Section V

THE POWER COMPANY'S SUPPLY SYSTEM

The Welder from the Utilities Standpoint

The electric utility's chief problem in supplying resistance welders is voltage drop. The problem is aggravated by the characteristics of the common welders. Their load is intermittent and of short duration; their power factor is low; their load is generally single phase.

The sudden decrease in line voltage caused by the welder, too rapid to be corrected by induction regulators, decreases the light output of lamps. When this voltage reduction, that is, voltage dip, is repeated at short intervals, the effect is termed "light flicker." The irritation caused by light flicker is a function of both the amount of change in light output and the frequency of the change.

From the standpoint of voltage drop in the distribution lines, a single-phase load connected phase-to-neutral, between line wire and neutral, will cause six times the voltage reduction between phase and neutral that will be caused by the same amount of 3-phase load. This is important because most lighting transformers are connected between phase wire and neutral. It is also true that, due to the inherent characteristic of a-c circuits termed reactance, which is roughly proportional to the distance between conductors, a low power factor load will cause a voltage reduction four to six times greater than one of high power factor supplying the same useful energy.

Moreover, such welders will impose on the electric distribution system a single-phase load even though the system be of a polyphase design. Various combinations of transformers can be used, but the effect on the supply system is essentially that of a single-phase load even though current may flow in all line conductors.[1]

To supply energy to resistance welders with their special characteristics the utility must often provide oversized facilities specifically to serve the welding load. Such added facilities may range from additional transformer capacity to the complete isolation of a heavy distribution circuit for the sole use of a small welder. A major problem is involved.

The Power Company's Supply System

Since the instantaneous voltage reduction, that is, voltage dip, is a direct function of the resistance and the reactance of the supply system from generator to the point of application of the load, the dip will be small at the generator and large at the point of load. The greater the impedance, that is, the combination of resistance and reactance, between the generator and the load, the greater will be the voltage dip produced by a given load.

As a general rule the power company's supply system will consist of the following elements:

1. The generator.
2. High-voltage bulk transmission from generator to switching station, 66 kv to 220 kv.
3. Step-down transformers at the switching station which reduce the voltage to normal subtransmission levels, 12 kv to 46 kv.
4. Subtransmission from switching station to individual distribution substations.
5. Step-down transformers which reduce the voltage to that of the medium voltage primary distribution circuits radiating from the distribution substation.
6. Regulating apparatus and their protecting reactors installed in the distribution substation to monitor the voltage being delivered.
7. The medium voltage primary distribution circuit between the distribution substation and the vicinity of the customer, 2.4 kv to 7.2 kv.
8. The step-down transformers used in the vicinity of the customer to reduce the primary circuit voltage to that of secondary or utilization circuits, below 600 volts.
9. The secondary voltage circuit from the step-down transformer together with the service tap to the customer's meter.

Individual systems, however, will vary considerably from this general pattern due to the character of territory being served and the various solutions suggested by economic comparisons. Moreover, the impedance of power systems will be found to vary over extremely wide limits depending upon the operating voltage, the capacity of the over-all system, the nature of the transmission and subtransmission networks used in supplying the distribution substations, and the size of substations themselves.[2]

It follows that the location of the industrial plant with respect to the power company's large distribution substations will determine the amount of welding load which can be supplied from the power company's lines. If the plant is in an established industrial area served by large substations and not too far from large generating stations, the voltage drop in the high-voltage system may be a negligible factor. However, the main business sections of large cities, even though often close to large substations, usually do not have distribution facilities suitable for welders and the cost of providing service at such locations may be prohibitive for even relatively small machines. On the other hand, if the industrial plant has been located in a rural or small town area, far removed from the power company's main sources of supply, as is becoming more common under the present-day trend towards decentralization of industry, the high-voltage system impedance may loom as a very troublesome factor.

Explanation of Terms

Unfortunately, in most writings on this subject, in the interests of brevity, terms are used rather loosely and not in accordance with recognized definitions.

This section of the report is concerned with the "light flicker" produced by electric lighting due to the operation of the welder, and with the supply of adequate voltage to the welder. Terms used herein may be defined as follows:

1. *Voltage Dip*. The transient reduction in voltage, appearing at the terminals of electric lamps. Irrespective of the type of connection used to supply the welder, this section of the report assumes that lighting is supplied from transformers connected between phase (line) conductor and neutral, and hence the voltage dip is measured between these two conductors.
2. *Light Flicker*. The variation in light output caused by repetitive voltage dips.
3. *Voltage Drop*. The loss of voltage due to the passage of current through a circuit from generator to load or through a portion of such circuit.
4. *Voltage Regulation*. The percentage which the difference between full-load voltage and no-load voltage bears to no-load voltage due to the operation of a welder, generally referred to the terminals of the same welder.
5. *Phase or Phase Wire*. One of the three line conductors of a 3-phase system, as distinguished from a neutral conductor.

Determination of Voltage Dip and Current for Single-Phase Welders

Instruments normally used to measure steady-state conditions are not applicable to the measurements of short-duration welding. For measuring current the pointer-stop ammeter is employed wherein a hand-operated stop restrains the indicating hand from returning to

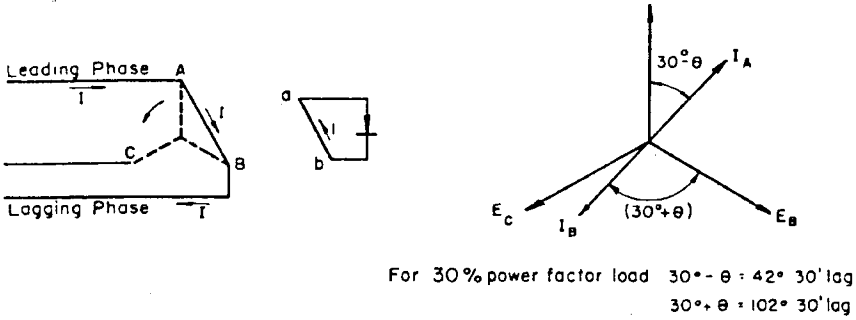


Figure 23. Vectors for single-phase load connected phase-to-phase

zero. This stop point is raised to successively higher levels until the surge of current just causes the hand to flutter, giving the indicated reading. A voltmeter of similar design also is used.[3]

However, for accurate current and voltage readings, and for weld durations of less than 10 cycles, the oscillograph or oscilloscope is recommended. Particularly useful are those designed for application of a bias voltage which results in an enlarged picture of only the tops of the voltage wave and hence allows measurement of small voltage variations.[4]

Computation of Voltage Dip and Voltage Regulation for Single-Phase Machines

In most cases, however, it is necessary to determine by calculation, in advance of installation, the dip which will be produced. Once the engineer has a clear understanding of the nature of single-phase load supplied from a 3-phase source the calculations are not difficult. Computation methods have been devised which require application of only the simpler mathematical operations of multiplication and addition.

Vector diagrams of single-phase loads supplied from 3-phase Y circuits are shown in Figures 23 and 24 and cover the recommended transformer arrangements of a single transformer connected phase-to-phase, between two of the phase wires; and three transformers connected Y-delta. The diagram in Figure 23 is equally applicable to a single-phase load connected between phases of a delta primary system.[5]

The full formula for voltage drop is

$$E = I(\cos\theta - j\sin\theta)(R + jX) \qquad (1)$$

of which the component in phase with the reference voltage is

$$e_1 = I(R\cos\theta + X\sin\theta) \qquad (2)$$

and the component in quadrature with the reference voltage is

$$e_2 = jI(X\cos\theta - R\sin\theta) \qquad (3)$$

To compute the change in a given reference voltage due to load flow, it is necessary only to select the corresponding current, determine the angle between this current and the reference voltage, and substitute in equations 2 and 3. Since the voltage dip which affects nearby lighting customers on a 3-phase 4-wire supply system is that appearing between phase wire and neutral, the phase-to-neutral voltage is taken as reference and the effect of the corresponding line current computed. Referring to Figure 24, the voltage dip on E_A will be

$$\begin{aligned} e_1 &= I_A(R\cos 72°\,30' + X\sin 72°\,30') \\ &= I_A(0.300R + 0.954X) \end{aligned} \qquad (4)$$

$$\begin{aligned} e_2 &= jI_A(X\cos 72°\,30' - R\sin 72°\,30') \\ &= jI_A(0.300X - 0.954R) \end{aligned} \qquad (5)$$

In most cases the in-phase dip computation will suffice, but until experience is gained it is well to compute both the in-phase and quadrature dips and compute the absolute dip, which in this example is

Absolute voltage dip

$$= E_A - \sqrt{(E_A - e_1)^2 + (e_2)^2} \qquad (6)$$

The rapid handling of angles and their sines and cosines often gives rise to errors. To reduce the time required for computation and reduce the possibilities of error, the dip components can be computed for various load power factors and arranged in tabular form for ready reference. This is accomplished by substituting the proper current and angular values in equations 2 and 3.

For a single-phase 100-kva load on a 4,160-volt Y-system, the ampere value of the line current is 24.1 for both A phase and B phase in the phase-to-phase arrangement and in the Y-delta case is 27.8 for A phase, referred to as the "loaded" phase, and 13.9 for B phase and C phase; see Figures 23 and 24 respectively.

The resulting Tables XVII and XVIII give the voltage dips, in terms of R and X, of a 100-kva load. They are equally applicable to 3-phase 4-wire systems of voltages other than 4,160 volts if multiplied by the following factor

Dip on E volt system

$$= \text{dip on 4,160-volt system} \times \left[\frac{4{,}160}{E}\right] \qquad (7)$$

where E is the phase-to-phase voltage of the system being used.

The factors of Table XVIII are also applicable in determining the over-all system regulation at the secondary terminals of the transformer supplying the customer's load. The following three equations give the regulation caused by a 100-kva single-phase load on a 4,160-volt 3-phase 4-wire system

Per cent line regulation per 100 kva, phase-to-phase, Y-delta or delta-delta connection

$$= \frac{27.8(R\cos\theta + X\sin\theta)100}{2{,}400} \qquad (8)$$

Per cent transformer regulation per 100 kva, Y-delta or delta-delta connection

$$= \frac{27.8(r\cos\theta + x\sin\theta)100}{2{,}400} \qquad (9)$$

Per cent transformer regulation per 100 kva, phase-to-phase connection

$$= \frac{3}{2} \times \frac{27.8(r\cos\theta + x\sin\theta)100}{2{,}400} \qquad (10)$$

Constants R and X are those of one phase wire from generator to supply transformer selected according to the transformer connection used, r and x are

Table XVII. Primary Volts Dip Per 100-Kva Single-Phase Load, Phase-to-Phase and Delta-Delta Connections

Load Power Factor	Leading Phase		Lagging Phase	
	In-Phase Drop	J Drop	In-Phase Drop	J Drop
100	$20.9R - 12.1X$	$20.9X + 12.1R$	$20.9R + 12.1X$	$20.9X - 12.1R$
70	$23.3R + 6.4X$	$23.3X - 6.4R$	$6.0R + 23.3X$	$6.0X - 23.3R$
50	$20.9R + 12.1X$	$20.9X - 12.1R$	$24.1X$	$-24.1R$
40	$19.4R + 14.3X$	$19.4X - 14.3R$	$-2.7R + 24.0X$	$-2.7X - 24.0R$
30	$17.8R + 16.3X$	$17.8X - 16.3R$	$-5.2R + 23.5X$	$-5.2X - 23.5R$

Table XVIII. Primary Volts Dip Per 100-Kva Single-Phase Load Y-Delta Connection

Load Power Factor	"Loaded" Phase		First Lagging Phase		Second Lagging Phase	
	In-Phase Drop	J Drop	In-Phase Drop	J Drop	In-Phase Drop	J Drop
100	$27.8R$	$27.8X$	$7.0R+12.0X$	$7.0X-12.0R$	$7.0R-12.0X$	$7.0X+12.0R$
70	$19.5R+19.8X$	$19.5X-19.8R$	$-3.7R+13.4X$	$-3.7X-13.4R$	$13.5R-3.5X$	$13.5X+3.5R$
50	$13.9R+24.1X$	$13.9X-24.1R$	$-7.0R+12.0X$	$-7.0X-12.0R$	$13.9R$	$13.9X$
40	$11.1R+25.5X$	$11.1X-25.5R$	$-8.2R+11.2X$	$-8.2X-11.2R$	$13.8R+1.5X$	$13.8X-1.5R$
30	$8.3R+26.5X$	$8.3X-26.5R$	$-9.4R+10.2X$	$-9.4X-10.2R$	$13.6R+3.0X$	$13.6X-3.0R$

the constants on a 2,400-volt base of the supply transformer carrying the load current (the "loaded" phase in the Y-delta case), and $\cos\theta$ is the power factor of the load. In the three equations the values of the expressions $27.8\ (R\cos\theta+X\sin\theta)$ and $27.8\ (r\cos\theta+x\sin\theta)$ are identical with those given in Table XVIII by the equation for the in-phase component of the drop on the "loaded" phase, for example, $8.3R+26.5X$ for a 30-per-cent power factor load.

Reactance of Open Wire Lines

Resistance and reactance of system elements such as transformers, reactors, and voltage regulators can be determined readily from apparatus test data. And since the conductors of underground or aerial cable are equally spaced, constants can be taken from standard tables. However, calculations involving open wire normally assume that open-wire circuits are arranged with the conductors at the vertices of an equilateral triangle, and, moreover, that a balanced polyphase load is being supplied. Both assumptions are fallacious when applied to welding loads. Circuits as a rule are arranged with flat configuration on horizontal crossarms, and a single-phase load will not result in balanced currents on a polyphase supply system.

The correct solution lies in the application of the general equations expressing the effect upon the reactance and resistance of a conductor of the presence of adjacent loaded conductors. It can be shown that, when applied to single-phase loads on 3-phase systems, the general equations can be greatly simplified and the interaction of adjacent conductors does not affect resistance values. The simplified reactance equations are given next. In the equations S_{AB}, S_{AC}, . . . are the physical separations in inches of phases A and B, phases A and C, . . . and S_A, S_B, and S_C are the resulting true equivalent spacings in inches from which the true reactance of each phase wire can be determined by referring to standard reactance tables.[6,7]

With the load connected phase-to-phase

Load A to B $\quad S_A=S_B=S_{AB}$ (11)

Load B to C $\quad S_B=S_C=S_{BC}$ (12)

Load C to A $\quad S_C=S_A=S_{AC}$ (13)

Equations 11, 12, and 13 therefore state in mathematical symbols the fact that for phase-to-phase loads the true equivalent spacing is equal to the distance between the two phase conductors.

With the load connected through Y-delta bank

When A is "loaded" phase

$$S_A=(S_{AB})^{1/2}(S_{AC})^{1/2} \tag{14}$$

$$S_B=(S_{AB})^2(S_{CB})^{-1} \tag{15}$$

$$S_C=(S_{AC})^2(S_{BC})^{-1} \tag{16}$$

When B is "loaded" phase

$$S_A=(S_{AB})^2(S_{AC})^{-1} \tag{17}$$

$$S_B=(S_{AB})^{1/2}(S_{CB})^{1/2} \tag{18}$$

$$S_C=(S_{AC})^{-1}(S_{BC})^2 \tag{19}$$

When C is "loaded" phase

$$S_A=(S_{AB})^{-1}(S_{AC})^2 \tag{20}$$

$$S_B=(S_{AB})^{-1}(S_{CB})^2 \tag{21}$$

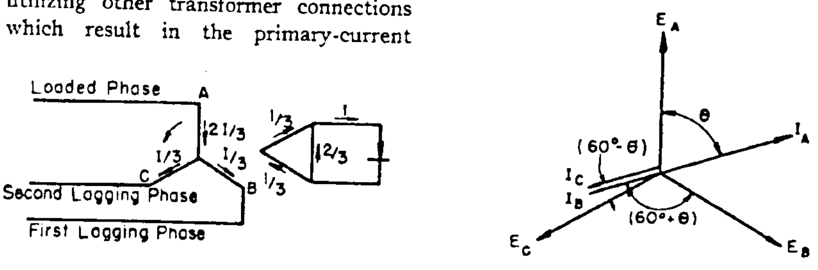
$$S_C=(S_{AC})^{1/2}(S_{BC})^{1/2} \tag{22}$$

The marked variation in reactance resulting from the application of these equations can be observed in Table XIX where there are tabulated the true values for three wire sizes and for the three conductor configurations shown in Figure 25. In the case of the Y-delta connection, values are given assuming in turn each phase as the "loaded" phase. Moreover, the constants given are equally applicable to single-phase loads on 3-phase systems utilizing other transformer connections which result in the primary-current vector relations of Figures 23 and 24.[1]

To summarize, the true values of open-wire resistance and reactance for single-phase welding problems involving phase-to-phase or Y-delta connections are:

1. Resistance is always taken as that shown in standard wire resistance tables. (Table XXI.)
2. For the phase-to-phase connection, reactance is taken as that value shown in standard wire reactance tables for the actual spacing between the two loaded wires.
3. For the Y-delta connection, reactance must be taken from Table XIX, which table must be expanded to cover the wire sizes and conductor configuration (on the crossarm) used on the system.

The application of the method to an actual problem would be made as follows. Assume a welder of 200-kva demand at 30-per-cent power factor supplied from a 4-kv circuit consisting of 300-ampere 10 per cent substation regulators protected by a 300-ampere 3 3/4 per cent reactor, 2,500 feet of 350,000 circular-mil cable and 4,000 feet of 2/0 open wire arranged on a standard crossarm with Configuration 1, Figure 25. Short-circuit current on the substation 4-kv bus is 15,000 amperes. Welder is supplied through a Y-delta transformer bank with phase B as the loaded phase. What voltage dip phase-to-neutral will appear on the primary circuit adjacent to the welder supply? For simplification only the in-phase values are computed here, using Table XVIII. Equipment, cable, and wire constants are selected from Tables XIX, XX, and XXI.



For 30% power factor load θ = 72° 30′ lag

$(60°+\theta)$ = 132° 30′ lag

$(60°-\theta)$ = 12° 30′ lag

Figure 24. Vectors for single-phase load supplied by Y-delta transformer bank

	Phase B	
	R	X
System 2,400/15,000		0.1600
300-ampere 3³/₄ per cent reactor		0.3000
300-ampere 10 per cent regulator	0.0180	0.3470
2,500 feet, 350,000 circular-mil cable	0.0900	0.0825
4,000 feet, 2/0 open wire	0.3284	0.4940
	0.4364	1.3835

$$\text{Voltage dip} = 2(8.3\times 0.4364+26.5\times 1.3835)$$
$$= 80.6 \text{ volts on a 2,400-volt base}$$
$$= 4.0 \text{ volts on a 120-volt base}$$

And from equation 8 and Table XVIII

Per cent line regulation

$$= \frac{2\times 27.8(R\cos\theta+X\sin\theta)100}{2{,}400}$$
$$= \frac{2(8.3R+26.5X)100}{2{,}400}$$
$$= \frac{2(8.3\times 0.4364+26.5\times 1.3835)100}{2{,}400}$$
$$= (7.24+73.4)100/2{,}400 = 3.36 \text{ per cent}$$

Selection of Welder Demand

Obviously, if the demand of the machine is unknown, the supply system cannot be designed and the voltage dip produced cannot be calculated. If the frequency of voltage dip is unknown, it cannot be determined whether the voltage dip will prove objectionable. For an intelligent and equitable solution, the electric utility requires the following data on the proposed welder:

1. Maximum short-circuit current at the welding head, with the machine throat set at standard R.W.M.A. dimensions.
2. Maximum open-circuit voltage on highest voltage tap.
3. Approximate working demand in kva.
4. Approximate working power factor.
5. Cycle of operation, including length of each weld in electric cycles and number of welds per hour.
6. Whether synchronous timing or heat control is to be used.
7. Heat control setting normally to be used.

