A STUDY OF VOLTAGE FLICKER CAUSED BY ELECTRIC ARC FURNACES

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Taipei, 1957

A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Electrical Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1971

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TABLE OF CONTENTS

INTRODUCTION

In the past twenty years, the capacity of electric arc furnaces has increased from 20 MVA to 80 MVA and even 100 MVA furnaces are under consideration.(1,2) The advantages of the arc furnaces are not entirely cost; the high heat concentration combined with quick regulation, metallurgical flexibility, contamination free melting and refining, inherent nature which can remove sulfur and phosphorus (eliminating the expense of buying premium grade of scrap) as well as easy starting and shut down, makes the electric arc furnace one of the most effective production tools in the steel industry.

As a power company looks at the electric arc furnace, the arc furnace represents a large increment of load, good revenue, high load factor (above 60%)(3) and concentrated service area. However, with accompanying flicker voltage, such a load may affect other electricity users which is of paramount concern to an electric utility company. In lighting, flicker is annoying; in television, objectionable from the critical user's viewpoint, and in certain technical or utilization processes it may even disrupt production.

The agony for the utility is that there is no criterion of how much arc furnace capacity a utility company should supply. Usually, the higher the short circuit capacity, the larger the furnace that may be served.(4)

CAUSE OF FLICKER

A. Arc Furnace Principle

The general construction features of an arc furnace as manufactured in this country vary, of course, with size and with the different manufacturers. The shell of a typical furnace consists of a steel plate construction with a refractory lining and is usually circular in cross-section. The hearth is a

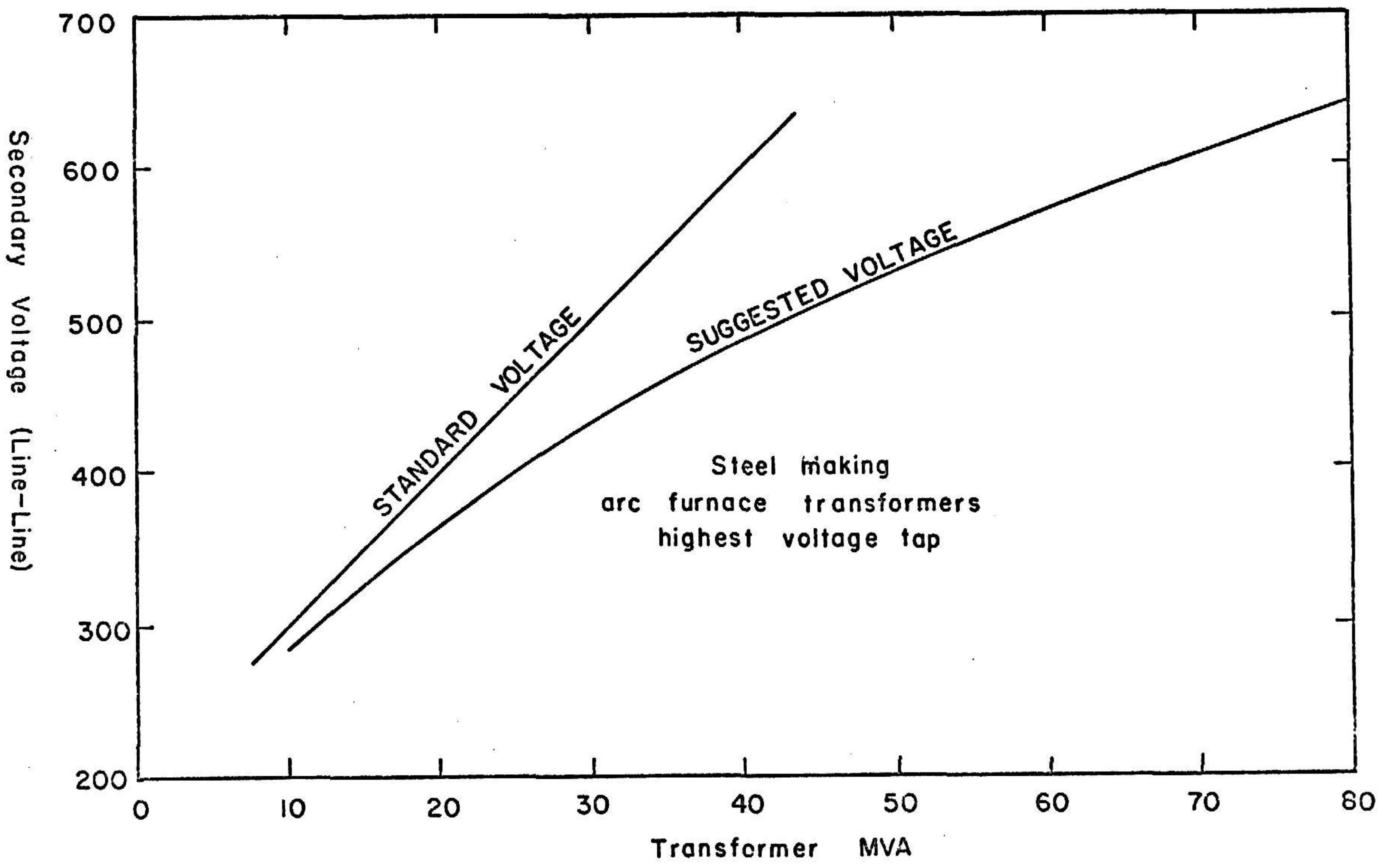


FIG. 1 ARC FURNACE TRANSFORMERS HIGHEST VOLTAGE TAP
IEEE-NEMA STANDARD AND INDUSTRY SUGGESTED

shallow bowl formed in the refractory lining of the bottom. The lining may be of acid or basic refractories. Suitable doors for charging the metal to be melted and a pouring spout for discharging the finished metal are provided. The roof is a removable member, made as a separate part of convenience in refilling and also in some cases to provide for overhead mechanical charging. In the roof are three equidistant opennings through which the vertical carbon or graphite electrodes can travel. The electrodes are manipulated by winches operated by motors with reversing control.

The methods of stating the size of a three-phase arc furnace is to rate the furnace in terms of the holding capacity in tons of molten metal or by the capacity of furnace transformer in MVA.

The method of operating an arc furnace so far as the charging of cold scrap is concerned, varies with the kind and degree of subdivision of the scrap. For instance, the weight of cold scrap in the form of roll turnings that can be charged in a furnace initially will rarely be enough to form the weight of molten metal desired, so that additional quantities can be added as the metal in the furnace becomes molten. This practice affects adversely both the energy consumption of KWH per ton and consumption of electrodes.

The open circuit voltage of three-phase arc furnaces varies with the capacity of the furnaces (Fig. 1).(5)

For arc furnace applications, transformers of special design are required. The secondary coil construction involves large heavy coils, requiring special bracing of the winding to meet the mechanical strength required with large variations of secondary current. Because of the magnitude of current required, multiple secondary coil terminals are brought out through the transformer tank cover.

Since a certain degree of flexibility of secondary voltage is desirable the general method of changing secondary voltage delivered to the furnace is by use of suitable tap in the primary winding.

B. Types of Flicker

Essentially, the furnace operation may be considered as a random occurrence of phase to phase short circuits, with the load swings causing corresponding voltage fluctuations. Three types of load swings may be generated by large arc furnaces, causing corresponding voltage swings.(6,7)

1. Cyclic

Single phase swings occur at a rate of 2-8 per second, and at a magnitude of roughly 40-50% of furnace rating, with the power factor of the swings at about 60%, well below normal furnace power factor. This flicker results from arc excursions in the molten metal and is most severe just after a charge of scrap.

2. Very Frequent

Single phase swings at a rate of no more than once per second, and at a magnitude of about 60-80% furnace rating. Power factor is about 60%. This flicker occurs in the initial melt-down period and just after a charge of scrap.

3. Gradual

Three phase power swings, lasting several seconds and having a magnitude equal to (or greater than) the furnace rating. Power factor may be as low as 50%. The character of such swings will depend on the sensitivity of the current control devices on a particular furnace.

C. Limitation of Flicker

After the study of the mechanism of the load swings in electric arc furnaces, the question arises as to what happens to the performance of such sensitive devices as light bulbs when their operating voltage is fluctuating.

