POWER FACTOR INVESTIGATION AND RECOMMENDED REMEDIES AT OLDS MOTOR WORKS

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SUPPLEMENTARY
MATERIAL
IN BACK OF BOOK

POWER FACTOR INVESTIGATION

AND RECOMMENDED REMEDIES

AT

OLDS MOTOR WORKS

A REPORT

SUBMITTED TO THE FACULTY OF

THE MICHIGAN AGRICULTURAL COLLEGE

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PREFACE.

The maintaining of the power factor of Alternating Current systems in industrial plants at as high a value as possible has, during the past few years, become of paramount importance. Especially during the recent world war was the necessity for a high power factor felt. In the attempt to cure the low power factor, a number of public and private power companies have inserted power factor penalty clauses in their rate schedules.

The Light and Power Commission of the City of Lansing has worked out a schedule which imposes a penalty on poor power factor and grants a bonus on good power factor. That the Olds Motor Works would suffer financially with the adoption of this penalty plan was recognized by the engineers and officials of the company. In order to attempt correction of the low power factor, a thorough survey of the conditions existing in the plant has been made. In the following pages we have endeavored to point out the defects existing in the factory and have suggested remedies to be applied, the practical aspects of the problem being mainly considered.

We are indebted to Messrs. Kidd, Bailey, and Blackman of the Olds Works for their assistance in making available to us the facilities of the plants for use in our investigation, and to Professors Folts and Cory of

the Michigan Agricultural College for advice and criticism. Much useful information has been secured from the publications of the Westinghouse Electric and Manufacturing Company, the Esterline Angus Company, and the H. L. Doherty Company. The Electrical World, the Electric Journal, and Clayton's Monograph on Power Factor Correction have also been consulted in preparing this thesis.

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INTRODUCTION.

The power in watts in a direct current circuit is equal to the product of volts and amperes. However, this may not be true in alternating current circuits. Usually the true power in a single phase circuit is somewhat less than the product of volts and amperes. For convenience, this product has been termed apparent power because of the direct current relationship. The unit of apparent power is the volt-ampere or the kilo-volt ampere (KVA).

In order to have some simple means of expressing the value of "true power" in terms of "apparent power", the term "power factor" has been employed.

The power factor of an alternating current circuit delivering power is defined as the ratio of the true power to the apparent power. That is, true power in watts equals volt-amperes multiplied by the power factor.

Now in an alternating current circuit the current and voltage are assumed to be varying according to sine waves. In any circuit the magnitude and position of the voltage wave on the time axis is fixed. Now the current wave may fall in time phase with the voltage wave, it may fall ahead of it, or it may fall behind it. If the two waves are in time phase, the power factor of the circuit is unity. If the current wave is ahead of the voltage wave, the current is said to be a "leading" current; and if the current wave is behind the voltage, the current is said to be a "lagging" current. (See Figs. 1 - 3).

The phase relationship of the current and voltage is dependent upon the relative amounts of resistance, inductance and capacitance of the circuit. In a circuit having resistance only, the voltage and current waves are in time phase and the power factor is unity. In a purely inductive circuit, the current lags behind the voltage by 90°, whereas in a purely condensive circuit the current leads the voltage by 90°. Where both inductance and capacity are present, the current leads or lags according to the relative magnitudes of the reactances. The ideal condition exists when the inductance and capacity are so balanced that their effects completely neutralize each other, and produce unity power factor.

Having stated the subject in general terms we will now proceed to an analytic discussion. Any true sine wave may be expressed as a vector. Since the voltage and the current are assumed to vary according to sine waves they will be treated as vectors in this discussion. In a circuit having resistance only, the current vector and the voltage vector would lie on the same straight

Vector Diagrams Showing Voltage-Current Relations in A.C. Circuits

FIG. 1.

CURRENT & VOLTAGE IN PHASE

FIG. 2

CURRENT & VOLTAGE OUT OF PHASE CURRENT LEADING VOLTAGE

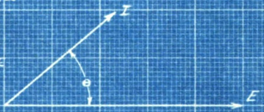


FIG. 3

CURRENT LAGGING VOLTAGE

line as in Fig. 1. Now if a certain amount of inductance is introduced into the circuit, the current will lag a certain amount behind the voltage as in Fig. 4. This current vector can be divided into two components, one in phase with the voltage and the other at right angles to it.

Now the power is equal to the voltage times the component of the current in phase with it. The horizontal component in the figure is called the real current as it is a measure of real power. The vertical component produces no power and is therefore often called the wattless current. However, this term wattless current is somewhat misleading because this current flowing through a wire will produce heat and consume power. It is now more common to speak of it as the reactive current.

An ammeter reads the vector sum of the real current and reactive current. If the angle of lag is known, it can be seen, by the geometry of the figure, that the real or inphase current is equal to the total current times the cosine of the angle of lag, (ϕ). Now since power is equal to volts times the inphase current, it must (by substitution) be equal to volts times total current times the cosine ϕ. But we have said that power is equal to volt-amperes times power factor. Therefore, power factor must be equal to cosine ϕ. This now becomes our new definition for power factor.

VECTOR DIAGRAMS
SHOWING
RELATION OF REAL AND
REACTIVE CURRENT COMPONENTS

FIG. 4

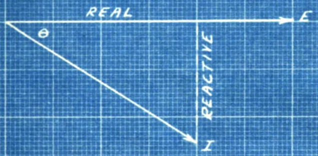


FIG. 5

We will now take up the factors which determine the angle of lag or lead. Let us consider again Fig. 4, but draw it as in Fig. 5. The voltage is here divided into its two components, one in phase with the current and the other at right angles to it. The inphase component is the voltage drop across the resistance or Ir and the quadrature component is the voltage drop across the reactance or Ix. The hypotenuse or Iz drop is equal to the impressed E.M.F. If each side of the triangle is divided by I, we have similar triangle with sides r, x, and z, known as the impedance triangle. Now from the geometry of the figure, the angle of lag or lead is equal to arc tan x/r. In other words the angle of lag depends upon the relative values of resistance and reactance.

The term reactance (x) can be divided into two classes, inductive reactance and condensive reactance.

Mathematically, inductive reactance in ohms is equal to $2\pi fL$, where f is the frequency and L is the inductance in henrys. Since frequency is constant in all commercial work, this can be dropped from consideration. The next question is what constitutes inductance. When ever a current is flowing through a circuit, a magnetic field is established around the wire. If the circuit is in the form of a coil, a great many of these lines of force will cut the circuit itself. Now if the current varies these lines of force will vary and an E.M.F. will be set up on the circuit which, according to Lenz's Law will oppose the original E.M.F. This magnetic property of the circuit is called inductance and the opposition to the flow of current due to this magnetic property of the circuit is called reactance.

Condensive reactance is just opposite in effect to inductive reactance. This makes it valuable for power factor correction, and it will be taken up in detail in a later chapter under power factor correction.

CAUSES OF POOR POWER FACTOR.

The power factor of a circuit depends upon the nature of the load as before stated. In a circuit composed of incandescent lamps the power factor is practically unity because the load is made up almost entirely of pure resistance. But when considerable inductive apparatus is present in the circuit the power factor is less than unity.

While inductance is the cause of low power factor, the magnitude of its effect depends upon the ratio between it and the resistance since the phase angle is equal to the arc tangent X/R.

Since inductance is, to a certain degree the cause of poor power factor, to locate the cause of poor power factor means the discovery of the sources of inductance or capacitance in the circuit. The induction motor offers a distinct problem which is taken up in later discussions. The various sources of inductance in alternating current circuits are induction motors, transformers, arc lamps and accessory apparatus, reactance coils and even transmission lines. Of these, the induction motor and the transformer are by far the most important and the rest will be dropped from this discussion. The importance of these pieces of apparatus is magnified when one considers the extent to which they are used in industrial establishments.

Reference to the performance curves of the induction motor, which may be seen in any standard text on Electrical Engineering or in another part of this thesis, will serve to impress the reader with the serious effects of the lightly loaded induction motor on power factor. The transformer offers a similar problem but the effect is not so far reaching as in the case of the induction motor. In the following paragraphs an analytic treatment will be made in an attempt to explain the effect of inductance and light loading upon power factor.

As before stated, the current drawn by an inductive circuit is composed of two components "power" and"reactive" current as shown in Fig. 4. The reactive component of the current is the "exciting" of "magnetizing" current. Its magnitude is governed largely by the dimensions and the material of the induction motor and the transformer. For motors of large pole pitch, the magnetizing current may be as low as 25% of normal full load current, but for machines having a large number of poles of small pitch it may be as high as 60% to 70% of the normal full load current. Referring to Fig. 6 the full load current is represented by OB and its magnitude is the same regardless of its phase position. Then if the reactive current is, say 80%, of full load current, Sin θ = AB/OB = .8 OB/OB = .80. Then the power factor is Cos θ or .60. It is seen that the power factor is always nearer unity at full load, for any given reactive component, because then the reactive component is the smallest in comparison.

However, it is extremely common to find machines loaded far below normal, and herein lies one of the greatest causes of low power factor. When a machine is lightly loaded the power component of the current is very small and the reactive magnetizing component is just as great as at full load. Hence the current vector OB (Fig. 6) takes the position OB' (Fig. 7) in which θ' becomes necessarily greater than θ and the power factor correspondingly less since power factor equals the Cosine θ. This is the explanation of the low power factor at light loads as is shown by the performance curves of induction motors.

With various degrees of loading the transformer performs in a manner similar to the induction motor but modern transformers are so designed as to draw a small magnetizing current and for this reason the effect upon the power factor is much less.

The evil of lightly loaded electrical apparatus is now known to be very prevelant in electrically operated plants. This is due largely to the fact that the power rating of machines installed for certain

Diagrams Showing that constant exciting current causes poor Power Factor at Light Loads.

FIG. 6

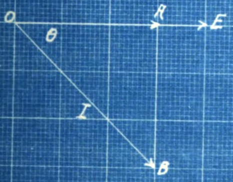


Fig. 6

FIG. 7

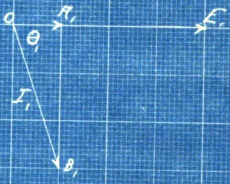


Fig. 7

purposes is invariably larger than required. The installer of the apparatus is desirous of putting in a machine that will carry the greatest possible load that may be put upon it. Here is the error, for such practice means the ignoring of the fact that any motor can stand an overload for a short period and a reasonable overload for a considerable period of time. For instance, a typical induction motor will carry a 300% load momentarily, 25% overload for 2 hours and 50% overload intermittently. Hence the folly of overmotoring, especially in view of the effect on power factor.

Overmotoring is often also due to changes made in the use of equipment from time to time, where a machine formerly used to do work requiring 3 horsepower and motored for this work is changed to do work requiring but 1 horsepower no change being made in the motor installation. The effect of such procedure on power factor is evident.

These are the primary causes of low power factor which are now causing central stations to base their charges for power upon KVA or apparent power instead of upon KW or real power.

EFFECTS OF POOR POWER FACTOR.

Low power factor results in many undesirable things. In general they are listed below:-

Increased losses in:-

(1) Exciters,

(2) Generator Fields,

(3) Generator Armatures,

(4) Distributing Lines,

(5) Transformers,

(6) Losses due to lower efficiency on account of unbalancing of equipment,

(7) In consumers' distributing system.

Reduced capacity of:-

(8) Generators,

(9) Distributing Lines,

(10) Transformers,

(11) Customers distributing systems,

Other effects:-

(12) Reduction of effective capacity of entire investment,

(13) Poor voltage regulation,

(14) Increased maintenance due to over-heating.

But the economic aspect of the problem is by far the greatest, for every evil of low power factor is ultimately an economic proposition. The power factor prevailing in a plant determines to little extent the size of conductors, switches, and like equipment necessary. Consequently the investment in such equipment is dependent to some extent on the power factor. Thus the economic importance of the problem is clearly brought out.

The undesirability of low power factor, from an economic viewpoint, is caused almost entirely by the fact that the design of all electric equipment is not on a KW or "power" basis but rather on a KVA basis. The reason for this is that the heating of the conductors in any equipment places a limit upon the allowable current. This maximum current multiplied by the rated voltage gives the KVA capacity. But the actual power, at any given power factor equals the KVA multiplied by the power factor. Hence, low power factor causes a proportionally low capacity. This is clearly shown by the curve (Fig. 8) which shows the relation between KVA and KW for various values of power factor from 0 to 100%. The reduced capacity of induction motors operating at low power factor is clearly shown by the curves (Figs. 9-13). The motors to which these curves apply are among those used at the Olds Plant. The reduction of capacity is not confined to motors alone but affects the capacity of all equipment. From this it may be seen that low power factor means a needlessly high initial investment in equipment.