The product of the short-circuit secondary current and open-circuit voltage, as defined here, is the short-circuited demand and therefore the maximum demand which the machine can create, and this value should be used in all calculations. If basic data on the machine are not available, the kva demand may be estimated by referring to data on similar machines detailed in the section of this report entitled "Resistance Welding Machines." This section also gives typical power factors of machines in operation.

In recommending the use of the short-circuited demand in all calculations, it is recognized that, while the demand in the first cycle may be equal to the short-circuited demand, over the total period of the weld the demand will be lower than that due to normal voltage drop in the supply system and due to the increased impedance of the machine caused by the presence of steel or other metal in the reactance loop of the throat. On the other hand, if the machine is energized at other than the proper point on the voltage wave, the resulting transient current, limited only by saturation, may be much greater than normal. The short-circuited demand formula makes allowance, although heavily discounted, for these possibly high transients. However, while these high transients may have a marked effect upon the quality of short duration welds, experience has indicated that, from the standpoint of flicker tolerance, as a general rule they may be completely discounted and that a further allowance may be made for the effects of normal voltage drop and the presence of the work piece in the throat. In total, this is equivalent to assuming the maximum demand of the machine as 90 per cent of its short-circuited demand when welding common steel and 95 per cent of its short-circuited demand when welding aluminum. Such reductions are not applicable when the machine is operated at less than its maximum capability.[8]

Further reductions in demand may be assumed due to the operation of electronic heat control and the effect of adjacent motor load. Under heat control, current is drawn for a limited portion of each half-cycle during the period of the weld. For calculating purposes "per cent heat control setting" is approximately equal to "per cent of that current which would flow without heat control."[4,9]

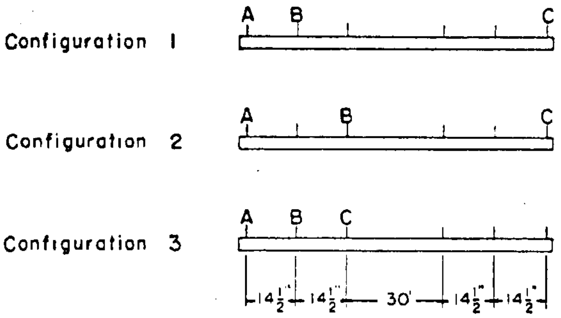


Figure 25 (right). Conductor configuration on crossarm

Table XIX. True Line Reactance for Open-Wire Circuits Single-Phase Load on 3-Phase System, Ohms per Thousand Feet of Conductor

		Load Served Through Y-Delta Transformation								
		Aφ Loaded			Bφ Loaded			Cφ Loaded		
Configuration*	Wire Size	Aφ	Bφ	Cφ	Aφ	Bφ	Cφ	Aφ	Bφ	Cφ
1	4	0.1401	0.0809	0.1648	0.0771	0.1379	0.1524	0.2020	0.1947	0.1586
	2/0	0.1257	0.0665	0.1505	0.0627	0.1235	0.1381	0.1862	0.1779	0.1443
	4/0	0.1204	0.0632	0.1452	0.0574	0.1182	0.1328	0.1810	0.1727	0.1390
2	4	0.1479	0.1189	0.1699	0.1098	0.1434	0.1423	0.1869	0.1678	0.1561
	2/0	0.1335	0.1045	0.1555	0.0954	0.1290	0.1280	0.1702	0.1534	0.1418
	4/0	0.1282	0.0992	0.1502	0.0901	0.1237	0.1227	0.1674	0.1481	0.1365
3	4	0.1272	0.1194	0.1511	0.1032	0.1194	0.1032	0.1511	0.1194	0.1277
	2/0	0.1127	0.1049	0.1367	0.0888	0.1049	0.0888	0.1367	0.1049	0.1122
	4/0	0.1077	0.0996	0.1314	0.0835	0.0996	0.0835	0.1314	0.0996	0.1077

		Load Served by Phase-to-Phase Transformer					
		Load A to B		Load A to C		Load B to C	
		Aφ	Bφ	Aφ	Cφ	Bφ	Cφ
1	4	0.1194	0.1194	0.1606	0.1606	0.1565	0.1565
	2/0	0.1049	0.1049	0.1463	0.1463	0.1422	0.1422
	4/0	0.0996	0.0996	0.1410	0.1410	0.1369	0.1369
2	4	0.1352	0.1352	0.1606	0.1606	0.1515	0.1515
	2/0	0.1208	0.1208	0.1463	0.1463	0.1373	0.1373
	4/0	0.1155	0.1155	0.1410	0.1410	0.1320	0.1320
3	4	0.1194	0.1194	0.1352	0.1352	0.1194	0.1194
	2/0	0.1049	0.1049	0.1208	0.1208	0.1049	0.1049
	4/0	0.0996	0.0996	0.1155	0.1155	0.0996	0.0996

* From Figure 25.

Table XX. Electrical Constants

Cable and Equipment at 2,400 Volts

Equipment	Unit	R	X
Substation Reactors			
200 ampere, $3^1/_4$%	ohms	0.00	0.45
300 ampere, $3^1/_4$%	ohms	0.00	0.30
Substation Induction Regulators			
150 ampere, 10%, single-phase	ohms	0.039	0.597
300 ampere, 5%, single-phase	ohms	0.010	0.149
300 ampere, 10%, single-phase	ohms	0.018	0.347
Cable for 4-Kv Circuits			
350,000 circular mil, 4/conductor	ohms/1,000 feet	0.036	0.033
2/0, 4/conductor	ohms/1,000 feet	0.094	0.036
Number 1, 4/conductor	ohms/1,000 feet	0.152	0.037
Distribution Transformers			
25 kva (2,400 volt)	ohms	3.59	5.35
50 kva (2,400 volt)	ohms	1.43	3.02
100 kva (2,400 volt)	ohms	0.69	1.90
200 kva (2,400 volt)	ohms	0.31	0.96

A limited number of tests have indicated that connected motor load in a plant has a tendency to reduce the amount of voltage dip caused by welders in the same plant. When the motor load is of the same order of magnitude as the demand of the welder, this reduction may be as much as 10 per cent of the voltage dip. Further and more precise data are presented in references 10 and 11.

Computation of Voltage Dip for 3-Phase Machines

In the last three years two new types of 3-phase welding machines have been placed in use. One of these is the metallic rectifier welder; the other is termed the frequency-converter welder.[12,13]

The metallic rectifier welder supplies direct current to the weld through a 3-phase full-wave metallic rectifier. Power supplied to the welder is continuous during the period of the weld, and is approximately balanced 3-phase and of a power factor in the order of 95 per cent.[14]

The frequency-converter welder supplies low-frequency alternating current to the weld through a 3-phase electronic tube converter, the individual pairs of converting tubes being connected phase-to-phase. Current drawn from the utility supply lines is of a pulsating nature, which at certain machine settings may be essentially single phase. The power factor is in the order of 80 to 85 per cent. Because of the cyclic nature of the load, the frequency-converter welder is in the same category as single-phase seam welders in determining allowable voltage dip, except in cases of single pulse welding.[12,15]

A more complete discussion of 3-phase machines is given in Section IV of this report.

Allowable Voltage Flicker

Much data have been secured to establish the tolerable limits of voltage dip. It has been established that the threshold of irritation is influenced by many factors such as the magnitude of voltage reduction, the rate of voltage reduction, the duration of voltage reduction, the frequency of voltage reduction, the location of the dip producing equipment, and the visual acuity of the individual observer.[16]

For the purposes of determining allowable voltage dip, reference usually is made to dip-limit curves, like those shown in Figure 26 which are composites based on tests conducted by the Electrical Testing Laboratories, the General Electric Company, the Edison Electric Institute, and numerous electrical utilities. They seek to record the average reaction of the average individual. Obviously, the reaction of many individuals will be stronger than the average, but this reaction will be considerably modified if the dip-producing equipment is on the customer's own premises.

Table XXI. Equivalent Electrical Constants

Open Wire—Copper (Ohms per 1,000 Feet, Single Conductor)

	Equivalent Spacing	Number 4*	Number 1	2/0	4/0
Resistance	All	0.257	0.131	0.0821	0.0515
Reactance	12 inches	0.1150	0.1057	0.1006	0.0953
	38.8 inches	0.1418	0.1326	0.1275	0.1222
	64 inches	0.1533	0.1440	0.1390	0.1337
	76 inches	0.1573	0.1480	0.1430	0.1377

* Solid

The section of the curves covering more than one fluctuation per second is applicable to seam and pulsation welders. The section covering one fluctuation in 1 second or more is applicable to spot, projection, flash, butt, and similar welders. From the viewpoint of the electrical utility, the curves apply to the voltage dip appearing on the primary distribution circuit (2,400 volts or more) at the last point common to both lighting and welding loads.

Duration of dip is also a factor. Ten to 15 cycles may be assumed normal. When the process produces a dip of 1/2 second or 1 second, the allowable dip should be reduced moderately. When the process produces a dip whose duration is 1/12th second or less, the allowable dip may be increased moderately. However, caution must be exercised at dip frequencies of more than one dip per second.[17]

The curves given here should be considered as suggestions to be modified on a basis of experience and engineering judgment. They approximate an average of many such curves now in use. In standardizing on a particular set of curves, it should be borne in mind that the absence of light flicker complaints may mean only that values chosen are too restrictive and that such values could be liberalized without causing trouble. On the other hand, in passing judgment upon a proposed voltage dip, it must be remembered that future changes in process may call for a revision of the weld duration and welding frequency of a given machine.

Most curves of allowable voltage dip are based on tests with incandescent lamps. Very little information is available as to the effect of voltage drop upon fluorescent lighting. Tests made indicate that certain types of fluorescent lamps are less susceptible than incandescent lamps of comparable light output.[18,19]

Voltage Regulation at the Welder

Computations must include the expected voltage regulation at the terminals of the welding machine. Exceeding the limits recommended in Section VI of this report may affect not only the quality of the weld but the operation of control apparatus as well. When it is found that the regulation of the proposed supply system exceeds the recommended limits, it often will prove more economical to reinforce the supply transformer by installing paralleling or larger units than to reinforce the distribution circuit. On the other hand, consultation with the customer and welder manufacturer may show that the anticipated voltage regulation will be satisfactory for the proposed machine.

Methods of Reducing Voltage Dip and Voltage Regulation of the Supply System

The voltage dip produced at a given point by the operation of a welding machine is directly proportional to (1) the impedance between that point and the utility generating station, and (2) the demand of the machine. Only a reduction in either (1) or (2) will reduce the dip or lower the over-all regulation.

Methods of reducing the impedance of the supply system are many. The application of each method must be considered[20] in the light of reduction obtained per dollar expended. Enumerated recognized procedures, as referred to an open-wire 3-phase 4-wire medium voltage system on which transformers connected between phase wire and neutral are utilized to serve lighting customers, are given:

1. Serving the single-phase load from a Y-delta transformer bank will reduce the lighting voltage dip to approximately two-thirds of the dip produced by serving the load from a single transformer connected from phase-to-neutral.

2. Serving the single-phase load from a single transformer connected phase-to-phase will reduce lighting voltage dip to approximately three-quarters of the dip produced by serving the load from a Y-delta bank, and to approximately one-half of the dip produced by serving the load from a single transformer connected from phase-to-neutral.

3. Rerouting the supply circuit to reduce the length of feed. Often this may be accomplished by transferring the load to another circuit.

4. Reinforcing of existing open-wire conductors. The reactance component, which is the predominant factor in low power factor loads, does not decrease appreciably with increased wire size, however.

5. If the voltage dips are tolerable at any point on the primary system, a separate conductor or conductors extended from that point to the load often will prove the most economical solution. Where the load is served Y-delta, the extension of a single conductor on the phase carrying two-thirds of the load current often will suffice.

6. Installing a series capacitor in the supply circuit to reduce circuit impedance or installing a voltage translator. Application of such devices requires a thorough study of resulting conditions at various points in the circuit and under varying conditions of load.[21,22,23]

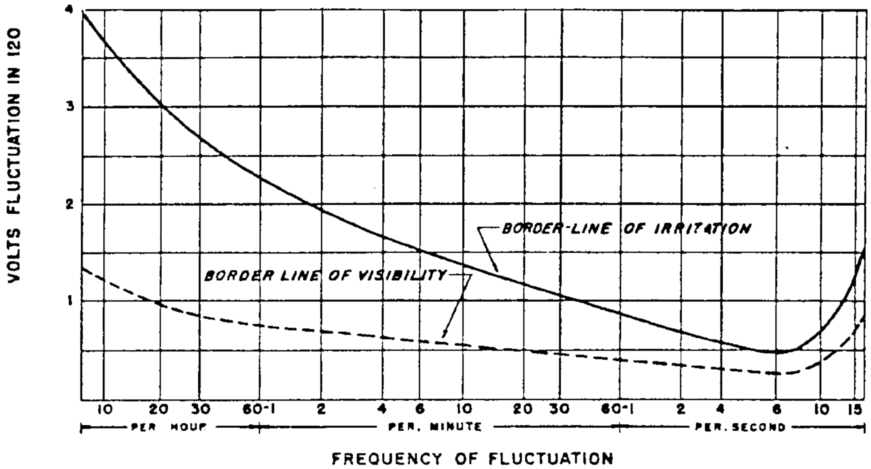


Figure 26. Relation of voltage dips to frequency

7. Isolating a primary circuit for the customer's exclusive use. Special attention must be paid to the possibility of high mechanical wear in the induction voltage regulators supplying the load. Either they must be prevented from operating, except during a small portion of each minute, or the operating band must be increased.

8. Isolating welding supply circuits on a special bus at the utility step-down substation. The economics of such a solution should be closely studied, however.

9. Serving the load from the subtransmission system at 13 kv, 26 kv, or similar voltage.

Reducing the Demand

Since the amount of voltage dip is proportional to both the impedance of the supply system and the load demand, the economical solution may lie in reducing or otherwise changing the characteristics of the demand. This can be accomplished in numerous ways. The first item to be investigated is the welding schedule. Perhaps the welding current may be decreased by increasing the weld time or by changing the mechanical pressure during the weld. Redesigning the workpiece may be the economical solution rather than endeavoring by the use of high currents to "bull it through."

Where the welding machine consists of single-phase welding units connected on each of the three phases, a change in the firing schedule may prove helpful. If the welding demands are at normal low power factors, it generally will be found preferable to fire all units at one time, rather than in sequence. To stay within allowable voltage dip limits it otherwise would be necessary to fire the individual units at time intervals of not less than one-third of the interval used for simultaneous firing. This applies for service either through a Y-delta or delta-delta transformer bank.

Electrical demand, from a standpoint of voltage dip produced, may be reduced effectively by a change in machine characteristics. The following alternatives should be investigated:

1. Use a welder with a smaller throat.

2. Installing a series capacitor at the machine will correct load power factor to unity and will reduce voltage dips to from 15 to 30 per cent of their uncorrected value. Such capacitors reduce the operating flexibility of the machine.[24]

3. Supplying the single-phase welders through a 3-phase motor generator set.

The effects of these various welding systems on the power supply are discussed more fully in the references and in other sections of this report.

Thermal Load on Transformers

The kva rating of a welding machine, as shown on the name plate, is the rating on a 50-per-cent duty cycle of the machine transformer (which reduces the plant voltage to that value required by the weld) and indicates the kva load it can safely carry at a 50 per cent duty cycle. It in no way indicates either the useful output of the machine in welding current or the maximum kva input to the machine from

Table XXII

Type of Welder	Multiplying Factor	
	1 or 2 Welders	3 or More Welders
Spot, butt, projection, flash, hydromatic welders	0.5	0.2
Spot, butt, and projection welders with pulsation control	0.5	0.4
Seam welders	0.7	0.7

the supply lines. The continuous rating of such a transformer is 70.7 per cent of its rating on a 50-per-cent duty cycle. The theoretical capacity of the same transformer operated at a 10-per-cent duty cycle is 224 per cent of its rating on a 50-per-cent duty cycle.

The equation for computing such values is equally satisfactory in determining the size of the utility supply transformer required to serve a welding load.

$$\text{Continuous kva rating required} = H\sqrt{\frac{S_1}{S_2}} \tag{23}$$

where

H = kva demand during load period
S_1 = load period in cycles
S_2 = total period in cycles
S_1/S_2 = the duty cycle

In most cases, however, more than one welder is being supplied at a given location. The thermal load of the group of welders, in such instances, can be approximated closely as the sum of the continuous kva rating required, equation 23, by the largest machine, plus 60 per cent of the sum of the continuous kva rating required by each of the remaining welders in the group.

If duty cycles are unknown and a rough approximation of load is required, an estimate can be made by multiplying the name-plate kva rating of each of the machines by the factors shown in Table XXII.

In using these equations or approximations to determine thermal load, it should be borne in mind that in many cases adequate voltage regulation at the welder will dictate larger transformers than are required to meet the calculated thermal loads.

Economic Considerations

Most welding operations have extremely low operating duty cycles resulting in high instantaneous demand and low kilowatt-hour consumption. The predominating factors determining the type of electric supply are the allowable voltage drop at the welder and the allowable voltage fluctuation as it affects nearby lighting. To limit these variations, oversized facilities often must be installed specifically to serve the welder. In such cases only a small portion of the total current-carrying capacity and revenue-producing capacity of supply conductors and transformers is used. For example, a 300-ampere 4,160-volt distribution circuit, commonly employed by utilities, is capable of supplying approximately 2,000 kva of steady 3-phase load. However, because of its critical magnitude-frequency characteristics, a seam welder drawing in excess of 100-kva maximum demand at a frequency of 4 cycles on, 4 cycles off, on such a circuit may cause objectionable lighting flicker throughout the area served. Hence it may be necessary for the power company to isolate the complete circuit or to install special facilities for the sole use of the welder. This is an item of major importance, since the investment in additional substation facilities and in outside-plant cable and overhead lines for a special supply circuit will be large. Obviously the costs of such outside-plant elements will be subject to considerable variation due to terrain, present density of construction, and many other factors.