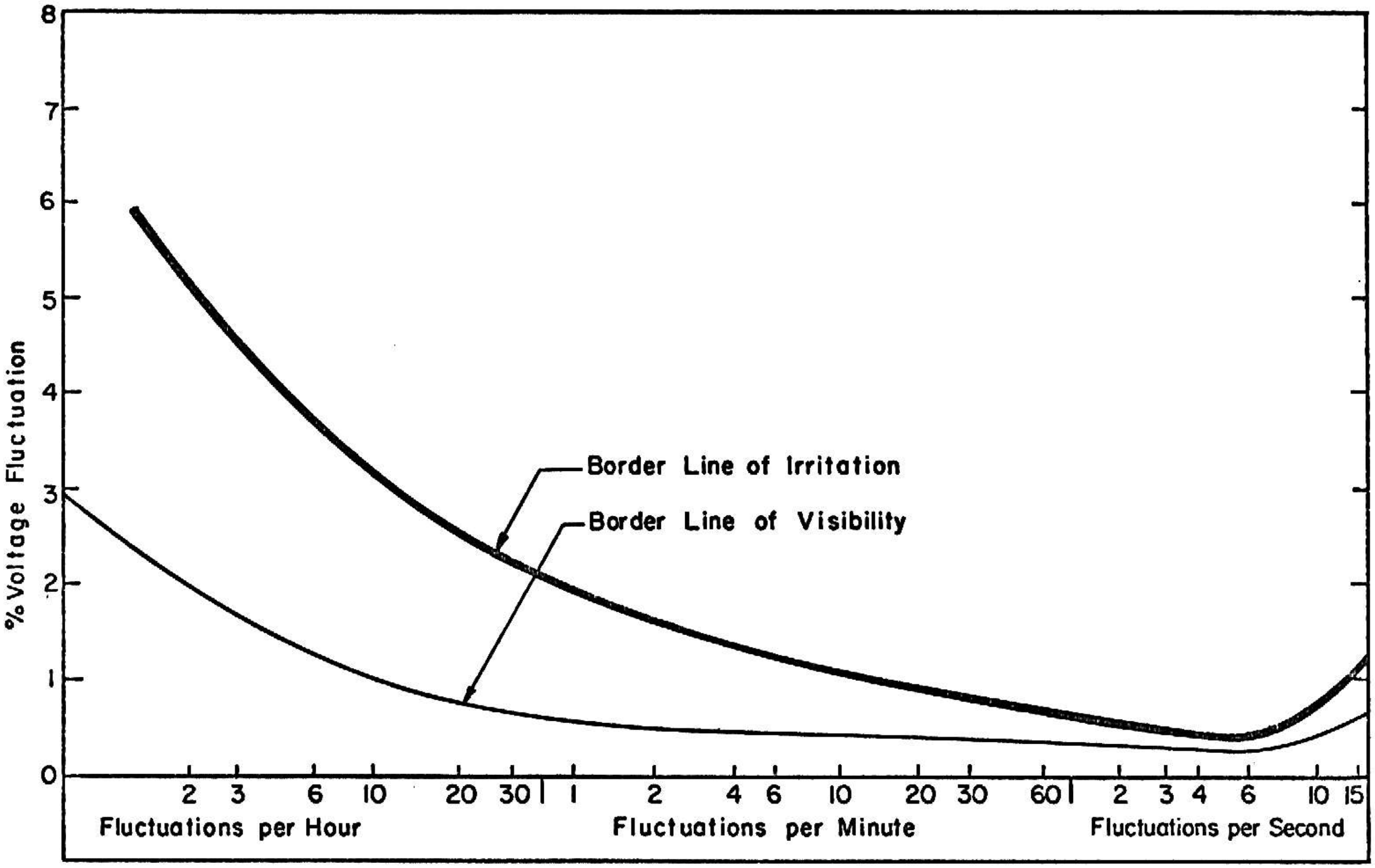


FIG. 2 RELATIONS OF VOLTAGE FLUCTUATIONS TO FREQUENCY OF THEIR OCCURRENCE (INCANDESCENT LAMPS)

The emission of visible light from the filament of a light bulb is a function of the power which in turn depends on the operating voltage. A drop of the line voltage from 100 to 99 per cent results in a decrease of approximately 3.4 per cent of the visible light emission after the filament has adjusted itself to the lower power level.(8)

It is obvious that the thermal inertia given by the diameter of the filament determines the speed of reaction. Small bulbs of the 15 or 25 watt type react much faster than 75 or 100 watt bulbs with their heavier filament. As for fluorescent light bulbs, the light output follows line voltage variation almost instantaneously.(8)

The problem of lighting flicker, however, cannot be entirely attributed to the light bulb. The human element enters the picture in a variety of factors including perceptibility, speed of reaction, irritation, etc. Contrary to physical conditions, these factors vary over a wide range and cannot be easily pinned down in figures and formulae. They require a statistical approach. Customer reaction to the flicker may vary, not only among utilities, but in different types of service territory served by one company. Customers have had differing experiences with electric service. Supposedly, the rural areas are more tolerant, but again, effects on television reception in fringe areas may counteract this tendency.

Based on the above facts, many flicker curves have been proposed to show permissible voltage fluctuation as a function of occurrence frequency.(6,9,10) The most widely adopted curve is shown on Fig. 2.

CALCULATION OF VOLTAGE FLICKER

A. Symmetrical Component Analysis of Electric Arc Furnace.(11,13)

An equivalent circuit for a three phase arc furnace could be present

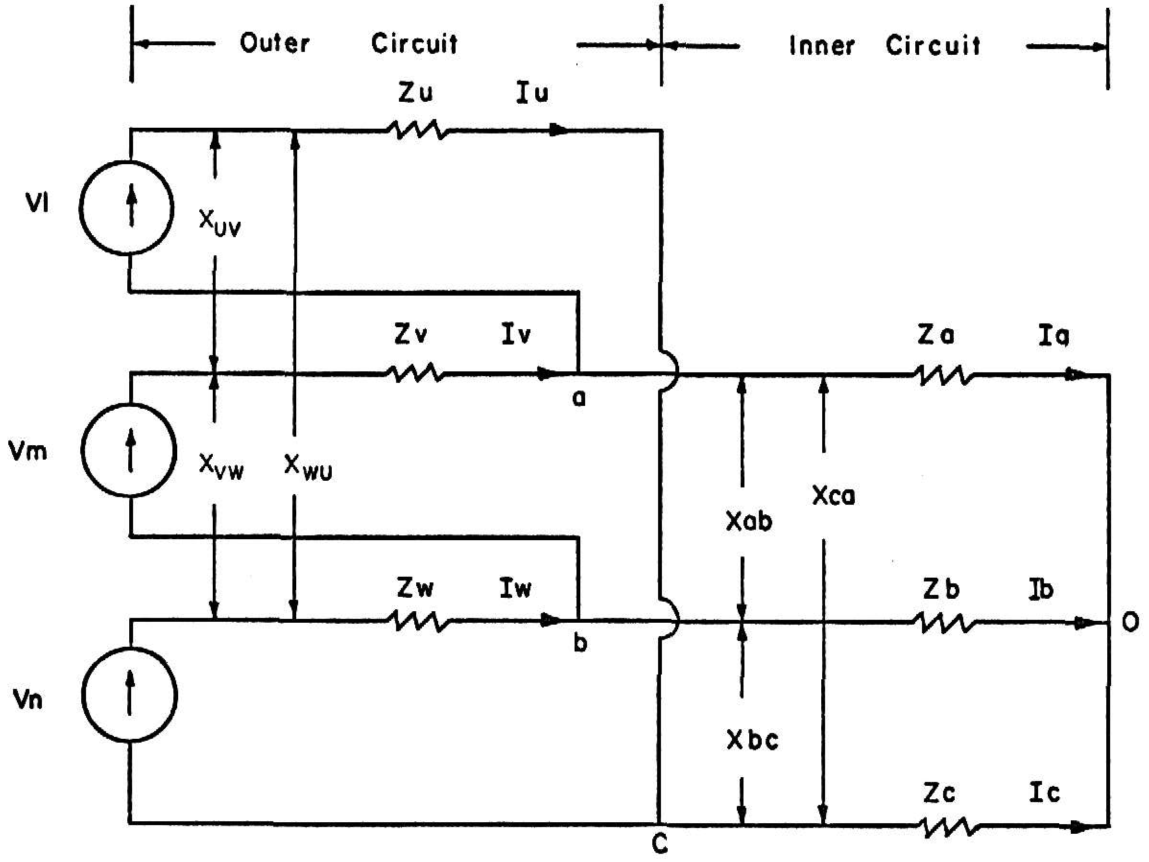


FIG. 3 SIMPLIFIED CIRCUIT FOR UNBALANCED ELECTRIC ARC FURNACE

as Fig. 3. The X_{uv}, X_{ab}, etc., denotes the mutual reactance between the u and v phases, the a and b phases, etc.

Taking the circuit constants, voltages and currents as shown in Fig. 3, the following five equations may be set up from Kirchhoff's laws:

$$I_a + I_b + I_c = 0 \tag{1}$$

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} Z_a & X_{ab} & X_{ca} \\ X_{ab} & Z_b & X_{bc} \\ X_{ca} & X_{bc} & Z_c \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} -1 & 1 & 0 \\ 0 & -1 & 1 \\ 1 & 0 & -1 \end{bmatrix} \begin{bmatrix} I_u \\ I_v \\ I_w \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} V_u \\ V_v \\ V_w \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} + \begin{bmatrix} Z_u & X_{uv} & X_{wu} \\ X_{uv} & Z_v & X_{vw} \\ X_{wu} & X_{vw} & Z_w \end{bmatrix} \begin{bmatrix} I_u \\ I_v \\ I_w \end{bmatrix} \tag{4}$$

$$\begin{bmatrix} V_l \\ V_m \\ V_n \end{bmatrix} = \begin{bmatrix} V_u \\ V_v \\ V_w \end{bmatrix} - \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{5}$$

Solving these equations simultaneously for V_l, V_m, and V_n, one obtains

$$\begin{bmatrix} V_l \\ V_m \\ V_n \end{bmatrix} = \left[\begin{matrix} -Z_a + X_{ca} - (Z_u - X_{uv})/3, & -X_{ab} + X_{bc} - (X_{uv} - X_{wu})/3, \\ Z_a - X_{ab} - (X_{uv} - Z_v)/3, & X_{ab} - Z_b - (Z_v - X_{vw})/3, \\ X_{ab} - X_{ca} - (X_{wu} - X_{vu})/3, & Z_b - X_{bc} - (X_{vw} - Z_w)/3, \end{matrix} \right.$$

$$\left. \begin{matrix} -X_{ca} + Z_c + (Z_u - X_{wu})/3 \\ X_{ca} + X_{bc} + (X_{uv} - X_{vw})/3 \\ X_{bc} - Z_c + (X_{wu} - Z_w)/3 \end{matrix} \right] \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + \begin{bmatrix} Z_u & X_{uv} & X_{wu} \\ X_{uv} & Z_v & X_{vw} \\ X_{wu} & X_{vw} & Z_w \end{bmatrix} \begin{bmatrix} I_{u0} \\ I_{u0} \\ I_{u0} \end{bmatrix} \tag{6}$$

Where $I_{u0} = (I_u + I_v + I_w)/3$.