FIG. 8

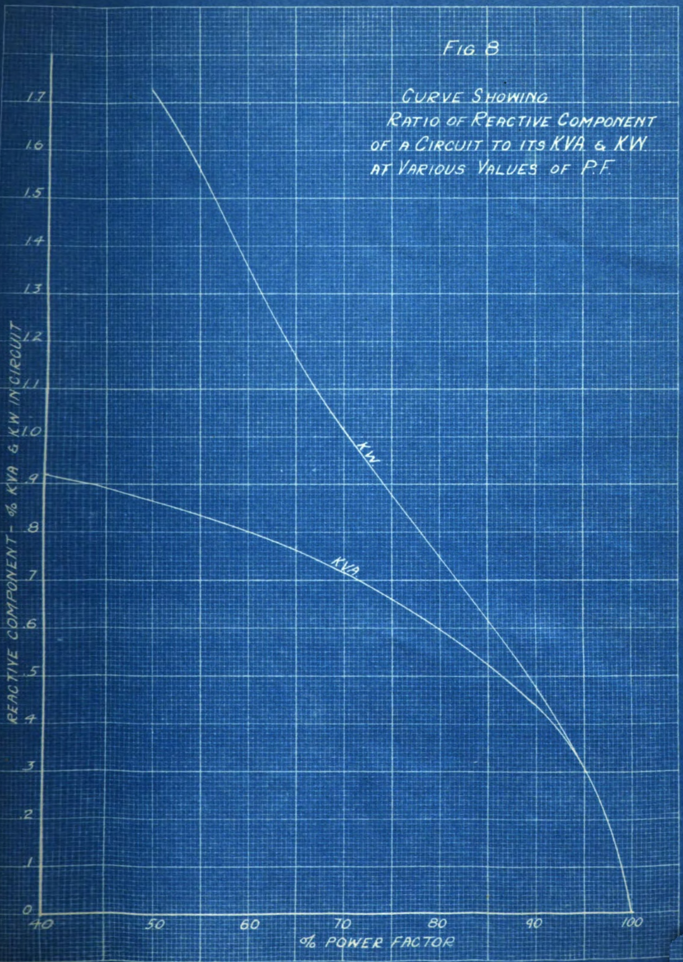
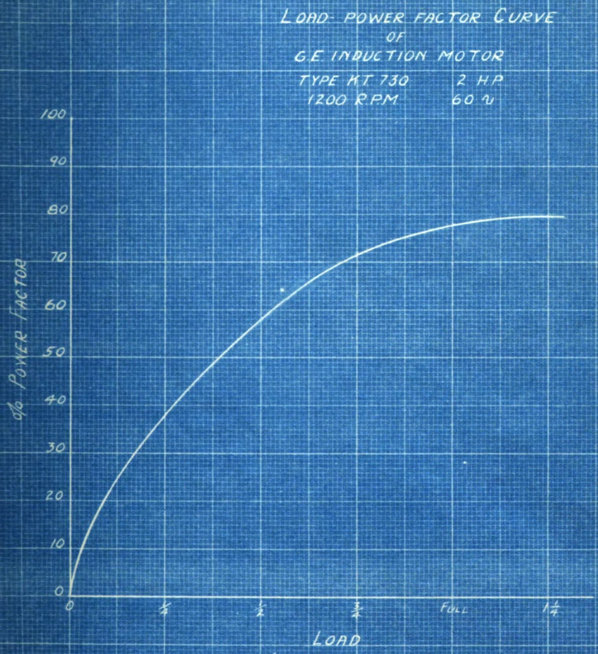

CURVE SHOWING
RATIO OF REACTIVE COMPONENT
OF A CIRCUIT TO ITS KVA & KW
AT VARIOUS VALUES OF P.F.
KW
KVA
REACTIVE COMPONENT - % KVA & KW IN CIRCUIT
% POWER FACTOR
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
40
50
60
70
80
90
100

FIG 9


LOAD- POWER FACTOR CURVE
OF
G.E. INDUCTION MOTOR
TYPE KT 730 2 H.P.
1200 R.P.M. 60 ~
% POWER FACTOR
100
90
80
70
60
50
40
30
20
10
0
0
1/4
1/2
3/4
FULL
1 1/4
LOAD

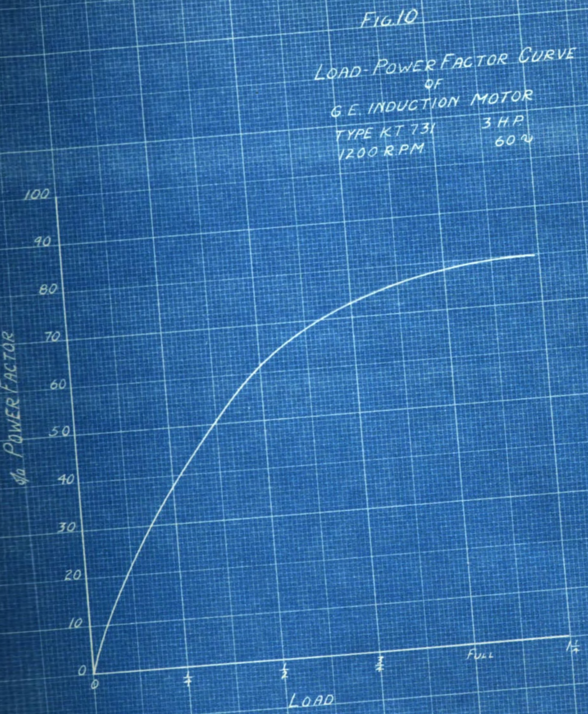


FIG. 10
LOAD-POWER FACTOR CURVE
OF
G.E. INDUCTION MOTOR
TYPE KT 731
3 H.P.
1200 R.P.M.
60 ~
% POWER FACTOR
100
90
80
70
60
50
40
30
20
10
0
0
¼
½
¾
FULL
1¼
LOAD

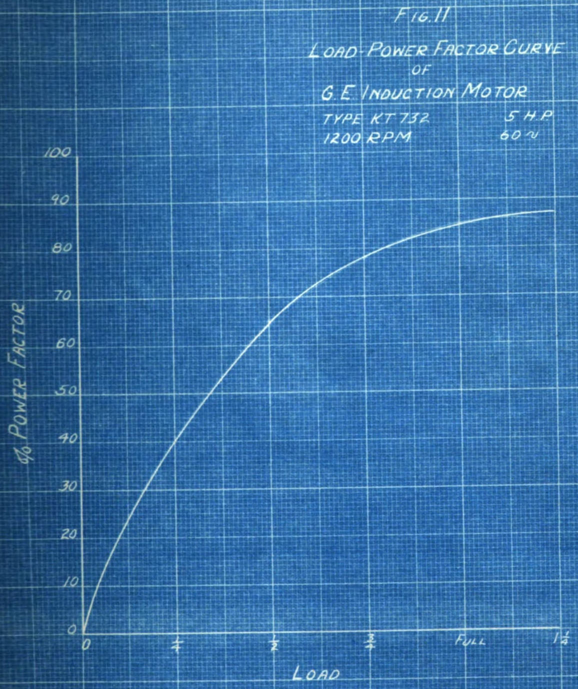


FIG. 11
LOAD-POWER FACTOR CURVE
OF
G.E. INDUCTION MOTOR
TYPE KT 732
5 H.P.
1200 RPM
60 ~
% POWER FACTOR
100
90
80
70
60
50
40
30
20
10
0
0
1/4
1/2
3/4
FULL
1 1/4
LOAD

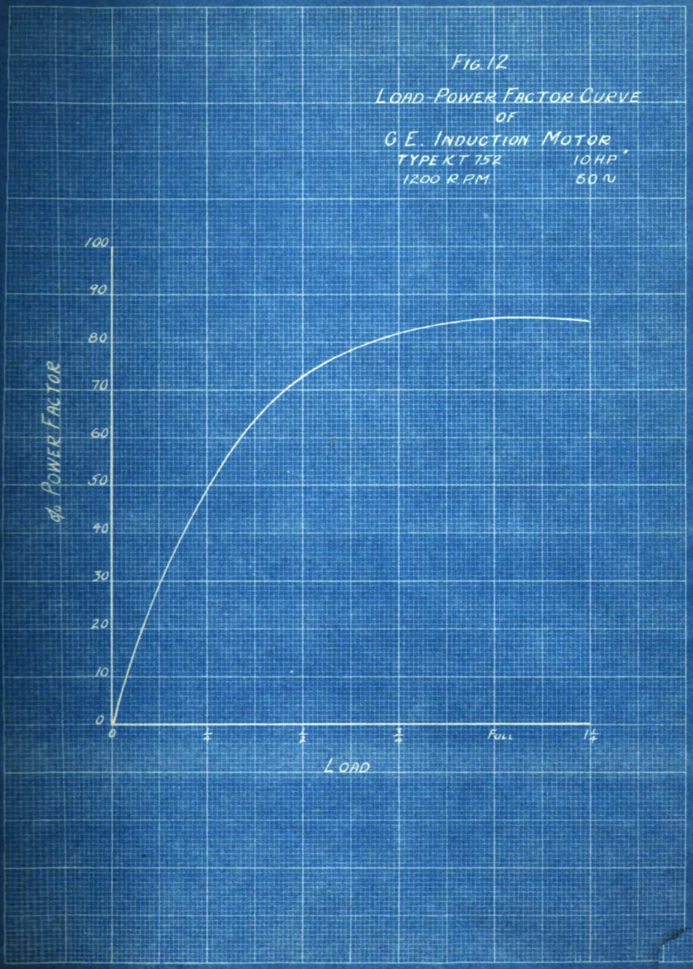
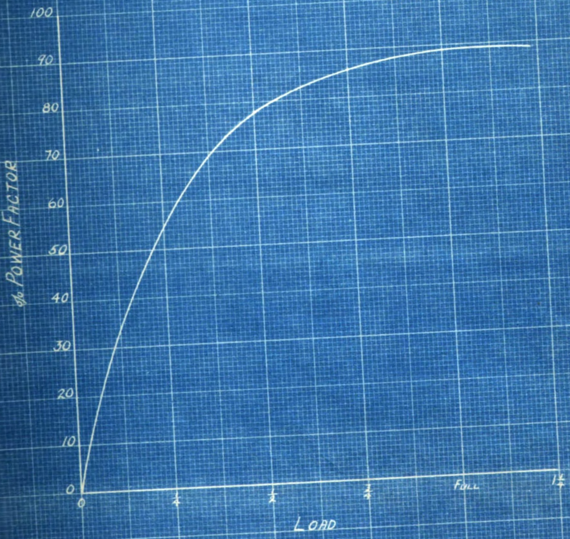


Fig. 12
Load-Power Factor Curve
of
G.E. Induction Motor
Type KT 752
10 H.P.
1200 R.P.M.
60 ~
% Power Factor
100
90
80
70
60
50
40
30
20
10
0
1/4
1/2
3/4
Full
1 1/4
Load

Fig. 13

Load-Power Factor Curve
of
G.E. Induction Motor
Type KT 346 50 H.P.
900 R.P.M. 60~



But the economic aspect does not end here. As has been mentioned, there is a growing tendency on the part of central stations to insist upon the inclusion of a power factor penalty clause in the customers contract. The following schedule shows the relation between cost and power factor for values of power factor from 30 to 100%, according to the practice of the City of Lansing. The multipliers listed are applied to the kilowatt hours recorded and the customer is charged the resulting rate for the product. Note that 80% is rated as normal power factor and a bonus is allowed for power used at a power factor in excess of 80%. A power factor of less than 80% results in a multiplier of greater than 1 being used and consequently a higher cost is paid for the power. At 100% power factor the multiplier is .933 while at 30% it is 1.622. Thus a power factor of 30% means a penalty of 74% of the lowest possible cost of power being paid. The effect of this on the operating cost is obvious.

Operating efficiency is also seriously affected by low power factor. This is because all losses are either the same or greater at lower factor than they are at high power factor. The copper loss, for instance, varies inversely as the square of the power factor as shown by the following development:

Let I = value of power component of current,

R = resistance of the circuit

Cos Θ = power factor.

Then the total or line current (in single phase circuits) $\frac{I}{\cos \Theta}$

$$\text{Copper loss} = \left(\frac{I}{\cos \Theta}\right)^2 R = \frac{I^2 R}{\cos \Theta^2}$$

Thus the copper loss varies inversely as the square of the power factor.

Among the principal evils of low power factor are excessive heating and poor voltage regulation. Taking up the first, it is due, in the case of the motor, to the effort of the motor to develop just as much power under heavy load as it would with high power factor. In so doing the motor draws an excessive total current in order that the useful or "power" component will be sufficient to do the work. Total current equals useful current. For example, if full normal power were developed by an induction motor operating at 50% power factor the total current would equal $\frac{\text{useful current}}{.50}$ or twice the useful current.

Hence the heating effect would be four times as great as at unity power factor since heating varies as the square of the current.

Poor regulation at low power factor is due to the abnormally high IR drop which is caused by the higher current flowing for the same capacity and also by the increased reactance drop. The diagram (Fig. 14), shows the effect of low power factor upon regulation. OA shows the position of the voltage vector at practically unity power factor and OA' the position at about 70% power factor. OB is the effective voltage on the motor and is taken at 100%. Vector OA shows the voltage vector under the first conditions. OA' is the vector representing the impressed voltage under the second conditions at which a power factor of about 70% prevails. By swinging the voltage vectors back to OX (the reference axis), it is seen that the lower the power factor the greater will be the impressed voltage required to give a certain impressed voltage, and therefore the poorer will be the regulation.

These effects are the principal ones encountered in power factor investigations and are the ones which will be improved by the installation of corrective apparatus.

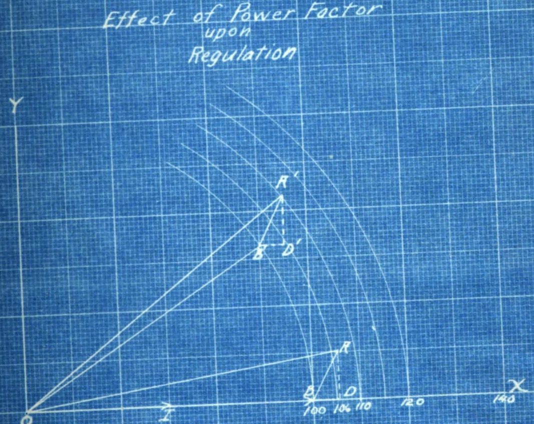

Effect of Power Factor
upon
Regulation
Y
R'
B'
D'
R
B
D
X
O
I
100
106
110
120
140

Fig. 14

BOARD OF WATER & ELECTRIC LIGHT COMMISSIONERS,
Lansing, Michigan.

Power Factor Correction which may be applied to any power user having a demand of 50 KW or more. Effective June 1, 1922.

Average Power Factor	Multiplier Constant	Average Power Factor	Multiplier Constant
100	.9330 -	65	1.0970 -
99	.9356	64	1.1062
98	.9382	63	1.1154
97	.9408	62	1.1246
96	.9434	61	1.1338
95	.9460 -	60	1.1430 -
94	.9490	59	1.1538
93	.9520	58	1.1646
92	.9550	57	1.1754
91	.9580	56	1.1862
90	.9610 -	55	1.1970 -
89	.9646	54	1.2096
88	.9682	53	1.2222
87	.9718	52	1.2348
86	.9754	51	1.2474
85	.9790 -	50	1.2600 -
84	.9832	49	1.2746
83	.9874	48	1.2892
82	.9916	47	1.3038
81	.9958	46	1.3184
80	1.0000 -	45	1.3330 -
79	1.0052	44	1.3498
78	1.0104	43	1.3666
77	1.0156	42	1.3834
76	1.0208	41	1.4002
75	1.0260 -	40	1.4170 -
74	1.0324	39	1.4362
73	1.0388	38	1.4554
72	1.0452	37	1.4746
71	1.0516	36	1.4938
70	1.0580 -	35	1.5130 -
69	1.0658	34	1.5348
68	1.0736	33	1.5566
67	1.0814	32	1.5784
66	1.0892	31	1.6002
		30	1.6220 -

Power factor shall mean the average power factor maintained by the customer during the month or period of time for which the electric energy is measured and shall be determined by the reactive component meter method and shall equal kilowatt hours (KWH) divided by the square root of the sum of the squares of kilowatt hours (KWH) and reactive kilovolt amphere hours (RKVAH). The Multiplier constant corresponding to the power factor for the month as determined by the above method shall be applied to the actual measured monthly consumption of electric energy. The product so obtained shall be known as billed electric energy and shall be the basis for computing and rendering customers bill in accordance with regular rate schedule.