Seam welders and large spot or flash welders often will require the installation of excessive capacity in the supply circuit, but for the normal moderately sized spot welders, the special facilities required generally will consist of oversized transformers and short extensions of utility lines.

Rates charged for service to welders must compensate the power company for the oversized or segregated facilities required to supply a single customer with due allowance for the revenue derived from the operation of nonintermittent equipment at the customer's plant. Most rates for normal, nonfluctuating power loads are based on combining a charge for energy consumed with a charge which varies with the customer's maximum electrical demand. The energy required for welding can be determined by the normal kilowatt-hour meter, but the maximum demand of a welder, unfortunately, is measurable only by the oscillograph or pointer-stop ammeter, and neither of these devices lend themselves to providing a metered demand for regular billing purposes. Hence power company demand charges for welders usually are made upon some other basis, such as carrying charges upon facilities specifically reserved for the welder, or surcharges based on the name-plate rating of the welder or the actual demand or maximum possible demand determined by test. It is obvious that it is to the advantage of the user to purchase a machine with as small a demand as possible consistent with the work to be performed.

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Section VI

INFORMATION FOR POWER USERS

Power for most resistance welding installations is furnished by a power company. Distribution within the plant must be provided by the user. The intermittent nature of resistance welding loads introduces some special problems not usually involved in providing power distribution for other types of load. This Section outlines the nature of these problems and methods for their solution, from the viewpoint of the user.

Selection of Welder

The selection of the type of welder to be used should be based not only upon the work to be done but also the effect of the welder on the power supply. For each type of welder considered, therefore, the user should employ information about welding performance and about required electrical input to each welding machine.

Descriptions of the most important types of welders are given in Section IV, beginning with the heading "Load Characteristics of Single-Phase A-C Direct Energy Welders" and continuing to the end of that Section.

Welder Input

Name-plate Rating

The kva rating of a welder is the maximum input kva which the welder can accept without overheating, when and if current flows 50 per cent of the time during any minute of operation.

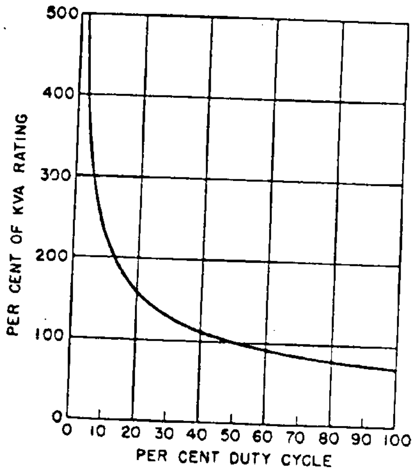

Figure 27. Allowable welder input as affected by duty cycle

Design of welder determines maximum input actually available

Actual Input

Often the welder carries current less than 50 per cent of the time. For such cases, the kva input can safely be in excess of the welder rating. Figure 27 shows how the allowable input to a welder varies with the duty cycle (defined as the ratio of weld time to total time).

The actual input to a resistance welder cannot be determined directly from its rating. It often greatly exceeds the 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 can 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 report for the type and rating of each welder.

The most important aspects of resistance welder input are kva demand, power factor, duty cycle, welds per minute, and whether the welder is single phase or three phase. Most welders are single phase.

Kva Demand

The kva demand is the input during welding. For a single-phase welder, it is the product of the rms line voltage and the rms line current during the weld. It may be from less than 30 kva for a small machine to over 1,000 kva for a large welder. Tables VI to XI give typical demands for welders with electrodes together (short-circuit). Demands will be less when welding (see "Use of Data on Expected Welding Current" later in this Section).

Power Factor

Typical power factors are given by Tables VI to XI for the short-circuit condition. As shown by Section IV, the presence of work between the electrodes increases the power factor somewhat. Use of electronic heat control, however, reduces power factor in proportion to the setting used. That is, at 75-per-cent heat (current) the power factor is three-fourths of the value for the same welder and work pieces at full heat. This effect is very important with welders using series capacitors. At full heat, the line power factor is practically unity for such welders. At about 90-per-cent heat the power factor is 90 per cent, and the voltage drop is considerably higher than at full heat, even though the demand is less. Voltage drops for such welders should be calculated for the most unfavorable heat setting, which is usually about 90 per cent.

Duty Cycle

The duty cycle is the ratio of weld time to total time for a weld. The weld time is usually from 1 to 30 cycles. The total time depends upon the number of welds per minute which can vary from few welds to several hundred. To calculate the per-cent duty cycle, multiply the weld time in cycles by the number of welds per minute and divide by 36 (if the line frequency is 60 cycles per second).

Duty cycles for spot welders are usually between 1 and 20 per cent. Seam welder duty cycles are often between 30 and 70 per cent.

Use of Data on Expected Welding Current

Tables XXIII to XXV show welding currents and weld times recommended[1] by the American Welding Society (AWS) for various common thicknesses of pieces to be welded. They are for spot, pulsation, and seam welding of low-carbon steel. The American Welding Society also has prepared tables for projection welding of low-carbon steel, and for spot welding of various other materials. Recommendations have not as yet been established by AWS for welding aluminum. In general, aluminum requires considerably more current (often more than twice as much) as is needed for welding the same thickness of low-carbon steel.

Information from Tables XXIII to

Table XXIII. Spot Welding Low Carbon Steel (SAE 1010)

Thickness "T" of Thinnest Outside Piece,*,** Inches	Weld Time (Single Impulse), Cycles (60 Per Second)	Welding Current (Approximate), Amperes
0.010	4	4,000
0.021	6	6,500
0.031	8	8,000
0.040	10	9,500
0.050	12	10,500
0.062	14	12,000
0.078	17	14,000
0.094	20	15,500
0.109	23	17,500
0.125	26	19,000

* Welding conditions determined by thickness of thinnest outside piece "T."

** Data for total thickness of pile-up not exceeding four "T." Maximum ratio between two thicknesses 3-to-1.

Table XXIV. Pulsation Welding Low-Carbon Steel (SAE 1010)

Combination of Thicknesses To Be Welded			Weld Time: On 20 Cycles, Off 5 Cycles; Number of Pulsations; Adjacent Welds		Welding Current (Approximate), Amperes
T-1	T-2	Single Welds, Cycles	1-Inch to 2-Inch Centers	2-Inch to 4-Inch Centers	
1/8	1/8	3	5	4	18,000
1/8	3/16	3	5	4	18,000
1/8	1/4	3	5	4	18,000
3/16	3/16	6	20	14	19,500
3/16	1/4	6	20	14	19,500
3/16	5/16	6	20	14	19,500
1/4	1/4	12	24	18	21,500
1/4	5/16	12	24	18	21,500
5/16	5/16	15	30	23	24,000

XXV can be used for estimating input currents to a welder, if certain data concerning the welder are available. For a conventional single-phase machine, the welder data required consist of the primary voltage, the method of heat adjustment used, and any two of the following, for the expected throat setting.

1. Maximum short-circuit kva input demand.
2. Maximum short-circuit secondary current.
3. Maximum secondary voltage.

Since (1) is the product of (2) times (3), any two of these data will yield the other. Typical values of (1) and (2) are given in Tables VI to XI.

When welding at the highest heat setting, the demand is about 90 per cent of the short-circuit demand. The secondary (welding) current is then 90 per cent of the maximum short-circuit secondary current.

For example, consider a 10-kva 60-cycle rocker arm welder, with an 8-inch throat, welding at maximum heat setting. From Table VI this welder will deliver 10,000 amperes at short circuit or 9,000 amperes to a weld. The demand at short circuit is 27 kva (from Table VI) and the maximum demand while welding is 90 per cent of 27 kva or 24.3 kva. At 440 volts, the line current is 550 amperes, because 24,300 volt-amperes divided by 440 volts is 550.

If the required welding current is less than about 90 per cent of the maximum short-circuit secondary current, a reduced heat setting will be required. To estimate the input current at reduced heat, it must be known whether heat is adjusted by taps, electronic heat control, or both.

For any given heat setting, the demand will be highest if the adjustment is made entirely by electronic heat control. It will be least if the adjustment is made entirely by taps, with the electronic control (if used) set at 100 per cent.

With electronic heat control the input demand is reduced from the maximum welding demand in the same proportion that the welding current is less than the current for 100-per-cent heat control setting. With the preceding example, suppose the machine is to weld two pieces of 0.021 low-carbon steel. From Table XXIII, the welding current should be 6,500 amperes. This is 72 per cent of the maximum welding current of 9,000 amperes. The required 6,500 amperes could thus be obtained by setting the electronic heat control at a setting of 72 per cent. The kva demand will then be 17.5 kva, because this is 72 per cent of the maximum welding demand of 24.3 kva.

When taps are used to reduce heat, the input current is reduced by the square of the proportion of reduced secondary current. For the example used, a secondary current of 6,500 amperes obtained by tap adjustment results in a demand of 12.6 kva because $24.3\ (0.72)^2 = 12.6$.

When a combination of taps and electronic control adjustment is used, secondary current and primary demand should be calculated for the tap used, assuming 100-per-cent control setting. Then these values can be reduced in proportion to the electronic heat control setting (note that 50-per-cent heat setting means 50-per-cent current rather than 50 per cent of thermal heat).

AVOIDING HIGH DEMANDS

By wise selection of the welding machine and by suitable use of taps, unnecessarily high demands can be avoided, without impairing welding performance. For a machine having taps and electronic heat control as well, coarse adjustment of heat should be obtained by taps, using the heat control for fine adjustment. If the throat area of the welder is kept at a practical minimum, the kva input required to provide a given welding current will be less than with a larger throat area.

For purposes of power supply design, it is often advisable or necessary to assume each welder will draw its maximum load. For this reason, the user should avoid selecting a machine which is much larger than necessary for the work to be done.

Demands can be reduced by employing special machines or equipment, such as are described in Section IV. However, the extra cost of such machines should be compared with the extra cost of a power supply adequate for conventional welders; see "System Cost" later in this Section.

MEASUREMENT OF INPUT

The current, voltage, and power input to a welder seldom can be measured accurately by conventional instruments because of the short weld time. A discussion of suitable measuring techniques is included in Section V under the heading, "Determination of Voltage Dip and Current for Single-Phase Welders."

Voltage Drop

LIMITS FOR VOLTAGE DROP

To check the suitability of an existing or proposed power system for resistance

Table XXV. Seam Welding Low-Carbon Steel (SAE 1010)

Thickness "T" of Thinnest Outside Piece,* Inches	On Time, Cycles (60 Per Second)	Off Time (Pressure-Tight), Cycles	Weld Speed, Inches per Minute	Welds per Inch	Welding Current (Approximate), Amperes
0.010	2	1	80	15	8,000
0.021	2	2	75	12	11,000
0.031	3	2	72	10	13,000
0.040	3	3	67	9	15,000
0.050	4	3	65	8	16,500
0.062	4	4	63	7	17,500
0.078	6	5	55	6	19,000
0.094	7	6	50	5.5	20,000
0.109	9	6	48	5	21,000
0.125	11	7	45	4.5	22,000

* See notes on bottom of Table XXIII.

welders, it is advisable to calculate expected voltage drops.[2]

The user is primarily interested in voltage drops within his own plant. A portion of these drops occur in the system of the power company, and the remainder in the substation transformers and the feeders of the user's plant.

The voltage drops in the power company system can be estimated after consultation between the user and the power company. They usually are kept to small values (often less than 1 per cent) to avoid light flicker on the premises of other power customers. (See Section V for a more complete discussion).

The voltage drops in the user's plant should not be too great too often for good welding results. They should not cause objectionable light flicker within the plant. They should not be severe enough to impair the performance of other loads which are sensitive to voltage changes.

Calculation of Drops

By voltage drop is meant the difference between the voltage for the condition of no load and for the condition after application of the load or loads being considered. For welders, the most important voltage drop is usually a line-to-line drop, because welders are connected line-to-line on a 3-phase system. For lights, momentary line-to-neutral drops (called dips in Section V) are important, if the lights are supplied from line-to-neutral.

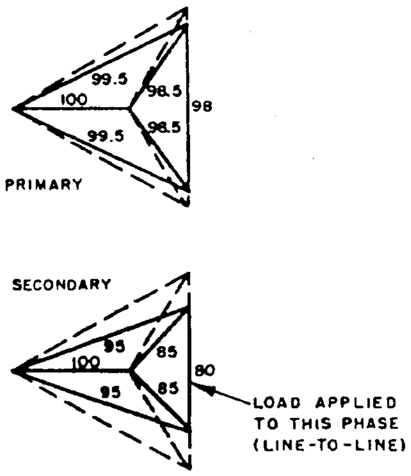

Figure 28. Voltages for delta-delta transformer with single-phase load

Load, transformer, and supply system all have same resistance/impedance ratio. Dashed lines show no-load voltages. Solid lines show voltages with load applied. Values given on figure are in per cent of no-load voltage. One tenth of total impedance is in primary supply. Primary system impedances are balanced

To calculate voltage drop it is necessary to have information about the impedance of the system, and about the demand and power factor of the load.

For single-phase welders, with power factors of 50 per cent or less, and for usual ratios of system resistance to system impedance of less than one-half, it is not necessary to know the exact power factor nor the exact resistance/impedance ratio for the system. The voltage drop can be estimated simply by multiplying the welder load by the system impedance.

To obtain the drop in volts, the load should be expressed in amperes, and the impedance in ohms. A given drop (IZ) in volts can be expressed in per cent by multiplying by 100 and dividing by the no-load voltage. For a single-phase system, this is the line-to-line no-load voltage. For 3-phase loads on a 3-phase system, divide IZ in volts by the line-to-neutral voltage to obtain the per cent voltage drop.

A more precise method of calculation is presented in Section V in equations 1 through 6.

A single-phase load will cause twice as much drop on a 3-phase system as will a 3-phase load of the same kva and power factor.

Phases Affected

Welders ordinarily are connected line-to-line. Lights may be supplied from either line-to-line or line-to-neutral voltage. The per cent 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 shown in Figure 28.

Sometimes it is desirable to know the voltage drops on the line-to-line phases other than that supplying the welder. These drops[2] 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 transformation is used, a single-phase line-to-line secondary load imposes a line-to-line load on the corresponding primary phase. When a delta-Y or Y-delta transformation is used, the per cent primary line-to-neutral drops correspond to the line-to-line drops obtained with a delta-delta transformer, if primary system impedances are balanced. Also the line-to-line drops correspond to the line-to-neutral drops obtained with a delta-delta transformer. This is illustrated by Figure 29.

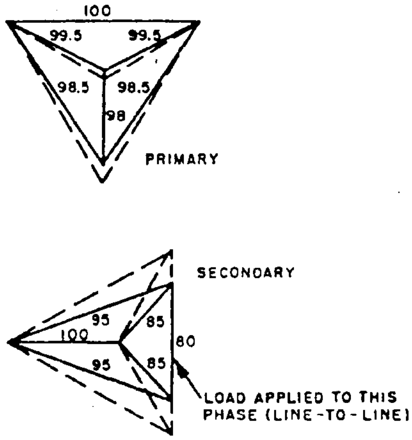

Figure 29. Voltages for delta-Y or Y-delta transformer with single-phase load. Same conditions as for Figure 28

If a welder is supplied from line-to-neutral as from a single-phase transformer connected line-to-neutral on a 2,300/4,160 Y system, the corresponding per cent primary line-to-neutral drop is from 1.5 to about 3.0 times the per cent primary line-to-line drop which would occur if the same welder kva were supplied line-to-line from either a single-phase or 3-phase transformer. The exact value depends upon the proportion of total impedance which is contributed by the neutral conductor.

Figures 28 and 29 are based on the assumption of balanced impedances for the primary supply system. When open-wire lines with flat spacings are used without transpositions, the methods given in Section V should be used to calculate primary system drops.

Primary Supply System

The voltage drop in the primary supply system will ordinarily be calculated by the power company. Sometimes a high-voltage distribution system exists within the plant, so that user must calculate drops in this system.

The drop in the high-voltage system contributes to the drop in the low-voltage system. The impedance of the primary system can be expressed in apparent impedance on the secondary side which can be added to the impedance in the secondary circuit. The apparent impedance equals the actual impedance (on the primary side) divided by the square of the ratio of high voltage to low voltage. Thus an impedance of 0.10 ohm in one primary phase of a 2,400-volt system appears as 0.001 ohm on the 240-volt side of a substation, because $0.001 = (0.10)(240/2{,}400)$. This should be added to the transformer impedance to obtain the effective impedance of the substation.

Table XXVI. Approximate Impedance Data for Single-Phase Distribution Transformers

25–500 Kva. Primary Voltage 15 Kv or less

Kva Rating	Per Cent R	Per Cent X	Per Cent Z
25	1.6	2.5	3.0
37.5	1.5	2.5	2.9
50	1.4	3.0	3.3
75	1.3	3.5	3.7
100	1.2	4.0	4.2
167	1.1	4.5	4.7
250	1.0	5.0	5.1
333	1.0	5.0	5.1
500	1.0	5.0	5.1

Table XXVII. Approximate Impedance Data for Single-Phase Power Transformers

Ratings above 500 Kva

Primary Kv Rating	Per Cent Z
2.2–23	5.5
34.5	6.0
46	6.5
69	7.0

Per cent resistance is approximately 1.0. Per cent X is approximately same as Z.

An estimate of the impedance of a high-voltage system often can be obtained from the calculated short-circuit kva. To do this, calculate the current in amperes which corresponds to this kva. Then

Impedance per line, ohms

$$= \frac{\text{(line-to-neutral voltage)}}{\text{(short-circuit current)}}$$

$$= \frac{\text{(line-to-line voltage)}}{\text{(1.732)(short-circuit current)}}$$

TRANSFORMERS

The impedance of transformers often is expressed in per cent. This means that a low-power-factor load current equal to the transformer rating will cause a per cent drop equal to this per cent impedance. For 3-phase transformers this is only true for balanced 3-phase loads. A single-phase low-power-factor load equal to the 3-phase transformer kva rating will cause a per cent drop equal to twice the per cent impedance of the 3-phase transformer supplying it. Larger or smaller loads will cause proportionally larger or smaller drops, of course.

The per cent impedance of a transformer can be expressed as a certain number of ohms on the secondary side. For a single-phase transformer, it is

$$\text{Ohms impedance} = \frac{\text{(rated volts)}}{\text{(rated amperes)}} \times \frac{\text{(per cent impedance)}}{100}$$

For a 3-phase transformer

Ohms impedance

$$= \frac{\text{(rated line-to-neutral volts)}}{\text{(rated line amperes)}} \times \frac{\text{(per cent impedance)}}{100}$$

Line-to-neutral voltage equals line-to-line voltage divided by 1.732.