With $a = e^{j2\pi/3}$, substituting

$$\begin{bmatrix} V_l \\ V_m \\ V_n \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} V_{10} \\ V_{11} \\ V_{12} \end{bmatrix}$$

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix}$$

into (6) and simplifying yields

$$\begin{bmatrix} V_{10} \\ V_{11} \\ V_{12} \end{bmatrix} = \begin{bmatrix} 0 & (a-1)(Z_{u2}-aX_{uv2})/3, & (a^2-1)(Z_{u1}-a^2-a^2X_{uv1})/3 \\ (a-1)(Z_{a1}-a^2X_{ab1}), & (a-1)\{Z_{a0}-X_{ab0}+(Z_{u0}-X_{uv0})/3\}, & (a^2-1)\{-aZ_{a2}-2a^2X_{ab2}+(Z_{u2}+2aX_{uv2})/3\} \\ (a^2-1)(Z_{a2}-aX_{ab2}), & (a-1)\{-a^2Z_{a1}-2aX_{ab1}+(Z_{u1}+2a^2X_{uv1})/3\}, & (a^2-1)\{Z_{a0}-X_{ab0}+(Z_{u0}-X_{uv0})/3\} \end{bmatrix} \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} + \begin{bmatrix} Z_u & X_{uv} & X_{wu} \\ X_{uv} & Z_v & X_{vw} \\ X_{wu} & X_{vw} & Z_w \end{bmatrix} \begin{bmatrix} I_{u0} \\ I_{u0} \\ I_{u0} \end{bmatrix} \qquad (7)$$

Where

$$\begin{bmatrix} Z_{u0} \\ Z_{u1} \\ Z_{u2} \end{bmatrix} = 1/3 \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} Z_u \\ Z_v \\ Z_w \end{bmatrix},$$

$$\begin{bmatrix} Z_{a0} \\ Z_{a1} \\ Z_{a2} \end{bmatrix} = 1/3 \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} Z_a \\ Z_b \\ Z_c \end{bmatrix},$$

$$\begin{bmatrix} X_{uv0} \\ X_{uv1} \\ X_{uv2} \end{bmatrix} = 1/3 \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} X_{uv} \\ X_{vw} \\ X_{wu} \end{bmatrix},$$

$$\begin{bmatrix} X_{ab0} \\ X_{ab1} \\ X_{ab2} \end{bmatrix} = 1/3 \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} X_{ab} \\ X_{bc} \\ X_{ca} \end{bmatrix}.$$

Moreover, since $I_{a0} = (I_a + I_b + I_c)/3 = 0$, Eq. (7) becomes

$$\begin{bmatrix} V_{10} \\ V_{11} \\ V_{12} \end{bmatrix} = \begin{bmatrix} Z_{u0} + 2X_{uv0}, & (a-1)(Z_{u2}-aX_{uv2})/3, & (a^2-1)\ (Z_{u1}-a^2X_{uv1})/3 \\ Z_{u1} - a^2X_{uv1}, & (a-1)\left\{Z_{a0}-X_{ab0}+(Z_{u0}-X_{uv0})/3\right\}, & (a^2-1)\left\{-aZ_{a2}-2a^2X_{ab2}+(Z_{u2}+2aX_{uv2})/3\right\} \\ Z_{u2} - aX_{uv2}, & (a-1)\left\{-a^2Z_{a1}-2aX_{ab1}+(Z_{u1}+2a^2X_{uv1})/3\right\}, & (a^2-1)\left\{Z_{a0}-X_{ab0}+(Z_{u0}-X_{uv0})/3\right\} \end{bmatrix} \begin{bmatrix} I_{u0} \\ I_{a1} \\ I_{a2} \end{bmatrix} \tag{8}$$

To avoid needless complexity Eq. (8) may be abbreviated as

$$\begin{bmatrix} V_{10} \\ V_{11} \\ V_{12} \end{bmatrix} = \begin{bmatrix} A_0 & B_0 & C_0 \\ A_1 & B_1 & C_1 \\ A_2 & B_2 & C_2 \end{bmatrix} \begin{bmatrix} I_{u0} \\ I_{a1} \\ I_{a2} \end{bmatrix}$$

In a three phase balanced system, where zero sequence, negative sequence currents and mutual impedance elements do not exist, as shown in Fig. 4A,(12) the balanced electric arc furnace can be represented by simple diagram as Fig. 4B.

