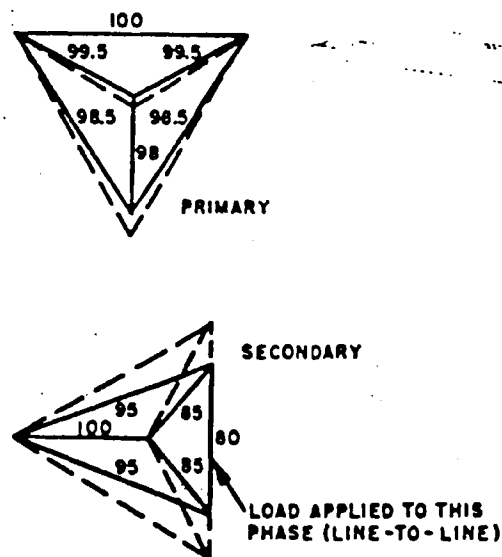
LOAD TRANSFORMER AND SUPPLY SYSTEM ALL HAVE SAME X/R

--- NO LOAD
 ——— WITH LOAD

VALUES GIVEN ARE IN PERCENT OF NO-LOAD VOLTAGE

$\frac{1}{10}$ OF TOTAL IMPEDANCE IS IN PRIMARY SUPPLY

Fig. 5 Delta - delta transformer with single-phase load (1093806)



SUPPLY IMPEDANCE ASSUMED BALANCED
 $\frac{1}{10}$ OF TOTAL IMPEDANCE IS IN PRIMARY SUPPLY

--- NO LOAD
 ——— WITH LOAD

VALUES GIVEN ARE IN PERCENT OF NO-LOAD VOLTAGE

Fig. 6 Delta - wye or wye - delta transformer with single-phase load (1093807)

The single-phase short-circuit kva of a three-phase system is approximately half the three-phase short-circuit kva. Hence, the same 200,000 kva, three-phase system has one percent impedance on the rating of a 1000 kva single-phase bank. ($1000/100,000 = 0.01$)

Note well that the interrupting capacity selected for switchgear often considerably exceeds the minimum short-circuit kva, which determines maximum voltage drops. Hence, the switchgear interrupting capacity used is not a reliable indication of the system impedance affecting voltage drops.

Phases Affected

Welders are ordinarily connected line-to-line. Lights may be supplied from either line-to-line or line-to-neutral voltage. The percent line-to-neutral drop caused by a line-to-line welder load is only slightly less than the line-to-line drop of the welder, except that there is practically no drop on the phase between neutral and the line to which the welder is not connected. This is illustrated by Fig. 5.

Sometimes it is desirable to know the voltage drops on the line-to-line phases other than that

supplying the welder. These drops are practically always less than the drop on the loaded phase, and are commonly about one-fourth the loaded-phase drop.

When a delta-delta transformer is used, a single-phase line-to-line secondary load imposes a single-phase load on the corresponding primary phase. When a delta-wye or wye-delta transformer is used, the percent primary line-to-neutral drops correspond to the line-to-line drops obtained with a delta-delta transformer. Also the line-to-line drops correspond to line-to-neutral drops obtained with a delta-delta transformer. This is illustrated by Fig. 6.

If a welder is supplied from line-to-neutral, as with from single-phase transformer connected line-to-neutral on a 2300/4160Y system, the corresponding percent primary line-to-neutral drop is from 1.5 to about 3.0 times the percent primary line-to-line drop which would occur if the same welder kva were supplied line-to-line from either a single-phase or three-phase transformer. The exact value depends upon the proportion of total impedance which is contributed by the neutral conductor.

LIGHT FLICKER

Frequency of Dips

The voltage drop which may be accepted without objectionable flicker is dependent on various factors, the most important of which is the frequency at which dips occur. Fig. 7 is a typical curve relating acceptable drop and flicker frequency. This curve or other slightly different curves or rules are used by power companies to determine the acceptability of welding loads on lines which also supply other customers.

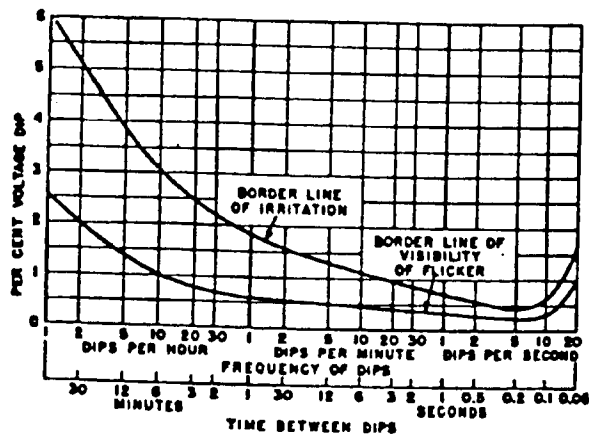


Fig. 7 Flicker of incandescent lamps caused by recurrent voltage dips (A128397)

Note that a drop as small as one-half percent may be objectionable. If only fluorescent lamps or large-sized incandescent lamps are used, somewhat higher drops may be accepted than those shown on Fig. 7.

Groups of Welders

When several welders operate independently, the frequency of drops increases and some large drops occur due to simultaneous operation of two or more machines. The frequency of occurrence of each possible drop value is dependent upon probabilities of simultaneous welds. Table I shows calculated frequencies for a number of cases. Fig. 8 shows results obtained by using the information of Table I with the border line of irritation shown on Fig. 7.

Short-circuit Kva Required

The power system stiffness required to avoid excessive voltage drop can be measured in terms of the short-circuit kva of the system. The larger this kva, the smaller will be the voltage drop caused by any given welder. On Fig. 8 are given values of required single-phase short-circuit kva divided by the kva demand of one welder. The figure shows that if there are three welders each with a demand of 100 kva and a duty cycle of five percent, each

operating at 60 welds per minute, the ratio is 200. This means that the single-phase short-circuit kva required is 200 times 100 kva or 20,000 kva. This assumes that all the welders are supplied from one phase. For example, if a single-phase power transformer supplies them from a primary system of negligible impedance, the short-circuit kva of the transformer must be at least 20,000. This would be the case for a transformer rated 1000 kva and having five percent impedance. To avoid flicker, the three-phase short-circuit kva of a three-phase system must be twice the required single-phase kva if the welders are all on one line-to-line phase, and lights are supplied from the same phase.

The calculations assume that all welders are alike. If the welders have differing demands or duty cycles, additional complexities are introduced. However, as a general rule flicker is mostly due to a few of the machines having the largest demands.

When welders are distributed on three phases of a three-phase system, the drops on any one phase caused by welders on other phases are usually comparatively small.

In typical cases, the three-phase short-circuit kva required to supply a group of three or more welders distributed among three phases is 20 to 30 percent more than the single-phase short-circuit kva shown on Fig. 3 for the same total number of welders.