A bank of three single-phase transformers can be treated as if it were a 3-phase transformer by using the current in the outgoing lines for rated output. Thus

Rated line current

$$= \frac{\text{(Rated bank kva)(1,000)}}{\text{(1.732)(rated line-to-line volts)}}$$

The impedance to be used is the same whether the 3-phase transformer or bank is connected delta-delta, delta-Y, or Y-delta. The impedance is considered to be in one line of a single-phase transformer, and in each line of a 3-phase transformer or bank.

As an example, consider a 500-kva 480-volt 3-phase transformer with 5-per-cent impedance, and a welding load which will draw 1,040 amperes (500-kva single-phase at 480 volts).

For the transformer

$$\text{Rated line current} = \frac{(500)(1{,}000)}{(1.732)(480)} = 600 \text{ amperes}$$

$$\text{Line-to-neutral voltage} = \frac{480}{1.732} = 277 \text{ volts}$$

$$\text{Ohms impedance} = \frac{(277)}{(600)} \times \frac{(5)}{(100)} = 0.0232 \text{ ohm} \quad \text{(in each line)}$$

Since the load is single-phase, not 3-phase, the current flows in two lines and encounters this impedance twice. Hence the voltage drop is

$$(1{,}040)(0.0232)(2) = 48 \text{ volts}$$

The per cent drop is

$$\frac{48}{480}(100) = 10 \text{ per cent}$$

It should be noted that, while this calculation makes the assumption that the load still draws 1,040 amperes even at 90-per-cent voltage, this simplification is usually satisfactory for most system design calculations.

CALCULATION OF FEEDER VOLTAGE DROP

The voltage drop in a cable or busway depends upon the length of run and the impedance per unit length. For single-phase loads, the total impedance of going and return conductors must be considered, whether the supply system is single phase or three phase. For 3-phase loads, the impedance of one conductor is used to calculate the line-to-neutral voltage drop. The per cent line-to-line drop is the same as the per cent line-to-neutral drop for a balanced 3-phase load.

Impedance Data

TRANSFORMER IMPEDANCE DATA

Approximate transformer impedance data are given by the following tables:

Table XXVI. Single-Phase Distribution Transformers

Table XXVII. Single-Phase Power Transformers.

Table XXVIII. Three-Phase Transformers, 100 to 500 Kva.

Table XXIX. Three-Phase Power Transformers.

When accurate data are required, manufacturers' information or name-plate data should be consulted.

FEEDER IMPEDANCE DATA

The following tables provide approximate resistance, reactance, and impedance information for use in making voltage drop calculations:

Table XXX. Impedance Data for Single Conductor Cables

Table XXXI. Impedance Data for Concentric Cables

Table XXXII. Impedance Data for Cables Laced Together

Table XXXIII. Impedance Data for Busways

Table XXVIII. Approximate Impedance Data for 3-Phase Transformers

100–500 Kva. Primary Voltage 15 Kv or less. Secondary Voltage 600 volts or less

Kva Rating	Per Cent Z
112.5	4.0
150	4.5
225	5.0
300	5.0
500	5.0

Per cent resistance is approximately 1.0. Per cent X is approximately same as Z.

Table XXIX. Approximate Impedance Data for 3-Phase Power Transformers

Ratings above 500 Kva

Primary Kv Rating	Per Cent X
11–23	5.5
34.5	6.0
46	6.5
69	7.0

Per cent resistance is approximately 1.0. Per cent Z is approximately same as X.

Table XXXI. Approximate Impedance Data for Single-Phase 2-Conductor Concentric Cable

Size	Approximate Ampere Capacity	Resistance (85C)	Ohms per 100 Feet of Cable* Reactance	Impedance
1/0	155	0.0247	0.00138	0.0248
3/0	208	0.0158	0.00129	0.0159
4/0	246	0.0126	0.00125	0.0127
250	273	0.0107	0.00123	0.0108
350	336	0.0077	0.00118	0.0078
500	415	0.00548	0.00115	0.00558
750	522	0.00365	0.00111	0.00382
1,000	610	0.00278	0.00109	0.00299
1,500	773	0.00192	0.00106	0.00219

* Values include going and return path.

Table XXXIV. Impedance Data for Bus Bars and Tubing

Figure 30 gives reactance data for round conductors, and Figure 31 gives reactance data for rectangular conductors.

The foregoing tables show that the resistance is a major part of the impedance of many cables and busways. Hence the voltage drop for low-power factor loads is appreciably less than the product IZ. It is advisable to use a more precise expression for voltage drop, such as was presented by equation 2 in Section V.

For convenience in making estimates of voltage drop, calculations have been made for the following tables, using equation 2 of Section V.

Table XXXV. Voltage Drops for Two Single-Conductor Cables

Table XXXVI. Voltage Drops for Three Single-Conductor Cables

Table XXXVII. Voltage Drops for Concentric Cable

Table XXXVIII. Voltage Drops for Busways

Approximate drops for 3-conductor cables can be obtained from Table XXXVI.

Light Flicker

Allowable Drops

The voltage drops which can be accepted without objectionable flicker are dependent on various factors, the most important of which is the frequency at which they occur. Figure 26 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.

It may be noted that a drop of less than 0.5 per cent can be objectionable. If only fluorescent lamps or large-sized incandescent lamps are used, somewhat higher drops can be accepted than those shown on Figure 26. Additional discussion is given in Section V under "Allowable Voltage Flicker."

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 XXXIX shows calculated[3] frequencies for a number of cases. Figure 32 shows results obtained by using the information of Table XXXIX with the border line of irritation shown on Figure 26.

System Stiffness Required

The power system stiffness required to avoid excessive voltage drop can be measured in terms of the per-cent voltage drop caused by one welder. Figure 32 shows that if there are three welders each with a duty cycle of 5 per cent, each operating at 60 welds per minute, the drop due to one welder should not exceed 0.5 per cent. This assumes that the supply system is single phase, or that on a 3-phase system 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 3-phase system, the drops on any one line-to-line phase caused by welders on other phases are usually comparatively small.

Table XXXIX and Figure 32 include only cases with a fairly small number of welders at duty cycles of 20 per cent or less, and production rates of 60 welds per minute or less. For larger duty cycles or for a large number of welders, flicker does not increase greatly 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 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 often are 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 higher drop from

Table XXX. Approximate Impedance Data for Single-Conductor 600-Volt Cables

Size	Ampere Capacity	A-C Resistance	Ohms* per 100 Feet of Run Nonmagnetic Duct Reactance	Impedance	Magnetic Duct Reactance	Impedance
8**	40	0.073	0.0047	0.073	0.0059	0.073
4**	70	0.029	0.0042	0.030	0.0053	0.030
2	115	0.020	0.0039	0.020	0.0049	0.020
1	130	0.016	0.0041	0.016	0.0052	0.016
0	150	0.012	0.0041	0.013	0.0051	0.013
000	200	0.0080	0.0038	0.0089	0.0048	0.0093
0000	230	0.0064	0.0037	0.0074	0.0046	0.0067
250	255	0.0055	0.0037	0.0066	0.0046	0.0072
350	310	0.0040	0.0037	0.0054	0.0046	0.0061
500	380	0.0029	0.0035	0.0045	0.0043	0.0052
750	475	0.0021	0.0033	0.0039	0.0042	0.0047
1,000	545	0.0017	0.0033	0.0037	0.0042	0.0045
1,500	625	0.0014	0.0033	0.0035	0.0041	0.0044

* Ohms for each conductor. For single-phase loads, multiply by 2 to obtain total (going plus return) ohms.

** Type *R-60C*, other sizes type *RH-75C*.

each welder than one for which flicker must be considered. However, the voltage must not be permitted to fall too often below a value which will be adequate for good welds.

If the only load is a single welder, a large voltage drop can be accepted because the drop occurs with every weld, and adequate welding heat usually can 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 usually are designed to operate satisfactorily between 90 and 110 per cent of the rated voltage. Thus drops up to 20 per cent may be acceptable if a suitable selection of control transformer taps be used. Even greater drops have sometimes been permissible.

The total voltage drop at the terminals of a welder consists of four parts. These are:

1. Drop caused by the welder itself (sometimes called[16] self-drop).
2. Drop caused by other welders (sometimes called[16] cross drop).
3. Drop caused by nonwelding load in the user's plant.
4. Changes in the power company voltage.

The amount of total drop which is considered acceptable should be determined by the user. Also he should determine the maximum acceptable amount of drop from causes other than the welder itself, because this drop (the sum of the last

Table XXXII. Approximate Impedance Data for Wires Laced Together

Calculated Data Per 100 Feet of Distance from Source to Load (200 Feet of Circuit)

Wires Per Leg	Size, AWG or Circular Mils	Approximate Current-Carrying Capacity (60° C Copper) (30° C Ambient) Amperes	D-C Resistance 25° C, Ohms	Reactance, Ohms	Voltage Drop Per 1,000 Amperes; 30 Per Cent Power Factor	
					Volts	Per Cent at 480 Volts
1	4/0	210	0.01	0.0059	8.72	1.82
1	500,000	350	0.0043	0.0056	6.63	1.38
2	4/0	400	0.0051	0.0022	3.63	0.76
2	500,000	650	0.0022	0.002	2.54	0.53
3	4/0	500	0.0034	0.0014	2.36	0.49
4	4/0	600	0.0026	0.001	1.72	0.36
3	500,000	850	0.0014	0.0013	1.63	0.34
4	500,000	1,000	0.0011	0.00089	1.17	0.24
6	500,000	1,300	0.00072	0.0006	0.79	0.17

Table XXXIII. Typical Values of Busway Impedance Data

	Copper Square Inch per Phase	Ampere Rating	Ohms per 100 Feet of Bus		
			Resistance	Reactance	Impedance
Single-phase* low-impedance busways	0.5	500	0.0024	0.0025	0.0035
	0.75	750	0.0016	0.0012	0.0020
	1.0	1,000	0.0013	0.0010	0.0016
	1.5	1,500			
	2	2,000	0.00058	0.00052	0.0078
	3	3,000	0.00035	0.00029	0.0045
	4	4,000	0.00029	0.00023	0.0037
3-Phase** low-impedance busways	0.5	500	0.0023	0.0016 –0.0024	0.0028 –0.0033
	0.75	750	0.0016	0.0010 –0.0011	0.0019 –0.0020
	1.0	1,000	0.0012	0.0008 –0.00095	0.0014 –0.0015
	1.5	1,500	0.00081	0.0005 –0.0007	0.00095–0.0011
	2	2,000	0.00058	0.0004 –0.00055	0.0007 –0.0008
	3	3,000	0.00035–0.00040	0.00024–0.00037	0.00042–0.00054
	4	4,000	0.00027–0.00032	0.00019–0.00029	0.00032–0.00043
3-Phase** plug-in busways	1/16	225	0.0069	0.0054	0.0087
	3/8	400	0.0033	0.0048	0.0058
	1/2	600	0.0025	0.0048	0.0054
	3/4	800	0.0016	0.0034	0.0038
	1	1,000	0.0012	0.0032	0.0034

* Multiply ohms by 2 to obtain total (going plus return) values for single-phase busways.

** Average line-to-neutral ohmic values are listed.

Table XXXIV. Bus-Bar and Tubing Data

Calculated Data per 100 Feet of Distance from Source to Load (200 Feet of Circuit)

Bars Per Leg	Spacing	Size Inches	Approx. Current Carrying Capacity, 35° C Rise, (Amperes)		D-C Resistance, 25° C Ohms	Reactance, Ohms	Voltage Drop per 1,000 Amperes 30 Per Cent Power Factor	
			Open	Housing			Volts	Per Cent at 480 Volts
1	8″ centers	1/4×2	750	490	0.0033	0.0126	13.0	2.71
1	8″ centers	1/4×4	1,400	950	0.0017	0.0098	9.84	2.05
1	2 1/4″ centers	1/4×2	750	490	0.0033	0.0072	7.86	1.64
1	2 1/4″ centers	1/4×4	1,400	950	0.0017	0.0048	5.07	1.06
1	1″ centers	1/4×2	720	450	0.0033	0.0041	4.91	1.02
2	3″ centers interlaced	1/4×2	1,400	950	0.0017	0.0039	4.19	0.87
1	1″ centers	1/4×4	1,370	900	0.0017	0.0025	2.88	0.60
2	3″ centers interlaced	1/4×4	2,600	1,800	0.00084	0.0025	2.73	0.57
2	1″ centers interlaced	1/4×2	1,350	870	0.0017	0.0018	2.25	0.47
1	1/2″ centers	1/4×4	1,370	900	0.0017	0.0014	1.83	0.38
2	1″ centers interlaced	1/4×4	2,500	1,700	0.00084	0.0011	1.27	0.26
1	2″ standard tube around 1 1/4 extra heavy tube		800		0.0017	0.00078	1.25	0.26
1	1/2″ centers	1/4×8	2,600	1,800	0.00084	0.00076	0.98	0.20
3	1″ centers interlaced	1/4×4	3,500	2,400	0.00056	0.0007	0.83	0.17
1	4″ Standard Tube around 3″ extra heavy tube		2,000		0.00054	0.0005	0.64	0.13
1	1/2″ centers	1/4×12	3,600	2,500	0.00056	0.0005	0.64	0.13

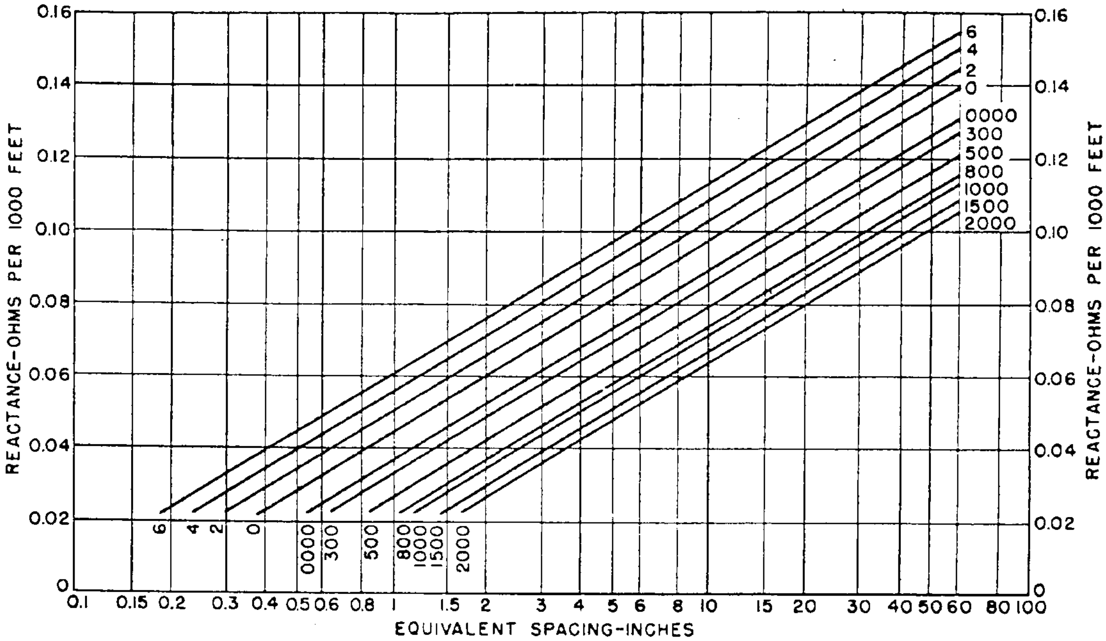

Figure 30. Reactance of round conductors. Frequency 60 cycles per second. Equivalent spacing is cube root of product of actual spacings. Conductor size shown on curves is American wire gauge number, or thousands of circular mils

three listed drops) determines the extent to which voltage can alter the heat to a weld. After estimates have been made of the last two drops, an allowance can be determined for drops due to other welders.

In practical applications,[4] 10 per cent has been found to be a typical allowance for drops due to other welders when welding low-carbon steel. Allowances of 5 per cent or less have been used, however, particularly when welding materials, such as aluminum, for which weld strength is relatively sensitive to changes in current.

An allowance of 10 per cent is not the same as ±10 per cent. The drop due to other welders is measured down from the voltage obtained when all these other welders are off.

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 seldom is used.

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.

It is, of course, 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 often can be made if excessive voltage drop is permitted with a very small percentage of the welds made.

Voltage Drop from Each Welder

Figure 33 shows[5] the maximum drop (for any one welder) which will not cause 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 per cent of the voltage obtained when no other welders operate. The voltage may dip below 90 per cent during a portion of the weld time, if it is sufficiently above 90 per cent during the remainder of the weld, so that the heating (rms value) for the entire weld is not inadequate.

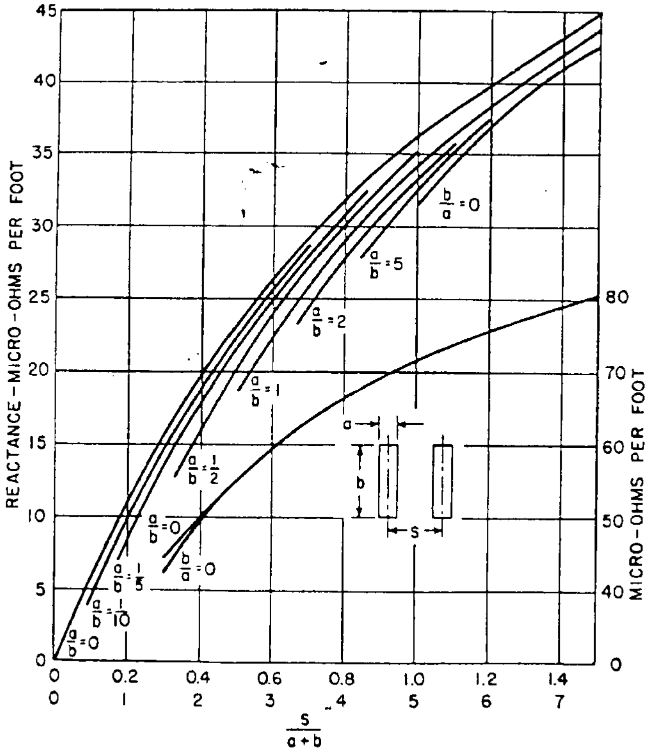

Figure 31. Reactance of rectangular conductors. Frequency, 60 cycles per second

Table XXXV. Approximate Voltage Drops for Two Single-Conductor Cables

		Voltage Drop, Line-to-Line, with Single-Phase Load at Rated Current for 100-Foot Run			
		2 Cables in Nonmagnetic Duct		2 Cables in Magnetic Duct	
Size	Ampere Capacity	30% Power Factor	50% Power Factor	30% Power Factor	50% Power Factor
8*	40	2.6	3.6	2.7	3.7
4*	70	2.0	2.7	2.2	2.9
2	115	2.5	3.3	2.7	3.4
1	130	2.5	3.1	2.7	3.3
0	150	2.5	3.1	2.7	3.3
000	200	2.5	3.0	2.9	3.3
0000	230	2.6	3.0	3.0	3.3
250	255	2.7	3.1	3.1	3.5
350	310	2.9	3.2	3.5	3.7
500	380	3.2	3.4	3.8	4.0
750	475	3.6	3.8	4.3	4.4
1,000	545	4.0	4.1	4.8	4.9
1,500	625	4.4	4.4	5.4	5.3

* Type *R-75C*, other sizes type *RH-60C*.