B. Computer Program for Flicker Calculation

For the study of the flicker problem, Mr. Bob Oltroggie of the

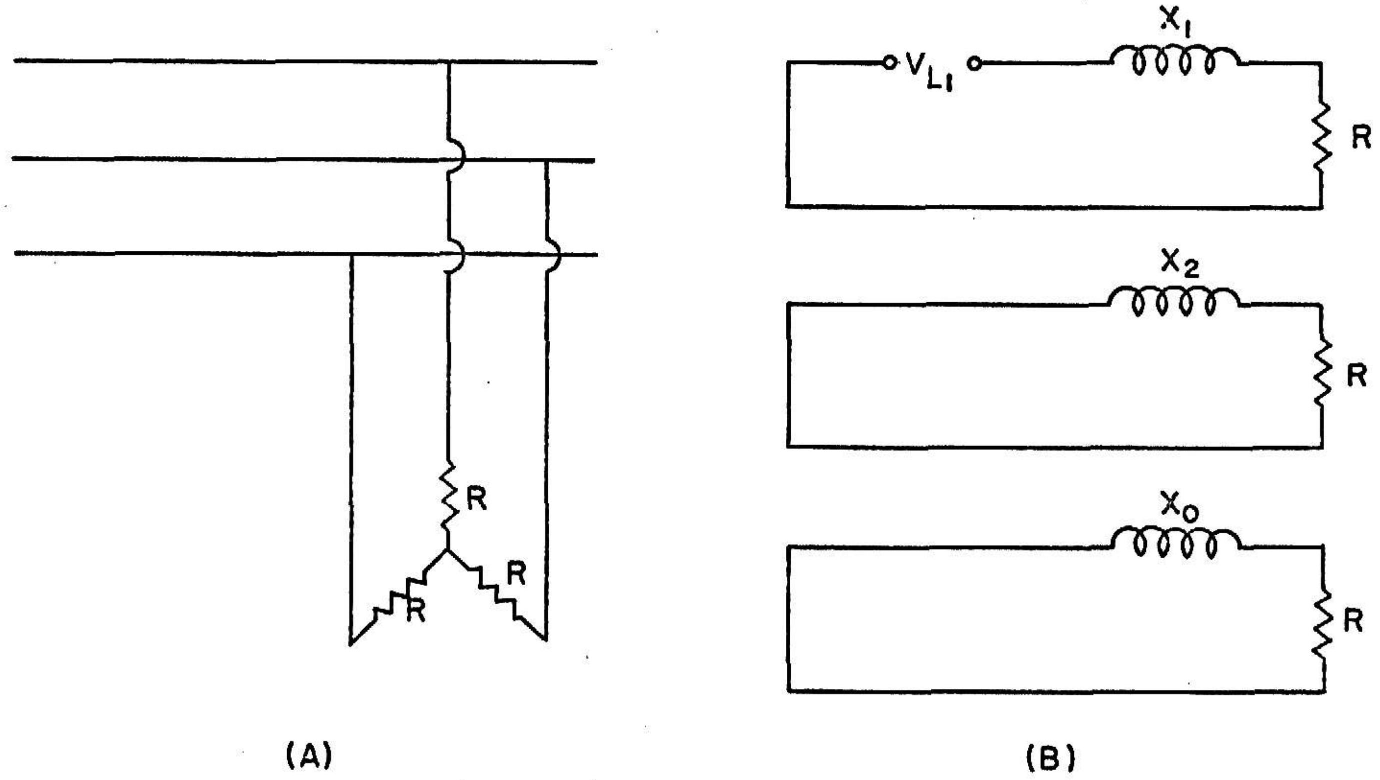


FIG. 4 POSITIVE, NEGATIVE AND ZERO SEQUENCE DIAGRAMS OF BALANCED THREE PHASE SHORT CIRCUIT

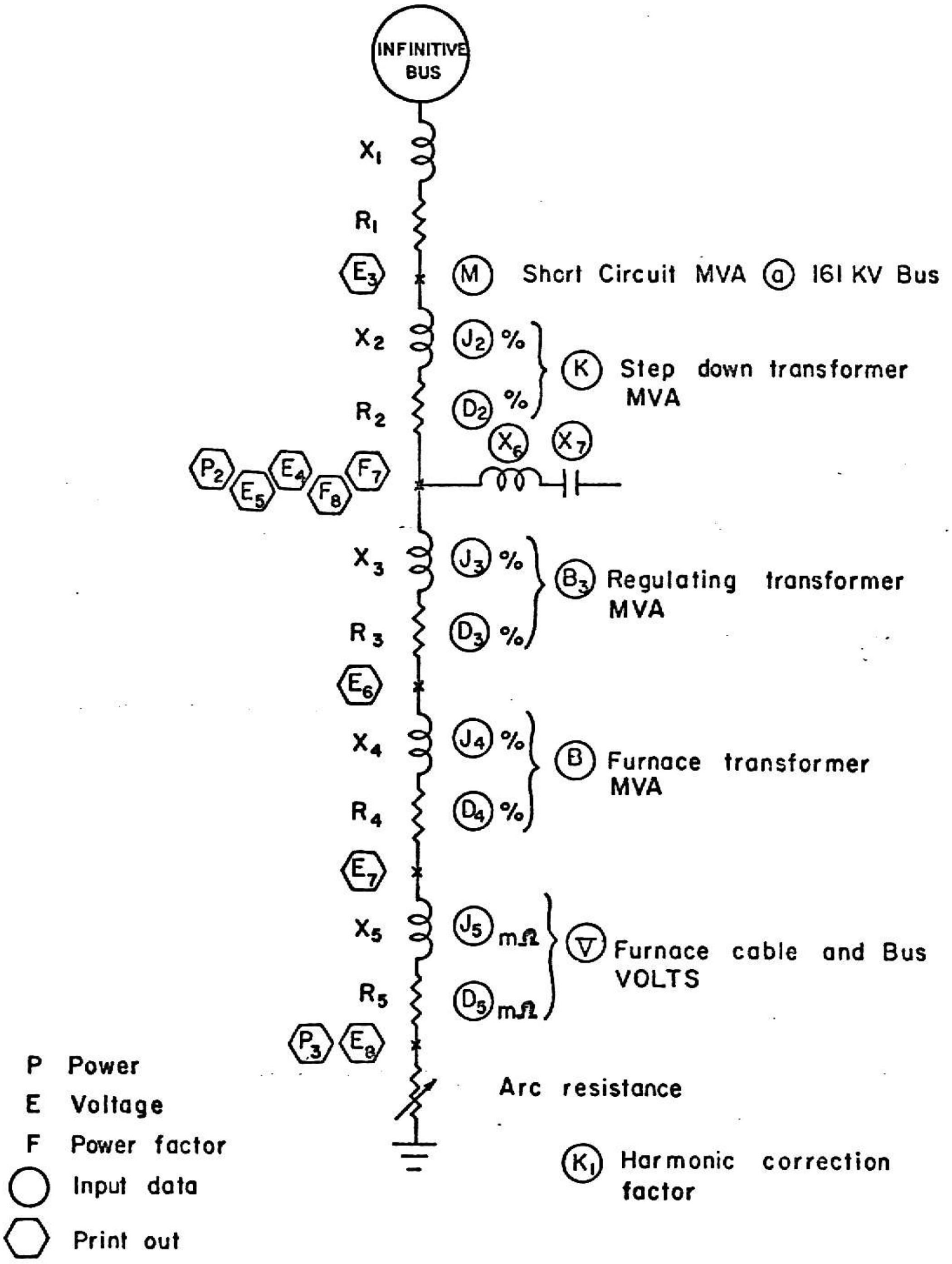


FIG. 5 EQUIVALENT CIRCUIT OF ARC FURNACE
FOR FLICKER PROGRAM

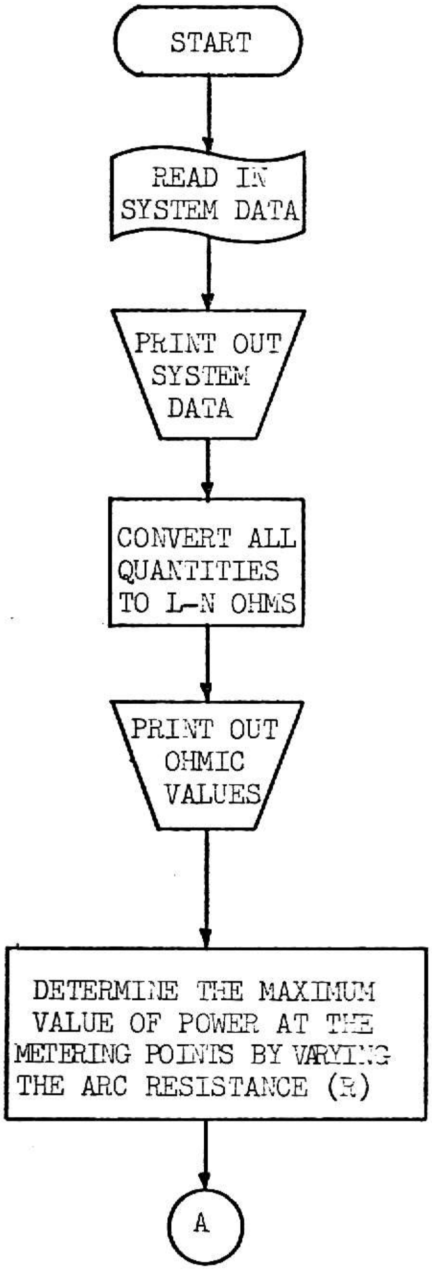


FIG. 6 FLOW DIAGRAM OF "FLICKR" PROGRAM

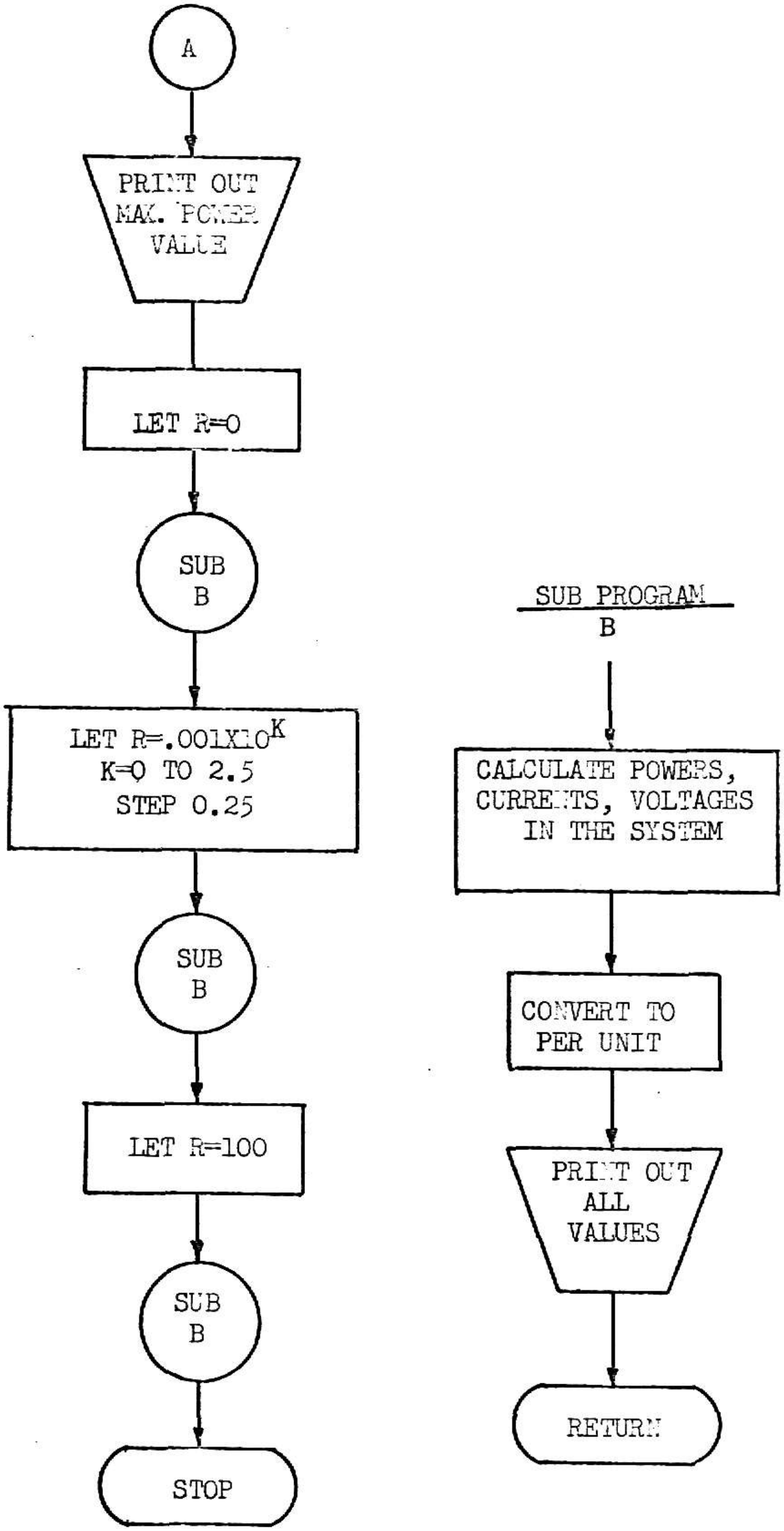


FIG. 7 FLOW DIAGRAM OF "FLICKR" PROGRAM

General Electric Company has written a program (appendix A) in BASIC using a G. E. 265 time sharing digital computer to calculate voltages and power factors at different metering positions of a furnace.

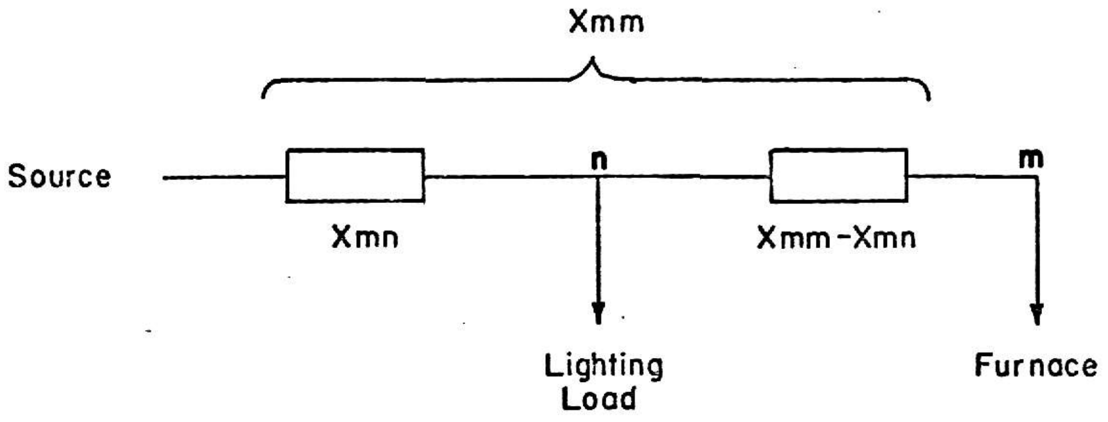
Fig. 5, 6, 7 present the equivalent circuit for the program and a brief explanation of the program which simulates the different operating conditions of an arc furnace by varying the arc resistance R.

VOLTAGE FLICKER OF MULTIPLE FURNACES

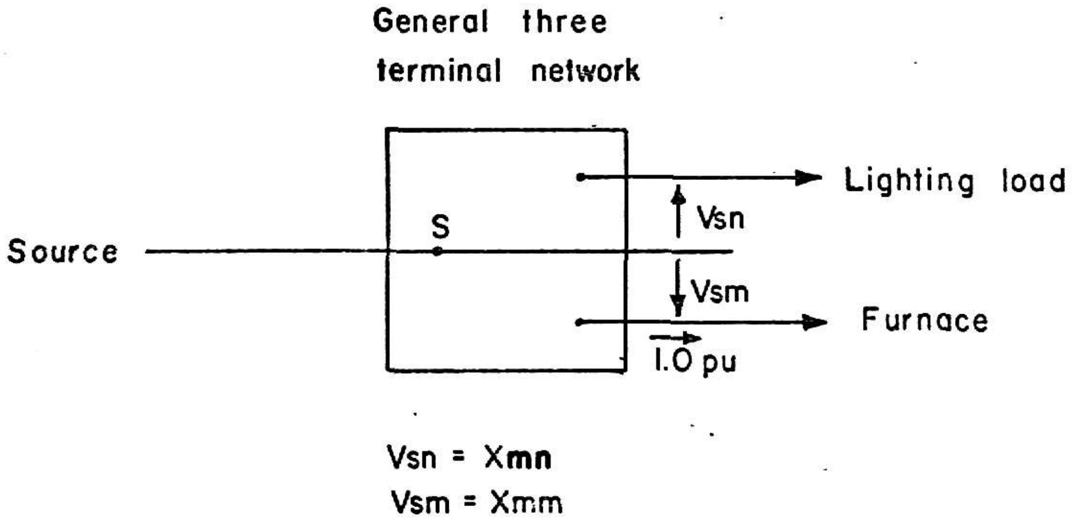
With two or more furnaces operating in parallel, the magnitude of the voltage fluctuations obviously is greater than with one furnace. It is also reasonable to assume that few fluctuations occur at the same instant in all furnaces (although that may happen on occasion). Generally, adding a second furnace which is substantially smaller than the first furnace will not appreciably increase the flicker.(15) The voltage swings are too irregular and difficult for the analyst to determine how much worse one condition is than another. Also, operating procedures of various plants vary.

Investigation has shown that the resultant rms voltage fluctuation is the square root of the sum of the squares of the individual rms voltages.(15,16) Moreover, when N furnaces of equal size are operated in parallel, the magnitude of the voltage fluctuation is the fluctuation produced by one furnace multiplied by a factor K_f, which is equal to $\sqrt{N}$. It is also found that the flicker level is reduced if one or more furnaces are in the refining cycle and that the fluctuation of a refining furnace can be considered about half that of a furnace in the melt-down cycle. Assuming, therefore, a mill with several equal sized furnaces, some of which are on the refining cycle, the multiplier becomes:

$$K_f = \sqrt{N + (0.25)N_r},$$



(A) Simple Radial Circuit



(B) General three terminal network.