Approved by the Board February 27, 1922.

Oscar E. Bulkeley, Supt.

REMEDIES FOR POOR POWER FACTOR.

THE STATIC CONDENSER.

The static condenser draws a current that is practically 90° ahead of the voltage. For this reason it is important in the correction of low power factors due to lagging currents.

A condenser is composed of two or more conductors separated by a dielectric. Commercially, the condenser unit is composed of a large number of couples of metal foil with paper laminations as a dielectric. The couples are treated under vacuum to withdraw all moisture, immersed in oil, and the container then hermetically sealed to prevent possible absorption of moisture from the air. For higher voltages mica is used as a dielectric.

A condenser introduces a reactance into the circuit which is opposite in effect to inductive reactance. It is called condensive reactance. Mathematically the reactance in ohms is equal to $1/2\pi fC$, where f is the frequency in cycles per second and C is the capacity in farads. Where no resistance is present, the amount of current flowing through the condenser is indicated by the equation:

$$I = 2\pi f C E$$

Where I = current in amperes

E = voltage on the condenser.

Then the volt-amperes it is capable of handling is given by the formula:

$$\text{Volt-amperes} = E\ I = 2\ \ f\ C\ E^2$$

$$\text{K.V.A.} = 10^{-3}\ 2\ \ f\ C\ E^2$$

From this:

$$C = \frac{\text{K.V.A.} \times 10^3}{2\pi f\ \ E^2}$$

This shows that the capacity required for a given correction is inversely proportional to the square of the voltage. From this it can be seen that it is desirable to have the voltage as high as possible.

The General Electric Company manufactures a condenser suitable for 2300 volts. It is designed to stand a much higher voltage in order to allow for a liberal factor of safety. Now it would not pay to put such a condenser as this across a low voltage line such as a 440 volt circuit. In this case the voltage impressed on it would be only 1/5 of what it could stand and the corrective effect would be only 1/25 of that which could be obtained. For this reason an auto transformer is used to step up the voltage to the rated voltage of the condenser.

The losses in a static condenser are very small. The loss due to leakage, in a well made condenser, should be an infinitesimal quantity. There is an appreciable loss due to dielectric hysteresis which seldom exceeds one half of one percent of the K.V.A. rating. There is also some copper loss in the leads to the condenser. When a transformer is used there is another loss introduced amounting to 1% or 2%. The total loss therefore varies from one half of one percent to two and one half percent.

The static condenser has no moving parts and therefore requires little or no attention. It is not as flexible as the synchronous condenser but it is well adapted to installations that are permanently fixed.

THE SYNCHRONOUS MOTOR.

A synchronous motor is similar to an alternator. Consider two alternators connected in parallel to the same bus bars with equal field excitations and running in synchronism carrying equal loads. In the series circuit between the alternators no cross-current is flowing and the voltage vectors are 180° apart. Now if the power supply is cut off from one alternator, its voltage will lag a certain angle behind the other alternator. This will cause a cross-current to flow in the loop circuit which transmits power to the first machine and it runs as a motor.

Like an alternator, the synchronous motor may either have a revolving field or a revolving armature. Also, like an alternator, it must have a source of direct current to excite its field.

The synchronous motor without auxiliary windings has no starting torque. It could be brought up to speed by another motor and synchronized into the line like an alternator. However, it is more common to start a synchronous motor from the alternating current side by use of an auxiliary winding. This winding consists of imbedding conductors in the face of the poles which converts the machine into a squirrel cage induction motor. It is also necessary to cut down the voltage by means of an auto-transformer for the starting period. As the machine comes up to speed it automatically falls into synchronism and full voltage may then be applied. The squirrel cage winding is automatically cut out as it would be cutting no lines of force at exactly synchronous speed.

In this discussion, we are especially concerned about the power factor characteristics of the synchronous motor. We will first take up a general explanation and then a vector analysis.

The value of the armature current depends partly upon the load on the motor, but also largely upon the value of the exciting current. The watt component of the current is determined by the load on the motor, and the wattless component by the value of the direct current excitation, so that the power factor depends very largely upon the excitation. Suppose the motor is running without a load. The watt component of the current is practically constant and relatively small. Under these conditions the power factor depends entirely upon the value of excitation. Neglecting the losses which occur in the machine, when the excitation is such that the E.M.F. indused by the main flux in the armature winding is exactly equal to the applied voltage, the machine would take no current. Actually, with this excitation, the armature takes a very small current at unity power factor. For all values of excitation less than the above, the power factor will be less than unity and rapidly approaching zero as excitation diminishes. This is due to the fact that the machine is not sufficiently excited with direct current, and the extra excitation necessary for establishment of an induced E.M.F. to balance the applied voltage must be provided by the alternating current supply. The current taken from the mains, being chiefly a magnetizing current, lags greatly behind the voltage.

If, on the other hand, the excitation is increased beyond the value corresponding to unity power factor, the machine is over-excited and tends to raise the voltage of the system by sending a current into the mains lagging by 90°. In this case the motor draws a leading current depending upon the amount of over-excitation.

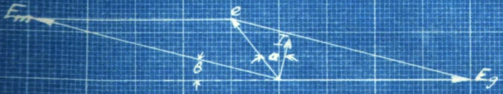
Having explained the power factor characteristics in general terms we will now take up a vector analysis. Considering two cases, one in which the field is under-excited and the other where it is over-excited.

The vector Eg represents the voltage of the generator. (Figs. 15 - 16). The vector Em represents the counter voltage of the motor which lags a certain angle (B) behind the 180° point depênding upon the load. The numerical value of Em is determined by the excitation of the field. We are taking up two

Vector Diagrams of Under-excited
and Over-Excited
Synchronous Motors

Fig. 15

Fig. 16



cases, one where Em is less than Eg and the other where Em is greater than Eg. The voltage tending to send current through the closed loop, consisting of the armature of the generator and the armature of the motor and line, will be the vector sum of the two voltages Eg and Em and it may be represented by vector e which is found by completing the parallelogram. The current in the loop will lag a certain angle a behind this resultant voltage due to the inductance of the circuit. Referring again to the figures, if the voltage Em is small it will cause the current I to fall behind the voltage Eg and if the voltage Em is large it will cause the current to fall ahead of the impressed voltage Eg. As the angle a is fixed, thus we see that the power factor of the current drawn by a synchronous motor is determined by field excitation.

The synchronous motor has a somewhat limited industrial application.

It cannot be used profitably:

(1) On small loads under 100 H.P.

(2) On intermittent loads involving frequent starting and stopping,

(3) Where variable speed or adjustable speed is demanded,

(4) Where it is necessary to start up under load,

Synchronous motors are used extensively for:

(1) Air Compressors,

(2) Line shafts,

(3) Motor generator sets,

(4) Centrifugal pumps.

The synchronous motor is frequently over excited and allowed to run without a load. In this case, it is called a synchronous condenser because it draws a current leading by nearly 90° and it can therefore be used in power factor correction. The sychronous condenser need not be built as rigidly as the synchronous motor as it does not carry a mechanical load.

THE PHASE ADVANCER.

Another method of correcting for poor power factor has found a limited application in European countries. This is known as the phase advancer.

In the first part of the discussion it was stated that poor power factor conditions were largely due to lightly loaded induction motors which draw a large magnetising current. Under the discussion of the synchronous motor we pointed out that the magnetisation could either be supplied by the direct current field or from the current in the armature. In the same way in an induction motor, the magnetisation may either be supplied through the static winding at line frequency or through the rotor winding at a very low frequency.

The phase advancer is an exciter which is used to supply current at a very low frequency to the rotor of an induction motor. When this current has the proper phase relationship it will supply the magnetisation. Then little or no magnetising current will be drawn from the line and the current will have nearly 100% power factor.

This method is not useful in our problem because it necessitates getting away from the ideal simplicity of the squirrel cage induction motor. The phase advancer method of power factor correction would require that all motors be of the wound rotor type. In addition to this it would require a separate exciter for each machine. In view of these facts we will drop this method from the discussion.

REMOTORING.

A remedy which is often employed to correct low power factor is a thorough remotoring of the plant. By referring to the load-power factor curves contained herein it is seen that an underloaded induction motor is a menace to good power factor. When a small capacity motor carries a load of but one-half normal the power factor is in the neighborhood of 65%, while at full load the value of the power factor is increased to 85%. It is obvious that the selection of the proper size of motor for each particular machine would result in a higher power factor.

In plants where the loads on the motors fluctuate in value, it is somewhat difficult to say what capacity motors should be chosen to drive the various machines. If a heavy intermittent load is demanded of a motor, it is safe to assume that the motor will operate without destructive heating at 50% overload. In choosing a motor, then, to drive a machine where a heavy load comes on only at intervals, the engineer is justified in choosing one considerably smaller. In this way the low power factor due to underloaded induction motors may be improved.

In remotoring it is well to keep in mind that for group drives of considerable size synchronous motors may be made use of. If the fields are over-excited the motors are caused to draw a leading current thereby materially improving the plant power factor. As a rule, however, synchronous motors are more expensive than induction motors, and the difficulties encountered in their operation limit their use in industrial plants.

Remotoring a plant has some features which renders its application as a cure for poor power factor of doubtful value. In the first place there are few concerns which are likely to go to the expense of removing a large number of motors, discharding them and purchasing others to take their places. Also the time required to make such changes would require, in many cases, a complete shutdown of the plant. Such procedure would not be countenanced by plant officials.

Where changes in present installations are made or where new machines are being put in, considerable care should be taken to see that a motor of proper size is installed. If this is done it not only causes a decrease in original cost but also results in an increased efficiency and a better power factor.

ADVANTAGES OF POWER FACTOR CORRECTION.

When industrial plants purchase their own power there are a number of advantages to be gained by maintaining a reasonably high power factor. The advantages all have a bearing on the cost of power or on the satisfactory operation of the motors.

The first advantage is that of better regulation in distribution systems the importance of which is very evident. As this has been mentioned before it will not be dwelt upon.

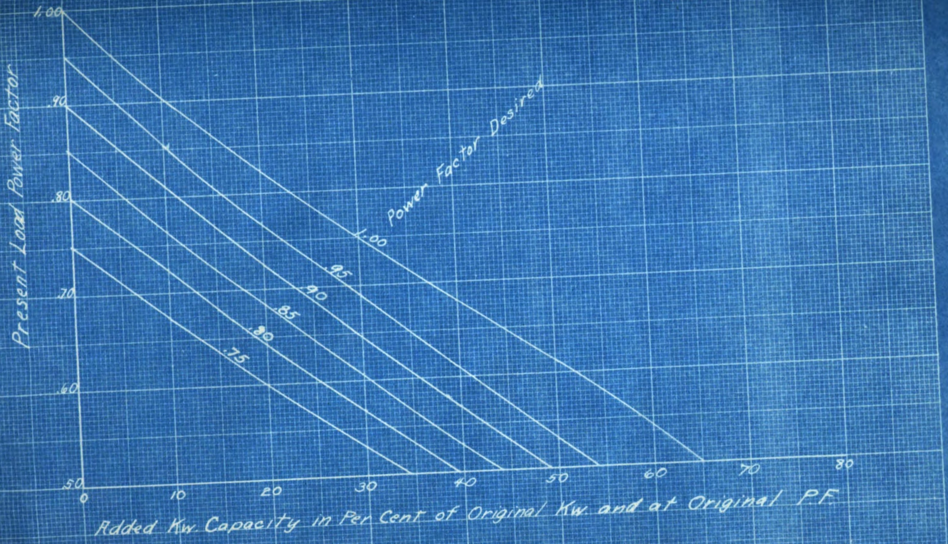
Another advantage which may be mentioned is that of increased KW capacity with high power factor. The effect may be seen graphically by referring to the curve, (Fig. 17).

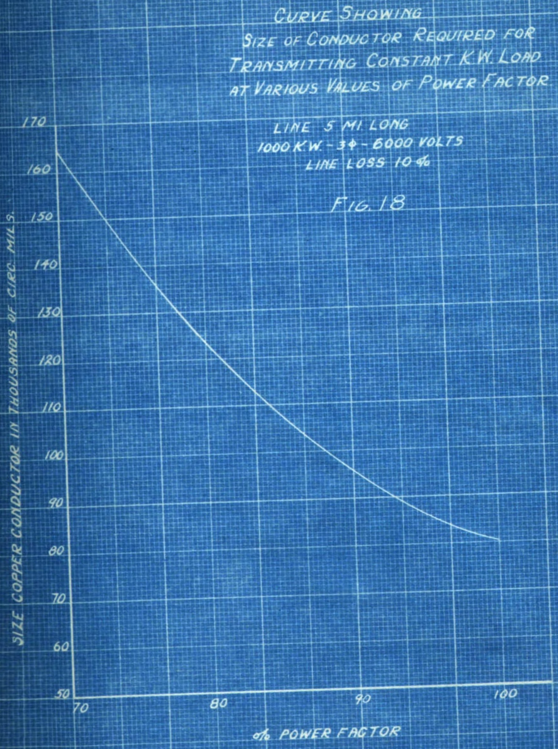
An advantage of no small importance is that with a high value of power factor a much smaller conductor may be used for supplying a given KW load than when poor power factor prevails assuming equal line losses. The curve accompanying (Fig. 8) shows the effect of power factor on the size of conductor required.

The biggest advantage, however, of maintaining high power factor involve the power factor penalty clauses which have been, of late, included in power contracts. A clause of this kind, which is operative in the City of Lansing, has been discussed previously.

Additional K.W. Capacity made Available by P.F. Correction.