Table XXXVI. Approximate Voltage Drops for Three Single-Conductor* Cables

		Voltage Drop, Line-to-Line, with 3-Phase Load at Rated Current for 100-Foot Run			
		3 Cables in Nonmagnetic Duct		3 Cables in Magnetic Duct	
Size	Ampere Capacity	30% Power Factor	50% Power Factor	30% Power Factor	50% Power Factor
8**	40	2.3	3.2	2.3	3.0
4**	70	1.7	2.3	1.9	2.5
2	115	2.2	2.0	2.3	2.9
1	130	2.1	2.7	2.3	2.9
0	150	2.1	2.7	2.3	2.8
000	200	2.2	2.6	2.5	2.9
0000	230	2.3	2.6	2.6	2.9
250	255	2.3	2.7	2.7	3.0
350	310	2.5	2.8	3.0	3.2
500	380	2.8	2.9	3.3	3.4
750	475	3.1	3.3	3.7	3.8
1,000	545	3.5	3.5	4.2	4.2
1,500	625	3.8	3.8	4.6	4.6

*Three-conductor cable has about 20 per cent less reactance, but very little less voltage drop, because of the effect of resistance.

** Type *R75C*, other sizes type *RH-60C*.

Figure 33 assumes that it is acceptable for one weld in 1,000 to have inadequate voltage.

Consider, for example, five welders at 5-per-cent duty cycle, supplied from a single-phase system. From the right-hand vertical scale of Figure 33, the maximum drop for any welder is 5 per cent.

For purpose of comparison let us calculate the maximum drop which can not cause inadequate voltage even with all welders operating at once. The drop due to one welder occurs with every weld so that this much of the drop can be compensated by heat setting adjustment. The remaining portion of the maximum possible drop is caused by four welders. The sum of their drops should not be more than 10 per cent, if inadequate welding voltage is to be completely avoided. Hence the allowable drop per welder is 2.5 per cent. This is only half the drop which can be permitted with adequate voltage for all but one weld in 1,000.

If the allowable drop is less than 10 per cent for a good weld, the values of drop per welder taken from Figure 33 must be reduced accordingly. Welding conditions which permit an allowance of more than 10 per cent will permit a corresponding increase in drop per welder, but for large allowances the possibility of incorrect control operation as well as reduced welding heat should be considered.

NUMBER OF WELDERS

The maximum allowable drop per welder does not decrease rapidly as the number of machines is increased. This is illustrated by Figure 33.

DUTY CYCLE

The allowable drop for each welder decreases as duty cycle increases. This also is shown by Figure 33. Since it importantly affects system cost, 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.

When all weld times are alike and are three cycles or more, the allowable drop for each welder is given by the right-hand vertical scale of Figure 33. When all of the welders have 1-cycle weld times, or whenever weld times are not all alike, the allowable drop is reduced. The left-hand vertical scale of Figure 33 introduces a 20-per-cent 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 number of their welds than do the welders with the longer weld times.

PROPORTION OF WELDS WITH INADEQUATE VOLTAGE

With the values given by Figures 33, one weld in 1,000 will experience a voltage drop of more than 10 per cent, averaged over the entire weld time.

The proportion of welds spoiled is higher than the proportion of welds with inadequate voltage. Some spoilage is due to causes such as defects in material or enlargement of electrode diameter by repeated use.

If the actual drop per welder is decreased about 20 per cent below the values given in Figure 33, the proportion of welds with inadequate voltage decreases to 1/10,000 or less. If the drop per welder is increased, the proportion of welds with inadequate voltage is greatly increased.

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

Table XXXVII. Approximate Voltage Drops for Concentric Cable

		Voltage Drop, Line-to-Line, at Rated Amperes for 100-Foot Run	
Size	Approximate Ampere Capacity	30% Power Factor	50% Power Factor
0	155	1.8	2.4
000	208	1.6	2.1
0000	246	1.4	2.0
250	273	1.4	1.9
350	336	1.3	1.8
500	415	1.2	1.7
750	522	1.2	1.6
1,000	610	1.2	1.4
1,500	773	1.2	1.4

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. ($100\times1/10{,}000=1/100$).

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 reduced greatly. For example, if one weld in 1,000 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 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

Figure 33 is based upon the condition that all welders have the same voltage drop and the same duty cycle. The figure can be used, however, for groups of welders which are not all alike, by finding an equivalent voltage drop and an equivalent duty cycle.

For the case of a group of welders whose voltage drops are different but whose duty cycles can be assumed to be alike and less than about 10 per cent, the following expression can be used for the equivalent voltage drop.

$$V=\frac{(V_1^2+V_2^2+\ldots)}{(V_1+V_2+\ldots)}$$

where V_1, V_2, . . . are voltage drops of individual welders.

The corresponding equivalent duty cycle is

$$d=\frac{(V_1+V_2+\ldots)}{nV}d_1$$

where

d = equivalent duty cycle
V = equivalent voltage drop
n = number of other welders
d_1 = duty cycle of individual welders (all the same)

The number of other welders (n) is one less than the total number of welders. Each welder can be considered in turn, its own voltage drop being omitted from the calculations. However, a simpler procedure is to consider the effect of all of the actual welders on one future additional small welder which is assumed to have a negligibly small self-voltage drop. Then all of the actual voltage drops are included in one calculation, and n is the number of actual welders.

Table XXXVIII. Approximate Voltage Drops for Busways

	Ampere Rating	Voltage Drop, Line-to-Line, at Rated Current* for 100-Foot Run			
		3-Phase Load**		Single Phase Load†	
		30% Power Factor	50% Power Factor	30% Power Factor	50% Power Factor
Low reactance busways	800–4,000	1.7–2.7	2.0–3.0	2.2	2.4
Plug-in busways	225	3.2	3.2	3.0	2.4
	400	4.4	4.4	4.2	4.2
	600	6.0	6.0	5.4	5.4
	800	6.1	6.1	5.5	5.5
	1,000	6.4	6.4	5.6	5.6

* All load assumed to be at end of run. For uniformly distributed load divide volts drop in table by 2.

** For 3-phase low-reactance busways, voltage drop range is caused by differences in design of various (3) manufacturers; larger current rating does not necessarily mean the larger drops listed.

For 3-phase plug-in busways, voltage drop given is average for the three phases; individual phase values are approximately the following percentages of average drop (B is middle conductor): AB—75 per cent; BC—90 per cent; CA—135 per cent.

† For 1-phase loads low-reactance busway assumed to be of single-phase design; single-phase loads on 3-phase low-reactance busways will cause slightly higher drops.

For plug-in busway, single-phase loads assumed to be taken from two adjacent conductors of 3-phase busway; voltage drops may be higher for 1-phase plug-in busway, if 1-phase design obtained by omitted middle conductor of 3-phase busway.

Table XXXIX. Calculated Frequencies of Voltage Drops Which May Cause Light Flicker

Number of Welders	Welds per Minute per Machine	Per Cent Duty Cycle	Weld Time, Cycles	Average Frequency			
				1 Machine Only	2 Machines Together	3 Machines Together	4 Machines Together
2	6	1	6	12/min.	7.2/hr.		
		5	30	12/min.	36/hr.		
		10	60	12/min.	1.2/min.		
		20	120	12/min.	2.4/min.		
	20	5	9	40/min.	2/min.		
		10	18	40/min.	4/min.		
		20	36	40/min.	8/min.		
	60	5	3	2.0/sec.	6/min.		
		10	6	2.0/sec.	12/min.		
		20	12	2.0/sec.	24/min.		
4	6	1	6	24/min.	43/hr.	10.1/day	1.0/mo.
		5	30	24/min.	3.42/min.	10.8/hr.	4.3/day
		10	60	23.3/min.	6.46/min.	39.5/hr.	1.44/hr.
		20	120	21.6/min.	11.5/min.	2.52/min.	11.5/hr.
	20	5	9	1.32/sec.	11.3/min.	35/hr.	14.4/day
		10	18	1.30/sec.	21.6/min.	2.24/min.	4.7/hr.
		20	36	1.19/sec.	38.4/min.	8.33/min.	38.6/hr.
	60	5	3	3.96/sec.	34.0/min.	1.74/min.	1.8/hr.
		10	6	3.89/sec.	1.08/sec.	6.71/min.	14.4/hr.
		20	12	3.58/sec.	1.92/sec.	25/min.	1.92/min.
8	6	1	6	47.8/min.	3.26/min.	5.81/hr.	2.3/day
		5	30	45.5/min.	14.4/min.	2.1/min.	10.8/hr.
		10	60	41.7/min.	24/min.	7.09/min.	1.2/min.
		20	120	27.6/min.	31.8/min.	18.8/min.	6.85/min.
	20	5	9	2.54/sec.	47.6/min.	7.02/min.	36/hr.
		10	18	2.27/sec.	1.32/sec.	23.6/min.	4.08/min.
		20	36	1.54/sec.	1.77/sec.	1.04/sec.	22.7/min.
	60	5	3	7.63/sec.	2.38/sec.	21.1/min.	1.80/min.
		10	6	6.80/sec.	3.96/sec.	1.18/sec.	12.2/min.
		20	12	4.61/sec.	5.30/sec.	3.13/sec.	1.14/sec.

When a cross-voltage drop of 10 per cent is permissible, the proportion of welds with inadequate voltage will be 1/1,000 or less if the following two conditions are met:

1. No individual welder has a voltage drop of more than 10 per cent.
2. The equivalent voltage drop does not exceed the drop per welder shown on Figure 33 at the equivalent duty cycle.

When the number of other welders (n) is taken to be the number of actual welders, use should be made of that curve on Figure 33 which corresponds to ($n+1$) welders.

As an example, consider the following three welders, having different demands and weld times, but the same duty cycle.

V_1 = 10 per cent
V_2 = 8 per cent
V_3 = 5 per cent
d_1 = 10 per cent
d_2 = 10 per cent
d_3 = 10 per cent

By inspection, we can see that condition 1 has been met because no individual voltage drop exceeds 10 per cent. The equivalent voltage drop is

$$V=\frac{(V_1^2+V_2^2+V_3^2)}{(V_1+V_2+V_3)}=\frac{100+64+25}{10+8+5}=\frac{189}{23}$$
$$=8.2 \text{ per cent}$$

The equivalent duty cycle is

$$d = \frac{V_1+V_2+V_3}{nV} = \frac{(23)}{(3)(8.2)}(10) = 9.4 \text{ per cent}$$

Since $(n+1)$ is four we use the curve on Figure 33 which corresponds to four welders. On this curve at a duty cycle of 9.4 per cent, the allowable voltage drop per welder is 4.1 per cent on the left-hand scale, which applies to the assumed condition of unequal weld times. This is only half the equivalent voltage drop of 8.2 per cent. To meet requirement 2, the system impedance or the welder demands must be reduced until the equivalent voltage drop no longer exceeds the allowable value. If all drops are reduced to one-half their former values, the equivalent voltage drop will become 4.1 per cent, as is acceptable.

When the welder duty cycles exceed 10 per cent, or when they are not all alike; a more complicated expression for equivalent voltage drop should be used. The following equation is applicable for duty cycles up to 50 per cent.

$$V = \frac{(V_1^2d_1+V_2^2d_2+\ldots) - \left(\frac{3}{2}\right)\left[(V_1^2d_1^2+V_2^2d_2^2+\ldots) - \left(\frac{1}{n}\right)(V_1d_1+V_2d_2+\ldots)^2\right]}{(V_1d_1+V_2d_2+\ldots)}$$

where d_1, d_2, . . . are the individual duty cycles, expressed as decimal numbers (such as 0.5).

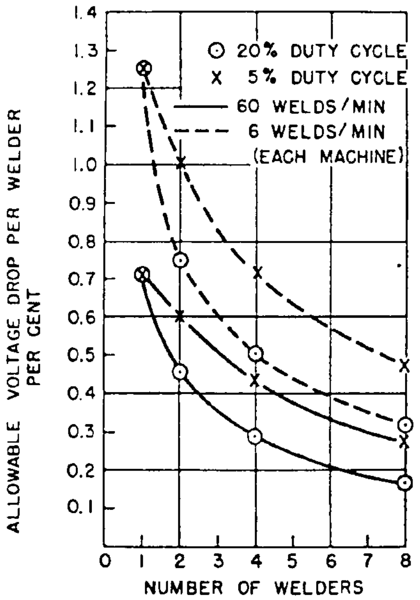

Figure 32. Allowable voltage drop per welder to avoid light flicker

All welders alike. Based on lower curve of Figure 26

The corresponding equivalent duty cycle is

$$d = \frac{(V_1d_1+V_2d_2+\ldots)}{nV}$$

NUMBER OF PHASES

Figure 33 corresponds to a single-phase system or to one line-to-line phase of a 3-phase system. If welders are distributed on three line-to-line phases, the permissible drop for each welder is usually more than shown by Figure 33.

If there are only two or three welders, each connected line-to-line on a different phase, a quite large drop can be permitted. This is true because a welder on one phase causes only one-fourth to one-half as much drop on other line-to-line phases, as on its own phase. Consequently, if two or three similar welders are connected to different phases of a 3-phase substation, there will be less interference than if the same welders are supplied by a single-phase substation of the same total kva and per-cent impedance. If there are four or more welders distributed among three phases, at least two will be on one phase.

Any one phase can be considered separately 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.

When a group of four or more similar welders are distributed on a 3-phase system, the required transformer kva to avoid interference is commonly about 125 per cent of the transformer kva required of a single-phase system, for the same welders.

Equivalent Continuous Load

From the standpoint of thermal capacity of distribution equipment, an equivalent continuous load can 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

It is convenient to note that the maximum safe equivalent continuous current for a welder is 70.7 per cent of the nameplate rating. 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-per-cent duty cycle. The equivalent continuous load for this machine is 200 times the square root of 0.25 or 200 ×0.5 = 100 kva. Figure 34 shows values of equivalent continuous current for various demands and duty cycles.

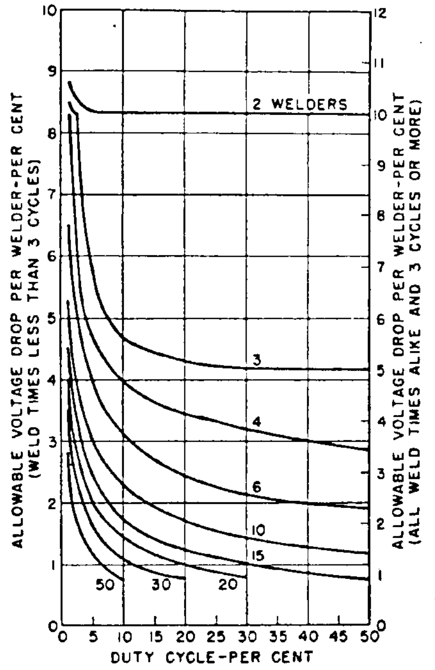

Figure 33. Allowable voltage drop per welder to avoid objectionable interference between welders

All welders demands and duty cycles alike. Voltage considered inadequate if rms valve during a weld is less than 90 per cent of value obtained when no other welders operate. One weld in 1,000 permitted to have inadequate voltage. Numbers on curves are total number of welders. Right-hand vertical scale can be used if all weld times are alike and are 3 cycles or more. For other cases, use left-hand vertical scale

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 values, multiplying these by their respective times of occurrences, adding the products, dividing by the total time, and taking the square root.

GROUPS OF WELDERS

For approximate calculations, a common procedure is to use the equivalent current of the largest welder load plus 60 per cent of the sum of the equivalent currents of the remaining welders. A precise method of determining equivalent continuous total load is presented in reference 6.

IDENTICAL WELDERS

When all welders are alike, curves[6] may be drawn, as shown on Figure 35, 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 approximate the actual equivalent load for the combination.

Capacitor Applications

There are several types of applications[7] 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

Such capacitors are selected to improve plant power factor rather than the power factor of any particular welder; see Figure 36. They tend to raise the system voltage slightly, but do not affect voltage drops because the voltage is increased as much at no-load as at other times.

SHUNT CAPACITORS SWITCHED WITH A WELDER

Technical and economic considerations have prevented any general use of shunt capacitors switched at the same time as a welder; see Figure 37.

SERIES CAPACITORS SWITCHED WITH A WELDER

Series capacitors selected to be switched by the same control used for the welder are a means of reducing the drop caused by the machine; see Figure 38. Since the selection of capacitors, control, welding transformer, and associated electric equipment should be co-ordinated closely with the welder design, recommendations 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 has been discussed in Section IV.

SERIES CAPACITORS CONTINUOUSLY CONNECTED

Series capacitors can be connected in a power supply circuit for a plant to reduce voltage drops. Such capacitors decrease the impedance 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 otherwise would 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.

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 can be selected to compensate for the reactance of the primary circuit so as to eliminate flicker of lights connected to other substations on the same circuit, as shown by Figure 39. 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 Figure 39 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 Figure 40. This equipment also can 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.