FIG. 8 DEFINITION OF X_{mm} (SELF DROP CONSTANT)
AND X (MUTUAL DROP CONSTANT)

Where N is the number of furnaces on melt-down and N_r is the number of furnaces on the refining cycle.

The problem of flicker level of two or more furnaces of different sizes operating in parallel can be estimated with a similar routine:

$$K_f = \sqrt{N + F_1^2 + F_2^2 ----- F_n^2}$$

Where N is the number of largest furnaces of the same size and F is the per-unit MVA of smaller furnace sizes. For any furnace on the refining cycle, one-half the per-unit size should be used in this equation.

The AIEE Committee on System Engineering and Working Group on Arc Furnaces has recommended and approved the mutual drop constant (X_{mn}) as an index of the ability of a power system to supply arc furnaces without objectionable flicker by correlating many operating furnaces.(14)

Referring to the Fig. 8A, the furnace transformer bus is designed as m and the location of the closest lighting load as n. With 1.0 per-unit reactive current (based on the furnace transformer name-plate kva) drawn from the system at point m, X_{mn} is defined as the voltage drop from the generator equivalent internal voltage to the point n. The quantity X_{mm} is defined as the voltage to the point m, and this quantity is designated as the "self-drop constant." The quantity X_{mn} is the reciprocal of the short-circuit capacity at the furnace transformer bus. For the simple radial circuit in Fig. 8A, X_{mn} is the reciprocal of the short-circuit capacity at the lighting tap, but in more general networks, this is not the case. The determination of X_{mn} and X_{mm} for the general 3-terminal net work is shown in Fig. 8B.

The assumptions used by the working group for setting up the 3-terminal network for the various furnaces covered by the survey are as follows:

1. Voltage of generators and synchronous condensers are equal and in phase.

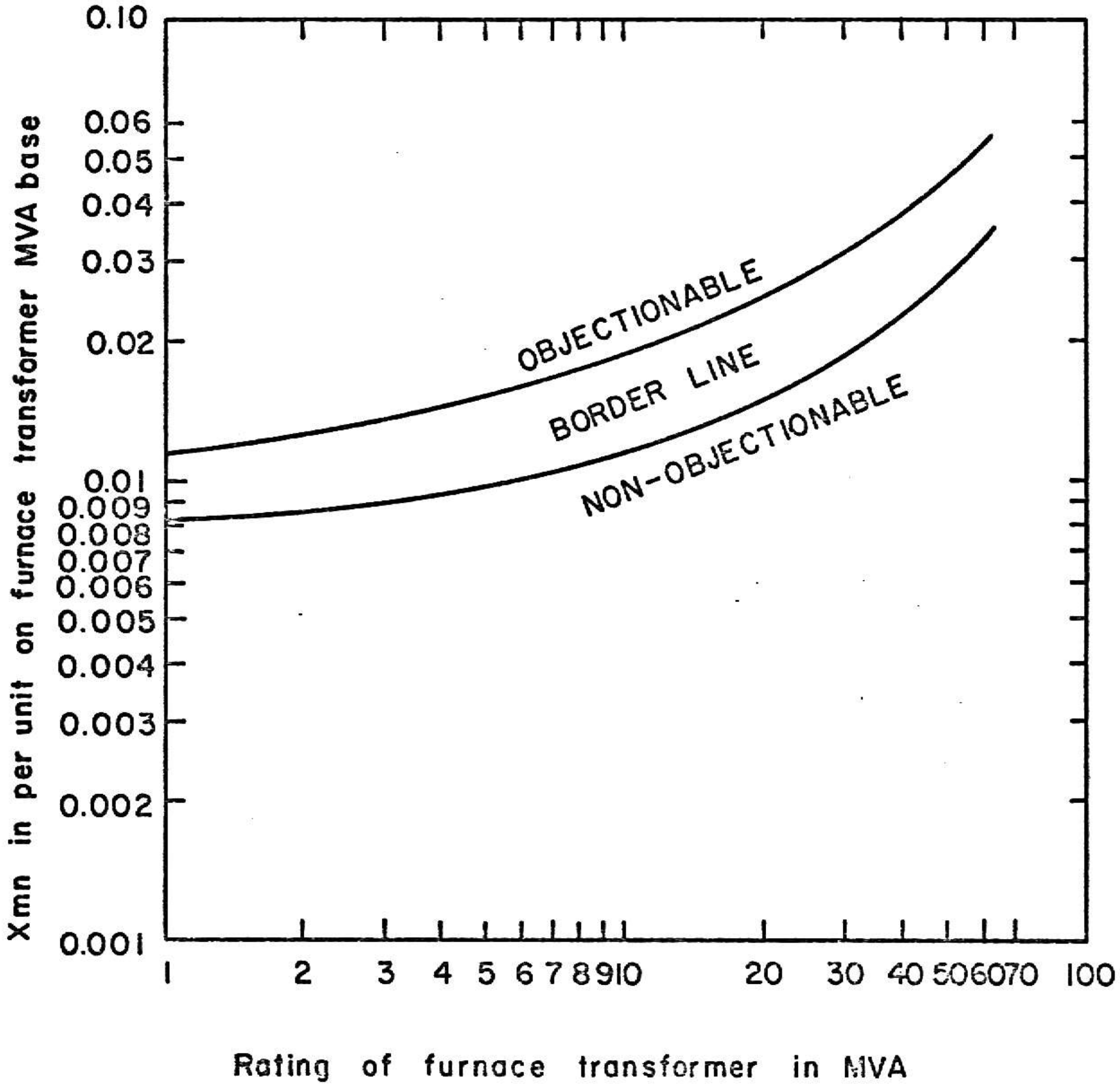


FIG. 9 ARC FURNACE FLICKER APPLICATION LIMITS
(SINGLE FURNACES INSTALLATION)

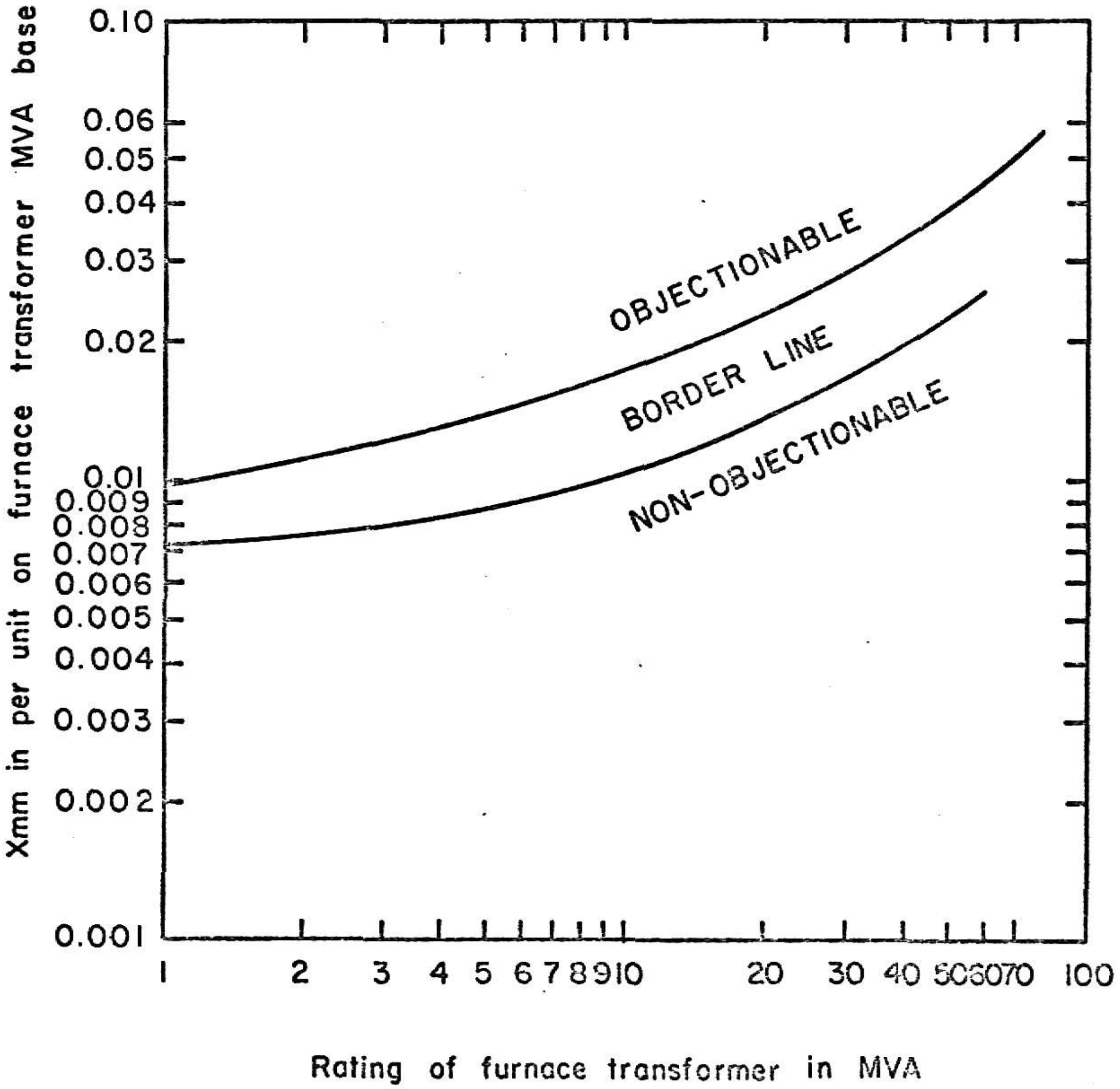


FIG. 10 ARC FURNACE FLICKER APPLICATION LIMITS
(TWO-FURNACE INSTALLATION)