Table I and Fig. 8 include only cases with a fairly small number of welders at duty cycles of 20 percent or less, and production rates of 60 welds per minute or less. For longer duty cycles or for a large number of welders, flicker does not greatly increase in severity because of the tendency for some of the load to be present at all times, so that the drop seldom falls to zero. However, at production rates above

TABLE I

Calculated Frequencies of Voltage Dips Which May Cause Light Flicker

Number of Welders	Welds per Minute per Machine	Percent Duty Cycle	Weld Time (Cyc.)	Average Frequency (Times/Sec.)			
				1 Machine Only	2 Machines Together	3 Machines Together	4 Machines Together
2	6	5	30	0.20	0.01	-	-
		10	60	0.20	0.02	-	-
		20	120	0.20	0.04	-	-
	20	5	9	0.67	0.033	-	-
		10	18	0.67	0.067	-	-
		20	36	0.67	0.133	-	-
	60	5	3	2.0	0.10	-	-
		10	6	2.0	0.20	-	-
		20	12	2.0	0.40	-	-
4	6	5	30	0.40	0.057	0.003	0.000005
		10	60	0.39	0.108	0.011	0.0004
		20	120	0.36	0.192	0.042	0.0032
	20	5	9	1.32	0.189	0.0097	0.00002
		10	18	1.30	0.360	0.0374	0.0013
		20	36	1.19	0.640	0.139	0.0107
	60	5	3	3.96	0.568	0.029	0.00005
		10	6	3.89	1.08	0.112	0.004
		20	12	3.58	1.92	0.416	0.032
8	6	5	30	0.76	0.24	0.035	0.003
		10	60	0.68	0.40	0.118	0.020
		20	120	0.46	0.53	0.313	0.114
	20	5	9	2.54	0.794	0.117	0.010
		10	18	2.27	1.32	0.394	0.068
		20	36	1.54	1.77	1.04	0.389
	60	5	3	7.63	2.38	0.352	0.030
		10	6	6.80	3.96	1.18	0.204
		20	12	4.61	5.30	3.13	1.74

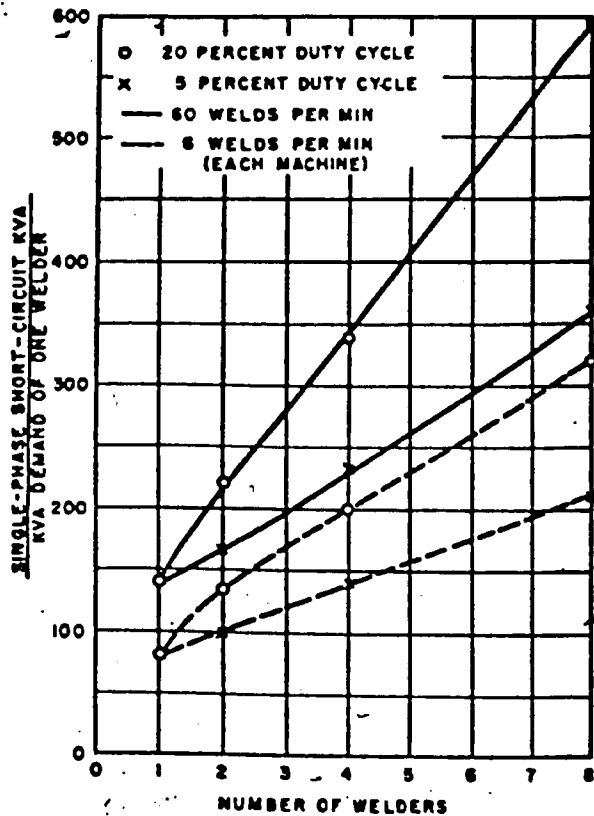


Fig. 8 Short-circuit kva required to avoid flicker (1093808)

60 welds per minute, the intervals between welds tend to be quite uniform in most cases so that overlaps of weld times of any two machines are often followed by a series of similar overlaps, tending to produce flicker at the frequency of welding. For such cases it is probably safe to employ a power supply which will not flicker when the three or four largest machines operate exactly together at the frequency most unfavorable for flicker. The lack of test data concerning response of the eye to random combinations of drops prevents development of a more precise rule.

WELDING VOLTAGE

Voltage Required

A welding power supply circuit to which no lights are connected can be permitted to have a much lower short-circuit kva than one for which flicker must be considered. However, the voltage must not too often be permitted to fall below a value which will be adequate for good welds.

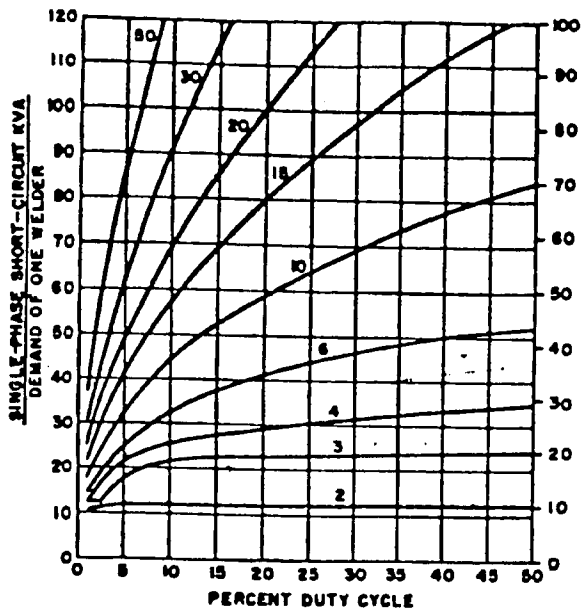
If the only load is a single welder, a large voltage drop may be accepted because the drop occurs with every weld, and adequate welding heat can usually be assured by adjusting taps or heat control to compensate for the low voltage. Of course, a large drop will reduce the maximum possible welder output somewhat. The voltage should not fall so low as to interfere with correct control operation unless the welder control is supplied from a separate synchronized source which does not experience the voltage drop. Controls are usually designed to operate satisfactorily between 80 and 110 percent of their rated voltage. Thus a drop as great as 20 percent may be acceptable and even greater drops have sometimes been permissible.

Groups of Welders

When only a few welders are supplied from one source and production requirements are not severe, interlocking may be used to prevent welding by two or more machines at once, thus preventing interference between machines and limiting the maximum drop to that of the largest machine. However, interlocking for more than two machines is complicated and production is affected because welders must wait until other welds are completed.

When a number of machines, without interlocking, are supplied from a single source, consideration must be given to the combined drops caused when two or more machines happen to weld at the same time.

Of course, it is possible to design a distribution system so that voltage drop is not excessive even when all machines weld at exactly the same time. However, it is often economically impractical to do this. A large saving in system-cost can often be made if excessive voltage drop is permitted with a very small percentage of the welds made.



VOLTAGE CONSIDERED INADEQUATE IF RMS VALUE DURING A WELD IS LESS THAN 90 PERCENT OF THE VALUE OBTAINED WHEN NO OTHER WELDERS OPERATE
 ONE WELD IN 1000 PERMITTED TO HAVE INADEQUATE VOLTAGE
 NUMBERS ON CURVES ARE TOTAL NUMBER OF WELDERS
 RIGHT HAND VERTICAL SCALE MAY BE USED IF ALL WELD TIMES ARE ALIKE AND ARE 3 CYCLES OR MORE. FOR OTHER CASES USE LEFT HAND VERTICAL SCALE

Fig. 9 Short-circuit kva required to avoid interference between welders (1093809)

Single-phase Short-circuit Kva Required

Fig. 9 shows the single-phase short-circuit kva required to prevent excessive interference between welders. It is assumed that the voltage for any weld is inadequate if its RMS value during the weld is less than 90 percent of the voltage obtained when no other welders operate. The voltage may dip below 90 percent during a portion of the weld time, if it is sufficiently above 90 percent during the remainder of the weld, so that the heating (RMS value) for the entire weld is not inadequate.

Fig. 9 assumes that it is acceptable for one weld in one thousand to have inadequate voltage.

