POWER-FACTOR ECONOMICS

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BY

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PREFACE

Power factor is dealt with in this book as it applies to industrial plants and the distribution systems of public utilities; thus the subject matter is divided into two parts. Its purpose is to answer the questions which arise when power factor is considered, and to provide simple, accurate means of solving power-factor problems.

W. Judson McClain, a former associate, checked most of the fundamentals involved. The National Electric Condenser Company supplied a great deal of information about capacitors and their use in industrial plants. The General Electric Company supplied basic information about motors and transformers and much of the data on distribution systems; many of the ideas and formulas used in connection with the latter originated in the engineering department of that company. The Aluminum Company of America, the Copperweld Steel Company, the Rural Electrification Administration, and the Anaconda Wire and Cable Company provided data about conductors. The Westinghouse Electric and Manufacturing Company, the Ideal Electric and Manufacturing Company, and the Wagner Electric Corporation supplied specific data. The cooperation of all was indispensable and is hereby gratefully acknowledged.

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PART I

INDUSTRIAL PLANTS

CHAPTER I

POWER FACTOR

Definition of Power Factor. Power factor is the proportion of useful to total current in an alternating-current circuit. Since the useful current is expressed as kilowatts and the total current as kilovolt-amperes, power factor is

$$\frac{\text{kilowatts}}{\text{kilovolt-amperes}} \tag{1}$$

An analogy to products manufactured in any plant would be the percentage of raw material turned out as a finished product, the raw material representing kilovolt-amperes, the finished product kilowatts, and the waste the reactive current.

Causes of Low Power Factor. If the circuit contains little or no inductance, as, for example, when it supplies only an incandescent lighting load, its power factor will be approximately 100 per cent or unity. If, however, it supplies motors or other inductive equipment, its power factor will be less than unity.

The most common inductive apparatus is:

Induction motors.
Transformers.
Gaseous and fluorescent lights.
Induction furnaces and ovens.

Induction motors are widely used because of their low price, high starting torque, facility of replacement, and because of simplicity of design—low maintenance and repair cost. Not all the current supplied to them is converted into mechanical energy and therefore is not entirely useful. Some is necessary to magnetize the fields, and this portion, owing to the opposition of the fields to changing current values, lags behind the useful or in-phase current. It is never consumed but imposes an additional load on the system equipment.

The cores of transformers act similarly to the fields of induction motors, whether they are used as part of the distribution system or as integral parts of mercury-vapor or fluorescent lamps, neon lights, or welding equipment. Their power factor is very low.

Induction furnaces and ovens are simply magnetic fields designed to induce currents and therefore produce heat in conductors coming within their influence, and again the power factor is poor.

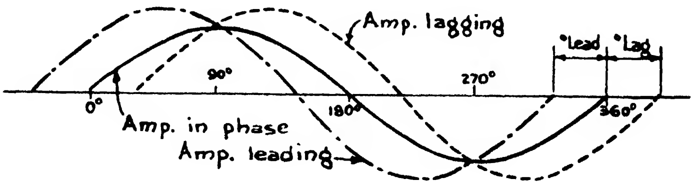

Fig. 1

Effects of Low Power Factor. Low power factor increases the amperage on the entire electrical system supplying the apparatus causing it. This means the plant distribution system, the plant substation, and the utility's distribution and transmission systems and generating equipment. Since kilovolt-amperes (kv-a.) is kilowatts (kw.) divided by power factor, a power factor of 50 per cent would necessitate the utilization of twice as much generating and distribution apparatus as a power factor of unity. Therefore it is economically advisable to have a system power factor approximating unity.

The voltage drop on a distribution system increases with the load carried. Then, the lower the power factor for a given useful load (kilowatts), the greater will be the loss in pressure.

The percentage voltage regulation of transformers becomes greater the lower the power factor, so that to maintain secondary voltages as closely as possible it is necessary to have high power factors.

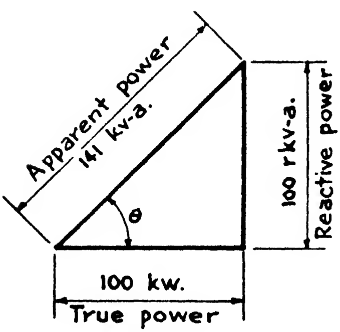

Fig. 2

All conductors offer resistance to the flow of electricity which results in the formation of heat. For a given set of conductors this loss varies as the square of the amperage. The amperage is minimum with unity power factor and increases as the power factor decreases. To maintain at a minimum the conversion of kilowatt-hours into wasted heat the power factor must be unity.