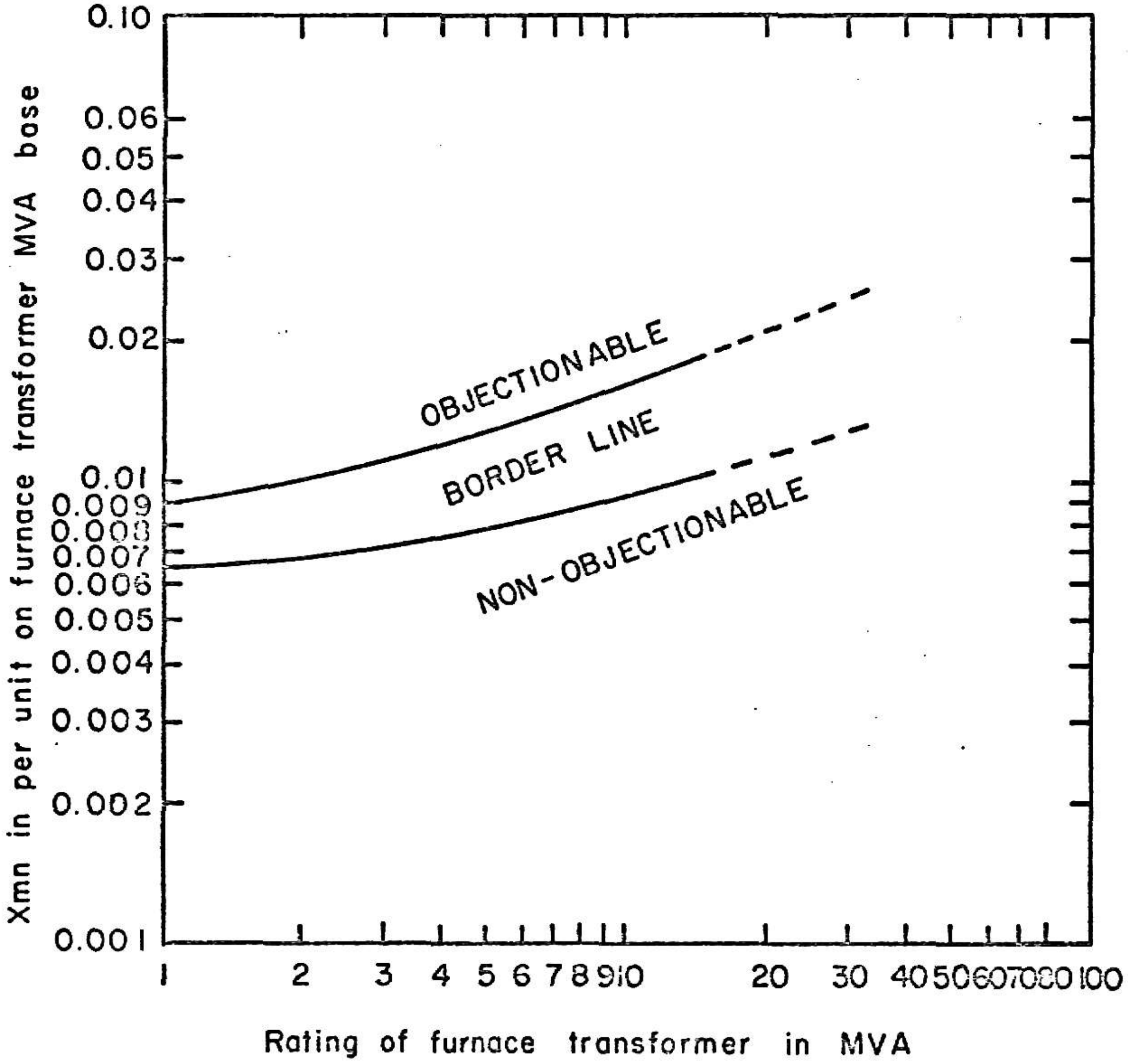


FIG. 11 ARC FURNACE FLICKER APPLICATION LIMITS
(THREE OR MORE IDENTICAL FURNACE
AT SAME LOCATION)

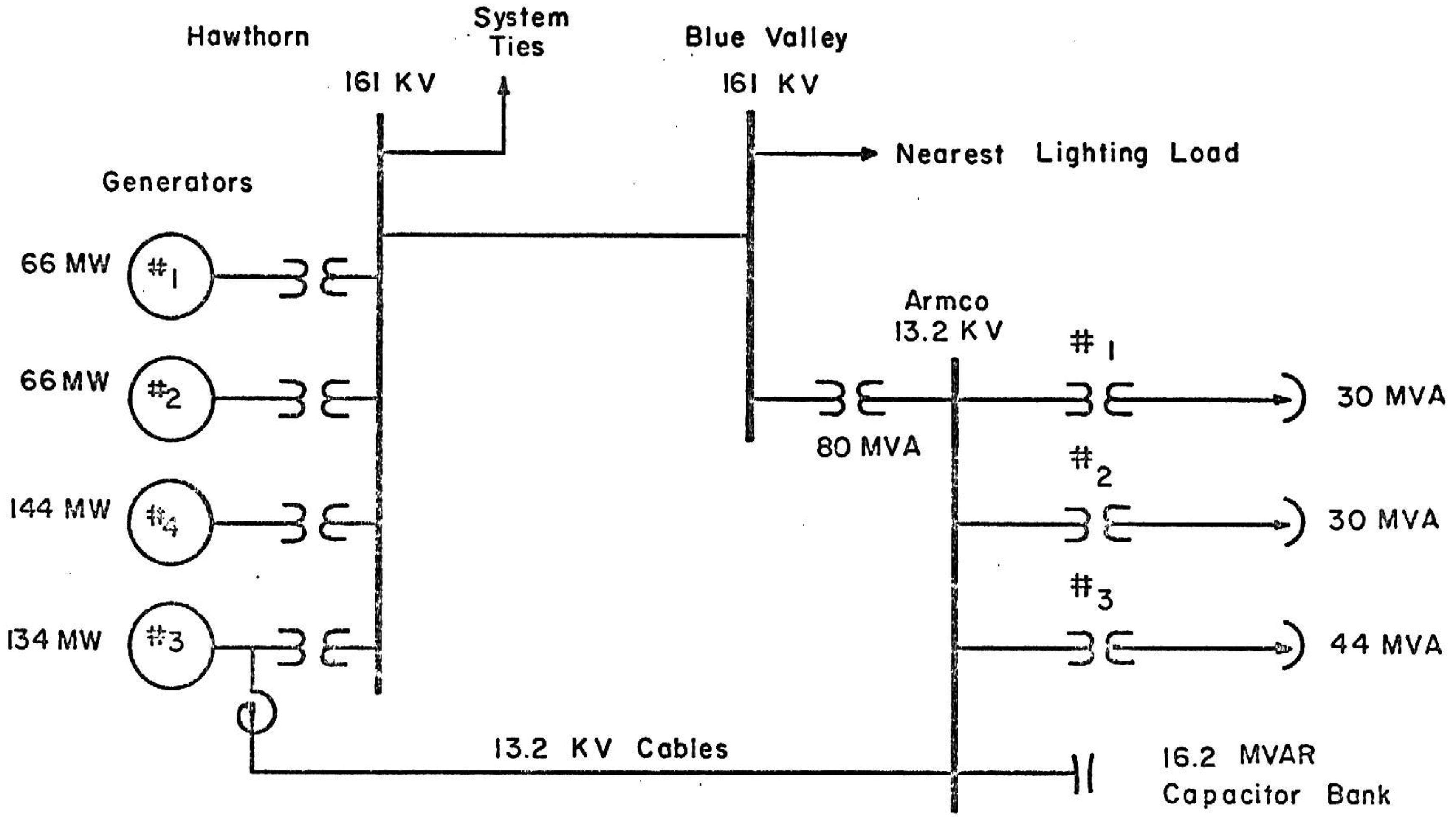


FIG. 12 POWER SUPPLY TO ARMCO SHEFFIELD PLANT
(1968)

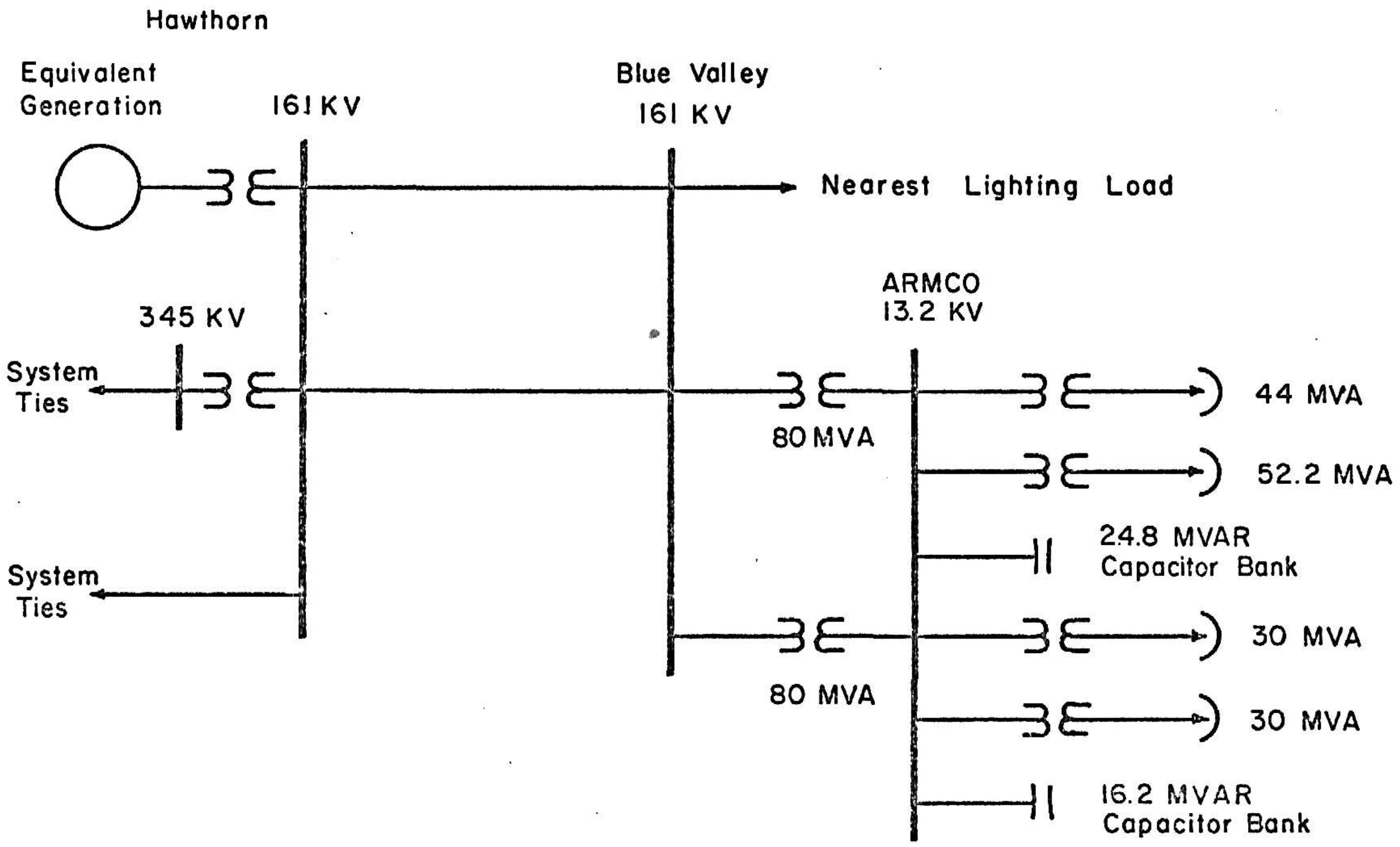


FIG. 13 POWER SUPPLY TO ARMCO SHEFFIELD PLANT
(1969)

2. Shunt impedance branches are neglected.
3. Subtransient reactance is used for all synchronous machines.
4. The resistance in lines, transformers, and generators are neglected.