Consider, for example, five welders at five percent duty cycle, each having a demand of 200 kva, supplied from a single-phase system. The ratio of short-circuit kva to welder demand kva given by the right-hand vertical scale of Fig. 9 is 20. Hence, the required single-phase short circuit kva is 4000 kva. This requirement can be met by a 300 kva single-phase transformer if the impedance of the transformer and the associated circuits is not over 7.5 percent ($300/0.075 = 4000$).

If the percent impedance were only five percent, a 200 kva source could be used. ($200/0.05 = 4000$)

For purposes of comparison let us calculate the short-circuit kva required to prevent inadequate voltage even with all welders operating at once. The drop due one welder occurs with every weld so that this much of the drop can be compensated by a heat setting adjustment. The remaining portion of the maximum possible drop is caused by four welders, having a total demand of 800 kva. This load should not cause more than ten percent drop if inadequate welding voltage is to be completely avoided. Therefore the single-phase short-circuit kva required is 8000 kva ($800/0.10 = 8000$). This is twice the value required to provide adequate voltage for all but one weld in a thousand.

Number of Welders

The required short-circuit kva does not increase rapidly as the number of machines is increased. This is illustrated by Fig. 9.

Duty Cycle

The short-circuit kva required increases as duty cycle increases. This is also shown by Fig. 9. Since it importantly affects system cost, the duty cycle should be estimated as accurately as is practicable. The effect of expected operating delays for individual machines may be included in duty cycle estimates, but time intervals, such as lunch periods when all welders stop operating, should not be considered. Reducing the duty cycle of any one welder does not reduce the proportion of its welds which are spoiled, but does reduce the number of spoiled welds made by other machines.

Weld Time

When all welds times are alike and are three cycles or more, the required short-circuit kva is given by the right-hand vertical scale of Fig. 9. When all of the welders have one-cycle weld times, or whenever weld times are not all alike, a greater short-circuit kva is required. The left-hand vertical scale of Fig. 9 introduces a 20 percent allowance for such conditions. When the weld times are not all alike, the welders with shorter weld times tend to have inadequate voltage for a larger proportion of their welds than do the welders with the longer weld times.

Proportion of Welds with Inadequate Voltage

With the values of short-circuit kva given by Fig. 9, one weld in 1000 will experience a voltage drop of more than ten percent, averaged over the entire weld time.

Ten percent has been selected as a typical allowance for welding mild steel. For materials which are more sensitive to variations in heat, such as aluminum, a smaller allowance will often be required. The allowance to be assigned for any group of welders should be determined by the user.

For an allowance smaller than ten percent, the short-circuit kva values from Fig. 9 should be proportionately increased. For example, if the allowance is five percent, short-circuit kva values from Fig. 9 should be doubled.

Welding conditions which permit an allowance of more than 10 percent will permit a corresponding reduction in short-circuit kva, but for large allowances the possibility of incorrect control operation, as well as reduced welding heat, should be considered.

The total voltage variation which a welder control experiences is partly due to its own welder, partly due to other welders, partly due to non-welding load, and partly due to variations in voltage level maintained by the power source. The allowance of ten percent used for Fig. 9 applies only to the contribution of other welders.

The proportion of welds spoiled is not the same as the proportion of welds with voltage drop exceeding the assigned allowance. Some spoilage is due to causes such as defects in material, which are independent of voltage. Some spoilage is due to combinations of causes. For example, electrode tips which have been spread by repeated use will make welds which are more sensitive to voltage drops than welds by new tips. Consequently the allowance assigned by the user to voltage drops should be less than the drop which can be accepted under ideal conditions, and the proportion of welds with inadequate voltage should be less than the allowable proportion of welds spoiled.

If the short-circuit kva is increased beyond the values given in Fig. 9, the proportion of welds with inadequate voltage decreases rapidly. This is illustrated by Fig. 10. This figure also gives some idea of the increase in this proportion as short-circuit kva is reduced.

Parts Having Several Welds

When a part to be welded has several welds, one or more of these welds may have inadequate voltage. For some parts, such as gas-tight seam-welded tanks or tubes, one bad weld will spoil the entire part. In such cases, the proportion of parts spoiled very nearly equals the number of welds per part times the proportion of bad welds. Consequently, the proportion of spoiled welds should be kept very low. For example, if one weld in 10,000 be spoiled and there are 100 welds per part, then about one of every 100 parts will have a bad weld. ($100 \times 1/10,000 = 1/100$)

If more than one bad weld in succession is required to spoil a part, the number of parts spoiled by a given number of welders at a given duty cycle is greatly reduced. For example, if one weld in 1000 has inadequate voltage, two such welds will occur in succession only once every 1,000,000 welds. However, to increase the number of welds on a particular part and yet maintain the same production of

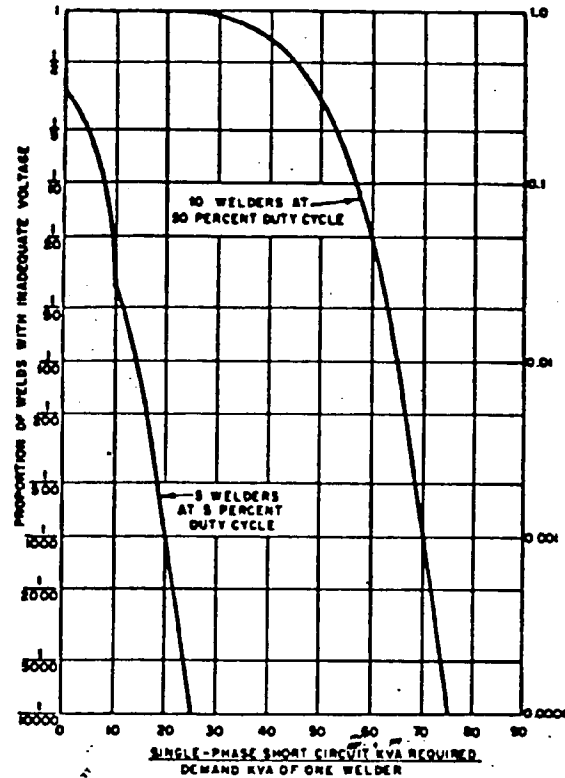


Fig. 10. (1093802)

these parts per hour requires that either the duty cycle or the number of welders be increased. Consequently, the number of parts spoiled by inadequate voltage is not necessarily reduced.

Welders with Different Demands and Duty Cycles

Fig. 9 is based upon the assumption that all welders have the same demand and the same duty cycle. This figure may be used for groups of welders which are not all alike by finding an equivalent demand and an equivalent duty cycle.

The equivalent demand is

$$I_e = \left(\frac{3}{2}\right) \frac{(A^2 + B^2)}{B} \quad (1)$$

Where

$$A^2 = \frac{d_1 \left(\frac{2}{3} - d_1\right) I_1^2 + d_2 \left(\frac{2}{3} - d_2\right) I_2^2 + \dots}{n} \quad (2)$$

n = number of other welders.

(A numbered subscript is used for each other welder.)

d = duty cycle.

$$B = \frac{d_1 I_1 + d_2 I_2 + \dots}{n} \quad (3)$$

The equivalent duty cycle is

$$d_e = \left(\frac{2}{3}\right) \frac{B^2}{(A^2 + B^2)} \quad (4)$$

The number of other welders (n) is one less than the total number of welders. For precise calculations, each welder should be considered in turn, its own demand and duty cycle being omitted from the calculations. However, a simpler procedure is to make a single calculation including all welders and use a curve from Fig. 9 corresponding to one more than the expected total number of machines. The result is the short-circuit kva required to prevent all the expected welders from interfering with an assumed future small additional welder.