Trigonometric Relations. The reactive or magnetizing current, whether lagging or leading, is always at a 90-degree angle to the power current. This enables their relation to be expressed with the useful or in-phase current (kilowatts) as the base of a triangle, and the reactive current (reactive kilovolt-amperes) as the perpendicular side. The hypotenuse represents the apparent power (kilovolt-amperes), which would be indicated by an ammeter.

Since by definition power factor is the proportion of useful to total current in an alternating-current circuit, its value would be the base divided by the hypotenuse of the triangle, or the cosine of θ. Theta is the phase angle or the displacement between the line current and line voltage. All the functions of the right-angle triangle hold for the components of the circuit.

TABLE I

TRIGONOMETRIC AND ELECTRICAL RELATIONS

$$\text{Kw.} = \cot\theta \times \text{rkv-a.}, \frac{\text{rkv-a.}}{\tan\theta}, \cos\theta \times \text{kv-a}, \sqrt{\text{kv-a.}^2 - \text{rkv-a.}^2}$$

$$\text{Rkv-a.} = \frac{\text{kw.}}{\cot\theta}, \sin\theta \times \text{kv-a.}, \tan\theta \times \text{kw.}, \sqrt{\text{kv-a}^2 - \text{kw.}^2}$$

$$\text{Kv-a.} = \frac{\text{kw.}}{\cos\theta}, \frac{\text{rkv-a.}}{\sin\theta}, \sqrt{\text{kw.}^2 + \text{rkv-a}^2}$$

$$\text{Sin}\,\theta = \frac{\text{rkv-a.}}{\text{kv-a}}, \tan\theta \times \cos\theta, \frac{\cos\theta}{\cot\theta}$$

$$\text{Cos}\,\theta = \frac{\sin\theta}{\tan\theta}, \sin\theta \times \cot\theta, \frac{\text{kw}}{\text{kv-a.}} = \text{power factor}$$

$$\text{Tan}\,\theta = \frac{\text{rkv-a.}}{\text{kw.}}, \frac{\sin\theta}{\cos\theta}$$

$$\text{Cot}\,\theta = \frac{\text{kw.}}{\text{rkv-a.}}, \frac{\cos\theta}{\sin\theta}$$

It will be readily seen from Fig. 2 that a reduction in the reactive current decreases the amperage, which will equal kilowatts only at unity power factor. The effect of adding capacitance is to shorten the reactive component or, if enough is added, to extend it on the other side of the base, making a leading power factor.

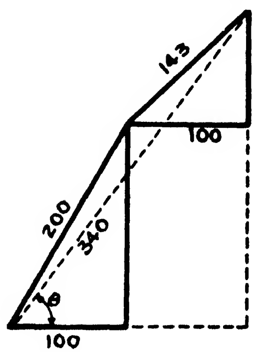

FIG. 3. Geometrical Addition of Loads

If loads at various power factors are added, the resulting kilovolt-amperes will not be the sum of the individual kilovolt-amperes, but will be the square root of the sum of the squares of the total reactive kilovolt-amperes and the total kilowatts. This is shown geometrically in Fig. 3, in which the individual loads are shown in solid lines and the combined load in dotted lines. The loads are 100 kw. or 143 kv-a. at 70 per cent power factor and 100 kw.

or 200 kv-a. at 50 per cent power factor. The kilovolt-amperage of the combined load is 340, not 343.

Using trigonometrical functions, the resulting kilovolt-amperes would be determined as follows:

$$\begin{aligned} \text{Tan } 70\% &= 1.0202 \times 100 \text{ kw.} = 102 \text{ rkv-a.} \\ \text{Tan } 50\% &= 1.7321 \times \underline{100 \text{ kw.}} = \underline{173 \text{ rkv-a.}} \\ & \qquad\qquad\quad 200 \text{ kw.} \quad\; 275 \text{ rkv-a.} \end{aligned}$$

$$\text{Tan } \theta = \frac{275}{200} = 1.375$$

$$\text{Cos } \theta = 0.588$$

$$\text{Kv-a.} = \frac{200 \text{ kw.}}{0.588} = 340$$

Power-Factor Tests. "Industrial power analyzers," assemblies of voltmeters, ammeters, wattmeters, and power-factor indicators, now marketed by several manufacturers, are the most convenient means of obtaining a picture of power conditions in an industrial plant.