FIG. 17




CURVE SHOWING
SIZE OF CONDUCTOR REQUIRED FOR
TRANSMITTING CONSTANT K.W. LOAD
AT VARIOUS VALUES OF POWER FACTOR
LINE 5 MI. LONG
1000 K.W. - 3Φ - 6000 VOLTS
LINE LOSS 10%
FIG. 18
SIZE COPPER CONDUCTOR IN THOUSANDS OF CIRC. MILS.
170
160
150
140
130
120
110
100
90
80
70
60
50
70
80
90
100
% POWER FACTOR

The penalty imposed by this clause when compared with the cost of installation and maintenance of static condensers shows very clearly that an industrial plant is well repaid for installing corrective apparatus. Fig. 19 shows the effect graphically. These curves were drawn from data calculated on the basis of original cost plus upkeep, interest on investment, and depreciation as compared with the cost of power per KW per year under the penalty clause. From this the net saving per KW per year is obtained. Details of these calculations are given in the following pages using several different values of power factor as the initial value.

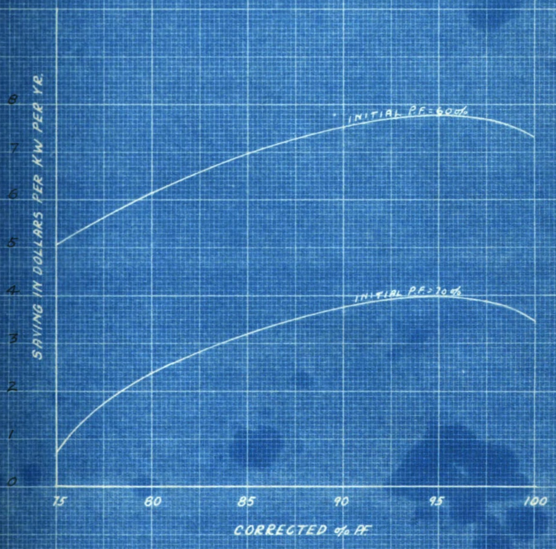
CURVE SHOWING

NET SAVING IN DOLLARS

PER K.W. PER YEAR

RESULTING FROM P.F. CORRECTION

FIG. 19



ORIGINAL POWER FACTOR 50%.

CORRECTED BY MEANS OF STATIC CONDENSERS

SAVING BASED ON THE PENALTY CLAUSE NOW IN

EFFECT IN THE CITY OF LANSING.

Power factor corrected to	Condenser required per K.W.	Original cost of static Condenser at $16 per K.V.A.	Annual Cost at $4 per K.V.A. (Int.upkeep & depreciation
75%	.85048	13.60	3.40
80	1.00906	16.10	4.03
85	1.11041	17.75	4.45
90	1.24791	19.95	4.98
95	1.40369	22.42	5.61
100	1.73205	27.75	6.94

Power factor corrected to	Saving per hour	Saving for 1 year 3000 hrs.	Net saving per KW per year
75%	.00468	14.04	10.64
80	.0052	15.60	11.57
85	.00562	16.86	12.41
90	.00598	17.94	12.96
95	.00628	18.84	13.23
100	.00654	19.62	12.68

ORIGINAL POWER FACTOR 60%

CORRECTED BY MEANS OF STATIC CONDENSERS

SAVING BASED ON THE PENALTY CLAUSE NOW IN

EFFECT IN THE CITY OF LANSING.

Power factor corrected to	Condenser required per K. W.	Original cost of static Condenser at $16 per K.V.A.	Annual cost at $4 per K.V.A. (Int. upkeep & depreciation)
75%	.45187	7.23	1.81
80	.6105	9.79	2.44
85	.71185	11.40	2.85
90	.84935	13.60	3.39
95	1.00303	16.05	4.01
100	1.33349	21.40	5.34

Power factor corrected to	Saving per hour	Saving for 1 year 3000 hrs.	Net saving per KW per year
75%	.0023	6.90	5.09
80	.00286	8.58	6.14
85	.00328	9.84	6.99
90	.00364	10.92	7.53
95	.00394	11.82	7.81
100	.0042	12.60	7.26

ORIGINAL FACTOR POWER 70%

CORRECTED BY MEANS OF STATIC CONDENSERS

SAVING BASED ON THE PENALTY CLAUSE NOW IN EFFECT IN THE CITY OF LANSING.

Power factor corrected to	Condenser required per K.W.	Original cost of static Condenser at $16 per K.V.A.	Annual cost at $4 per K.V.A. (Int. upkeep & depreciation
75%	.13826	2.215	.555
80	.10600	4.75	1.19
85	.3988	6.39	1.59
90	.53584	8.61	2.15
95	.69152	11.09	2.76
100	1.01998	16.31	4.08

Power factor corrected to	Saving per hour	Saving for 1 year 3000 hrs.	Net saving per KW per year
75%	.00064	1.92	.65
80	.00119	3.57	2.38
85	.00158	4.74	3.15
90	.00194	4.82	3.67
95	.00224	6.72	3.96
100	.0025	7.50	3.42

THE POWER FACTOR CORRECTION PROBLEM AT THE OLDS MOTOR WORKS.

DESCRIPTION OF THE PLANT.

This plant, engaged exclusively in the manufacture of automobiles, is one of the largest purchasers of electrical energy in the city of Lansing. It is completely electrified having more than 1200 motors aggregating approximately 6000 horsepower. In addition to this it is equipped with electric ovens for enamel drying, electric welders, and an electro-plating shop.

Power is delivered to the plant by a four wire, three phase, sixty cycle transmission line operating at four thousand volts. The company owns its own transformers and pays for the energy delivered at a point near the plant on the high tension side. The four thousand volt line is used for the outdoor primary distribution to the transformer banks located in the various sections of the plant. For power purposes the voltage is stepped down to 440 volts and distributed by several circuits from the switchboard room to the machine panel locations. The lighting circuits are supplied by separate transformers at 110 volts.

The total transformer capacity at the present time is about 9050 KVA divided as follows:-

Motor power--------	5100 KVA
Enameling ovens ---	2500
Welders -----------	100
Lighting ----------	1350
Total -----------	9050 KVA

Machine requirements in the past have been such that the individual drive predominates although a portion of the machines in the motor plant are group driven. Excessive use of the individual drive has resulted in an extremely large number of motors of small size (5 HP and under). Since these are all of the squirrel cage induction type the result has been a serious reduction in power factor.

The design of the distribution circuits, both primary and secondary, has been so liberal that even under the present conditions the system has not been loaded in excess of its KVA capacity. In fact, about the only major criticism which may be made of the plant distributing system is the absence of any means of shifting the load; at present carried by two banks of transformers, to a single bank during the season of light load. In other words the system lacks flexibility.

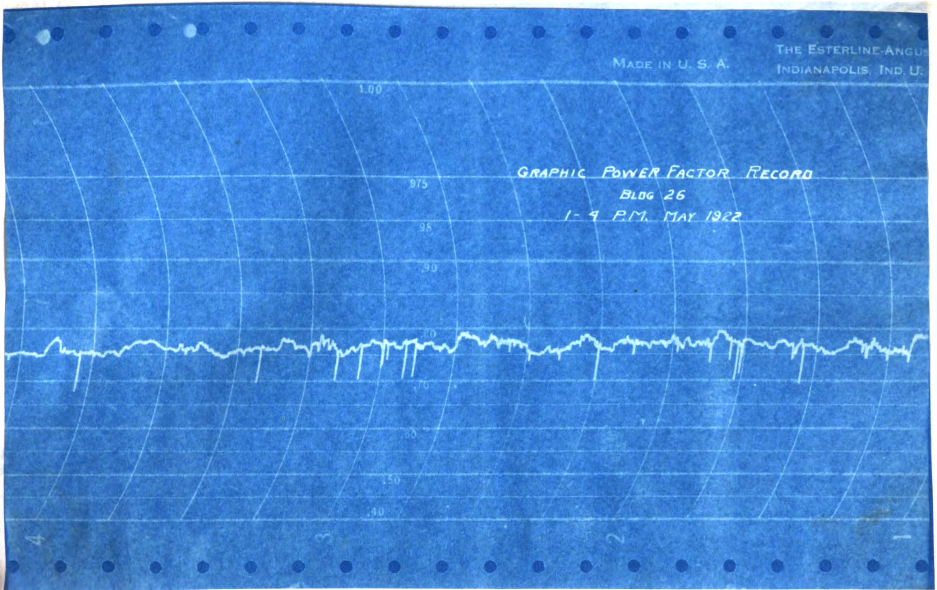
POWER FACTOR CONDITIONS PREVAILING IN OLDS PLANT.

In order to ascertain the exact power factor prevailing in the various sections of the plant during various portions of the day, a graphic power factor meter was made use of. Graphic power factor readings, covering at least three consecutive operating days, were taken on each of the transformer banks. Typical portions of the curves obtained are found among the following pages. From these curves the average, minimum and maximum power factor for each bank was obtained, the results being tabulated below:

LOCATION	MAX.PF	MIN. PF	AV. PF
Bldg. #26	80%	70%	77%
Motor Plant (west)	56	40	47
Motor Plant (east)	52	40	45
Stores K	80	70	70
Axle Plant	65	47	55
Enameling Plant	99	99	99

From an inspection of the above data it is at once apparent that the necessity for power factor correction is especially urgent in the case of both the east and west banks of the motor plant and of the axle plant.

The correction of the poor power factor existing in the motor and axle plants becomes of even greater importance when we consider that the load on the bank at the enameling plant with a power factor of 99% will be greatly reduced in the near future and will thus still further lower the plant power factor. In addition, the bulk of the energy consumption, following the reduction in the enameling plant load, will be in the motor and axle plants.


MADE IN U. S. A.
THE ESTERLINE-ANGUS
INDIANAPOLIS, IND. U.
GRAPHIC POWER FACTOR RECORD
BLDG 26
1-4 P.M. MAY 1922
1.00
975
95
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70
.50
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4
3
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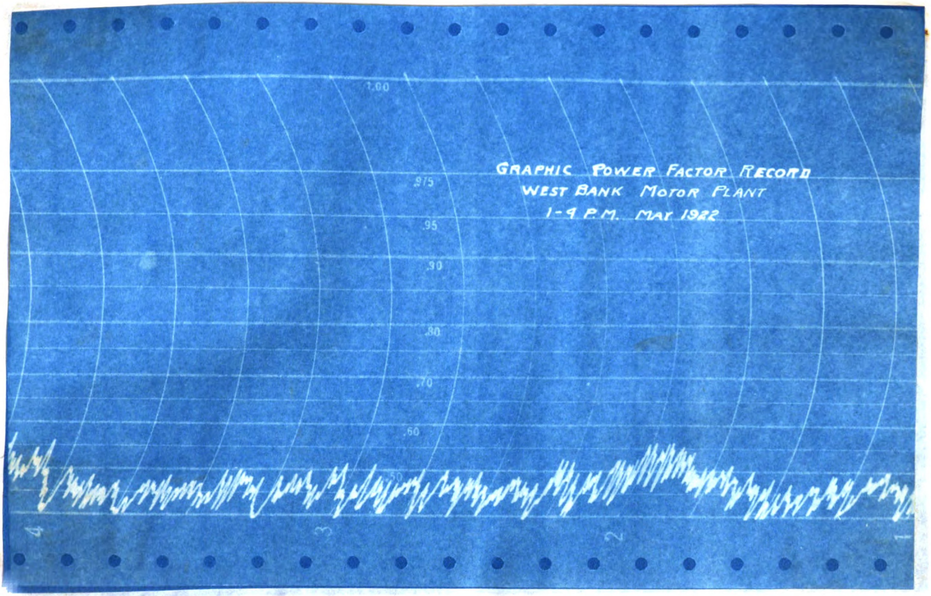
1


GRAPHIC POWER FACTOR RECORD
WEST BANK MOTOR PLANT
1-9 P.M. MAY 1922
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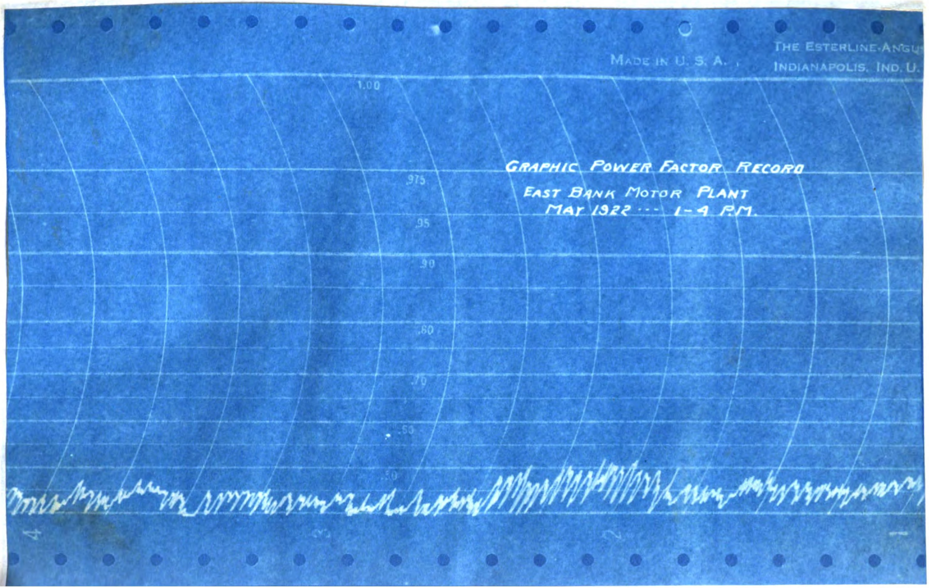
THE ESTERLINE-ANGU
INDIANAPOLIS, IND. U.
MADE IN U. S. A.
GRAPHIC POWER FACTOR RECORD
EAST BANK MOTOR PLANT
MAY 1922 ··· 1-4 P.M.
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.95
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.70
.60
.50
4
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2
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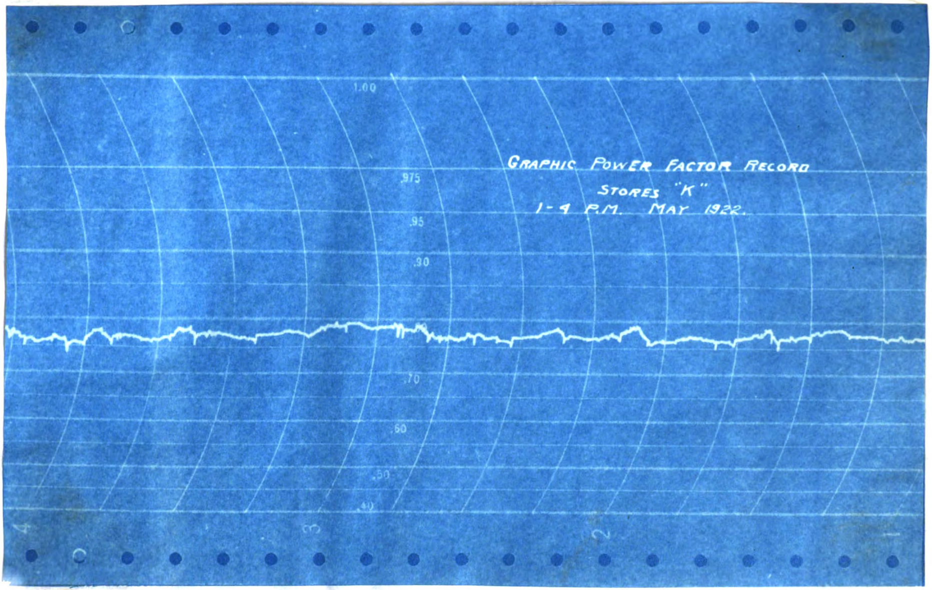