If the short-circuit kva obtained by use of the equivalent demand is less than the short-circuit kva required to limit the drop by the largest machine to the assigned allowance, this larger short-circuit kva should be used.

Example: For example, consider three welders as follows, supplied from a single-phase system:

$I_1 = 300 \text{ kva}$	$d_1 = 0.02$
$I_2 = 100 \text{ kva}$	$d_2 = 0.02$
$I_3 = 100 \text{ kva}$	$d_3 = 0.02$

From (2)

$$A^2 = \frac{(0.02)(.667-.02)(300)^2 + (0.02)(.667-.02)(100)^2 + (0.02)(.667-.02)(100)^2}{3} = \frac{1170 + 130 + 130}{3} = 477$$

From (3)

$$B = \frac{(0.02)(300) + (0.02)(100) + (0.02)(100)}{3} = 3.33$$

The equivalent demand is

$$I_e = \left(\frac{3}{2}\right) \frac{(A^2 + B^2)}{B} = \left(\frac{3}{2}\right) \frac{(477 + 11)}{3.33} = 220 \text{ kva}$$

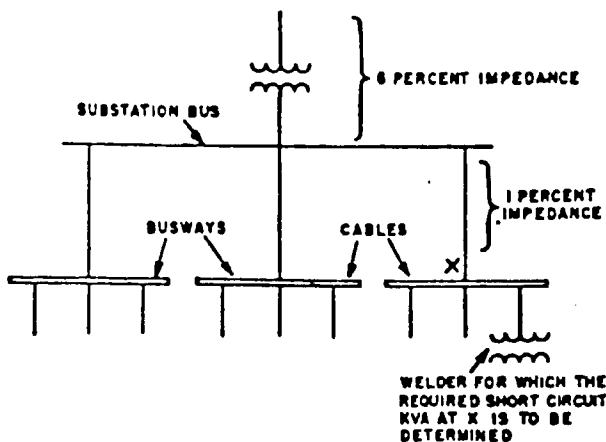


Fig. 11 Distribution system for welders (1093801)

The equivalent duty cycle is

$$d_e = \left(\frac{2}{3}\right) \frac{B^2}{(A^2 + B^2)} = \left(\frac{2}{3}\right) \frac{11.1}{(477 + 11)} = 0.015$$

From Fig. 9 for four welders with a demand of 220 kva each and a duty cycle of 1.5 percent, the required single-phase short-circuit kva is 12 times 220 kva or 2640 kva. The largest welder has a demand of 300 kva, so to limit its drop to ten percent would require a single-phase short-circuit kva of about 3000 kva. Since this is larger than 2640 kva, the larger value (3000 kva) should be used. In most cases, the value obtained by use of the equivalent demand and duty cycle will be the larger short-circuit kva.

Location of Welders

The short-circuit kva from Fig. 9 corresponds to a system impedance common to all welders. Any impedance associated with only one welder need not be considered. Occasionally the amount of impedance shared by a welder with others depends upon the location of each other welder. For example, consider a welder supplied from a busway which is in turn supplied by a feeder cable from a substation bus as shown by Fig. 11. Welders on the same busway share the substation and cable impedance with this welder. Welders on other feeders share only the substation impedance with this welder. In determining the short-circuit kva required at the end of the cable, the welders on other feeders may be considered as being located at the end of this same cable but having their demands reduced in proportion to their reduced share of the total impedance.

Number of Phases

Fig. 9 gives single-phase short-circuit kva required. The three-phase short-circuit kva of a three-phase system is twice the single-phase short-circuit kva available between any two lines. Hence, if all the welders were connected to one phase, the required three-phase short-circuit kva could be obtained by doubling the values given by Fig. 9.

If welders are distributed on the phases, the required three-phase short-circuit kva would be less than twice the single-phase kva given by Fig. 9.

If there are only two or three welders, each on a different phase, the required three-phase short-circuit kva will generally be equal to or less than the single-phase kva given by Fig. 9. This is true because a welder on one phase causes comparatively little drop on other phases.

If there are four or more similar welders distributed among three phases, the required three-phase short-circuit kva will be about 110-150 percent of the single-phase kva given by Fig. 9. The larger percentages apply to cases with only a few welders with very low duty cycles. A more common value is 125 percent.

If necessary, the short-circuit kva required of a three-phase system can be determined by calculating the single-phase short-circuit kva required of each phase and doubling the largest of these values to obtain the required three-phase short-circuit kva. The single-phase short-circuit kva required

for any phase may be determined by assuming all welders to be connected to it, but those welders which are actually on other phases should then be assumed to have their demands reduced. The assumed demand is proportional to the fraction of a welder's own phase drop which occurs on the phase considered.

EQUIVALENT CONTINUOUS LOAD

From the standpoint of thermal capacity of distribution equipment, an equivalent continuous load may be found for any welder or group of welders.

The equivalent continuous current is useful in selecting welder feeder equipment and in determining the amount of power transformer capacity available for other loads. When the duty cycle or the number of welders per substation is large, substation size may be determined by equivalent continuous load instead of voltage drop.

Individual Welders

For a single welder, having a single value of RMS demand during the weld time, the equivalent continuous load equals this demand multiplied by the square root of the duty cycle. For example, consider a welder drawing 200 kva at 25 percent duty cycle. The equivalent continuous load for this machine is 200 times the square root of 0.25 or $200 \times 0.5 = 100$ kva.

For flash welders, or other welders with more than one value of RMS current during the weld time, the equivalent continuous current can be calculated by finding the squares of all RMS a-c current values, multiplying these by their respective times of occurrence, adding the products, dividing by the total time, and taking the square root.

Groups of Welders

For a group of welders, we should use the following procedure which takes into account the probabilities of overlap of weld times:

- (1) Calculate the equivalent continuous load for each welder
Call these values i_1 and i_2 , etc. for the various machines
- (2) Calculate the average load of each welder
This is the average of all RMS a-c values. For a welder with a single value of demand, it is this demand multiplied by the duty cycle.
Call the average loads a_1 and a_2 , etc.
- (3) For each welder calculate the "standard deviation" (sigma)
This is the root mean square of all deviations from the average load. The following

formula may be used for finding this "standard deviation" for each welder:

$$\sigma_1 = \sqrt{i_1^2 - a_1^2} \text{ etc.} \quad (5)$$

- (4) Calculate the standard deviation for the group of loads, using the following formula:

$$\sigma_T = \sqrt{\sigma_1^2 + \sigma_2^2 + \dots} \quad (6)$$

- (5) Calculate the average load for the group

It is usually acceptable to assume all machines have the same power factor, in which case the total average load is:

$$a_T = a_1 + a_2 + \dots \quad (7)$$

If differences in power factor must be considered, we must first find for each machine the average of two vector components which are respectively in phase and out of phase with some reference vector such as the supply voltage. Two sums should then be found, one for each type of component. The vector resultant of these sums is the total average current

- (6) Calculate the equivalent continuous load for the group, as follows:

$$i_T = \sqrt{\sigma_T^2 + a_T^2} \quad (8)$$

Number of Phases

This procedure is applicable for single-phase welders on a single-phase system, three-phase welders on a three-phase system, and single-phase welders all on one phase of a three-phase system.

When single-phase welders are distributed line-to-line on three phases of a three-phase system, the equivalent continuous current in each line can be calculated by considering only those machines connected to the line selected for calculation.

If the welders all have the same power factor, the line currents due to welders on one of the line-to-line phases which connect to this line will be 60 degrees out of phase with the currents due to welders on the other phase considered. The average currents in the two phases should therefore be added vectorially to consider this phase angle difference when obtaining the average line current.