A voltmeter, ammeter, and wattmeter, with the necessary current-transformers, are the essential instruments usually available for power-factor tests. The kilovolt-amperage is obtained from the readings of the first two, and when divided into the wattmeter reading gives the power factor. See Table V, page 17. Voltmeters are connected in parallel and ammeters in series.

Spot tests by utilities are usually made by timing the readings of rotating standard kilowatt-hour and reactive-kilovolt-ampere-hour meters. The reactive meter differs from the wattmeter only in that it has an auto-transformer connected in its circuit to displace the phase angle 90 degrees. The reactive-hour-meter reading divided by the watt-hour-meter reading gives the tangent of the angle the cosine of which equals the power factor. See Table II.

TABLE II

Tangents

To determine the average power factor divide the registration of the reactive-kilovolt-ampere-hour meter by that of the kilowatt-hour meter; find in the table the number which most closely approximates the quotient (tangent) obtained; read the power factor in two decimal places from the column at the left, and the third place will be at the top of the column containing the quotient. For example, 15,000 rkv-a-hr. divided by 10,000 kw-hr. = 1.5. The corresponding power factor would be 0.555.

To determine the size capacitor required where power factor is determined by spot tests multiply the difference of the tangents corresponding to the original and desired power factors by the load in kilowatts. For example, it is desired to improve the power factor of a 100-kw. load from 60.4 to 90 per cent. The tangent of 60.4 per cent is found to be 1.3195, and of 90 per cent 0.4843. The difference = 0.8352 × 100 kw. = 84 kv-a. capacitor required.

P.F.	0	1	2	3	4	5	6	7	8	9
1 00	0									
0 99	.1425	.1351	.1272	.1190	.1100	.1004	.0897	.0777	.0634	.0448
0 98	.2031	.1978	.1923	.1868	.1811	.1752	.1691	.1629	.1563	.1496
0 97	.2506	.2462	.2418	.2372	.2326	.2279	.2231	.2183	.2133	.2083
0 96	.2917	.2878	.2838	.2799	.2758	.2718	.2676	.2635	.2592	.2550
0 95	.3287	.3251	.3215	.3179	.3143	.3104	.3069	.3031	.2993	.2955
0 94	.3629	.3596	.3563	.3529	.3495	.3461	.3427	.3392	.3357	.3322
0 93	.3952	.3921	.3889	.3857	.3825	.3793	.3761	.3728	.3695	.3662
0 92	.4260	.4230	.4200	.4169	.4138	.4108	.4077	.4046	.4015	.3982
0 91	.4556	.4527	.4498	.4468	.4438	.4409	.4379	.4350	.4320	.4289
0 90	.4843	.4815	.4786	.4761	.4729	.4701	.4672	.4643	.4614	.4585
0 89	.5123	.5095	.5068	.5040	.5012	.4984	.4956	.4928	.4900	.4871
0.88	.5398	.5370	.5343	.5316	.5288	.5261	.5233	.5206	.5178	.5151
0.87	.5667	.5641	.5614	.5587	.5560	.5533	.5506	.5479	.5452	.5425
0.86	.5934	.5907	.5881	.5854	.5827	.5801	.5774	.5748	.5721	.5694
0.85	.6197	.6171	.6145	.6119	.6092	.6066	.6040	.6013	.5987	.5960
0.84	.6459	.6433	.6407	.6381	.6355	.6329	.6302	.6276	.6250	.6224
0.83	.6720	.6694	.6668	.6642	.6616	.6590	.6564	.6538	.6512	.6486
0.82	.6980	.6954	.6928	.6902	.6876	.6850	.6824	.6798	.6772	.6746
0.81	.7240	.7214	.7188	.7162	.7136	.7110	.7084	.7058	.7032	.7006
0.80	.7500	.7474	.7448	.7422	.7396	.7370	.7344	.7318	.7292	.7266
0 79	.7761	.7735	.7709	.7683	.7656	.7630	.7604	.7578	.7552	.7526
0 78	.8023	.7997	.7970	.7944	.7918	.7892	.7865	.7839	.7813	.7787
0 77	.8286	.8260	.8233	.8207	.8181	.8154	.8128	.8102	.8075	.8049
0 76	.8552	.8525	.8498	.8472	.8445	.8419	.8392	.8366	.8339	.8313