Distribution Systems

VOLTAGE

The most economical voltage[8] for supplying welders is usually 480 volts. Use of 277/480Y substations is advan-

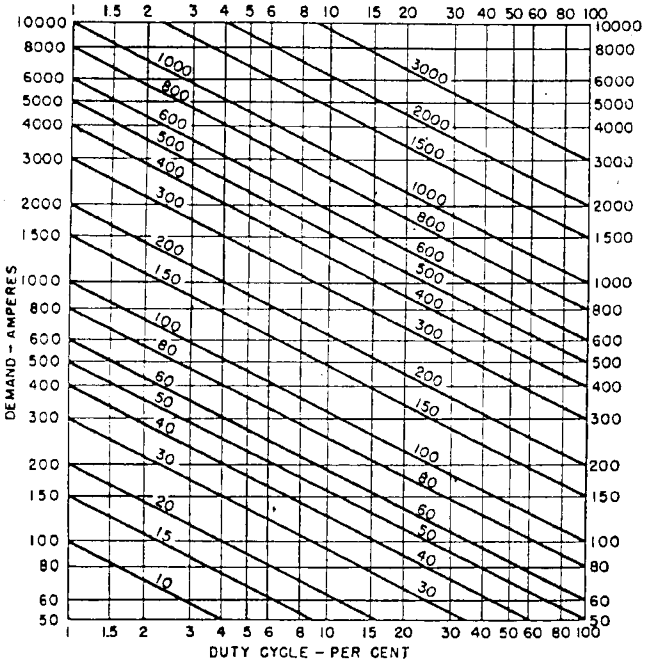

Figure 34. Equivalent continuous current to a resistance welder

Numbers on curves are amperes equivalent current

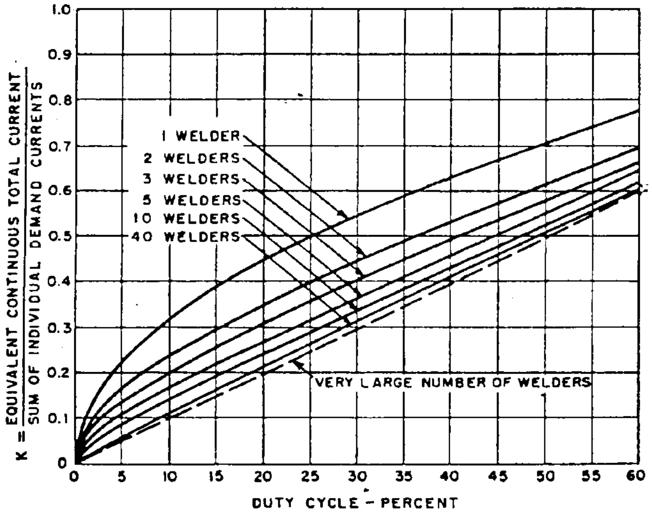

Figure 35. Equivalent continuous total current for a group of resistance welders

All welders alike. Single-phase welders supplied from a single-phase system

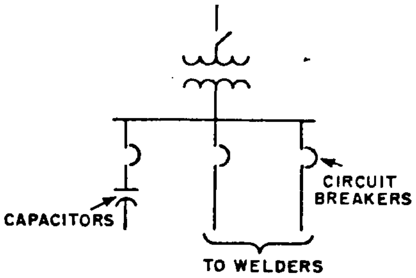

Figure 36 Shunt capacitors continuously connected

tageous since they permit neutral grounding. Exceptionally large welders sometimes may be advantageously supplied at 2,400 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[8] 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 Figures 41 through 43.

The simplest system is the radial type, Figure 41. Such systems commonly supply welding, lighting, and power when welding loads are not so large as to cause objectionable flicker.

The secondary selective system, Figure 42, not only provides added reliability but permits segregation of lighting and welding loads except when the tie circuit 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 then would have to be accepted under emergency conditions, which require closing of the tie circuit breaker.

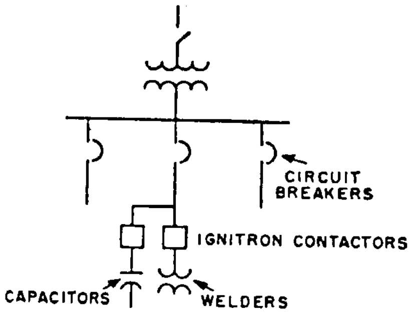

Figure 37. Shunt capacitors switched with a welder

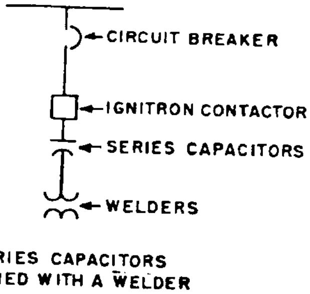

Figure 38. Series capacitors switched with a welder

A network system, Figure 43, 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.

It is sometimes advisable to supply a single large welder from a different substation than other smaller welders to reduce the effect of the voltage drop of the large machine. A welder doing especially sensitive work may warrant a separate substation to protect it from drops due to other machines.

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.

It is usually economical to supply lights from the same substation as other industrial loads except large 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 3-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 3-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 nonwelding load from a single-phase transformer so the entire cost of this transformer is chargeable to the welding load. A 3-phase transformation, on the other hand, often offers economies because its full thermal capacity can be utilized by combining welding and other loads. Furthermore, 3-phase substations are more salvageable when the power system changes are made. In addition, 3-phase substations can supply 3-phase welders. Consequently, 3-phase substations are usually preferable.

The feeder circuits supplied by a 3-phase substation may be either 3-phase or single-phase, whichever is the more economical.

Transformer Impedance

For any given load demand, the voltage drop at the substation bus is determined by the impedance of the transformers plus the impedance of the primary supply system. Usually, the transformer impedance is by far the larger of these impedances. The transformer impedance is proportional to its per cent impedance and inversely proportional to its kva rating. The impedance can be lowered by lowering the per cent impedance by special design. Also, the impedance can be lowered by increasing the kva rating, since the per cent impedance for standard designs tends to remain about the same. A transformer with special low impedance entails a somewhat lower initial cost than a transformer of standard design

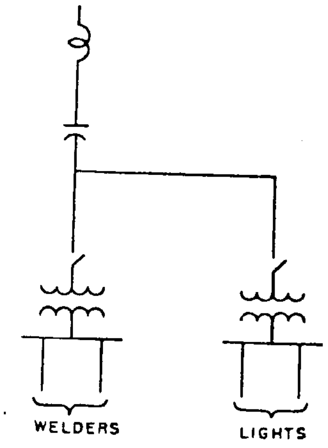

Figure 39. Compensation of primary circuit reactance by series capacitors

having sufficiently larger kva rating to result in the same impedance as that of the special transformer. However, disadvantages of using special low-impedance designs usually make standard designs preferable in spite of their slightly higher initial cost. Among these disadvantages is the lower continuous load capacity of the special designs and the fact that they cannot be paralleled with transformers of standard design. These factors can be important when changes in plant layout are considered. In addition, the bracing of windings of low-impedance transformers is inadequate for the maximum short-circuit currents which can be encountered in many cases.

The American Standards Association (ASA) Standards for transformers[9] specify that transformers with impedance of 4 per cent or more shall be capable of withstanding a short circuit at the secondary terminals with full voltage maintained at the primary. Transformers with lower per cent impedance are required to withstand only 25 times normal current, because of the difficulty of bracing windings for higher currents. It is preferable to apply such transformers only at locations having sufficient primary power supply impedance so that the total impedance of transformer and supply will not be less than 4 per cent.

Standard transformers larger than 150 kva usually have impedances of more than 4 per cent. Some smaller standard transformers, with lower impedances, have been connected to high-capacity supply systems. However, the hazard to windings with much less than 4 per cent impedance is a significant one, because the stresses caused by short-circuit currents are proportional to the square of the currents, and thus increase very greatly as current is permitted to increase.

All transformers have adequate bracing for the currents encountered in normal welding operations.

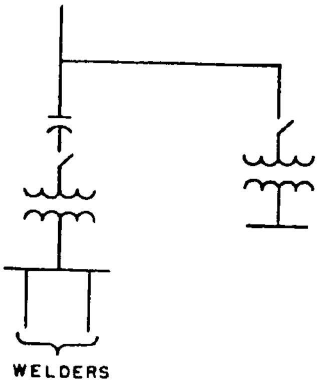

Figure 40. Compensation of substation reactance by series capacitors

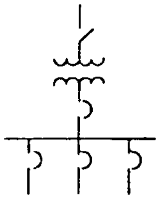

Figure 41. Radial distribution system

Substation Size

When the total plant load, including welding and lights, can be supplied by a substation of about 750 kva or less, a single radial substation is usually satisfactory. For larger total load it is nearly always most economical to employ several substations, the optimum size being about 500 to 1,500 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 run 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 low-voltage switchgear. Use of series capacitors at substation primaries is advantageous for installations which would otherwise require such large substations.

Feeder Circuits

Welders always should be located as near to the substation as is practicable in order to minimize voltage drops and to avoid undue expense for low-impedance feeders.

Feeder circuits usually employ cable or busway, or a combination of cable and busway. Figure 44 illustrates a typical combination. Busways are placed at convenient locations throughout the load area. Cables are used to connect individual machines to them. Cables or busways can be used to bring power from the substation to the bus runs from which loads are supplied.

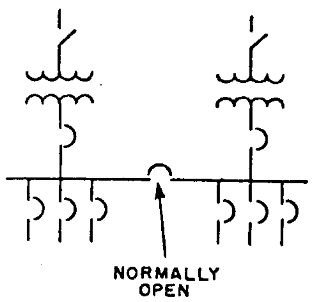

Figure 42. Secondary-selective distribution system

Calculation of voltage drop in feeder circuits has been discussed in this section under "Voltage Drop."

Busways

A busway has the advantage of being very adaptable to changes in machine locations. Many include plug-in devices for ease in making connections. For larger ampere ratings, low-impedance designs are often used.

For supplying a group of welders with no other load, low-impedance busway is usually preferable to plug-in busway. The plug-in type is satisfactory for combined motor and welder loads, especially when the current drawn by the largest welder is small compared to the total load. Where the load in a factory or department consists of motor load with several small welders, and one or two large welders, it may prove to be economical to use plug-in busways for all loads except the large welders. These could be supplied by a run of single-phase low-impedance busway or by concentric cables.

Some years ago it was often advisable for plant engineers to design special low-impedance busways for supplying welders. This is no longer necessary because standard low-impedance busways are now

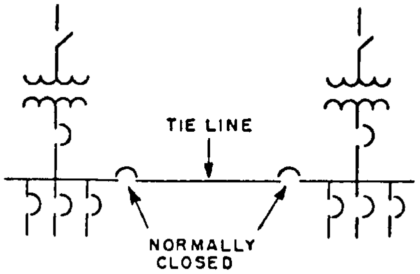

Figure 43. Network distribution system

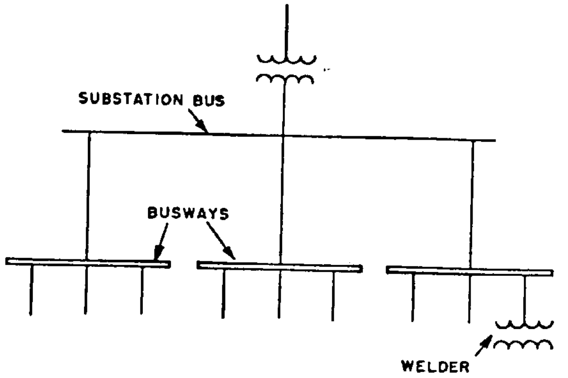

Figure 44. Typical welder power distribution system

available from several manufacturers. Proper design of a busway is more complicated than the simplicity of its geometric configuration would suggest, because such factors as current-carrying capacity, voltage drop, and ability to carry short-circuit currents must all be considered. When selecting a busway, manufacturers' information regarding these factors should be consulted.

CABLES

For individual welders, concentric cable is used widely. Two single-conductor cables in conduit can be used, but will have a higher voltage drop for a given length of run.

For indoor locations armored 2-conductor or 3-conductor cables should be considered, because they have lower installed costs than comparable cables in conduit.

When the current delivered is large, it is often more economical[10] to employ several moderate-sized cables (such as 250,000 circular mils) in parallel rather than one or more larger cables.

A short circuit in a cable or the circuits it supplies can cause a very high overload for the cable during the time the fault is being interrupted. The cable should be of sufficient size to prevent excessive temperature rise in the cable during this time. Table XL shows minimum[8,11] cable sizes corresponding to various values of short-circuit current.

CURRENT-CARRYING CAPACITY

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

1. The current-carrying capacity is not less than equivalent continuous load current. It should be noted that the maximum safe equivalent continuous load kva of a welder is 70.7 per cent of the welder rating. See section entitled "Equivalent Continuous Load."

2. Voltage drops will not be excessive (they usually will not be for moderate run lengths, but voltage drop should be checked).

3. Stresses and temperature rises during interruption of fault currents will not be dangerous.

The National Electrical Code imposes[17] the following additional limitations (paraphrased from 1951 Code, Sections 6331 and 6332):

1. The circuit current-carrying capacity should not be less than the sum of the equivalent continuous current of the largest welder plus 60 per cent of the equivalent continuous currents of all other welders.

2. The circuit current-carrying capacity should not be less than one-third the pickup current of the overcurrent protective device used for the circuit.

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 required for a given total number of welders is reduced. 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.

It is suggested that for a first trial layout 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. Often, however, a larger number of smaller feeders will require less total conductor cost by avoiding long lengths of large conductors.

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. See "Calculation of Feeder Voltage Drop" and "Feeder Impedance Data" earlier in this section.

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 circuit-breaker tripping or fuse blowing by welding load currents.

INTERRUPTING CAPACITY

Adequate interrupting capacity is essential. A calculation[12] of short-circuit current should be made at each location for a protective device, and its interrupting capacity should be at least as great as the short-circuit current.

The same impedances used to calculate voltage drops usually are used to calculate short-circuit current. To obtain this current, divide the system line-to-neutral volts by the total impedance per line in ohms.

The total impedance includes that of the primary power supply system, the substation transformers, and any feeder cable or busway between the substation and the location of the protective device. When motors are operated from the substation, contribution from them should be added to the short-circuit current. A typical value is 500 per cent of their total rated current.

The total short-circuit current obtained in the manner just described should be multiplied by 1.25 to account for the effect of offset current waves, before selecting interrupting capacities of air circuit breakers.

Tables XLI and XLII show calculated short-circuit currents for single-phase and 3-phase substations.

When system impedance can vary with operating conditions, the lowest value should be used for calculating short-circuit current, and the highest value of impedance used for calculating voltage drop.

Savings in cost of low-voltage circuit breakers often can be made by employing cascade operation in which a backup cir-

Table XL. Minimum Cable Sizes

Short-Circuit Current*	Minimum Conductor** Size, AWG or Circular Mils
5,000	8
10,000	4
15,000	2
25,000	1
35,000	1/0
50,000	3/0
75,000	300,000
100,000	500,000

* This is 125 per cent of the symmetrical short-circuit current.

** Instantaneous trip device is assumed to operate.

Table XLI. Available Short-Circuit Current from Single-Phase Substations

Secondary Rating 480 Volts, Single-Phase*

	Substation Kva Rating											
	25	37.5	50	75	100	167	250	333	500	667	833	1,000
	Normal Current, Amperes at 480 Volts											
Available Primary 3-Phase Short-Circuit Kva	52	78	104	156	208	347	521	694	1,042	1,388	1,736	2,083
	Total Low-Voltage Short-Circuit Current, Thousands of Amperes											
25,000	2.0	3.0	3.4	4.5	5.2	7.2	9.2	11.1	14.3	16.0	17.8	19.3
50,000	2.1	3.1	3.6	4.9	5.6	8.1	10.7	13.4	18.3	21.4	24.6	27.5
100,000	2.1	3.3	3.7	5.0	5.9	8.6	11.6	15.0	21.4	25.5	30.2	34.7
150,000	2.2	3.3	3.8	5.1	6.0	8.8	12.0	15.7	22.6	27.3	32.8	38.1
250,000	2.2	3.3	3.8	5.2	6.1	9.0	12.3	15.9	23.7	28.8	35.2	41.3
500,000	2.2	3.3	3.8	5.2	6.1	9.2	12.5	16.5	24.6	30.1	37.2	44.0
Unlimited	2.2	3.4	3.9	5.3	6.2	9.3	12.8	17.0	25.6	31.7	39.5	47.3
Transformer impedance per cent	3.0	2.9	3.3	3.7	4.2	4.7	5.1	5.1	5.1	5.5	5.5	5.5

* For other secondary voltage ratings, multiply tabulated currents by ratio (480/new voltage).
Substation connected line-to-line to 3-phase supply.
Motor load assumed to be absent.

cuit breaker is used with a group of feeder circuit breakers. A heavy feeder fault trips the backup circuit breaker and the feeder circuit breaker, thus permitting the use of smaller interrupting capacities on the load side of the backup circuit breakers. Some types of low-voltage circuit breakers however, will not operate successfully in cascade.

Circuit breakers have a-c interrupting ratings established by tests made in accordance with standards recognized by AIEE and ASA. Similar standards have not yet been adopted for fuses. At present the only standards in use are the requirements of Underwriters' Laboratories, based on tests at 10,000 amperes direct current.

Overload Protection

Protective devices should provide overload protection as well as short-circuit protection. The overload-protective device used for a welder feeder should protect (1) the welding machine, (2) the feeder between the device and the machine, and (3) the electronic or magnetic contactor controlling the welding machine. When an electronic contactor is used it is usually the circuit element most susceptible to damage by overload, because of its relatively short thermal-time constant.

Fuse Selection

Fuse characteristics vary so widely from manufacturer to manufacturer and type to type that, at this time, it is impossible to make specific recommendations on the selection of fuse sizes for a particular welding system. A welding machine manufacturer or large user of welding machines should develop for his own use detailed sets of application curves or tables based on the types of fuses he expects to use. For this purpose, curves of blowing time versus overload current should be obtained from the fuse manufacturer. It must be remembered when using such curves that the current values given are currents to blow the fuse and that in application these values must be lowered to include a factor of safety.

The fuse continuous current rating can be set equal to the equivalent continuous current of the welding load. This equivalent current can be taken to be 70.7 per cent of the current corresponding to the welder rated kva.

For some fuses with relatively short melting times, somewhat larger fuse ratings must be selected to avoid unnecessary fuse blowing. An empirical method for fuse selection in such cases is proposed by reference 13.

Selection of Circuit Breakers

The steps to select the proper circuit breaker for a welder are as follows:

1. Obtain or calculate the short-circuit (fault) current of the power supply source for a fault at the point of application of the circuit breaker. From Table XLIII select the smallest circuit breaker having an interrupting rating at least as great as the fault current.

2. Determine the equivalent continuous current of the welder load from Figure 34 using the expected welding current and operating duty cycle. From Table XLIII select the smallest circuit breaker having a continuous rating at least equal to this equivalent load.

3. Select the largest of the circuit-breaker ratings obtained by steps 1 and 2 and employ a circuit breaker having an instantaneous trip with a calibration range which will permit a setting somewhat above the maximum rms demand current of the welder. Manufacturers offer special trip ranges for this purpose. A calibration setting of 150 per cent of the maximum rms current will provide proper protection without false operation for the majority of cases.

When nonsynchronous welder control is used, transients which occur at the beginning of some welds cause the maximum peak current to be as much as 300 per cent of the value with synchronous control. This should be considered when

Table XLII. Available Short-Circuit Current from 3-Phase Substations

Secondary Rating: 480 Volts, 3-Phase*

	Substation Kva Rating							
	150	225	300	500	750	1000	1500	2000
	Normal Current, Amperes							
Available Primary 3-phase Short-circuit Kva	181	270	361	601	902	1203	1804	2406
	Total Low-Voltage Short-Circuit Current, Thousands of Amperes							
50,000	5.6	7.6	9.9	15.5	20.6	26.1	35.6	43.7
100,000	5.8	7.8	10.3	16.7	22.5	29.2	41.3	51.4
150,000	5.8	7.9	10.5	17.1	23.3	30.4	43.8	56.1
250,000	5.9	8.0	10.6	17.5	24.0	31.5	46.0	58.8
500,000	5.9	8.1	10.7	17.8	24.5	32.4	47.9	62.7
Unlimited	5.9	8.1	10.8	18.1	25.0	33.4	50.1	66.7
Transformer impedance per cent	4.5	5.0	5.0	5.0	5.5	5.5	5.5	5.5

* For different voltage base, multiply short-circuit current values in table by the ratio (480/new voltage)
Motor load assumed to be absent.