Expressing current in amperes instead of kva is advisable when making such calculations, because three-phase and single-phase circuits have different values of kva per ampere.

The three-phase kva corresponding to the equivalent continuous line current to a group of similar welders distributed evenly among the line-to-line phases is slightly greater than the equivalent continuous kva for these same machines connected to a single-phase supply.

Example: As an example of the method presented, consider three welders with inputs as follows, all at 0.5 power factor, and five percent duty cycle:

$$\begin{aligned} I_1 &= 1000 \text{ amperes} \\ I_2 &= 500 \text{ amperes} \\ I_3 &= 100 \text{ amperes} \end{aligned}$$

For each welder, the equivalent continuous load is:

$$\begin{aligned} i_1 &= 1000 \sqrt{0.05} = 224 \text{ amperes} \\ i_2 &= 500 \sqrt{0.05} = 112 \text{ amperes} \\ i_3 &= 100 \sqrt{0.05} = 22.4 \text{ amperes} \end{aligned}$$

For each welder the average load is:

$$\begin{aligned} a_1 &= 1000 (0.05) = 50 \text{ amperes} \\ a_2 &= 500 (0.05) = 25 \text{ amperes} \\ a_3 &= 100 (0.05) = 5 \text{ amperes} \end{aligned}$$

For each welder the standard deviation (σ) is, from (5),

$$\begin{aligned} \sigma_1 &= \sqrt{(224)^2 - (50)^2} = 218 \text{ amperes} \\ \sigma_2 &= \sqrt{(112)^2 - (25)^2} = 109 \text{ amperes} \\ \sigma_3 &= \sqrt{(22.4)^2 - (5)^2} = 21.8 \text{ amperes} \end{aligned}$$

The standard deviation for the group is:

$$\sigma_T = \sqrt{(218)^2 + (109)^2 + (21.8)^2} = 245 \text{ amperes}$$

If the welders are connected to a single-phase supply, the average load for the group is, from (7)

$$a_T = 50 + 25 + 5 = 80 \text{ amperes}$$

For this case, the equivalent continuous load is, from (8)

$$I_T = \sqrt{(245)^2 + (80)^2} = 258 \text{ amperes}$$

For a 440 volt, single-phase circuit this is 113 kva.

If the three welders had been connected to a three-phase system, each to a different line-to-line phase, the maximum equivalent continuous line current would be that for the line to which the two larger machines connect (since all machines have the same duty cycle). If we call this line A, the standard deviation of its current is

$$\sigma_A = \sqrt{(218)^2 + (109)^2} = 244 \text{ amperes}$$

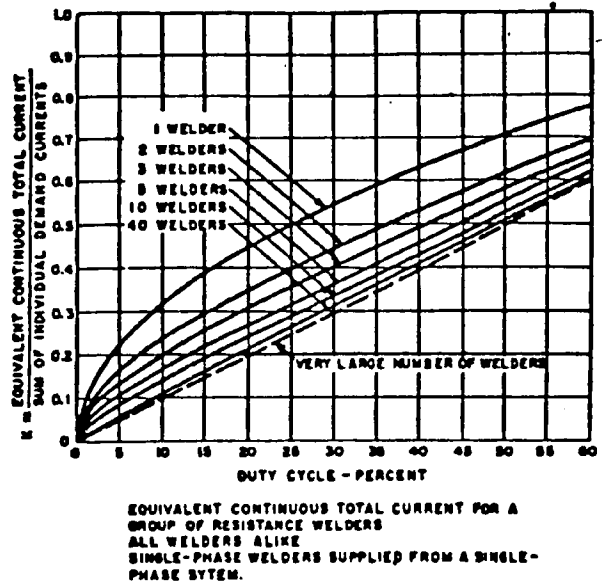


Fig. 12 Equivalent continuous current as affected by duty cycle and number of welders (1093476)

The average line current is obtained by vector addition of a_1 and a_2 , recognizing their 60 degree phase angle differences. If we use I_1 as a reference vector, the expression for this vector addition is

$$\begin{aligned} a_A &= \sqrt{(a_1 + a_2 \cos 60^\circ)^2 + (a_2 \sin 60^\circ)^2} = \\ &= \sqrt{(50 + 25 \times 0.5)^2 + (25 \times 0.866)^2} = \\ &= 66.2 \text{ amperes} \end{aligned}$$

The equivalent continuous line current is therefore

$$I_A = \sqrt{(244)^2 + (66.2)^2} = 252 \text{ amperes}$$

For a 440 volt three-phase circuit, this is 193 kva.

Identical Welders

When all welders are alike, curves may be drawn, as on Fig. 12, showing equivalent continuous current as affected by duty cycle and number of welders.

Steady Load

If the equivalent continuous load current for a group of welders is added to the current of a steady load, such as an industrial heating load, the resulting sum will be slightly higher than the actual equivalent continuous current for the combined load. A precise result can be obtained by adding the steady load to the average welder load, and calculating the equivalent continuous current by the method described. This procedure merely recognizes the fact that the standard deviation of a steady load is zero.

CAPACITOR APPLICATIONS

There are several types of applications of capacitors to circuits supplying power to resistance welding machines. It is important to understand basic characteristics of each and their differences.

Shunt Capacitors Continuously Connected

Since the power factor of most welding loads is quite low, shunt capacitors are often justified for power factor improvement. It is usually preferable for these to be connected to the supply source by separate switching means, which normally leave the capacitors connected to the line most or all of the time. (See Fig. 13.) Such capacitors are selected to improve plant power factor rather than the power factor of any particular welder.

The plant power factor for billing purposes is often based on metered reactive kva, which is usually averaged over a time interval of 15 minutes or more. The metered reactive kva of a welder or group of welders is equal to the average reactive load, which is much less than the momentary demand. Continuously connected shunt capacitors tend to reduce the metered reactive kva. The capacitor kva may be subtracted directly from the average lagging reactive load kva unless the net reactive kva may go leading at times, and detents on the meter prevent negative registration at such times.

When there are a substantial number of welders supplied by one substation, continuously connected shunt capacitors are usually the most economical means for power factor improvement.

Shunt Capacitors Switched with a Welder

Shunt capacitors may be selected to improve the power factor of the current to any particular welder and be so controlled that the capacitor is connected only when the welder operates. The same electronic contactor which controls the welder should not be

used for the capacitors; instead a separate special electronic contactor should be used for the capacitors, arranged to operate at the same time as the welder control. The cost of the additional electronic contactor is a principal reason why series capacitors switched with a welder are usually more economical than shunt capacitors switched with the same machine. (See Fig. 14.)

Series Capacitors Switched with a Welder

Series capacitors selected to be switched by the same control used for the welder are a means of improving the power factor and thereby reducing the demand of a welder. (See Fig. 15.) Since the selection of capacitors, control, welding transformer, and associated electrical equipment should be co-ordinated closely with the welder design, recommendations and quotation on series capacitors for any particular welder should be obtained by the user from the welder manufacturer. The effect of series capacitors on welder demand and power factor have been discussed earlier in this article.

Series Capacitors Continuously Connected

Series capacitors may be connected in a power supply circuit to compensate for the reactance of power transformers, cables, or overhead lines. Such capacitors increase the effective short-circuit kva of the system as far as voltage drop on the load side of the capacitors is concerned. A protective gap is provided to by-pass the capacitors in case of an overcurrent which would otherwise cause too much voltage to appear across the capacitors. Consequently, the interrupting capacity required of circuit breakers on the load side of the capacitors is not increased by use of the series capacitors.