TABLE II—*Continued*

P.F	0	1	2	3	4	5	6	7	8	9
0 75	.8819	.8792	.8765	.8739	.8712	8685	.8658	.8632	.8605	.8578
0 74	.9089	.9062	.9035	.9008	.8981	.8954	.8927	.8900	.8873	.8846
0 73	.9362	.9335	.9307	9280	.9253	.9225	.9198	.9171	.9144	.9116
0 72	.9639	.9611	.9583	.9555	.9528	9500	.9472	.9445	.9417	.9390
0.71	.9918	.9890	.9862	.9834	.9806	.9778	.9750	.9722	.9694	.9666
0.70	1 0202	1.0173	1.0146	1 0116	1.0088	1.0059	1.0031	1 0003	.9974	9947
0 69	1.0490	1.0461	1 0432	1.0403	1 0374	1 0345	1.0316	1 0288	1.0259	1.0231
0 68	1.0782	1.0753	1.0724	1.0694	1.0665	1 0636	1 0607	1.0578	1.0548	1.0519
0.67	1.1080	1.1050	1.1020	1 0990	1.0960	1 0931	1.0901	1.0872	1.0842	1.0812
0 66	1.1383	1.1352	1.1322	1.1292	1.1261	1 1230	1.1200	1.1170	1.1140	1.1110
0 65	1 1692	1.1660	1 1629	1 1598	1.1567	1.1537	1.1506	1.1475	1.1444	1.1414
0 64	1.2005	1 1974	1.1943	1.1910	1.1879	1 1847	1.1816	1.1785	1.1754	1.1722
0 63	1.2327	1.2295	1.2262	1.2230	1.2198	1.2166	1.2133	1.2101	1.2069	1.2038
0 62	1 2655	1.2622	1.2589	1.2556	1.2523	1.2490	1.2457	1.2428	1.2392	1.2359
0 61	1.2990	1.2956	1.2923	1.2889	1 2855	1.2821	1.2788	1.2754	1 2721	1.2688
0 60	1.3333	1.3299	1.3264	1.3229	1.3195	1 3161	1.3127	1.3092	1.3058	1.3024
0 59	1.3685	1.3650	1.3613	1.3578	1.3543	1.3508	1 3473	1.3438	1 3403	1 3368
0 58	1.4045	1.4009	1.3972	1.3936	1 3899	1 3864	1.3828	1 3792	1.3756	1.3721
0 57	1.4415	1.4377	1 4341	1.4303	1.4266	1.4229	1.4192	1.4155	1 4119	1 4082
0.56	1.4795	1.4756	1.4718	1 4680	1.4641	1.4604	1.4565	1 4528	1.4490	1.4453
0 55	1 5185	1.5146	1.5106	1.5067	1.5027	1.4988	1.4949	1.4911	1.4872	1.4833
0 54	1.5587	1.5546	1.5505	1.5465	1.5424	1.5384	1.5344	1.5304	1.5260	1.5225
0.53	1.6000	1.5958	1.5917	1 5875	1.5833	1.5792	1.5750	1.5709	1 5669	1.5628
0 52	1.6427	1.6383	1.6340	1.6297	1.6255	1.6211	1.6169	1.6126	1.6084	1.6042
0 51	1.6866	1.6822	1.6773	1.6733	1.6689	1.6645	1 6601	1.6556	1.6513	1.6470
0.50	1.7321	1.7274	1.7228	1.7183	1.7137	1.7091	1.7046	1.7001	1.6956	1.6911
0 49	1.7790	1.7742	1.7695	1.7648	1.7600	1.7554	1.7506	1.7460	1.7413	1.7367
0 48	1.8276	1.8227	1.8178	1.8128	1.8080	1.8031	1.7983	1.7935	1.7886	1.7838
0 47	1.8780	1.8729	1 8678	1.8627	1.8577	1.8526	1.8476	1.8425	1.8376	1.8326
0.46	1.9303	1.9249	1.9197	1.9144	1.9092	1.9039	1.8986	1.8935	1.8883	1.8832
0.45	1.9845	1.9790	1.9735	1.9680	1.9625	1.9572	1.9517	1.9463	1.9409	1.9356
0 44	2.0410	2.0352	2.0295	2.0237	2.0180	2.0124	2.0069	2.0012	1.9956	1.9900
0.43	2.0996	2.0936	2.0877	2.0817	2.0758	2.0699	2.0641	2.0582	2.0524	2.0467
0.42	2.1608	2.1546	2.1484	2.1422	2.1360	2.1298	2.1237	2.1177	2.1116	2.1056
0.41	2.2246	2.2181	2.2116	2.2052	2.1987	2.1923	2.1860	2.1796	2.1733	2.1670
0.40	2.2913	2.2845	2.2778	2.2710	2.2642	2.2576	2.2509	2.2443	2.2377	2.2311
0.39	2.3611	2.3539	2.3469	2.3398	2.3328	2.3258	2.3188	2.3119	2.3050	2.2981
0.38	2.4341	2.4267	2.4193	2.4118	2.4045	2.3971	2.3899	2.3827	2.3754	2.3682
0.37	2.5110	2.5031	2.4953	2.4875	2.4797	2.4721	2.4644	2.4568	2.4492	2.4417
0 36	2.5916	2.5833	2.5751	2.5669	2.5588	2.5507	2.5427	2.5346	2.5267	2.5188