GRAPHIC POWER FACTOR RECORD
STORES "K"
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.95
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.60
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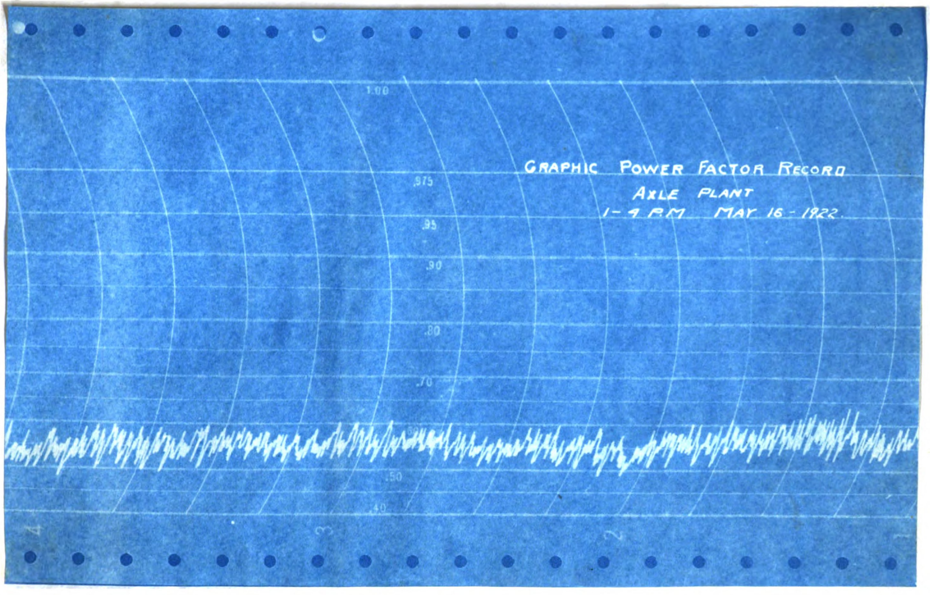
.40
4
3
2
1


GRAPHIC POWER FACTOR RECORD
AXLE PLANT
1-4 P.M. MAY 16-1922.
1.00
.975
.95
.90
.80
.70
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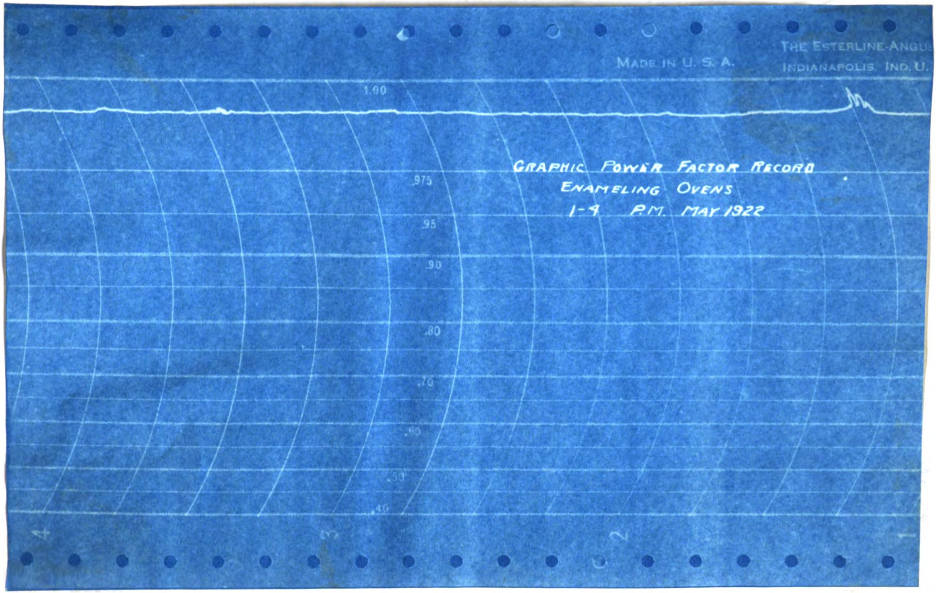
.40
4
3
2
1


THE ESTERLINE-ANGUS
INDIANAPOLIS, IND. U.
MADE IN U. S. A.
GRAPHIC POWER FACTOR RECORD
ENAMELING OVENS
1-4 P.M. MAY 1922
1.00
.975
.95
.90
.80
.70
.60
.50
.40
1
2
3
4

CAUSE OF POWER FACTOR CONDITIONS IN MOTOR PLANT AND AXLE PLANT.

The poor power factor in these plants is partly due to the liberal use of individual induction motor drive. Although a portion of the machines are group/driven the great majority have individual drives.

Lightly loaded motors or over-motoring is the greatest evil. The degree to which over-motoring has been carried can perhaps best be shown by the data on the following page. This data is reproduced from a sheet taken at random from the graphic wattmeter readings recorded on individual machines in the motor plant.

This sheet may be taken as representative of the conditions existing throughout the plant as the average condition shown by this sheet is practically an average for the entire plant.

The average load may be taken as 40.5% or less than half of the rated load. From an examination of the representative power factor curves of typical motors, Figs. 9 - 15 included in this group, the reason for this poor power factor becomes obvious.

A large proportion of the motors here are under 10 H.P. and small motors inherently have a poorer power factor than larger motors of the same type. In addition they are usually selected with less care from an engineering standpoint than are the larger ones. Usually, the person responsible for specifying the size of the motor adds a few H.P. to be on the safe side. This results in more trouble in the smaller sizes than in the larger ones.

Another point which has probably had considerable effect in the present over-motoring is the utilization of motors and machines for work differing in character from that for which they were originally selected.

In fact over-motoring was not so serious an evil at least from the Company's standpoint, until the power factor penalty clause in the purchase of power became operative.

Underloaded transformers might also be considered as an aid in producing the low power factor now prevailing but their effect is so slight in comparison with the effect of the induction motors that it may be disregarded.

Make of Machine	Motor Make	Rated H.P.	Motor R.P.M.	Aver. K.W.	Max. K.W.	Aver. H.P.	Max. H.P.
Grinder	G.E.	7 1/2	1200	2.	3.	2.68	4.025
Grinder	G.E.	7 1/2	1200	2.5	3.75	3.35	5.7
Lathe	G.E.	10	1200	1.25	2.5	1.675	3.35
Lathe	W.H.E.	5	1200	1.25	2.5	1.675	3.35
Grinder	G.E.	7 1/2	1200	6.25	12.5	8.38	16.75
Drill	G.E.	10	1200	2.5	5.	3.35	6.7
Mill	G.E.	3	1200	1.75	1.75	2.35	2.35
Miller	G.E.	7 1/2	1200	2.5	6.25	3.35	8.38
Lathe	G.E.	1/2	1800	.25	.25	.335	.335
Lathe	W.H.E.	5	1160	1.25	2.5	1.675	3.35
Lathe	W.H.E.	7 1/2	1160	1.25	1.5	1.675	2.01
Drill	G.E.	2	1200	1.25	1.87	1.675	2.51
Drill	G.E.	1	1800	.5	.5	.67	.67
Drill	G.E.	3	1200	1.25	1.87	1.675	2.51
Drill	G.E.	1	1800	.63	1.25	.845	1.675
Mill	G.E.	2	1200	.5	.63	.67	.845
Mill	G.E.	7 1/2	1200	1.25	1.87	1.675	2.51
Drill	G.E.	3	1200	.63	.63	.845	.845

Make of Machine	Motor Make	Rated H.P.	Motor R.P.M.	Aver. K.W.	Max. K.W.	Aver. H.P.	Max. H.P.
Drill	G.E.	3	1200	.63	1.25	.845	1.675
Mill	G.E.	5	1800	.5	.63	.67	.845
Lathe	W.E.	3	1140	2.5	5.	3.35	6.7
Drill	G.E.	1 1/2	1200	1.37	5.	1.8235	6.7
Tapper	G.E.	1	1200	.63	.63	.845	.845
Miller	G.E.	7 1/2	1200	6.25	10.	8.38	13.4
Drill	Hobart	2	1800	.63	1.	8.45	1.34
Drill	G.E.	1	1200	.37	.37	.496	.496
Drill	G.E.	7 1/2	1200	.25	.25	.335	.335
Miller	G.E.	7 1/2	1200	1.25	1.57	1.675	2.11
Lathe	G.E.	7 1/2	1200	1.25	2.5	1.675	3.35
Lathe	G.E.	7 1/2	1200	.93	1.57	1.245	2.11
Lathe	G.E.	7 1/2	1200	1.25	1.87	1.675	2.51
Lathe	G.E.	2	1200	1.25	1.87	1.675	2.51
Drill	G.E.	3	1200	.3	.63	4.025	.845
Drill	G.E.	1 1/2	1200	.63	.87	.845	1.17
Drill	G.E.	1/2	1800	.25	.25	.335	.335
Lathe	G.E.	2	1200	.63	1.25	.845	1.675
Lathe	G.E.	2	1200	.5	1.	.67	1.34
Grinder	G.E.	10	1200	2.5	5.	3.35	6.7

REQUIREMENTS FOR POWER FACTOR CORRECTION.

Before prescribing remedies to be applied to the various sections of the works it would be well to review the conditions as they now are. The prevailing conditions in regard to load and power factor of the various transformer banks are listed below:

LOCATION	CONNECTED LOAD	PRESENT PF.
Motor Plant	2000 H.P.	45%
Axle Plant	1600	55
Stores K	1200	77
Bldg. #26	260	77
Enameling ovens	--	99

From the above figures it is evident that there is no need for correcting the power factor at the enameling ovens, both on account of the high power factor now existing but also because in a short time the use of electrically heated ovens will be discontinued. The power factor at Stores K and at Building #26 is also comparatively high and since the proportion of the total load carried by these transformers is relatively small no correction will be attempted at these points. Our attention will then be confined to the correction needed at only the motor plant and the axle plant.

An investigation of the operating conditions revealed that the average load factor at these points is .400. For this reason we will further limit our problem to the condition set forth below.

LOCATION	CONNECTED LOAD H.P.	LOAD FACTOR	ACTUAL LOAD HP	ACTUAL LOAD KW	PRESENT PF	KVA REQD. FOR CORRECT.
Motor Plant	3000	.4	1200	900	45%	1500
Axle Plant	1600	.4	640	480	53%	600

LOCATION	MOTOR PLANT	AXLE PLANT
Connected Load HP	3000	1600
Load Factor	.4	.4
Actual Load HP	1200	640
Actual Load KW	900	480
Present PF	45%	53%
KVA required for Correction	1500	600

The above correction is based on a correction of the power factor to 95%, this having been found by actual analysis to be the most economical correction to make. The details of this analysis have been previously discussed. Curves in Fig. 19 illustrate this analysis.

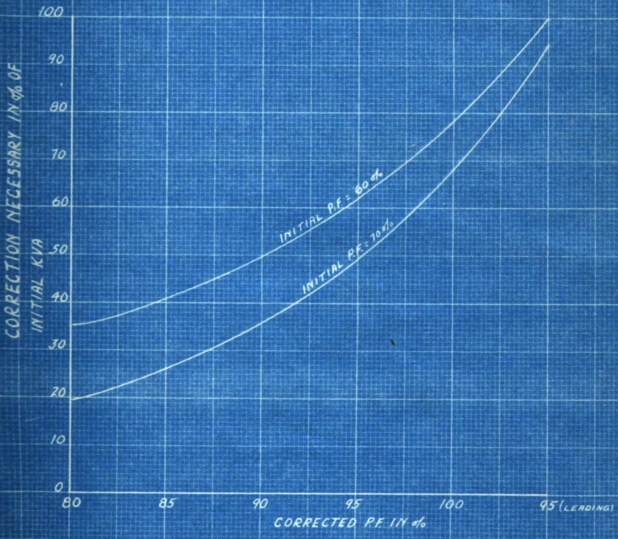
At this point it would be well to discuss the general method of determining the amount of corrective

capacity required for any system. The method depends on the trigonometric existing between the real power and the reactive power which has been discussed previously. From Fig. 20 can be obtained the correction necessary for various values of power factor and power. The data necessary for plotting these curves was calculated by making use of the trigonometric relations mentioned above.

The problem now resolves itself into one of supplying the necessary corrective KVA in the amounts specified. The means of accomplishing this will be taken up in the following articles.

FIG. 20

CURVE SHOWING
CORRECTION REQUIRED
TO IMPROVE POWER FACTOR
OF CONSTANT K.W. LOAD



RECOMMENDED REMEDIES

PLAN I REMOTORING.