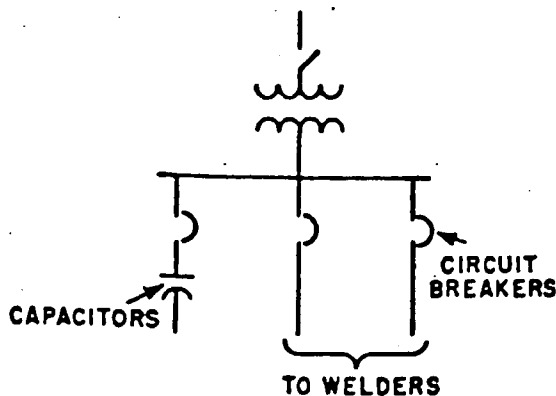


Fig. 13 Shunt capacitors continuously connected
(1093800)

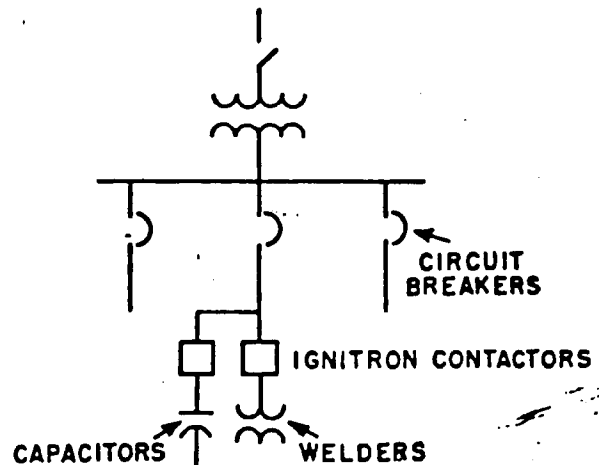


Fig. 14 Shunt capacitors switch with a welder
(1093799)

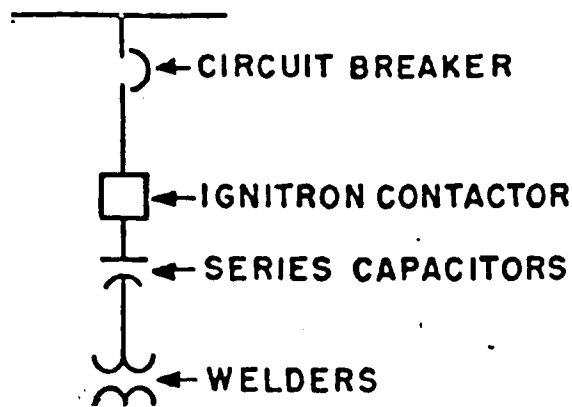


Fig. 15 Series capacitors switched with a welder (1093798)

Location of Capacitors

Continuously connected series capacitors are usually furnished for connection in the supply circuit of a substation because the cost of equipment for a high voltage circuit is less than for welding-substation secondary voltages.

Capacitors may be selected to compensate for the reactance of the primary circuit so as to eliminate flicker of lights connected to other substations

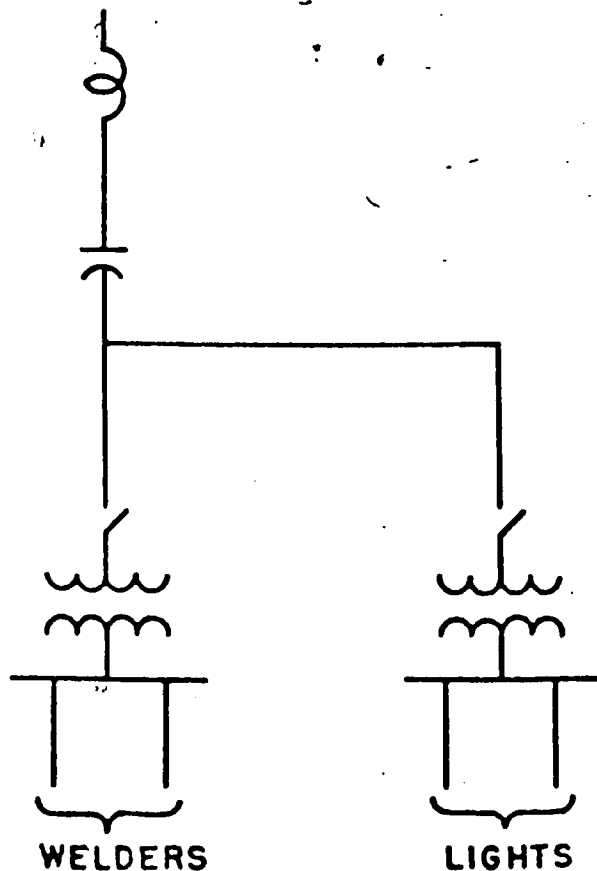


Fig. 16 Compensation for line reactance (1093797)

on the same circuit, as shown by Fig. 16. Such a capacitor equipment has relatively little effect on voltage drops at the secondary of the welding substation because these drops are mostly determined by the reactance of the substation. If the equipment of Fig. 16 were designed to compensate for this reactance also, undesirable voltage rises would be applied to the other substation shown.

The reactance of the welding substation can be compensated by a series capacitor equipment at its primary, connected so that there are no other substations on the load side of the capacitors. (See Fig. 17.) This equipment can also be selected to compensate for the reactance of the primary circuit, but will have no effect on the substations on the supply side of the capacitors.

Maximum Loads

The protective gap is adjusted to operate only when the load is several times the substation rating. When loads are suddenly applied or suddenly removed, as with welding, transients may cause the gap to operate at loads less than those corresponding to the setting. These transients may be accentuated by excessive transformer saturation if the voltage rise through the capacitor is too great. Consequently, the capacitor equipments are not well suited to loads which often greatly exceed the substation rating. However, occasional peaks due to very rare combinations of welders may be permitted to reach high values if distorted secondary voltages and possible gap operation following such peaks may be accepted. A permanently connected shunting resistor is furnished with the capacitor equipment to

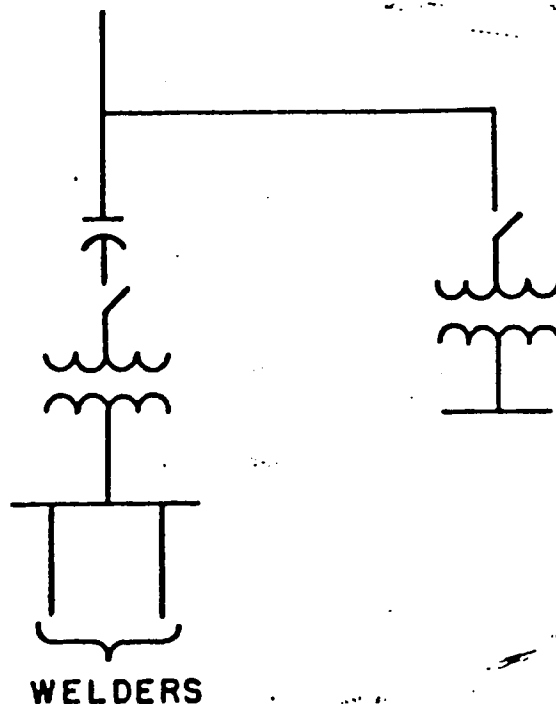


Fig. 17 Compensation for substation reactance (1093796)

prevent resulting saturation conditions from lasting more than a few cycles.