TABLE III

Difference in Tangents

The size of capacitor necessary to raise the power factor is found by multiplying the load in kilowatts by the constant corresponding to the original and desired power factors. For example, the size capacitor necessary to improve the power factor of a 400-kw. load from 60 to 95 per cent would be 1.0046 × 400 = 402 kv-a.

Original Power Factor	Desired Power Factor				
	80%	85%	90%	95%	100%
36%	1.8416	1.9719	2 1073	2 2629	2 5916
37	1.7010	1.8913	2 0267	2.1823	2.5110
38	1 6841	1.8144	1.9498	2.1054	2.4341
39	1.6111	1 7414	1.8768	2 0324	2.3611
40	1.5413	1.6716	1 8070	1.9626	2.2913
41	1.4746	1.6049	1.7403	1.8959	2.2246
42	1.4108	1.5411	1.6765	1.8321	2.1608
43	1.3496	1.4799	1.6153	1.7709	2.0996
44	1.2910	1.4213	1.5567	1.7123	2.0410
45	1.2345	1.3648	1.5002	1.6558	1.9845
46	1.1803	1.3106	1 4460	1.6016	1.9303
47	1.1280	1.2583	1.3937	1 5493	1.8780
48	1.0776	1.2079	1.3433	1.4989	1.8276
49	1.0290	1.1593	1.2947	1.4508	1.7790
50	0.9821	1 1124	1.2478	1.4034	1.7321
51	0 9366	1 0669	1.2023	1.3579	1 6866
52	0.8927	1.0230	1.1584	1.3140	1.6427
53	0.8500	0 9803	1 1157	1.2713	1.6000
54	0.8087	0 9390	1.0744	1.2300	1 5587
55	0.7685	0 8988	1.0342	1.1898	1 5185
56	0.7295	0.8598	0.9952	1.1508	1.4795
57	0.6915	0.8218	0.9572	1.1128	1 4415
58	0.6545	0.7848	0.9202	1.0758	1.4045
59	0.6185	0.7488	0.8842	1.0399	1.3685
60	0.5833	0.7136	0.8490	1.0046	1.3333
61	0.5490	0.6793	0.8147	0.9703	1.2990
62	0.5155	0.6458	0.7812	0.9368	1.2655
63	0.4827	0.6130	0.7484	0.9040	1.2327
64	0.4505	0.5808	0.7162	0.8718	1.2005
65	0 4192	0.5495	0.6849	0.8405	1.1692

TABLE III—*Continued*

Original Power Factor	Desired Power Factor				
	80%	85%	90%	95%	100%
66	0.3883	0.5186	0.6540	0.8096	1.1383
67	0.3580	0.4883	0.6237	0.7793	1.1080
68	0.3282	0.4585	0.5939	0.7495	1.0782
69	0.2990	0.4293	0.5647	0.7203	1.0490
70	0.2702	0.4005	0.5359	0.6915	1.0202
71	0.2418	0.3721	0.5075	0.6631	0.9918
72	0.2139	0.3442	0.4796	0.6352	0.9639
73	0.1862	0.3165	0.4519	0.6075	0.9362
74	0.1589	0.2892	0.4246	0.5802	0.9089
75	0.1319	0.2622	0.3976	0.5532	0.8819
76	0.1052	0.2355	0.3709	0.5265	0.8552
77	0.0786	0.2089	0.3443	0.4999	0.8286
78	0.0523	0.1826	0.3180	0.4736	0.8023
79	0.0261	0.1564	0.2918	0.4474	0.7761
80	......	0.1303	0.2657	0.4213	0.7500
81	......	0.1043	0.2397	0.3953	0.7240
82	......	0.0783	0.2137	0.3693	0.6980
83	......	0.0523	0.1877	0.3433	0.6720
84	......	0.0262	0.1616	0.3172	0.6459
85	......	......	0.1354	0.2910	0.6197
86	......	......	0.1091	0.2647	0.5934
87	......	......	0.0824	0.2380	0.5667
88	......	......	0.0555	0.2111	0.5398
89	......	......	0.0280	0.1836	0.5123
90	......	......	......	0.1556	0.4843
91	......	......	......	0.1269	0.4556
92	......	......	......	0.0973	0.4260
93	......	......	......	0.0665	0.3952
94	......	......	......	0.0342	0.3629
95	......	......	......	......	0.3287
96	......	......	......	......	0.2917
97	......	......	......	......	0.2506
98	......	......	......	......	0.2031
99	......	......	......	......	0.1425