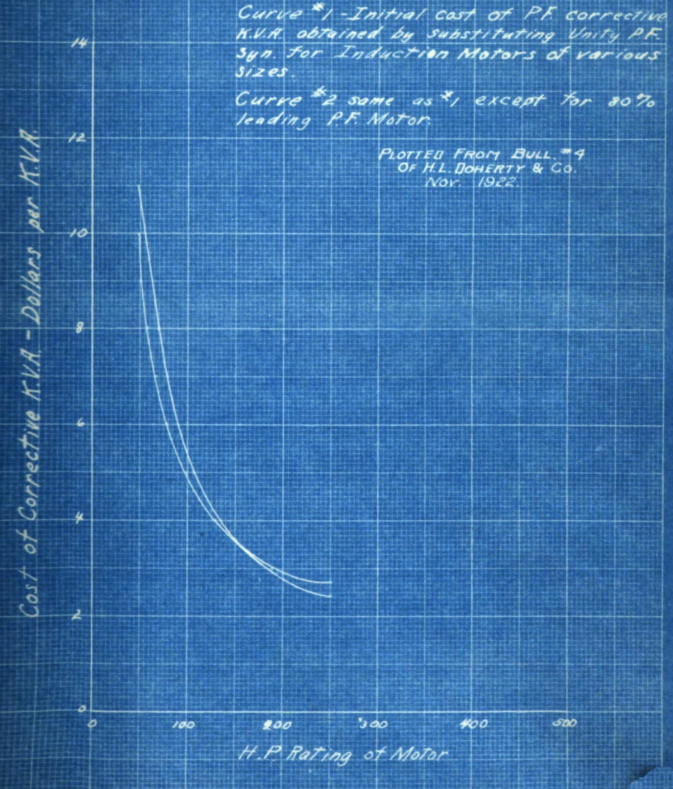
It is evident from the preceeding discussion that the underloaded induction motor is the chief cause for the low power factor existing in the plant. To correct this condition the first remedy which comes to mind is to effect a rearrangement of motors so that each motor is carrying approximately full load. There are some objections to this plan and some of them will be discussed in the following paragraphs.

To disconnect the motors which are now driving the individual machines or groups and to substitute motors which have nearer the required capacity would be a very expensive undertaking. However, considerable rearranging could be done with good results. For instance, if a certain machine driven by a five horse power motor was found to require but three horse power and a three horse power motor was available from another overmotored machine, the three horse power motor could be installed to drive the first machine.

It is recommended that in instances where new installations are made and where changes are necessary in the location of machine in the future that care be taken to see that a motor of proper size be installed.

FIG. 21

Cost of Corrective K.V.A.
obtained by Substituting synchronous
for Induction motors.



PLAN II STATIC CONDENSERS.

The static condenser is now in use in a large number of plants in this country and has received much favorable comment.

For low voltage work the unit condenser is designed for a working voltage up to about 600 volts and is controlled by an oil switch provided with a no-voltage coil and overload release. It is also fitted with auxiliary contacts which discharge the condenser through resistances when the switch is in the off position. For higher voltages either unit condensers designed for the voltage or a number of lower voltage condensers may be used.

In the general discussion it was shown that the capacity varied directly as the frequenty and as the square of the impressed voltage. For this reason the logical place to use these condensers would be on the high side of the transformer banks using the commercial 2300 volt condenser star connected. This would obviate the necessity of using auto transformering with the condensers and would simplify the installation.

The proper place to apply corrective devices is at the load since this increases the K.W. capacity of the secondary distribution system. However, in this case the liberal design of the secondary circuits renders this unnecessary at the present time. This will reduce the initial cost of the static condenser installation and render possible the grouping of the condensers in a single apartment with a consequent saving of valuable floor/space in the plant. From a comparison of Curves 1 and 4 of the Price Curve sheet, the saving in the initial investment can be determined.

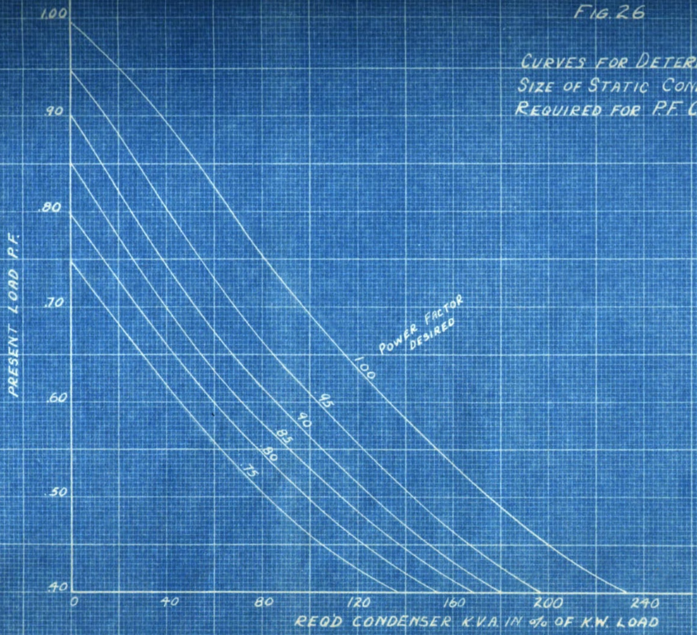
Since economic considerations alone should govern the choice of methods to be employed in correcting the power factor it would be well to make an approximation of the initial cost and upkeep of the necessary condenser capacity for both the motor plant and axle plant.

From previous discussion, the amount of reactive KVA necessary for raising the power factor in the motor plant from its present value of 45 to a future value of 95 is about 1500 KVA and for the axle plant is about 600 KVA. From the price curve for static condensers the original cost for the motor plant using five three hundred KVA units would be about $17,300 or using the General Electric Company price list about $23,800, although the former would probably be more nearly correct at this time.

In a similar manner the initial cost for the axle plant (using two three hundred units) would be $6,900 and $9,950 respectively. The total cost would be $24,200 and $33,750.

Fig. 26

Curves for Determining
Size of Static Condenser
Required for P.F. Correction



PLAN III THE SYNCHRONOUS CONDENSER AND MOTOR.

In making changes in the future it would be well to bear in mind that synchronous motors can be obtained which are adapted for use on group drives and line shafts. We would not, however, recommend that this method be employed except in cases where it is necessary to make changes. The cost of synchronous motors in small sizes (less than 100 HP) is very high and it is much better to concentrate all the correction in one large machine.

The statements, under the static condenser plan, regarding the amount of correction required, apply equally well to the synchronous machine. The amount of correction to be made is about 2100 KVA. If a synchronous condenser is to be used we recommend that one machine of 2100 KVA capacity be installed. The reasons for using but one machine for the entire plant are:

1. The cost per KVA is less in the larger machine,
2. The losses decrease with the size of the machine;
3. The attendance and maintenance required are reduced to a minimum with one machine.
4. Foundations for one large machine less costly than for two smaller machines,

5. Less floor space required.

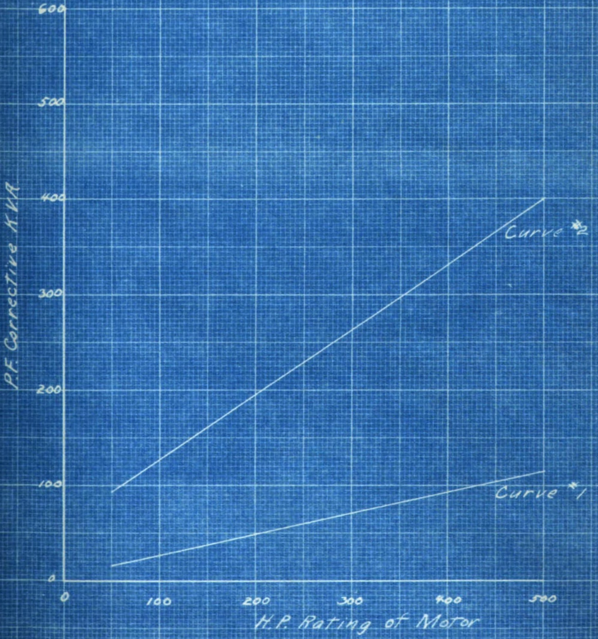
The initial cost of a synchronous condenser of 2100 KVA computed on the basis of $12 per KVA (see price curve) will be $25,200. This price does not include the cost of foundations, building and other auxiliaries.

FIG 22

P.F. Corrective K.V.A. Curves

Curve #1 - P.F. Corrective K.V.A. obtained by substituting Unity P.F. Syn. Motor for Induction motor sq. cage type 30% exciting K.V.A. assumed for motors of various sizes.

Curve #2 same as #1 except for 80% lead P.F. Syn. motor instead of Unity P.F. Motor.



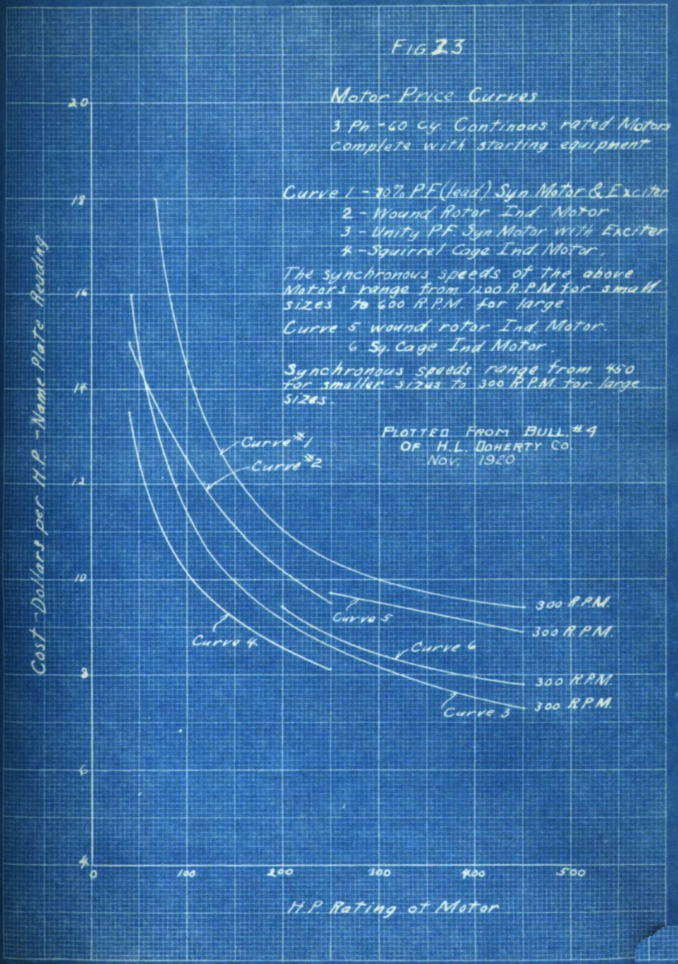


FIG 23
Motor Price Curves
3 Ph - 60 cy. Continous rated Motors complete with starting equipment
Curve 1 - 80% P.F. (lead) Syn. Motor & Exciter
2 - Wound Rotor Ind. Motor
3 - Unity P.F. Syn Motor with Exciter
4 - Squirrel Cage Ind. Motor.
The synchronous speeds of the above Motors range from 1200 R.P.M. for small sizes to 600 R.P.M. for large.
Curve 5 wound rotor Ind. Motor.
6 Sq. Cage Ind. Motor.
Synchronous speeds range from 450 for smaller sizes to 300 R.P.M. for large sizes.
PLOTTED FROM BULL. #4
OF H.L. DOHERTY CO.
NOV. 1920
Curve #1
Curve #2
Curve 4
Curve 5
Curve 6
Curve 3
300 R.P.M.
300 R.P.M.
300 R.P.M.
300 R.P.M.
Cost - Dollars per H.P. - Name Plate Reading
20
18
16
14
12
10
8
6
4
0
100
200
300
400
500
H.P. Rating of Motor

COMPARISON OF STATIC AND SYNCHRONOUS CONDENSERS.

As we have shown there are two methods of supplying a leading current, namely, the static condenser and the synchronous condenser, and we will now compare the two.

First cost - The first cost of static condensers is much lower than the synchronous condenser in small sizes up to 500 K.V.A. Above this the synchronous condenser is the cheaper. Refer to Curve No. 24.

Losses - The losses in a static condenser vary from 1/2% to 1% depending on whether it is necessary to use an auto-transformer. In the synchronous machine the losses range from 4% in the 500 K.V.A. size to 18% in the 30 K.V.A. condenser.

Floor space - The synchronous condenser requires less floor space especially in larger sizes.

Flexibility - The synchronous condenser is very flexible, as the power factor may be varied at will by a field theostat. The static condenser can be varied by constructing it in steps of 30 or 60 K.V.A. and cutting in and out steps as occasion demands.

Attendance - No attendance is required with the static condenser.

Heating - There is lower temperature rise in the static condenser. The General Electric static condenser is designed for a 10° rise.

Maintenance - Since the static condenser has no moving parts, no lubrication is needed and the depreciation is much less than the synchronous machine.

The choice between the two depends largely upon the conditions in the plant.

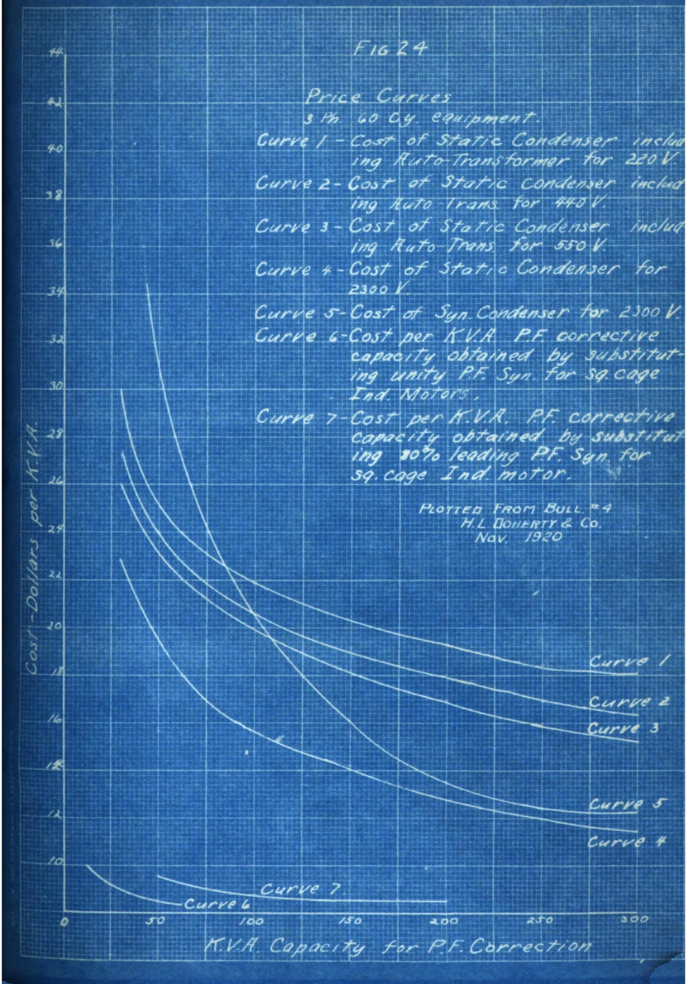


FIG 24
Price Curves
3 Ph 60 Cy. equipment.
Curve 1 - Cost of Static Condenser includ
ing Auto-Transformer for 220 V.
Curve 2 - Cost of Static condenser includ
ing Auto-Trans. for 440 V.
Curve 3 - Cost of Static Condenser includ
ing Auto-Trans. for 550 V.
Curve 4 - Cost of Static Condenser for
2300 V.
Curve 5 - Cost of Syn. Condenser for 2300 V.
Curve 6 - Cost per K.V.A. P.F. corrective
capacity obtained by substitut-
ing unity P.F. Syn. for sq. cage
Ind. Motors.
Curve 7 - Cost per K.V.A. P.F. corrective
capacity obtained by substitut
ing 80% leading P.F. Syn. for
sq. cage Ind. motor.
PLOTTED FROM BULL. #4
H.L. DOHERTY & CO.
NOV. 1920
Curve 1
Curve 2
Curve 3
Curve 5
Curve 4
Curve 7.
Curve 6
Cost-Dollars per K.V.A.
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
0
50
100
150
200
250
300
K.V.A. Capacity for P.F. Correction

RECOMMENDATION.