The self- and mutual-drop constants can be determined by network deduction by use of calculating board or digital computer.

Fig. 9, 10, 11 present the results of the study, plots of X_{mn} against furnace size for installations with one, two and three or more larger furnaces with some smaller furnaces ignored.

The AIEE working group's survey mainly dealt with electrode voltages of 350 volts or below. However, it is understood (14) that the larger furnace operates with higher electrode voltages and consequently, the gap between electrodes and melt is larger. The influence of wave ripple decreases with increased gap or arc voltage. Therefore, the problem of lighting flicker in relative terms is less critical with large furnaces.

FLICKER STUDY OF SHEFFIELD PLANT OF ARMCO STEEL CORPORATION

Since 1950's, Kansas City Power and Light Company has been serving the Sheffield Plant of Armco Steel Corporation at Kansas City, Missouri.

In 1968, the capacity of Sheffield Plant consisted of three furnaces of 30, 30, 44 MVA, supplied by an 80 MVA transformer which steps down from the 161 KV bus at Blue Valley substation to 13.2 KV bus at the Sheffield plant. Also, there were six overhead 13.2 KV, 500 MCM cables connected directly from Hawthorn station generator Unit No. 3 to the Sheffield bus.(17)(Fig. 13) These cables were removed after the new 80 MVA transformer was installed.

Armco Steel has planned to add a new furnace of 52.2 MVA which probably will be uprated to 58 MVA in the future. To meet the increased load, the Kansas City Power and Light Company has installed another 80 MVA transformer at Blue Valley substation in 1969. (Fig. 14)

To investigate to what extent the furnace operation at Sheffield Plant may cause voltage fluctuations at the Blue Valley 161 KV bus where the nearest lighting loads are connected, the following studies were conducted.

A. Field Tests

1. A visicoder (Honeywell Model 1612) record of voltages at different furnace operating conditions were made. The operating conditions and results were analyzed below:

Operating Condition No. 1

Scrap was just contacted by electrode.
#1 furnace working in high tap but flat bath.
#2 furnace refining (low tap)

Voltage Fluctuation	Average Flicker Per Second A-Phase	B-Phase	C-Phase
0-2.2%	4.1	0.9	1.8
2.2-5%	4.1	4.5	4.1
5-8%	0.9	2.3	2.7
8-10%	0.5	0.5	0.9
10-15%	0	1.4	1.4
15% Up	0	0.5	0.5

Operating Condition No. 2

3 minutes after breaker was closed.
#1, #2 furnace conditions same as condition No. 1.

Voltage Fluctuation	Average Flicker Per Second A-Phase	B-Phase	C-Phase
0-2.2%	1.5	0.7	0.4
2.2-5%	5.5	4.6	4.4
5-8%	3.0	2.6	3.3
8-10%	0.4	0.4	1.7
10-15%	0	0	1.7
15% Up	0	0	0.7

Operating Condition No. 3

7 minutes after breaker was closed.
#1 furnace on low tap.
#2 furnace off.

Voltage Fluctuation	Average Flicker Per Second A-Phase	B-Phase	C-Phase
0-2.2%	0.4	2.7	0
2.2-5%	4.2	5.4	5.8
5-9%	4.2	1.9	4.2
8-10%	0	0	0.8
10-15%	0	0	0
15% Up	0	0	0

Operating Condition No. 4

13½ minutes after breaker was closed, cave-in on #3 furnace.
#1 furnace off.
#2 furnace off.

Voltage Fluctuation	Average Flicker Per Second A-Phase	B-Phase	C-Phase
0-2.2%	1.6	2.8	3.6
2.2-5%	6.8	5.6	6
5-8%	2.8	3.2	1.2
8-10%	0	0	0
10-15%	0	0	0
15% Up	0	0	0

Operating Condition No. 5

18 minutes after the breaker was closed.
#1 furnace off.
#2 furnace off.

Voltage Fluctuation	Average Flicker Per Second A-Phase	B-Phase	C-Phase
0-2.2%	4.4	0.4	2.5
2.2-5%	4	2.4	3.1
5-8%	0.4	0	0.8
8-10%	0	0	0
10-15%	0	0	0
15% Up	0	0	0

Operating Condition No. 6

22 minutes after breaker was closed.
#1 furnace off.
#2 furnace off.

Voltage Fluctuation	Average Flicker Per Second A-Phase	B-Phase	C-Phase
0-2.2%	3.7	2.5	3.7
2.2-5%	6.6	6.1	4.2
5-8%	0.8	1.2	0.8
8-10%	0	0	0
10-15%	0	0	0
15% Up	0	0	0

Operating Condition No. 7

#3 furnace cave in.
#1 furnace off.
#2 furnace off.

Voltage Fluctuation	Average Flicker Per Second A-Phase	B-Phase	C-Phase
0-2.2%	2.3	3.5	1.9
2.2-5%	5.8	4.1	6.2
5-8%	4.1	1.9	3.1
8-10%	0	0.4	0.4
10-15%	0	0	0
15% Up	0	0	0

Operating Condition No. 8

#3 furnace tried to catch a cave-in but the electrodes pulled out.
#1, #2 furnaces off.

Voltage Fluctuation	Average Flicker Per Second A-Phase	B-Phase	C-Phase
0-2.2%	2.7	2.7	1.9
2.2-5%	4.1	3.9	6.5
5-8%	0.4	0	1.1
8-10%	0	0	0.4
10-15%	0	0	0
15% Up	0	0	0

Operating Condition No. 9

3rd charge for #3 furnace.
2nd charge for #2 furnace.
1st charge for #1 furnace.

Voltage Fluctuation	Average Flicker Per Second A-Phase	B-Phase	C-Phase
0-2.2%	5.3	2.9	4.1
2.2-5%	5.3	1.0	7.6
5-8%	0.6	2.3	2.3
8-10%	0	0.6	1.2
10-15%	0	0	0
15% Up	0	0	0

Operating Condition No. 10

3rd charge for #3 furnace.
2nd charge for #2 furnace.
1st charge for #1 furnace.

Voltage Fluctuation	Average Flicker Per Second A-Phase	B-Phase	C-Phase
0-2.2%	3.9	3.9	2.6
2.2-5%	6.5	7.0	6.1
5-8%	1.3	1.7	1.7
8-10%	0	0	0
10-15%	0	0	0
15% Up	0	0	0

2. The voltage was recorded at the Blue Valley 161 KV bus by a Brush recorder. The magnitude of the very frequent flicker was about 0.071%.
3. A visual test was performed with a light bulb. No flicker was observed during the test.

B. Computer Calculation

Table 1 shows the system and input data for the cases of:

1. The year 1968, normal system condition with no. 3 furnace (44 MVA) in operation.
2. The year 1969, with normal system condition with no. 4 furnace (52.2 MVA) in operation.
3. The year 1969, furnace no. 4 (52.2 MVA) operated at all system ties connected, with Hawthorn Unit no. 3 the only generating unit in the metropolitan Kansas City area.

DATA / CASE	M	K	B3	B	J2	D2	J3	D3	J4
1968	5492.1,	100,	100,	44,	10.4,	0.153,	0,	0,	5.6,
1969N	7153.0,	200,	100,	52.2,	10.4,	0.153,	0,	0,	4.32,
1969H3	4683.9,	200,	100,	52.2,	10.4,	0.153,	0,	0,	4.32,
1969H5	5566.6,	200,	100,	52.2,	10.4,	0.153,	0,	0,	4.32,
1969UR	7153.0,	200,	100,	58.0,	10.4,	0.153,	0,	0,	4.8,

D4	J5	D5	J6	C	V	K1
0.56,	3.1166,	0.34033,	0,	16.1,	540,	0.05
0.432,	2.8,	0.3,	0,	41,	540,	0.05
0.432,	2.8,	0.3,	0,	41,	540,	0.05
0.432,	2.8,	0.3,	0,	41,	540,	0.05
0.48,	2.8,	0.3,	0,	41,	540,	0.05