TABLE IV

Natural Trigonometric Functions

Angle	Sine	Cosine (Power Factor)	Tangent	Cotangent	
0° 00′	0000	1 0000	.0000	.	90° 00′
10	0029	1 0000	.0029	343.7700	50
20	.0058	1 0000	.0058	171 8900	40
30	.0087	1 0000	.0087	114.5900	30
40	.0116	.9999	.0116	85.9400	20
50	0145	.9999	.0146	68.7500	10
1° 00′	0175	.9999	.0175	57.2900	89° 00′
10	.0204	.9998	.0204	49.1040	50
20	0233	9997	.0233	42.9640	40
30	0262	.9997	.0262	38 1880	30
40	0291	.9996	.0291	34 3860	20
50	0320	.9995	.0320	31 2420	10
2° 00′	.0349	.9994	.0349	28 6360	88° 00′
10	0378	9993	.0378	26 4320	50
20	.0407	.9992	.0408	24 5420	40
30	.0436	9991	.0437	22 9040	30
40	.0465	.9989	.0466	21 4700	20
50	.0494	9988	.0495	20 2060	10
3° 00′	.0523	.9986	0524	19 0810	87° 00′
10	.0552	9985	0553	18 0750	50
20	.0581	9983	0582	17 1690	40
30	.0611	.9981	.0612	16 3500	30
40	.0640	.9980	.0641	15 6050	20
50	0669	.9978	.0670	14 9240	10
4° 00′	.0698	.9976	.0699	14.3010	86° 00′
10	.0727	9974	.0729	13.7270	50
20	.0756	.9971	.0758	13.1970	40
30	.0785	9969	0787	12 7060	30
40	.0814	.9967	.0816	12 2510	20
50	.0843	.9964	.0846	11.8260	10
5° 00′	.0872	.9962	.0875	11.4300	85° 00′
10	.0901	.9959	.0904	11.0590	50
20	.0930	.9957	.0934	10.7120	40
30	.0959	.9954	.0963	10.3850	30
40	.0987	.9951	.0992	10.0780	20
50	.1016	.9948	.1022	9.7882	84° 10′
	Cosine (Power Factor)	Sine	Cotangent	Tangent	Angle

TABLE IV—*Continued*

Angle	Sine	Cosine (Power Factor)	Tangent	Cotangent	
6° 00′	1045	9945	1051	9 5144	84° 00′
10	1074	9942	1081	9 2553	50
20	.1103	9939	1110	9 0098	40
30	1132	9936	.1139	8 7769	30
40	.1161	.9932	.1169	8 5555	20
50	.1190	9929	.1198	8.3450	10
7° 00′	1219	.9926	.1228	8.1443	83° 00′
10	1248	9922	.1257	7 9530	50
20	.1276	.9918	.1287	7 7704	40
30	1305	.9914	.1317	7.5958	30
40	.1334	.9911	.1346	7.4287	20
50	.1363	.9907	.1376	7.2687	10
8° 00′	.1392	.9903	.1405	7 1154	82° 00′
10	.1421	.9899	.1435	6 9682	50
20	1449	.9894	.1465	6.8269	40
30	.1478	.9890	.1495	6 6912	30
40	.1507	.9886	.1524	6 5606	20
50	.1536	.9881	.1554	6.4348	10
9° 00′	.1564	.9877	.1584	6 3138	81° 00′
10	.1593	.9872	.1614	6.1970	50
20	.1622	.9868	.1644	6.0844	40
30	1651	.9863	.1673	5.9758	30
40	.1679	.9858	.1703	5 8708	20
50	.1708	.9853	.1733	5.7694	10
10° 00′	1737	.9848	.1763	5 6713	80° 00′
10	.1765	.9843	.1793	5.5764	50
20	.1794	.9838	.1823	5 4845	40
30	.1822	.9833	.1853	5.3955	30
40	.1851	.9827	.1884	5.3093	20
50	.1880	.9822	.1914	5.2257	10
11° 00′	.1908	.9816	.1944	5.1446	79° 00′
10	.1937	.9811	.1974	5.0658	50
20	.1965	.9805	.2004	4.9894	40
30	.1994	.9799	.2035	4.9152	30
40	.2022	.9793	.2065	4.8430	20
50	.2051	.9788	.2095	4.7729	78° 10′
	Cosine (Power Factor)	Sine	Cotangent	Tangent	Angle