Table XLIII. Ratings of Standard* Air Circuit Breakers—600 Volts—(Magnetic Type)

Interrupting Rating Amperes Rms	Normal Current Rating Amperes Rms
15,000	15, 20, 25, 35, 50, 70, 90, 100, 125, 175, 200, 225
25,000	35, 50, 70, 90, 100, 125, 150, 175, 200, 225, 250, 300, 350, 400, 500, 600
50,000	100, 125, 150, 175, 200, 225, 250, 300, 350, 400, 500, 600, 800, 1,000, 1,200, 1,600
75,000	2,000, 2,500, 3,000
100,000	4,000, 5,000, 6,000, 8,000, 10,000

*From reference 18.

calculating the maximum rms current for circuit breaker trip selection. (These transients are usually neglected in making calculations of demand for determination of voltage drops and equivalent continuous currents.)

The maximum rms current for trip selection should be based on the condition with the welder electrodes together (short-circuited).

Two-pole and 3-pole circuit breakers are available for welding applications as required for 1-phase or 3-phase welders or circuits.

When a circuit breaker is used for a circuit supplying more than one welder, the instantaneous tripping device should be set above the maximum possible total current.

Some time delay tripping devices used with circuit breakers are not suitable for the frequent picking up which occurs, without tripping, when short-time welding loads repeatedly exceed the pickup current of the device, tending to cause excessive wear of the mechanical parts of the device.

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 determined largely by a few large welders, it may be economical to use special means to reduce the demands of these machines. Methods for doing this are described in Section IV. In the case of large 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.

It is seldom advisable to employ special demand-reducing means to a large number of welders in a group. Installation of a power supply adequate for use with conventional machines for all or most of the welders is usually more economical.

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

Summary of System Design

Design of a distribution system for supplying welders is basically a process of comparing trial designs to discover which will meet the requirements with the greatest over-all economy.

The procedure is essentially the same for studying an existing system as for planning a new one. When an existing system is to be considered, it merely becomes the first trial design, and if it meets the requirements no further trials are necessary.

REQUIREMENTS

The principal requirements have been described already in this report. They can be summarized as follows:

1. Reliability requirements, which determine the necessary number of sources of power, and affect the type of system selected; that is, whether radial, secondary-selective, or a network.
2. Voltage drop limitations:
   a. For lights.
   b. For welders:
      i. To prevent the drop caused by any welder from too greatly reducing its own maximum output, or from affecting operation of its own control.
      ii. To avoid excessive interference between welders.
   c. For other loads.
3. Current-carrying requirements.
4. Circuit protection requirements.
5. Special requirements, such as for load balance, or plant power factor, or imposed by local codes.

These requirements are often considered in the order listed. The limitations on voltage drop are usually the most important factors determining system design.

Ample provision should always be made for future increases in load.

PORTIONS OF SYSTEM

A suggested approach is to study separately the requirements of portions of the system.

1. Primary supply
2. Substations
3. Feeders

PRIMARY SUPPLY

The requirements for the primary supply will be established by the power company. For any given primary arrangement, and welding load, the primary voltage drop is a fixed amount. This must be subtracted from the allowable total drop to determine the permissible drop for the remainder of the system.

SUBSTATIONS

If lights are supplied from the secondary of the substation, the substation size ordinarily will be determined by the limitation they impose upon voltage drop at the secondary bus. If lights are not connected to the substation, the voltage drop limitations for proper operation of the welders usually will be most important. The voltage drop at a welder is affected by the drop in its feeder, of course, and the amount of drop which can be permitted at the substation depends on the amount permitted to occur in the feeder. The proportion to be taken by each is determined by costs.

TRIAL ALLOCATION OF VOLTAGE DROPS

A satisfactory procedure is to allocate by trial a certain portion of the total drop to feeders, and to design a feeder system which will maintain voltage within the allocated limits; then a substation can be selected which will prevent total drop from becoming excessive. The total cost of substation and feeders then can be found for that trial allocation of voltage drop. A second trial can be made using a different allocation of drop between substation and feeders. A few trials will show the proper allocation for minimum system cost. Each trial design must be checked to be sure that it meets all system requirements as well as voltage drop limitations.

For most cases, the best allocation will be one for which the majority of the drop occurs in the substation. When feeder lengths are kept short, by locating all welders close to the substation, the size of feeders often is determined by current-carrying requirements instead of by voltage drop limitations. A good first trial allocation of voltage drop to a feeder is the drop which will occur when the feeder has just sufficient current-carrying capacity for its load.

Example of System Design

As an illustration of the suggested procedures, we shall show steps in design of a system for supplying a single large welder. We shall assume that:

1. No other load is to be supplied by the welder substation.
2. The maximum no-load secondary voltage will be 480 volts, called 100-per-cent voltage.
3. The welder is rated 440 volts and has adequate output at 85 per cent of 480 volts (93 per cent of 440 volts).
4. At 85-per-cent voltage, the welder will draw 1,000 amperes at 30-per-cent power factor.
5. The duty cycle is 5 per cent.
6. The substation is to be located 85 circuit feet from the welder.
7. The primary supply system can accept the load.
8. The drop in the primary supply is 1 per cent.
9. The primary no-load voltage can vary between 100 and 95 per cent of 4,160 volts due to causes other than welding.
10. The primary system has 100,000 3-phase short-circuit kva.

Since the possible primary system voltage change is 6 per cent, and the maximum allowable drop at the welder is 15 per cent, the sum of the drops in the substation and feeder cannot exceed 9 per cent.

A trial allocation of voltage drop in the feeder will be made, based on a selection which just provides adequate current-carrying capacity.

The equivalent continuous current to the welder, taken from Figure 34 is 224 amperes. (This is 1,000 times the square root of the duty cycle.)

A concentric cable size 4/0 will carry a total of 246 amperes, which is sufficient. (See Table XXXVII).

From Table XXXVII the voltage drop at the rating of 246 amperes at 30-per-cent power factor for one 4/0 concentric cable 100 feet long is 1.4 volts. For a current of 1,000 amperes and a cable length of 85 feet, the voltage drop is

$$(1.4)\frac{(85)}{(100)}\frac{(1{,}000)}{(246)} = 4.84 \text{ volts}$$

This is therefore 1.0 per cent of 480 volts.

Allowing this 1-per-cent drop for the feeder leaves 8-per-cent allowable drop for the substation. The load current of 1,000 amperes corresponds to 480 kva at 480 volts single-phase. Since the impedance of a standard transformer will be less than 9 per cent, a transformer rated less than 480 kva can be used. Table XXVI shows that a 333-kva single-phase transformer can be expected to have an impedance of 5.1 per cent.

The voltage drop at 1,000 amperes is approximately

$$\frac{(480)}{(333)}(5.1) = 7.3 \text{ per cent}$$

Since the next smaller transformer size (250 kva) will cause a drop of 9.7 per cent (too high), the 333-kva rating is selected. Its rated current is 694 amperes which is ample for the equivalent continuous load of 224 amperes.

The short circuit at the secondary of the substation now can be found. From table XLI it is 15,000 amperes for a 333-kva transformer connected line-to-line to a primary system having 100,000 short-circuit kva.

From Table XLIII a low-voltage circuit breaker can be selected with an interrupting capacity of 15,000 amperes, and a continuous current rating of 225 amperes. This rating is sufficient for the expected short-circuit current and for the equivalent continuous load current of 224 amperes.

The first trial design of the system is now complete, and an estimate can be made of the installed cost and of the cost of power. These costs should be compared with the corresponding costs of any other trial designs considered.

In many cases, the second trial design will be based on selection of an oversized secondary feeder, which has a lower voltage drop than the first trial selection (which was based on current-carrying capacity). A lower feeder drop permits a higher substation drop and may make it possible to use a smaller transformer. The oversized feeder will be justified if its extra cost is exceeded by savings in the substation.

Savings will be made in transformer cost and may be made in switchgear cost, if the smaller substation permits use of circuit breakers of lower interrupting capacity.

For the example considered, the next smaller size of transformer is 250 kva for which the voltage drop was calculated to be 9.7 per cent. This is excessive for this case, even without any drop in the feeder; therefore, the first allocation of voltage drop can be considered to be satisfactory.

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Section VII

TYPICAL WELDING POWER INSTALLATIONS

The preceding sections of this report detail the underlying principles of design of a welding supply system. They must of necessity be studied thoroughly before the actual design of the system is undertaken.

As a means of supplementary information, which can be used as a further guide to design, this section describes a number of actual installations in satisfactory operation. Broadly speaking, all of these installations illustrate the application of basic design principles.

To emphasize these basic principles, a brief résumé follows.

Basic Design Principles

Voltage and Thermal Limits

In a distribution system for general power and lighting thermal load limits are usually of most importance. Because of the low duty cycle at which most resistance welding machines operate, thermal limits in the design of a power supply system for welding assume lesser importance and the controlling factor becomes voltage drop limits. In most cases, if the resulting design is satisfactory from a voltage drop standpoint, it will be found that ample thermal capacity has been provided.

With low power-factor welding loads, reactance has a much greater effect on voltage drop than has resistance. The reactance of all elements of the supply system therefore must be given special study.

Transformers

Selection of transformer size and impedance is a matter of over-all economy. Lower impedance means higher short-circuit currents, hence heavier circuit protection. Low-impedance transformers must have special mechanical designs, hence paralleling two or more units may achieve low impedance with standard designs. This is more fully discussed in Section VI of this report.

Welding Feeders

The closer the centers of conductors of opposite polarity, the lower the reactance. Because of the effect of reactance, many designers avoid using larger size cables, and as an alternative use paired smaller conductors so installed as to give good interlacing of conductors of opposite polarity. Low-reactance bus duct is becoming increasingly popular. In all cases, of course, circuit runs must be kept to a minimum.

Circuit Protection

The resistance welder installation requires a high capacity tap from the plant distribution system, and the overcurrent protection for this tap may be very expensive. If the welder controls are within 25 feet of the tap point, the National Electric Code permits the omission of circuit overcurrent protection at the tap.

Special Local Requirements

In some cases state and local electric codes are more restrictive than is the National Electric Code, hence specific study is required. Most codes allow determination of capacity based on estimated operating conditions; others require that the design be based on 100-per-cent load factor of all connected machines. In the latter case, special dispensation often may be secured from the code authorities.

Because of the character of their local distribution system, the electrical utility may also have special requirements as to welder size and distribution of welders amongst the phases, hence the need for consultation during the design period.

Combined Loads

It is generally not good practice to combine lighting loads and welding load on the same feeder because of light flicker; in fact, in many cases it will be found desirable to supply lighting from a separate transformer.

Table XLIV. Resistance Welder Electric Power Systems—Typical Installations

Example Number	Transformer Voltage and Kva Capacity		Per Cent Impedance	Feeder Data**	Name-plate Kva		Number of Welders
					Welder Load	Largest Unit	
1(A)	6,920/460, single-phase	2,000 2,000	6.5 6.5	2—1/4"×3" 2—1/4"×4"	30,000	800	180
1(B)	6,920/460, single-phase	1,500	5.5	4—1/4"×3" 2—1/4"×4"	15,000	500	90
1(C)	6,920/460, single-phase	333	1.75	2—1/4"×3"	5,000	500	30
1(D)	6,920/460, single-phase	900	2.85	2—1/4"×3" 4—1/4"×2"	4,000	250	25
1(E)	6,920/460, 3-phase	1,500	5.5	3—1/4"×2"	2,500	500	15
1(F)	6,920/460, 3-phase	1,500	5.5	1—1/4"×2"	1,000	100	10
2(A)	26.4 kv/460, 3-phase	1,200 1,200	9.3	2,000-ampere *L.R.B., 3-phase	7,500	50	150
2(B)	4 kv/440, 3-phase	1,000 1,000 1,000	6	1,000-ampere *L.R.B., 3-phase	2,700	75	90
3(A)	11.5 kv/480, 3-phase	1,000 1,000	5.5	3,000-ampere 2,000-ampere 1,000-ampere 800-ampere *L.R.B., 3-phase	12,000	400	60
3(B)	11.5 kv/480, 3-phase	833	3.5		3,200	300	10
4(A)	13.2 kv/110/220/330/440/550, single-phase	450	3.3	1/4"×4" bus closely spaced	1,030	50	33
4(B)	13.2 kv/220, 3-phase	650	3.2	3-750,000 circular mils	200	30	7
4(C)	26 kv/4,160/220/440, single-phase	1,000	3.0	2,000-ampere *L.R.B.	1,050	200	12
5	4,800/480, 3-phase	2,000	5.5	3,000-ampere *L.R.B.	16,540	160	104

* Low reactance bus.

** Bar bus unless otherwise indicated.

On the other hand, motor loads may often be combined with welding loads to good advantage. Of course, such combination may dictate the use of polyphase rather than single-phase feeders.

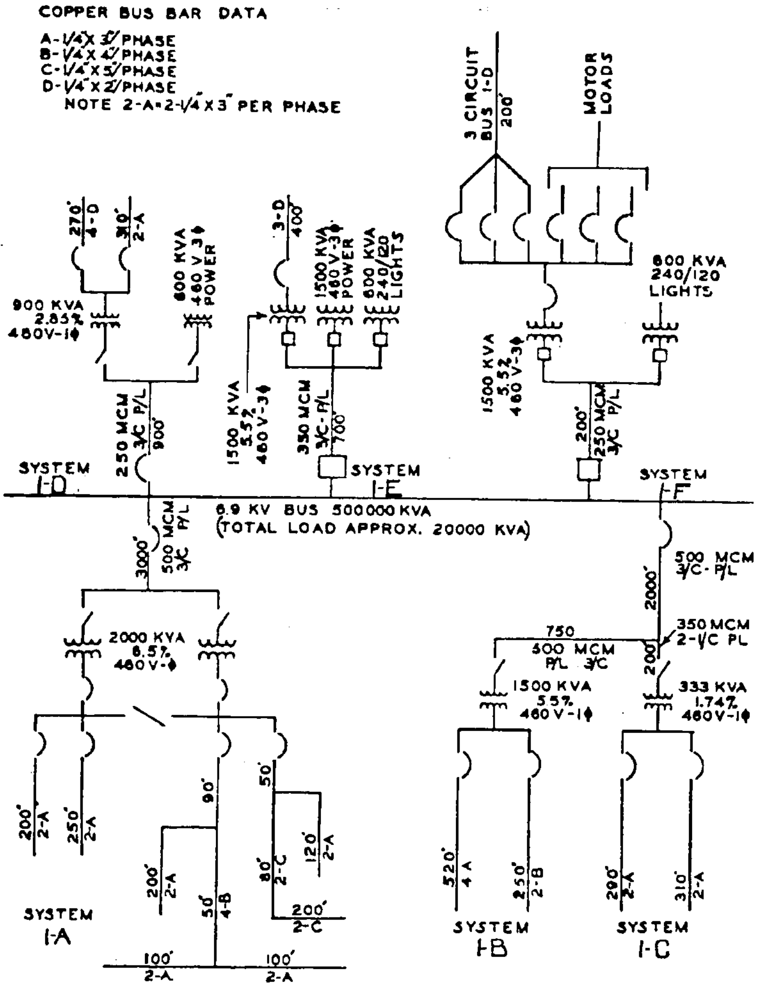
Typical Installations

In the typical installations which follow, each functioning satisfactorily, the approaches to adequate design vary, yet each is an application of the principles laid down in this report.

Table XLIV summarizes the installations illustrated.

Example 1(A-F)

The power distribution system for resistance welders in a household appliance plant has been isolated from the supply for other operations to a large extent. This was done principally to limit the extent of power outages resulting from welder machine transformers failing, and from excessive current resulting from welding electrode wear.



Example 1(A-F). Power distribution system for resistance welders in a household appliance plant

The majority of the welding operations do not require a gas-tight joint; therefore, the tolerable voltage variation is limited to the requirements of strength and appearance.

The extent of the actual voltage variation is a very elusive quantity due to the many variables in the welding process and the lack of adequate measuring facilities. For estimating purposes a 10-per-cent variation is applicable in most cases.

The power transformers used in these systems have been with one exception, standard single-phase units of 300, 500, or 667 kva which formerly were used in 3-phase banks for motor power systems. The one exception, system "C," is a single-phase unit built to supply 2,000 amperes at 460 volts on a 50-per-cent power factor load at 10-per-cent duty cycle with a maximum voltage drop of 5 per cent. This transformer, built in a load center unit, makes a convenient power source to locate near the welder loads.

The power feeders used are of the low-impedance busway type with the individual welders being supplied from a tap box with conduit and cable. The feeders are protected with instantaneous circuit breakers of suitable interrupting capacity.

Evaluating the performance of these power systems becomes quite a problem. As has been indicated, the measurement of voltage variation under all possible operating conditions would require a very extensive and highly detailed survey. Also, the relation between the voltage variation and the quality of the finished product would require another extensive survey of several very indefinite variables.

Most success, for providing an adequate power source, has been the result of close co-ordination between the welding and power engineers. They took into consideration the estimated power requirements, the quality of weld required, and, most important, the facilities available to meet production schedules in the time allowed.