Economic Considerations

When continuously connected series capacitors are used, the size of the substation required is ordinarily determined by the equivalent continuous load current, and for welding loads this is usually considerably smaller than would otherwise be required. This offers savings in the cost of transformers and switchgear. However, since the cost of a complete series capacitor equipment may approach that of the transformers with which they are used, a net saving is seldom obtained unless the size of substation otherwise required is at least 1000 kva. When welders are large and secondary voltage must be held within close limits, the size of such an alternative substation may be so large that capacitors offer a considerable net saving.

Required Information

To assure proper co-ordination of the capacitor protective equipment with the characteristics of the

load, supply system and substation transformers, propositions for such series capacitor equipments should be referred to the General Office. Request for quotations should include the following information:

- (1) One-line diagrams of primary and secondary distribution systems
- (2) Voltage, frequency, maximum and minimum short-circuit currents, and number of phases of primary supply system
- (3) Voltage, frequency, kva rating, and number of phases of substation transformers. For existing equipment, include also impedance, manufacturer's name, and serial number
- (4) Demands, duty cycles, and number of phases for all welders
- (5) Total amount of other substation load, with nameplate data for all motors of hp rating in excess of 10 percent of the substation kva rating.

DISTRIBUTION SYSTEMS

Voltage

The most economical voltage for supplying welders is usually 480 volts. Use of 277/480Y substations is recommended since they permit neutral grounding. Exceptionally large welders may sometimes be advantageously supplied at 2400 volts. Use of 240 volt systems is usually undesirable because of the higher cost of associated cables, switchgear, and welder control equipment.

Type of System

The same types of distribution systems which are applicable for other industrial loads may be used for supplying resistance welders. The most important types are radial, secondary selective, and network systems. These systems are illustrated by Fig. 18 to 20.

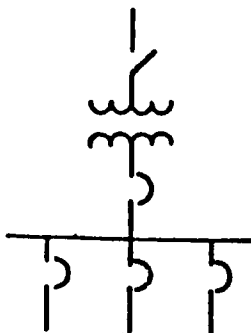


Fig. 18 Radial system (1093795)

The simplest system is the radial type (Fig. 18). Such systems commonly supply welding, lighting, and power when welding loads are not so large as to cause objectionable flicker.

The secondary selective system (Fig. 19) not only provides added reliability, but permits segregation of lighting and welding loads except when the tie breaker is closed because one transformer is out of service. When the welding load is substantial, this system may be less costly than the radial system because smaller transformers may be used when welding and lighting loads are separated. Of course, flicker would then have to be accepted under emergency conditions which require closing of the tie breaker.

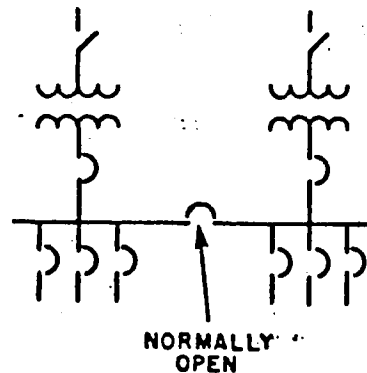


Fig. 19 Secondary selective system (1093794)

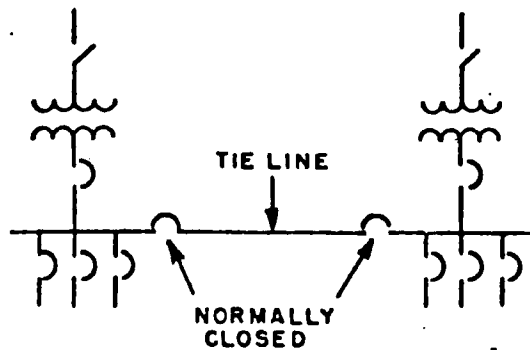


Fig. 20 Network system (1093793)

A network system (Fig. 20) may be advantageous when the need for low system impedance and anticipated large shifts in locations of load concentrations justify the additional complexity and the cost of the higher switchgear interrupting capacities required.

Sometimes it is advisable to supply a single large welder from a different substation than other smaller welders, in order to reduce the effect of the voltage drop of the large machine.

Load Combinations on One Substation

Motors, industrial heating, and many other loads except lights are less sensitive to intermittent voltage drops than are welders. Hence, motor and heating loads can be supplied from a substation which is only large enough to avoid interference between welders. The equivalent continuous load of the welders is usually small enough to permit a substantial proportion of other load, except when the number of welders per substation is very large.

Usually it is economical to supply lights from the same substation as other industrial loads except welders. When the substation voltage is 480 volts, lighting may be supplied through small air-cooled, 480-120 volt transformers or by use of 277 volt fluorescent fixtures connected from line to neutral.

Shunt capacitors for plant power factor improvement, together with suitable switching equipment, may be connected at the bus or to feeders.

Number of Phases

The kva rating of a three-phase transformer of standard design large enough to limit the voltage drop of a single-phase welder to a specified amount is about twice the kva rating of a comparable single-phase transformer. Similarly, the three-phase kva rating required to supply a group of single-phase welders without interference between machines is somewhat larger than the kva rating required of a single-phase transformer. However, it is seldom possible to supply non-welding load from a single-

phase transformer so the entire cost of this transformer is chargeable to the welding load. A three-phase transformer, on the other hand, often offers economies because its full thermal capacity can be utilized, combining welding and other loads. Furthermore, three-phase substations are more salvageable when power system changes are made. In addition, three-phase substations can supply three-phase welders. Consequently, three-phase substations are usually preferable.

The feeder circuits supplied by a three-phase substation may be either three-phase or single-phase, whichever is the more economical.

Transformer Reactance

Using transformers of special low percent impedance is seldom advisable. Such transformers, when of less than four percent impedance, are not adequately braced to withstand a secondary terminal short-circuit with full primary voltage applied. To avoid possible damage, the supply circuit should include sufficient impedance to limit the current to 25 times normal. Use of such system impedance defeats the purpose of a low transformer impedance.

Substation Size

When the total plant load, including welding and lights, can be supplied by a substation of 750 kva or less, a single radial substation is usually satisfactory. For larger total loads it is nearly always most economical to employ several substations, the optimum size being about 500-1500 kva, each substation being located close to the center of its load area.

When the supply to a group of welders is divided between two or more transformers which are not in parallel, the total kva required is greater than for a single transformer large enough to supply all the welders. The system cost per kva increases, however, as the substation size exceeds about 750 kva, because of the longer feeder runs and the need for switchgear of higher interrupting capacity. Consequently, it is often satisfactory to use the same sizes of substation as are best for supplying other industrial loads. When the welders are so large that only a few of them can be supplied from one such substation, it may be found economical to use larger substation sizes. For such large substations it may be advantageous to connect transformers in parallel to permit use of the same transformer sizes used for other loads in the same plant. It is seldom advisable to use substations so large as to require larger interrupting capacities than are available with standard drawout low-voltage switchgear. Use of series capacitors at substation primaries is advantageous for installations which would otherwise require such large substations.

FEEDER CIRCUITS

Individual Welders

Two-conductor concentric armored cable is usually preferable for circuits supplying individual welders. Such cable has a lower voltage drop and a lower installed cost than two single-conductor cables in conduit.

Groups of Welders

Busways are widely used for distributing power to groups of welders, primarily because of their adaptability to changes in machine locations. Busways (such as General Electric type LVD feeder busway) are available with low-impedance designs especially adapted to welding loads. For small welders, however, less costly bus (such as General Electric type FVK plug-in busway) is satisfactory.