After a careful consideration of all the elements involved in this problem, it is our opinion that the following suggested remedy best fits the situation:-

Character of Corrective Apparatus:-

Static condensers of 2300 volt, 3 phase star connected.

Size and location of Units:-

Seven - three - hundred KVA units. Five of these units to be connected to the circuit near the east bank of transformers of the Motor Plant, and the remaining two units to be installed on the roof of the axle plant close to the axle plant transformer bank.

Summary of reason underlying the choice of this plan:-

First:- Remedy is immediately effective.

Second:- Quickness, ease and simplicity of installation.

Third:- Initial cost lower than other plan. (See approximate prices plan II)

Fourth:- Maintenance and repairs lower than by any other plan.

Fifth:- Does not require special foundations or occupy valuable floor space.

THE INSTRUMENTS USED IN THIS INVESTIGATION ARE AS FOLLOWS.

1. Esterline-Angus Graphic Wattmeter,

   Serial No. 8506 Type MS Phase All Wire All

   Volts 100 - 200 - 500 Watts 1000 - 2000 - 5000

   Movement "A" 100 V 2721 ohms. Movement "B" 100 V 2684 ohms.

1. Esterline-Angus Graphic Power Factor Meter EA

   Serial No. 8109 Type MS Phase 3 Wire --

   Volts 500 Amperes 5

2. Esterline-Angus Universal Current Transformers EA

   Serial No. 50576 Cycles 60 No. 50580

   Voltage ratios from 5/1 to 160/1

INVENTORY OF INDUCTION MOTORS.

OLDS MOTOR WORKS.

AXLE PLANT.

H.P.	MAKE	R.P.M.	TYPE
2	GE	1200	KT730
2	GE	1200	KT730
5	GE	1200	KT732
2	GE	1200	KT730
2	WE	1200	KT730
2	GE	1200	KT730
1	GE	1200	KT712
1	GE	1200	KT712
15	GE	1200	KT302
1 1/2	GE	1200	KT713
1	GE	1200	KT712
1/2	GE	1800	KT110
-	GE	1700	KMA
2	GE	1800	KT713
2	GE	1200	KT730
2	GE	1200	KT730
5	GE	1200	KT732
2	GE	1200	KT730
5	GE	1800	KT730
2	WE	1800	KT710
2	GE	1800	KT713
2	GE	1800	KT122
1	GE	1200	KT712
5	GE	1200	KT732
2	GE	1200	KT6
2	GE	1800	KT713
3	Watson	1720	KH
3	GE	1800	KT730
5	GE	1200	KT732
10	GE	1200	KT732
10	WE	1740	354-A
3	GE	1200	KT731
7 1/2	GE	1200	KT751
1	Burke	1200	EBI
1	GE	1200	KT712
3	GE	1800	KT712
1 1/2	GE	1200	KT140
2	GE	1800	KT230
3	GE	1800	KT730
7 1/2	GE	1200	KT751
2	GE	1200	KT730
15	GE	1200	KT302
5	GE	1200	KT732

AXLE PLANT.

H.P.	MAKE	R.P.M.	TYPE
2	GE	1800	KT713
7 1/2	GE	1200	KT751
10	GE	1200	KT752
1	GE	1800	KT711
1 1/2	GE	1200	KT713
10	GE	1200	KT752
3	GE	1800	KT730
1 1/2	GE	1200	KT713
10	GE	1200	KT752
3	GE	1800	KT730
1 1/2	GE	1200	KT713
5	GE	1200	KT732
3	GE	1200	KT731
7 1/2	GE	1200	KT751
2	GE	1200	KT732
10	GE	1200	KT752
5	GE	1200	KT732
3	GE	1200	KT731
1	GE	1200	KT712
2	WE	1200	KT730
5	WE	1800	KT731
5	GE	1200	KT732
10	GE	1200	KT732
1 1/2	GE	1200	KT713
-	--	750	Special
7 1/2	GE	1200	KT751
10	GE	1200	KT752
10	GE	1200	KT752
10	GE	1200	KT752
10	GE	1200	KT752
3	GE	1200	KT730
10	GE	1200	KT752
10	GE	1200	KT752
1	GE	1200	KT752
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
7 1/2	GE	1200	KT751
7 1/2	GE	1200	KT751
2	WE	1200	KT730
2	WE	1200	KT730
2	GE	1200	KT730
-	--	750	Special
2	GE	1200	KT730
3	GE	1200	KT731
1 1/2	GE	1800	KT712
7 1/2	GE	1200	KT751
1 1/2	GE	1800	KT712
3	GE	1200	KT731
3	GE	1200	KT731
1	GE	1200	KT712

AXLE PLANT.

H.P.	MAKE	R.P.M.	TYPE
1	GE	1200	KT712
1	GE	1200	KT712
2	GE	1800	KT712
2	GE	1800	KT
2	GE	1800	KT
5	GE	1200	--
15	GE	1200	KT
3	GE	1200	KT302
15	GE	1200	KT302
10	GE	1200	KT752
7 1/2	GE	1200	KT751
1	GE	1200	KT712
1	GE	1200	KT712
3	GE	1200	KT731
-	--	750	special
1	GE	1800	KT711
10	GE	1200	KT752
2	GE	1800	KT713
2	GE	1200	KT730
5	GE	1200	KT731
-	--	1700	KMA
10	GE	1200	KT752
10	GE	1200	KT752
7 1/2	GE	1200	KT751
7 1/2	GE	1200	KT751
5	GE	1200	KT732
5	GE	1200	KT732
7 1/2	WE	1800	KT732
1	GE	1200	KT750
5	GE	1200	KT732
7 1/2	WE	1800	KT750
1	GE	1200	KT712
20	GE	1200	KT312
3	GE	1200	KT731
1	GE	1200	KT712
5	GE	1200	KT732
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
10	GE	1200	KT752
10	GE	1200	KT752
10	GE	1200	KT752
20	GE	1200	KT312
2	GE	900	KT160
2	GE	900	KT731
3	GE	900	KT752
3	GE	900	KT180
3	GE	900	KT180
3	GE	900	KT751
3	GE	1200	KT751
3	GE	1200	KT751

AXLE PLANT.

H.P.	MAKE	R.P.M.	TYPE
3	GE	1200	KT751
2	GE	1800	KT713
-	Watson	1720	HD3
-	Watson	1720	HD3
5	WE	1200	KT180
7 1/2	WE	1800	KT750
7 1/2	WE	1800	KT750
5	Al.Chm.	1140	--
10	GE	1200	KT752
1 1/2	WE	1800	KT712
5	WE	1200	KT180
5	GE	1800	KT731
3	GE	1200	KT731
5	Al.Chm.	1140	--
5	GE	1200	KT732
1	GE	1800	KT712
7 1/2	WHE	1750	--
3	GE	1200	KT731
10	GE	900	KT302
10	GE	1200	KT752
7 1/2	GE	1200	KT751
3/4	GE	1800	KT710
1	GE	1800	KT711
1 1/2	WE	1800	KT712
5	GE	1200	KT732
2	WE	1200	KT730
25	GE	900	KT326
10	GE	1200	KT752
10	GE	1200	KT752
7 1/2	GE	1200	KT761
7 1/2	WHE	850	--
7 1/2	WHE	1120	--
7 1/2	WHE	850	--
7 1/2	WHE	1120	--
7 1/2	WHE	850	--
7 1/2	WHE	1120	--
20	WHE	900	--
3	GE	1200	KT731
1/2	GE	1800	KT110
2	GE	900	KT160
7 1/2	GE	1200	KT751
1	GE	1800	KT711
3	GE	1200	KT731
1	GE	1200	KT712
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
5	GE	1200	KT732
20	GE	1200	KT512

AXLE PLANT.

H.P.	MAKE	R.P.M.	TYPE
10	GE	1200	KT752
1	GE	1800	KT712
3	GE	1200	KT731
1	GE	1800	KT711
5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
5	GE	1200	KT732
1	GE	1200	KT712
-	--	750	Special
-	--	750	Special
7 1/2	GE	1200	KT751
2	GE	1800	KT713
3	WE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
2	GE	1200	KT730
1 1/2	--	1700	KMA
10	GE	1800	KT712
5	GE	1200	KT752
10	GE	1200	KT732
5	Al.Chm.	1140	--
1	GE	1200	KT712
7 1/2	GE	1200	KT751
3	Globe	1750	--
3/4	WE	1800	KT710
10	GE	1200	KT752
1	GE	1800	KT711
5	GE	1200	KT732
1	GE	1800	KT711
5	GE	1200	KT732
5	GE	1200	KT732
10	GE	1200	KT752
25	GE	900	KT326
10	GE	1200	KT752
7 1/2	GE	1200	KT751
7 1/2	GE	1200	KT751
5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
1	Burke	1200	RBV

AXLE PLANT.

H.P.	MAKE	R.P.M.	TYPE
2	GE	1800	KT122
2	GE	1800	KT122
3/4	WE	1800	KT710
2	GE	1200	KT730
7 1/2	GE	1200	KT751
5	GE	1200	KT732
20	GE	1200	KT512
20	GE	1200	KT512
3	GE	900	KT186
1 1/2	WE	1200	KT140
3	GE	1200	KT730
5	GE	1200	KT732
7 1/2	GE	1200	KT751
2	GE	1200	KT730
2	GE	1800	KT122
1 1/2	GE	1800	KT712
5	Al.Chm.	1140	--
5	Al.Chm.	1140	--
25	GE	900	KT326
7 1/2	GE	1200	KT751
5	GE	1200	KT751
2	GE	600	KT180
7 1/2	GE	1200	--
3/4	GE	1800	KT710
3/4	GE	1800	KT710
-	--	750	Special
-	--	750	Special
-	--	750	Special
3/4	GE	--	RSA
3/4	GE	--	RSA
3/4	GE	--	RSA
3/4	GE	--	RSA
3/4	GE	--	RSA
2	GE	1200	KT730
2	GE	1200	KT730
2	GE	1200	KT730
5	GE	1200	KT731
5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
2	GE	1200	KT730
5	GE	1200	KT732
2	GE	1200	KT730
2	GE	1200	KT730
2	GE	1200	KT730
1 1/2	GE	1800	KT712
1 1/2	GE	1800	KT712

AXLE PLANT.

H.P.	MAKE	R.P.M.	TYPE
3	GE	1800	KT730
20	GE	1200	KT312
20	GE	1200	KT312
10	GE	1200	KT752
2	GE	1200	KT730
2	GE	1800	KT713
2	GE	1800	KT122
3	GE	1800	KT765
2	GE	1800	KT122
2	GE	1200	KT730
1	WE	1800	KT711
1/4	GE	1200	KTFR28
-	--	750	Special
2	GE	900	KT160
7 1/2	GE	1200	KT751
3	GE	1200	KT731
10	GE	900	KT302
20	GE	1200	KT312
25	Robbins Myers	1750	K
25	Robbins Myers	1750	K
1 1/2	GE	1200	KT713
1 1/2	GE	1200	KT713
5	GE	1200	KT732
50	WHR	680	CCL
25	GE	1800	KT312

MOTOR PLANT BLDG. #21.

H.P.	MAKE	R.P.M.	TYPE
5	GE	1200	KT732
7 1/2	GE	1200	KT751
7 1/2	GE	1200	KT751
2	GE	1200	KT730
1	GE	1800	KT711
10	GE	1200	KT752
5	GE	1200	KT732
5	GE	1200	KT732
2	GE	1800	KT713
2	GE	1800	KT713
1/2	GE	--	--
2	GE	1800	KT713
3	GE	1800	KT730
2	WHE	--	CSA
2	WHE	--	CSA
3	GE	1800	KT730
3	GE	1800	KT730
3	GE	1800	KT730
5	WHE	--	CCL
30	WHE	--	CCL
15	GE	1200	KT312
15	Watson	--	KH
15	Watson	--	KH
15	Watson	--	KH
10	GE	1200	--
10	GE	1200	--
7 1/2	GE	1200	KT751
1 1/2	GE	1200	KT713
-	USE	--	--
1	GE	1200	KT712
2	GE	1200	KT730
5	GE	1200	KT732
5	GE	1200	KT732
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731
3	GE	1200	KT731

MOTOR PLANT BLDG. #21.

H.P.	MAKE	R.P.M.	TYPE
3	GE	1200	KT731
3	GE	1200	KT731
5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
1	GE	1200	KT712
1	GE	1200	KT712
1	GE	1200	KT712
1	GE	1200	KT712
1	GE	1200	KT712
1	GE	1200	KT712
5	GE	1800	KT731
5	GE	1800	KT731
5	GE	1800	KT731
5	GE	1800	KT731
5	GE	1800	KT731
5	GE	1800	KT731
5	GE	1800	KT731
5	GE	1800	KT731
5	GE	1800	KT731
5	GE	1800	KT731
5	GE	1800	KT731
5	GE	1800	KT731
5	GE	1800	KT731
1	GE	1800	KT711
1	GE	1800	KT711
15	GE	1200	KT502
5	USE	850	--
15	GE	900	KT8278
15	GE	1200	KT502
15	GE	1200	KT502
15	GE	1200	KT512
15	GE	900	KT522
15	GE	900	KT522
20	GE	1200	KT512
20	GE	1200	KT512
7 1/2	GE	1200	--
2	GE	900	KT731
2	GE	900	KT731
7 1/2	WE	1800	KT750
7 1/2	WE	1800	KT750
7 1/2	WE	1800	KT750
7 1/2	GE	1800	KT750
7 1/2	GE	1800	KT750
15	GE	1800	KT752
15	GE	1800	KT752
15	GE	1800	KT752

MOTOR PLANT BLDG. #21.