TABLE 1. INPUT DATA FOR ARMCO FLICKER STUDY

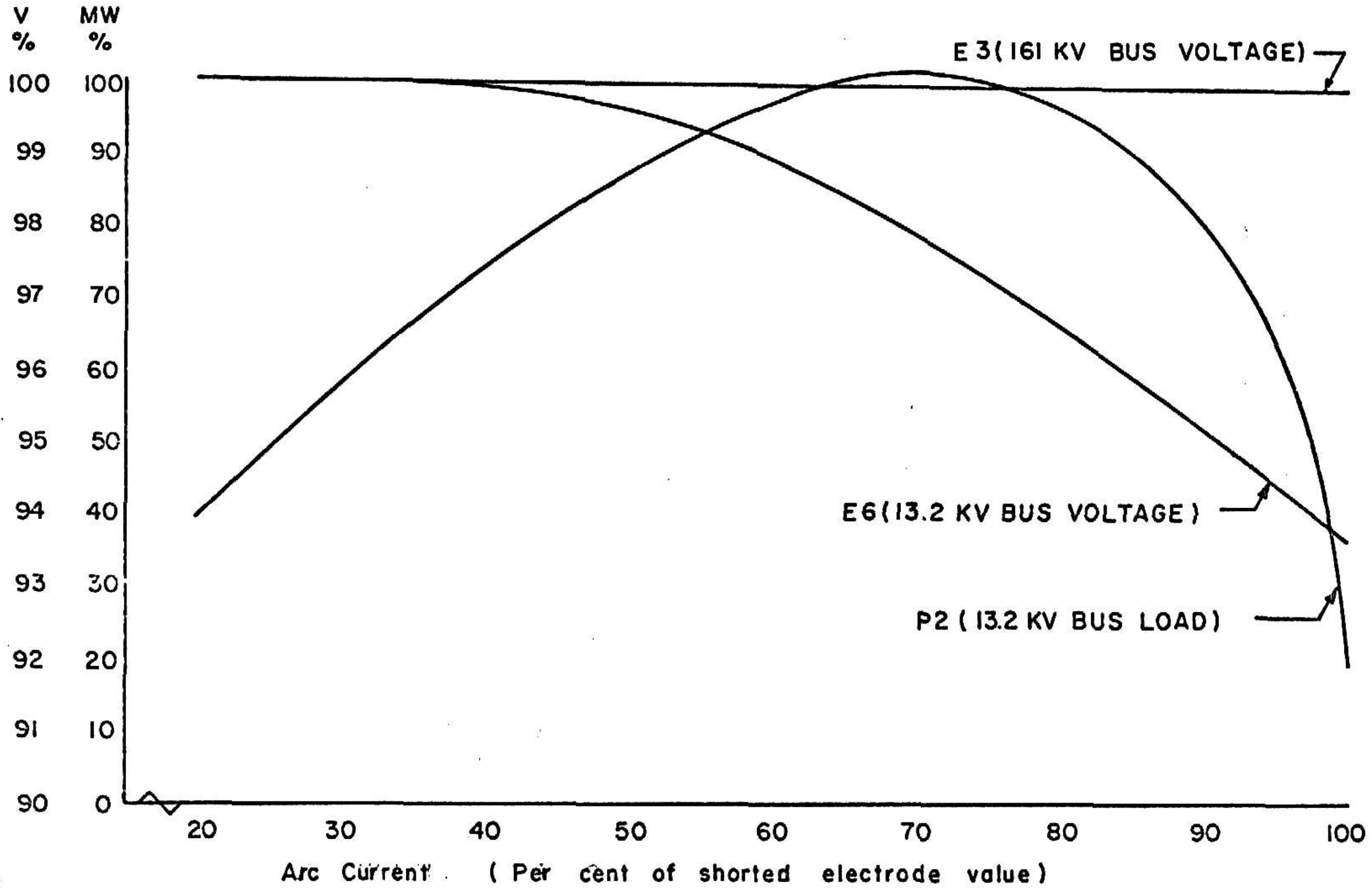


FIG. 14 1968, NO. 3 FURNACE (44 MVA) WITH NORMAL SYSTEM

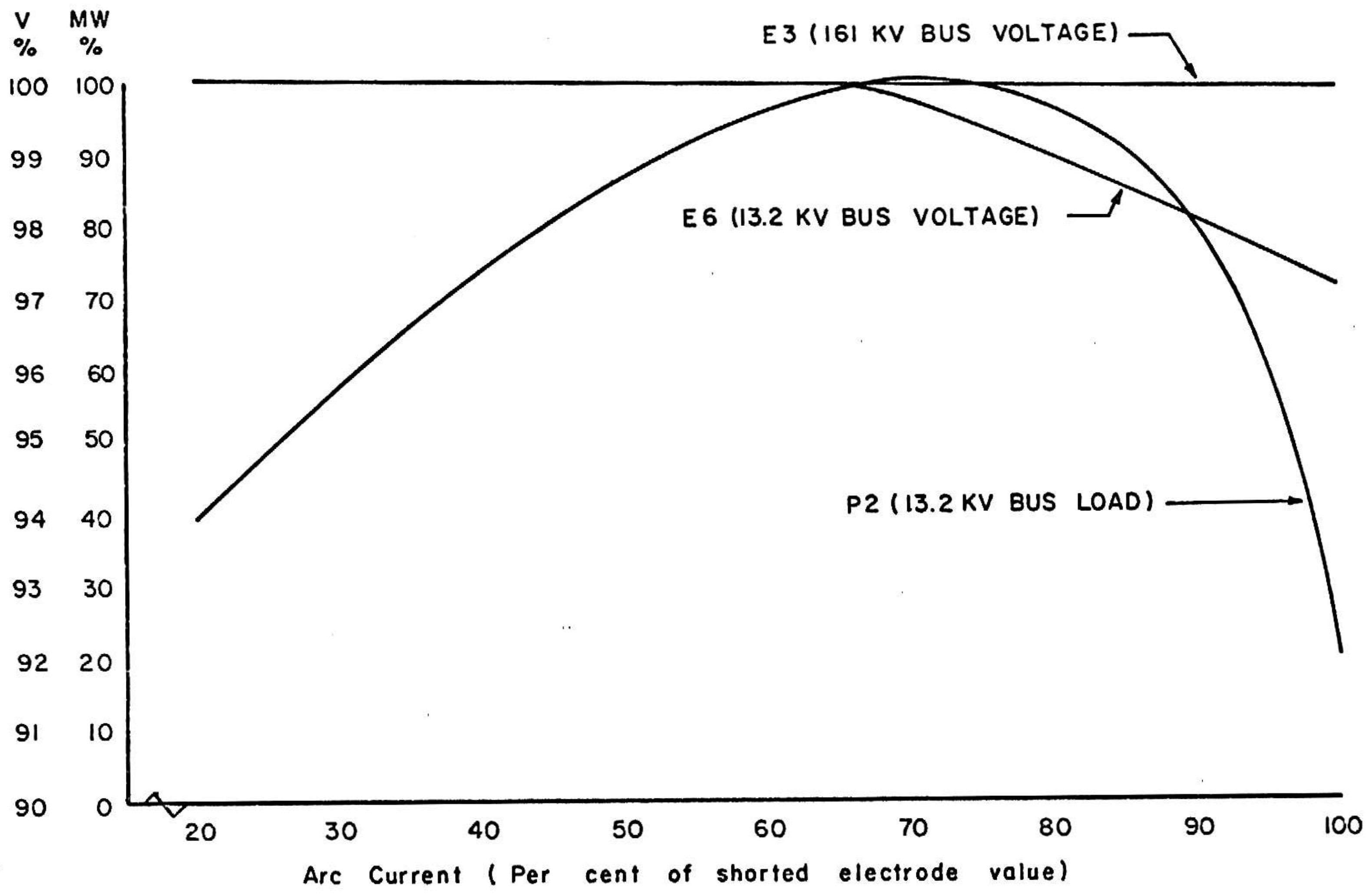


FIG. 15 1969, NO. 4 FURNACE (52.2 MVA) WITH NORMAL SYSTEM

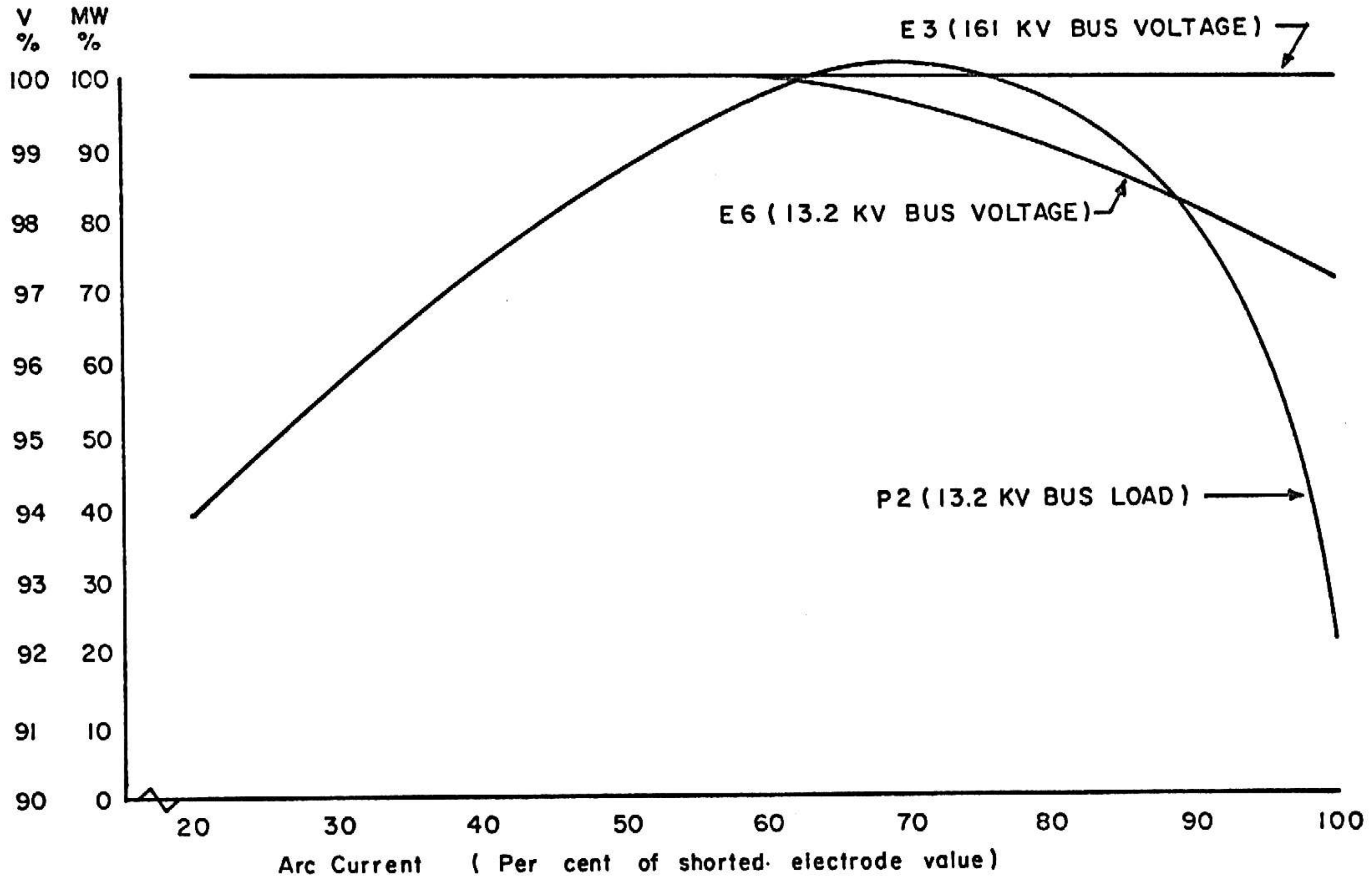


FIG. 16 1969, NO. 4 FURNACE WITH HAWTHORN UNIT 3 AND NORMAL SYSTEM