Busway is not an economical way to transmit blocks of power over long runs having no taps. When such runs are necessary, cable should be used between the substation and a section of busway used for distributing the power to individual loads. When current delivered to the busway is large, it is usually more economical to use several moderate-size cables (such as 250 MCM) in parallel than to use one or more larger cables.

When there are only a few welders, located close to the substation, busways may be eliminated, the welder cables being brought directly to the substation. In such cases, it is sometimes advantageous to connect more than one welder to a single breaker.

Current Carrying Capacity

The capacity of busways and cables should be sufficient so that:

- (a) The equivalent continuous load current is equalled or exceeded by the rating. It should be noted that the maximum equivalent con-

TABLE II

Minimum Cable Sizes

Short Circuit Current ¹	Minimum Conductor ² Size
5,000	8
10,000	4
15,000	2
25,000	1
35,000	1/0
50,000	3/0
75,000	300 MCM
100,000	500 MCM

1. This is 125 percent of the symmetrical short-circuit current.
2. Instantaneous trip device assumed to operate.

tinuous load kva of a welder is 70.7 percent of the welder rating

- (b) Voltage drops will not be excessive (they usually will not be for moderate run lengths, but voltage drop should be checked)
- (c) Stresses and temperature rises during interruption of fault currents will not be dangerous

See Table II for cables and Table III for busways

The National Electric Code imposes the following additional limitations (paraphrased from 1947 Code, Section 6331):

- (d) The circuit current carrying capacity should not be less than the sum of the equivalent continuous current of the largest welder plus 60 percent of the equivalent continuous currents of all other welders. (This sum usually exceeds the equivalent continuous total current for a group of spot or projection welders)
- (e) The circuit current carrying capacity should not be less than one-third the pick-up current of the overcurrent protective device used for the circuit.

TABLE III

SHORT-CIRCUIT RATINGS OF STANDARD DESIGN IN ASYMMETRICAL AMPERES

Ampere Rating	LVD Feeder Busway	
	LVD 3 Copper Bars	LVD 5 Aluminum Bars
600		25,000
800		25,000
1000		50,000
1350 - 1800		50,000
2000 - 3000		75,000
4000		100,000

FVK Plug-in Busway	
Ampere Rating	FVK Busway
225	15,000
400	25,000
600	25,000
800	25,000
1000	25,000

Special busway designs with higher short-circuit ratings can be supplied. Refer to Distribution Assemblies Department for proposal.

Use of Reactors

On circuits which supply non-welding loads or small welders only, so that voltage drop is not of major importance, current limiting reactors may be used at the substation to permit application of cables and busways which would otherwise have inadequate size and strength to carry faults until fault interruption is completed.

Feeder Size

The number of welders to be connected to one feeder, and consequently the feeder rating, should be determined by a study of the proposed installation.

In general, as the number of welders per feeder is increased, the total feeder current-carrying

capacity multiplier is reduced (See Fig. 12). This tends to permit savings in cost of cables and busway, but, if carried too far, may impair operating flexibility by shutting down too many machines in case of a feeder fault.

For a first trial layout it is suggested that the feeders be arranged so that their required current carrying capacities correspond to the largest available ampere ratings of feeder circuit breakers which have just sufficient interrupting capacity for use at the substation.

The cost of circuit breakers should, of course, be included with cable, busway, and installation costs when estimating the costs of alternative feeder arrangements.

Voltage drop should be checked for each feeder.

PROTECTIVE EQUIPMENT

The basic principles for short-circuit protection of all systems are applicable for systems supplying welders. Sometimes special precautions are required to avoid unnecessary tripping by welding load currents.

Interrupting Capacity

Adequate interrupting capacity is essential. The short-circuit kva values used in checking voltage drops by means of Fig. 8 and 9 give an indication of required interrupting capacity. However, it is advisable to calculate short-circuit current independently by conventional procedure, because the short-circuit kva is usually a minimum required value while the interrupting capacity should be based on the maximum short-circuit current.

Savings in cost of circuit breakers can often be made by employing cascade operation, in which a heavy fault trips all breakers supplying it, thus permitting the use of smaller interrupting capacities on the load side of the back-up breakers. All types of low-voltage breakers will not, however, operate successfully in cascade. For example, Trumbull Type AT breakers will not cascade with General Electric Type AK breakers.

Types of Equipment

Drawout air circuit breakers are recommended for substations. If a feeder supplies only a single welder, no protective device is required at the welder. On feeders which supply more than one load, a protective device is required for each welder. Enclosed circuit breakers, mounted on or near the welder, are preferred for maximum safety and convenience. For welders with equivalent continuous load circuits under 200 amperes, a fused switch is often used because of the cost savings offered. Switches should employ fuses of adequate interrupting rating (such as General Electric Type CLF fuses) and the switch should be designed and tested for use with such fuses (as with the Trumbull Type

HCI switch) to assure that the switch will close and hold during the time the fuse is interrupting. Fused switches are not recommended for supplying groups of welders, because of the likelihood of operators opening the switch during overcurrents, and because the fuses will not co-ordinate properly with the tripping devices of circuit breakers which may be used for the individual welders.

Two-pole circuit breakers are available for the single-phase loads commonly encountered in welding.

Tripping Devices

Adjustable instantaneous trips are preferred for breakers for individual welders. These should be set to operate at a current slightly above the welder demand current. In selecting the breaker and its trip range, provision should be made for possible increases in welder demand, up to the maximum possible value for the welder considered.

Caution should be exercised in selecting tripping devices for breakers supplying groups of welders. Instantaneous trips should be set above the maximum total demand current, to avoid occasional tripping by simultaneous operation. Time delay direct tripping devices should be used only if they can be set at values of minimum pick-up current which are reached infrequently by the load. If the normal demand of any one welder exceeds the pick-up setting used, the resulting repeated picking-up will wear out the device, even though the weld time is not long enough to cause tripping. The time setting of the trip device should be sufficient so that even unfavorable combinations of welder loads will not cause tripping. With Type AK air circuit breakers a variety of tripping characteristics are available. Usually the tripping characteristic with instantaneous trip at 15 times normal will be satisfactory for feeders supplying groups of welders, but trip coils can be easily changed, even after breaker installation, if necessary.

SYSTEM COST

The cost of a distribution system supplying welders will be approximately the same as for a similar system for general industrial loads of the same total substation kva using the same substation sizes. When the substation size is determined by the necessity of limiting welder voltage drops, and all of the current carrying capacity not used by the welders cannot be utilized by other loads or is not needed for reserve capacity, the portion of the substation cost attributable to the resulting excess current carrying capacity is a part of the cost of supplying the welders.

The cost per welder of power supply for a large group of welders is usually less than for supplying only a few welders of the same type.

When the system design is largely determined by a few large welders, it may be economical to use special means to reduce the demands of these machines. In the case of multiple-electrode welders, the cost of reducing demand is so low as to be nearly always justified, because the only equipment required is a control which causes welds to occur in sequence instead of all at the same time.

In order to properly consider possible use of special welders or special means of reducing demand, cost and performance data should be obtained from welder manufacturers.

PRIMARY SUPPLY

Sometimes a major portion of the voltage drop due to welders occurs in the supply circuits provided by the power company. It may be advisable for these circuits to be modified when welding load

is added or when a plant distribution system is to be furnished or adapted for welders. Consequently, it is ordinarily advisable to consult with the power company at such times.

REFERENCES

1. Power Supply for Resistance Welding Machines, AIEE Publication S-45, 1952.