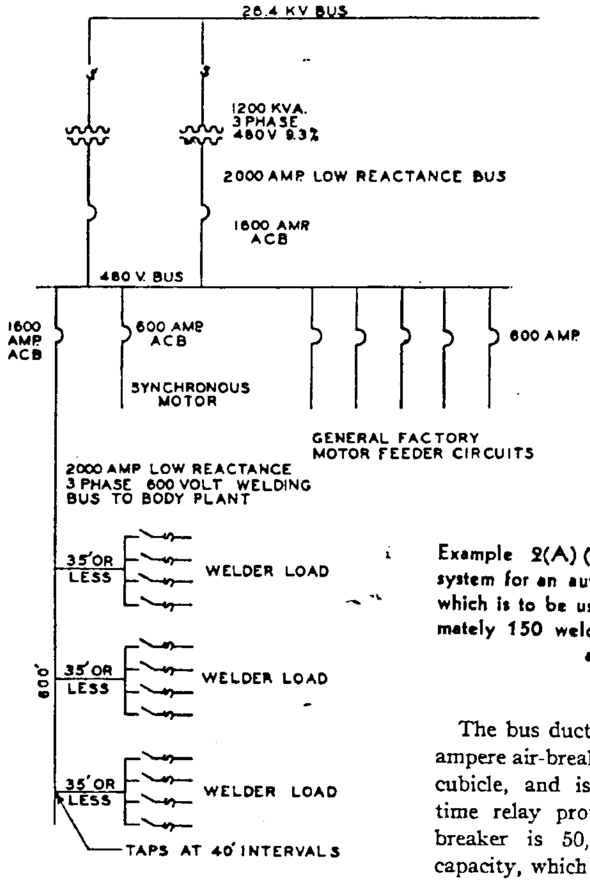
The tabulated data for example 1(A-F) are as follows (figures are approximate):

	System						
	A	B	C	D	E	F	Total
Date installed	1948	1948	1950	1950	1945	1945	
Name-plate kva	30,000	15,000	5,000	4,000	2,500	1,000	57,000
Thermal load kva	900	450	150	120	75	30	1,725
Number of machines	180	90	30	25	15	10	350

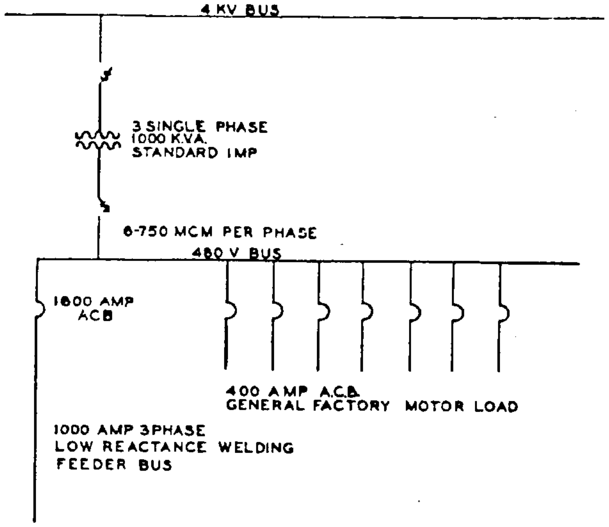
Example 2(A)

An electric power system is required in a new automobile plant, a portion of which is to be applied exclusively to welding. There are to be approximately 150 welders, principally of 50-kw size, and they are to be distributed over an area of approximately 160 feet by 600 feet. It is determined that the best voltage regulation which could be produced economically is necessary, but that in no case should it exceed 10-per-cent variation. It is decided that the power system for motor service is to be separated from the welding system.

One of the power company require-



Example 2(A) (left). An electric power system for an automobile plant, a portion of which is to be used for welding. Approximately 150 welders, mostly of 50-kw size, are used



Example 2(B) (above). An electric power system for an assembly plant with transformers and switchgear serving both welding and other power requirements

ments is that loads should be balanced equally on three phases. Although 3-phase design in welding power systems has no particular advantage, it is found practical to accede to their request.

All national, state, and local code requirements have to be met as to the size of the conductors, changing the sizes of the conductors, and so forth.

In this connection it is decided to arrange the bus down the middle of the welding area, grouping the welding controls on platforms above the floor, so that they will be within the 25 foot limit of the main bus. In this method, current protection will not have to be provided for changing wire size.

Fifty-per-cent bus capacity taps are provided at building columns so that the connections to the welding control panels can be located at any point along the main bus. Low-reactance bus duct of 2,000-ampere capacity is provided for the main feeder with taps arranged as indicated. Calculations indicate that the 2,000-ampere bus duct will provide voltage regulation within the limits originally decided upon. This bus duct is suspended near the ceiling and near the columns so as to be generally out of the way of other equipment.

The bus duct is connected to a 1,600-ampere air-break switch in the switchgear cubicle, and is provided with delayed time relay protection. The air circuit breaker is 50,000-ampere interrupting capacity, which is required by the power supply. This interrupting capacity has proved satisfactory as determined by calculations involving the utility substation capacity and transmission-line size.

For transformers two 1,200 kva 9.3-per-cent impedance transformers are purchased and operated in parallel. The parallel operations give low enough impedance so that voltage variation through the transformers will be at a reasonable figure. This is a standard size of transformer which has been used here for many years and has been kept because of interchangeable characteristics.

The welding control panels are entirely self-contained and include an air circuit breaker with instantaneous trips. The other controls necessary for the operation of the welders are selected according to standard practice. Vacuum-tube circuit breakers are used and are protected by water flow relays.

The distance from the welding controls to the welders is rarely over 40 feet, so that voltage drop at this point is not excessive.

The welders themselves are hung from trolleys on trolley beams so that they can travel along the floor with the bodies being constructed.

Since arc welders must be used in the area, they are supplied from the same source. The controls are mounted on the platform adjacent to the resistance welder controls and with the 440-volt leads connecting the arc welding transformers. The arc welders are also supported from the same tramrail on trolleys, so that they can move along with the work. This method of construction permits full use of the floor with no obstruction by equipment.

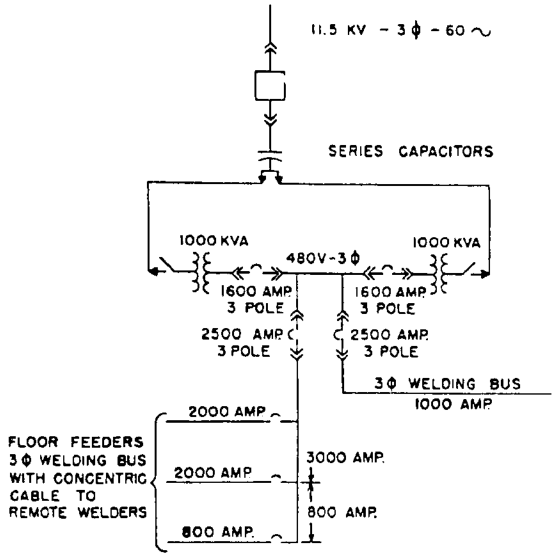
Subsequent operation of this plant has proved satisfactory regarding the electric power system and the voltage furnished to the welders.

EXAMPLE 2(B)

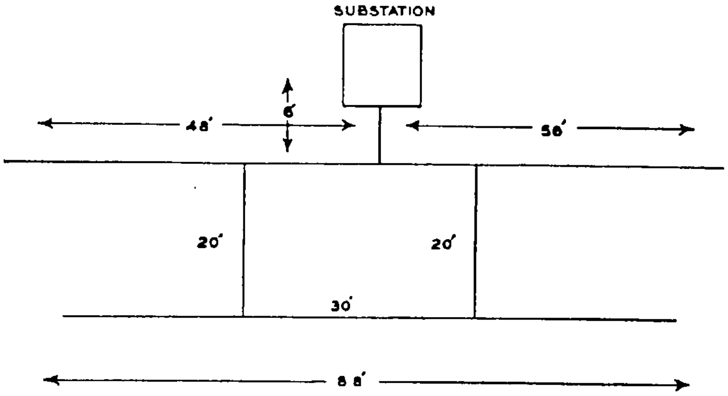
The electric power system required for a new assembly plant, which is to be located in an existing building, requires the use of existing electric equipment as far as practical. There were to be approximately 90 welders, principally of 30-kva size, and they were to be distributed over an area of 80 feet by 320 feet. The transformers and switchgear are to serve both the welding and other power requirements. Voltage variation is not to exceed 10 per cent for the welding operations. All of the national, state, and local codes, as well as the power company's requirements, have to be followed.

The electrical company provides the transformers for the 440-volt service from their 4,000-volt primary line.

The existing fuse-type switchgear is used for the power feeders and a 50,000-ampere interrupting capacity air circuit breaker cubicle is transferred from another



Example 3(A) (left). Series capacitors installed in a 3-phase power supply for resistance welders



Example 4(A) (above). Layout for a plant using 85 per cent of its capacity for resistance welding of small nonferrous parts

plant. One circuit breaker is changed to accommodate the 1,000-ampere low-reactance bus feeder, which is to supply the welding power.

The state code requires that: (1) A proposed distribution system must have anticipated capacity for 100-per-cent load factor, or (2) existing systems must have capacity to handle 100-per cent of actual load.

It is found that a 1,000-ampere 3-phase bus will take care of the welders with the estimated initial starting production at 100-per-cent load factor.

As the production rate increases it is possible to comply with the state law by checking the actual existing power load so as to come within their requirements. By following this method of complying with the state law requiring 100-per-cent load factor, it is possible to design according to accepted methods where lower load factors are permitted.

The bus duct is located along a column line at sufficient height to clear all productive equipment and yet allow feeder taps to be taken to the welder controls, which are located in groups at the base of each column.

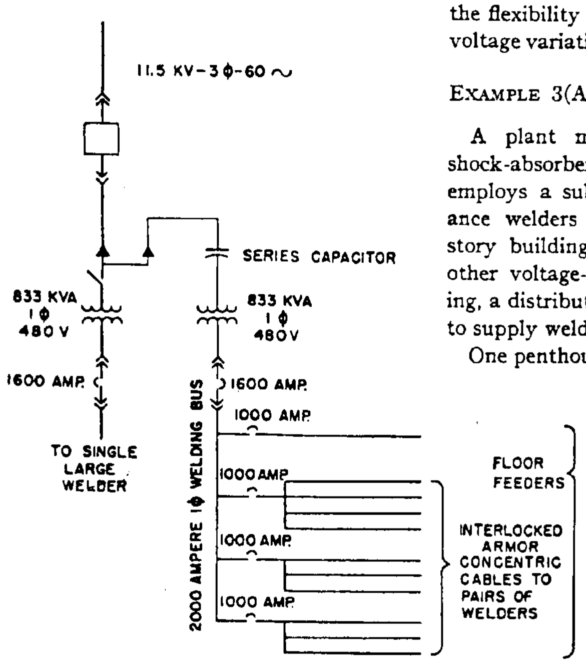
It is necessary to locate a 400-ampere fuse disconnect switch immediately ahead of each group of welder controls. This is to conform to the state electrical code.

A 3-phase bus duct is required because of the utility company requirements that all loads be balanced between the phases. Little or no difficulty is experienced with the flexibility of this system nor with the voltage variation

EXAMPLE 3(A)

A plant mass-producing automobile shock-absorbers and similar accessories employs a substantial number of resistance welders on all floors of a multi-story building. To separate lights and other voltage-sensitive loads from welding, a distribution system was established to supply welding only.

One penthouse substation was provided rather than install a substation on each floor. This was necessary because of space limitations on the manufacturing floors. Also, the total substation kva required was less than with individual floor substations, because of the effect of load diversity.



Example 3(B). Series capacitors installed in a single-phase power supply for resistance welders

The substation is illustrated in example 3(A). There are two, 1,000-kva 3-phase transformers in parallel. Series capacitor equipment is used in the primary line supplying these transformers. Without the capacitors, a much larger substation would have been required, which would have necessitated switchgear of much higher interrupting capacity and more expensive low-voltage busway, adequately braced for higher short-circuit currents. The capacitors were selected to neutralize practically all of the reactance of the substation, and designed to be by-passed during short circuit.

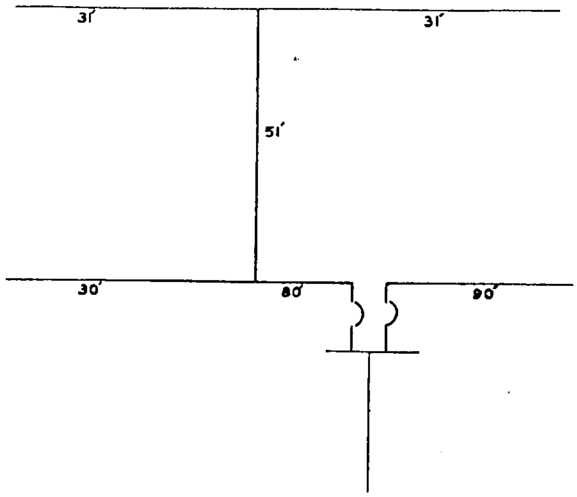
Low-reactance busway is used for interfloor risers and for main feeders on each floor. Concentric cable is used between the busways and individual welders.

Air circuit breakers in cascade provide short-circuit protection. A circuit breaker is used for each transformer secondary, the two main feeders, each floor feeder, and each individual welder cable.

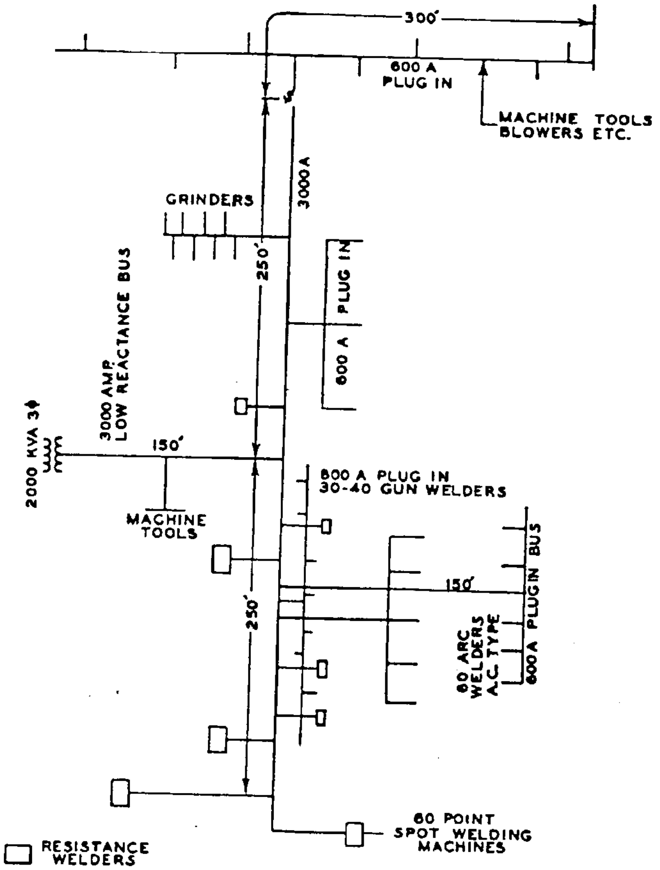
Interlocking between welders is not used except between two large 400-kva welders located on one floor. There are a total of 60 welders with a total connected rating of 12,000 kva.

All welders are single phase but are distributed on the three phases to provide a nearly balanced load as required by the power company supplying power to the primary line.

Excellent results have been obtained with practically no spoilage caused by voltage drops. It is probable that some



Example 4(B) (above). System with 100 per cent of its capacity for welding of small nonferrous parts with magnetic force welders



Example 4(C)(right). Installation used entirely for welding of ferrous material

motor load could be supplied from the welding system, but other provision has been made for all nonwelding load.

Example 3(B)

In another plant of the same company as example 3(A), there is a similar installation using one 833-kva 1-phase (3½ per cent) transformer with a series capacitor at its primary. This plant also has one very large welder (600 kva) which is supplied by an identical 833-kva (3½ per cent) transformer without a capacitor. This arrangement provides separation of this large machine from other welders. While the voltage drop at the large machine is substantial, it is compensated by adjustment of the welder heat setting. Had the large machine been connected to the capacitor-compensated transformer, the capacitor voltage rise would probably have been so high when this load was applied that the transformer would saturate, giving rise to ferro-resonant conditions which might cause too frequent operation of the protective air gap used with the series capacitors.

Example 4(A)

A department of this company is using approximately 85 per cent of its capacity for the resistance welding of small nonferrous parts.

The electric supply system is as follows: The incoming supply line is 13,200 volts. The wire size of the high-voltage line is 1-inch copper pipe and the line consists of a loop. This installation is approximately one mile from a large distribution station which in turn is fed by a 26,000-volt line. The momentary voltage variation of this 13,200-volt line is so small that it is difficult to measure, probably under 1 per cent, and the voltage drift over a few hours is also very small.

The welding substation is located adjacent to the welding section and the layout is as follows: Substation transformer: 450 kva, single phase; primary 13,200 volts; secondary 110-220-330-440-550; impedance 3.3 per cent.

All busses from substations to welders are 3/8 by 4-inch copper and are closely spaced. All five voltages are carried to each welder with a selector switch at each welder so that any of the five voltages may be supplied to any welder.

The connected load is: 33 resistance welders (mostly bench type); 1,030 kva. The average welder loading is 60 per cent or 618 kva. The average duty cycle is 2½ per cent.

Example 4(B)

This system is using 100 per cent of its capacity for the welding of small nonferrous parts and using magnetic force welders.

The incoming supply line is 13,200 volts and is the same line described in Example 4(A).

The substation transformer also is used for general plant power for the adjacent departments. The substation transformer is: 650 kva; primary 13,200 volts to secondary 220, 3-phase; transformer impedance 3.3 per cent.

The line to the welder is three 750,000-circular-mil cables and is 192 feet to the end of the installation. There is a 150-horsepower synchronous motor at the start of the welding installation (135 feet) from the substation. The synchronous motor greatly reduces the line voltage variation. However, there is approximately 11-per-cent momentary voltage variation and it is considered that this variation is too great for a standard resistance welder on nonferrous welding. Special machines are used to help compensate for the voltage variation.

Example 4(C)

This installation is used entirely for the welding of ferrous material. The supply line is 26,000 volts and this is transformed to 4,160 volts within the plant to feed the welding transformer. There is no load other than welding on the welding substation transformer.

The welding substation is located in the same area with the welders and the layout is as follows: Substation transformer: 1,000 kva; primary 4,160 volts; secondary 220–440; impedance 3 per cent.

All electric busses from substation to the welders are 3-conductor scrambled 2,000-ampere extra-low impedance type.

The connected load is 1,050 kva. There is allowance for a 75-per-cent increase in connected load.

The welding machines range from 20 to 200 kva. Both 220 and 440 volts are carried to all machines so that either can be used on any machine. It is estimated that the average duty cycle can be approximately 25 per cent with this type of work.

EXAMPLE 5

In the layout for the distribution of electric power for an automobile body plant having a large number of welders as well as many motor-driven machines, such as building equipment, heating and ventilating units, machine tools, and conveyors, it was decided that all devices would be connected to the same 3-phase distribution. The welding quality required could accept a 6- to 7-per-cent voltage variation.

The connected load and estimated duty cycles with calculated average kva demand were as follows:

Machine	Connected Kva Load	Duty Factor, Per Cent	Average Kva Demand
Large welding machines..	6,500	8	520
A-c arc welders..........	840	25	210
Spot and gun welders....	8,200	10	820
Motors (plant machinery)	1,000	70	700
	16,540	13.6	2,250

A standard 2,000-kva 3-phase 5.5-per-cent impedance transformer was selected together with a 3,000 ampere low-reactance 3-phase bus duct extending 400 feet along the center of the shop.

Plug-in bus duct or load center motor controls were taken off the 3,000-ampere bus at suitable intervals by means of high interrupting capacity instant trip circuit breakers.

The largest multitransformer press-type welding machine makes approximately 100 spot welds. In utilizing a simple selector switch six groups of welds are made in quick succession (two groups on each phase); this limits the current to 1,000 amperes.

This arrangement means that 1,000-ampere fluctuation on the average base load per phase is the normal recurring disturbance. Two or three of these 1,000-ampere loads are possible at one time, but no known trouble has been experienced from this cause.

An oscillogram taken during normal full production conditions shows 5.5-per-cent voltage disturbance at the end of the longest circuit. This leads one to believe that the common use of a transformer and its proper low-voltage circuit for motors and welders often can give a practical and economical factory power distribution.