TABLE IV—*Continued*

Angle	Sine	Cosine (Power Factor)	Tangent	Cotangent	
12° 00′	2079	.9782	.2126	4.7046	78° 00′
10	2108	9775	.2156	4.6382	50
20	2136	9769	.2186	4 5736	40
30	2164	9763	.2217	4.5107	30
40	2193	9757	.2248	4.4494	20
50	2221	9750	.2278	4 3897	10
13° 00′	2250	9744	2309	4 3315	77° 00′
10	2278	.9737	.2339	4.2747	50
20	.2306	9730	2370	4.2193	40
30	.2335	9724	.2401	4 1653	30
40	2363	.9717	.2432	4.1126	20
50	.2391	.9710	.2462	4.0611	10
14° 00′	.2419	.9703	.2493	4 0108	76° 00′
10	.2447	9696	.2524	3 9617	50
20	.2476	.9689	.2555	3 9136	40
30	.2504	.9682	.2586	3.8667	30
40	2532	.9674	.2617	3.8208	20
50	2560	9667	.2648	3.7760	10
15° 00′	.2588	.9659	.2680	3 7321	75° 00′
10	.2616	.9652	2711	3 6891	50
20	.2644	.9644	.2742	3 6470	40
30	.2672	9636	2773	3.6059	30
40	.2700	.9629	2805	3 5656	20
50	2728	.9621	.2836	3 5261	10
16° 00′	.2756	.9613	.2868	3 4874	74° 00′
10	.2784	.9605	.2899	3.4495	50
20	.2812	.9596	.2931	3.4124	40
30	.2840	.9588	.2962	3.3759	30
40	.2868	.9580	.2994	3.3402	20
50	2896	.9572	.3026	3.3052	10
17° 00′	.2924	9563	.3057	3 2709	73° 00′
10	2952	9555	.3089	3.2371	50
20	2979	.9546	.3121	3 2041	40
30	3007	9537	.3153	3.1716	30
40	3035	.9528	.3185	3.1397	20
50	3063	.9520	.3217	3 1084	72° 10′
	Cosine (Power Factor)	Sine	Cotangent	Tangent	Angle

TABLE IV—*Continued*

Angle	Sine	Cosine (Power Factor)	Tangent	Cotangent	
18° 00′	3090	.9511	.3249	3 0777	72° 00′
10	.3118	9502	3281	3 0475	50
20	.3145	9492	3314	3 0178	40
30	.3173	.9483	3346	2 9887	30
40	3201	9474	3378	2 9600	20
50	.3228	9465	.3411	2 9319	10
19° 00′	.3256	9455	.3443	2 9042	71° 00′
10	.3283	9446	.3476	2 8770	50
20	.3311	9436	3509	2 8502	40
30	3338	9426	.3541	2 8239	30
40	.3366	9417	3574	2 7980	20
50	.3393	9407	.3607	2 7725	10
20° 00′	3420	9397	.3640	2 7475	70° 00′
10	.3448	.9387	.3673	2.7228	50
20	.3475	.9377	3706	2 6985	40
30	.3502	9367	.3739	2 6746	30
40	.3529	9357	.3772	2 6511	20
50	.3557	.9346	.3805	2 6279	10
21° 00′	.3584	.9336	.3839	2.6051	69° 00′
10	.3611	.9325	3872	2 5826	50
20	3638	.9315	.3906	2 5605	40
30	.3665	.9304	.3939	2 5386	30
40	3692	9294	.3973	2 5172	20
50	.3719	.9283	.4007	2.4960	10
22° 00′	.3746	9272	.4040	2 4751	68° 00′
10	.3773	9261	.4074	2.4545	50
20	3800	.9250	.4108	2.4342	40
30	3827	.9239	.4142	2.4142	30
40	.3854	9228	.4176	2.3945	20
50	.3881	.9216	.4211	2.3750	10
23° 00′	.3907	.9205	.4245	2.3559	67° 00′
10	3934	.9194	.4279	2.3369	50
20	.3961	.9182	.4314	2.3183	40
30	.3988	9171	.4348	2.2998	30
40	.4014	.9159	4383	2.2817	20
50	.4041	.9147	.4418	2.2637	66° 10′
	Cosine (Power Factor)	Sine	Cotangent	Tangent	Angle