H.P.	MAKE	R.P.M.	TYPE
7 1/2	GE	1800	--
3	Fair.Morse	1200	BFRH5B
2	Hobart	1200	--
2	Hobart	1200	--
2	Hobart	1200	--
5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
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5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
50	GE	900	KT346
50	GE	900	KT346
50	GE	900	KT346
50	GE	900	KT346
50	GE	900	KT346
50	GE	900	KT346
50	GE	900	KT346
50	GE	900	KT346
50	GE	900	KT346
50	GE	900	KT346
50	GE	900	KT346
50	GE	900	KT346
50	GE	900	KT346
50	GE	900	KT346
50	GE	900	KT346
50	GE	900	KT346
50	GE	900	KT346
30	WE	1200	KT332

MOTOR PLANT BLDG. #21.

H.P.	MAKE	R.P.M.	TYPE
25	GE	1200	KT532
7 1/2	WE	900	KT302
1	GE	1200	KT712
1	GE	1200	KT712
1	GE	1200	KT712
1	GE	1200	KT712
1	GE	1200	KT712
1	GE	1200	KT712
1	GE	1200	KT712
1	GE	1200	KT712
1	GE	1200	KT712
1	GE	1200	KT712
2	GE	1800	KT713
2	GE	1200	KT730
2	GE	1200	KT730
2	GE	1800	KT730
2	GE	1800	KT730
2	GE	1200	KT730
2	GE	1200	KT730
2	GE	1200	KT730
2	GE	1200	KT730
2	GE	1800	KT730
2	GE	1200	KT730
2	GE	1200	KT730
2	GE	1200	KT730
2	GE	1200	KT730
2	GE	1200	KT730
7 1/2	GE	1200	KT751
7 1/2	GE	1200	KT751
7 1/2	GE	1200	KT751
7 1/2	GE	1200	KT751
7 1/2	GE	1200	KT751
7 1/2	GE	1200	KT751
7 1/2	GE	1200	KT751
7 1/2	GE	1200	KT751
7 1/2	GE	1200	KT751
7 1/2	GE	1200	KT751
7 1/2	GE	1200	KT751
7 1/2	GE	1200	KT751
7 1/2	GE	1200	KT751
7 1/2	GE	1200	KT751
7 1/2	GE	1200	KT751
7 1/2	GE	1200	KT751
3	GE	1800	KT730
3	GE	1800	KT730
3	GE	1800	KT730
3	GE	1800	KT730
3	GE	1800	KT730
3	GE	1800	KT730

MOTOR PLANT BLDG. #21.

H.P.	MAKE	R.P.M.	TYPE
3	GE	1800	KT730
3	GE	1800	KT730
3	GE	1800	KT730
3	GE	1800	KT730
3	GE	1800	KT730
3	GE	1800	KT730
3	GE	1800	KT730
3	GE	1800	KT730
3	GE	1800	KT730
3	GE	1800	KT730
1 1/2	GE	1200	KT713
1 1/2	GE	1200	KT713
1 1/2	GE	1200	KT713
1 1/2	GE	1200	KT713
1 1/2	GE	1200	KT713
1.1/2	GE	1200	KT713
1 1/2	GE	1200	KT713
1 1/2	GE	1200	KT713
1 1/2	GE	1200	KT713
1 1/2	GE	1200	KT713
1 1/2	GE	1800	KT712
10	GE	1200	KT752
10	GE	1200	KT752
10	GE	1200	KT752
10	GE	1200	KT752
10	GE	1200	KT752
10	GE	1200	KT752
5	GE	1800	KT731
5	GE	1800	KT731
5	GE	1800	KT731
3	WHE	1800	CSA
1/2	GE	1800	KT110
20	WHE	860	CS
40	GE	1800	KT325
1	GE	1200	KT712
1/2	CW	1710	--
30	GE	1200	KT332
20	WHE	860	CS
2	WHE	1120	CS
2	WHE	1120	CS
40	GE	900	KT342
10	WE	1200	KT342
10	WE	1200	KT342
5	WE	1800	GL7
7 1/2	GE	1200	KT751
7 1/2	GE	1200	KT751
7 1/2	GE	1800	KT730
1	GE	1200	KT712
10	GE	1800	KT751
15	GE	1200	KT302

MOTOR PLANT BLDG. # 21.

H.P.	MAKE	R.P.M.	TYPE
5	GE	1200	KT732
1 1/2	GE	1200	KT713
5	GE	1200	KT732
10	GE	1200	KT752
1	GE	1200	KT[illegible]52
7 1/2	GE	1200	KT751
10	GE	--	--
7 1/2	GE	1200	KT751
2	GE	1200	KT730
5	GE	1200	KT732
1 1/2	GE	1200	KT713
1 1/2	GE	1200	KT713
2	Howell	--	--
7 1/2	GE	1200	KT751
7 1/2	Hager	--	--
3	GE	1200	KT731
3	Fair.Morse	--	B46B
1	GE	1200	KT712
1	GE	1200	KT712
1 1/2	GE	1200	KT713
1	GE	1200	KT712
1 1/2	GE	1200	KT713
5	GE	1200	KT732
1 1/2	GE	1200	KT713
10	GE	1200	KT752
3	GE	1200	KT731
5	GE	1800	KT731
1	Howell	1800	80
2	Hobart	1200	--
15	GE	1200	1-9
20	GE	1200	KT312
3	Howell	1800	--
2	WH	1200	KT132
20	GE	1200	KT312
20	GE	1200	KT312
3/4	Elec.Spec.	1800	L24
3	Fair.Morse	1800	H6B
3	Wagner	1200	STBP
5	GE	1200	KT732
5	GE	1200	KT732
1 1/2	GE	900	KT730
2	GE	1200	KT730
5	GE	1200	--
1/2	Sprague	1200	--
1	GE	1200	--
2	GE	1200	KT140
20	GE	900	KT526
7 1/2	GE	1200	--
4	GE	1200	KT732

MOTOR PLANT BLDG. #21.

H.P.	MAKE	R.P.M.	TYPE
10	GE	1200	--
3	GE	900	KT750
20	GE	900	KT526
25	GE	1200	KT326
1/2	GE	1800	FR28
1/2	GE	1800	FR28
2	GE	1200	KT140
3	Al.Chm.	1140	--
3	Al.Chm.	1140	--
7 1/2	Eager	1800	--
15	GE	1200	KT302
15	GE	1200	KT302
15	GE	1200	KT302
15	GE	1200	KT302
15	GE	1200	MT302
15	GE	1200	KT302
15	GE	1200	KT302
10	GE	1200	KT752
2	Rob.Myers	--	K
5	Hobart	1200	--
15	GE	1200	I
7 1/2	GE	1200	KT751
3	Al.Chm.	1140	--
3	Al.Chm.	1140	--
15	Al.Chm.	1150	--
1 1/2	GE	1200	KT713
1/2	Al.Chm.	1130	--
7 1/2	GE	1800	KT730
3	GE	1200	KT731
15	GE	1200	KT302
1	GE	1200	KT712
1	GE	1200	KT712
20	GE	1200	KT712
10	GE	1200	KT752
15	GE	1200	MT322
15	GE	1200	MT322
5	GE	1200	KT732
5	GE	1200	KT732
15	GE	1200	KT302
10	GE	1200	KT732
1	GE	1200	KT712
1	GE	1200	KT712
1	GE	1200	KT712
1	GE	1200	KT712
1	GE	1200	KT712
5	GE	1800	KT731
1	GE	1200	KT712
5	GE	1200	KT732
5	GE	1200	KT732

MOTOR PLANT BLDG. #21.

H.P.	MAKE	R.P.M.	TYPE
5	GE	1200	KT732
5	GE	1200	KT732
5	GE	1200	KT732
1 1/2	GE	1200	KT713
1	GE	1200	KT712
2	GE	1800	KT713
2	GE	1200	KT730
6	GE	1200	KT732
2	GE	1200	KT730
1	GE	1800	KT711
1	GE	1200	KT712
10	GE	1200	KT732
5	GE	1200	KT732
3	GE	1200	KT731
5	GE	1200	KT732
7 1/2	GE	1200	KT731
3	Wagner	--	--
5	GE	1200	KT732
10	GE	1200	KT752
7 1/2	GE	--	--
7b1/2	GE	1200	KT751
3	GE	1200	KT731
1	GE	1200	KT712
5	GE	1200	KT732

WOOD SHOP BLDG. #36.

H.P.	MAKE	R.P.M.	TYPE
5	GE	1800	KT160
7 1/2	GE	1200	KT751
7 1/2	GE	1200	KT751
5	GE	1200	KT732
2	GE	1200	KT730
2	GE	1200	KT730
2	GE	1200	KT730
2	GE	1200	KT730
2	GE	1200	KT730
2	GE	1200	KT730
3	GE	1200	KT731
2	GE	1200	KT730
2	GE	1200	KT730
5	Robbins-Myers	1200	K
5	GE	1200	KT731
3	GE	1200	KT731
5	GE	1200	KT752
1	GE	1200	KT712
30	GE	1200	--
7 1/2	GE	1200	KT751
3	GE	1200	KT731
2	GE	1800	KT713
3	GE	1200	KT731
5	GE	1200	KT732
10	WE	900	KT312
2	Wagner	1800	9WLEP
1 1/2	GE	1800	KT712
3	GE	1200	KT731
1/4	GE	1725	KT731
3	GE	1800	KT730
3	GE	1800	KT730
3	GE	900	KT180
3	GE	1200	KT731
3	GE	1800	KT730
3	GE	1200	KT731
3	WE	1800	KT731
7 1/2	GE	900	KT752
10	GE	1200	--
7 1/2	--	--	--
3	WE	900	KT180
2	GE	1800	KT713
7 1/2	Lincoln	3600	ID
3	GE	1200	KT731
5	GE	1800	KT160
5	GE	1800	KT160
3	WE	1800	KT330
3	WE	1800	KT730
30	GE	900	KT332
2	GE	1800	KT713

WOOD SHOP BLDG. #26.

H.P.	MAKE	R.P.M.	TYPE
2	GE	1800	KT713
5	GE	1810	KT160
3	GE	1200	KT
10	WE	570	KT326

SHEET METAL BLDG. #27.

H.P.	MAKE	R.P.M.	TYPE
10	GE	900	KT312
25	GE	900	KT332
1	GE	1200	KT712
7 1/2	GE	--	KT180
15	GE	1200	--
1	WE	1800	KT711
50	GE	900	--
50	GE	900	--
50	GE	900	--
25	GE	1200	KT322
7 1/2	Hager	--	--
50	GE	900	KT346
25	GE	1200	KT326
75	WE	600	HD6
20	GE	1200	KT312
50	GE	900	KT346
30	WHE	1120	CCL
3	GE	1200	KT731
100	GE	1800	--
5	Al.Chm.	1750	--
3	WE	1800	CL7A
5	WE	1800	KT150
3	GE	900	KTK140
20	GE	900	KT326
20	GE	900	KT326
5	GE	1200	KT326
7 1/2	GE	1200	KT181
10	GE	1200	KT302
7 1/2	GE	1200	KT181
5	Watson	1200	KH
10	GE	1200	KT302
10	Fair.Morse	1200	13

SEWING ROOM.

H.P.	MAKE	R.P.M.	TYPE
1	GE	450	KT180
1	GE	450	KT180
1	GE	450	KT180
1	GE	450	KT180
1	GE	450	KT180
1	GE	450	KT180
1	GE	450	KT180
1	GE	450	KT180
1	GE	450	KT180
1/4	GE	1800	KT180
5	WHM	1150	CCL
1	GE	450	KT180
1	GE	450	KT180
1	GE	450	KT180
1	GE	450	KT180
1	GE	450	KT180
1	GE	450	KT180
1	GE	450	KT180
1	GE	450	KT180
1	GE	450	KT180
1	GE	450	KT180
1	GE	450	KT180
1/2	GE	1200	KT710
1/2	GE	1200	KT710

BOW ROOM.

H.P.	MAKE	R.P.M.	TYPE
5	WHM	1700	CCL
20	Ideal	1150	A120-15

FINAL INSPECTION.

H.P.	MAKE	R.P.M.	TYPE
15	GE	1200	KT204

WOOD SHOP (PERMANENT).

H.P.	MAKE	R.P.M.	TYPE
75	WHM	690	CCL

WOOD SHOP (PERMANENT).

H.P.	MAKE	R.P.M.	TYPE
7 1/2	--	900	--
40	WHE	850	OCL
7 1/2	--	900	--
30	WHE	112	--
5	WHE	1800	--

BOILER ROOM.

H.P.	MAKE	R.P.M.	TYPE
2	Watson	850	KH
5	GE	1080	MTC5160
30	GE	820	ITO500
1	Hammer	2500	RSA
104	GE	900	I8
225	EM	857	--
75	WHE	690	--
104	GE	--	18
50	WHE	860	[illegible]
75	WHE	690	OCL

TOOL ROOM.

H.P.	MAKE	R.P.M.	TYPE
50	GE	900	KT546
25	GE	900	KT522
25	GE	900	KT522
2	WHE	1800	KTCCI

FINAL ASSEMBLY.

H.P.	MAKE	R.P.M.	TYPE
50	GE	900	KT546
30	WE	900	KT536
30	WHE	1120	OCL
5	WE	1800	OL74A
5	WE	1800	O174A

ELEVATOR MOTORS.

H.P.	R.P.M.	NO.	In Bldg. No.
15	600	1	15
15	600	2	20
7 1/2	900	3	20
25	--	4	8
5	1750	5	9
20	1120	6	2
7 1/2	900	7	6
10	850	8	19
10	850	9	19

Coal Hoist Motor 10 H.P. GE

Coal Crusher Motor H.P. GE 1200 R.P.M.

In addition to the above there are 70 fan spray motors.

[redacted]

[redacted] [redacted]