TABLE IV—*Continued*

Angle	Sine	Cosine (Power Factor)	Tangent	Cotangent	
24° 00′	4067	.9136	4452	2 2460	66° 00′
10	.4094	.9124	4487	2 2286	50
20	4120	9112	4522	2 2113	40
30	4147	9100	.4557	2.1943	30
40	.4173	.9088	.4592	2 1775	20
50	.4200	.9075	.4628	2 1609	10
25° 00′	.4226	.9063	4663	2.1445	65° 00′
10	.4253	.9051	.4699	2 1283	50
20	4279	.9038	4734	2 1123	40
30	.4305	.9026	.4770	2.0965	30
40	4331	9013	4806	2 0809	20
50	.4358	.9001	.4841	2 0655	10
26° 00′	.4384	.8988	.4877	2 0503	64° 00′
10	.4410	.8975	.4913	2.0353	50
20	.4436	8962	.4950	2 0204	40
30	4462	8949	.4986	2 0057	30
40	.4488	.8936	.5022	1.9912	20
50	.4514	.8923	.5059	1.9768	10
27° 00′	.4540	.8910	.5095	1 9626	63° 00′
10	.4566	.8897	.5132	1 9486	50
20	.4592	.8884	.5169	1 9347	40
30	.4618	.8870	.5206	1.9210	30
40	.4643	.8857	.5243	1.9074	20
50	.4669	.8843	.5280	1.8940	10
28° 00′	.4695	.8830	.5317	1.8807	62° 00′
10	.4720	.8816	.5355	1.8676	50
20	.4746	.8802	.5392	1.8546	40
30	.4772	.8788	.5430	1.8418	30
40	.4797	.8774	.5467	1.8291	20
50	.4823	.8760	.5505	1.8165	10
29° 00′	.4848	.8746	.5543	1.8040	61° 00′
10	.4874	.8732	.5581	1.7917	50
20	.4899	.8718	.5619	1.7796	40
30	.4924	.8704	.5658	1.7675	30
40	.4950	.8689	.5696	1.7556	20
50	.4975	.8675	.5735	1.7437	60° 10′
	Cosine (Power Factor)	Sine	Cotangent	Tangent	Angle

TABLE IV—*Continued*

Angle	Sine	Cosine (Power Factor)	Tangent	Cotangent	
30° 00′	5000	8660	5774	1.7321	60° 00′
10	.5025	8646	.5812	1 7205	50
20	5050	8631	.5851	1 7090	40
30	.5075	8616	5891	1.6977	30
40	5100	8602	.5930	1 6864	20
50	.5125	8587	5969	1 6753	10
31° 00′	.5150	.8572	.6009	1.6643	59° 00′
10	5175	8557	6048	1 6534	50
20	5200	8542	6088	1 6426	40
30	5225	8526	.6128	1 6319	30
40	5250	8511	.6168	1.6212	20
50	.5275	8496	6208	1 6107	10
32° 00′	5299	8481	6249	1 6003	58° 00′
10	.5324	8465	6289	1 5900	50
20	5348	8450	6330	1 5798	40
30	5373	.8434	.6371	1 5697	30
40	.5398	.8418	.6412	1 5597	20
50	5422	.8403	.6453	1.5497	10
33° 00′	.5446	8387	6494	1 5399	57° 00′
10	5471	8371	.6536	1 5301	50
20	5495	.8355	6577	1.5204	40
30	.5519	8339	.6619	1.5108	30
40	.5544	.8323	6661	1 5013	20
50	5568	.8307	6703	1.4919	10
34° 00′	.5592	8290	.6745	1.4826	56° 00′
10	.5616	8274	.6788	1 4733	50
20	5640	8258	.6830	1.4641	40
30	.5664	.8241	.6873	1.4550	30
40	.5688	.8225	.6916	1.4460	20
50	.5712	.8208	.6959	1.4370	10
35° 00′	.5736	.8192	.7002	1.4281	55° 00′
10	5760	.8175	.7046	1.4193	50
20	5783	.8158	.7089	1.4106	40
30	.5807	.8141	.7133	1.4019	30
40	5831	.8124	.7177	1.3934	20
50	.5854	8107	.7221	1.3848	54° 10′
	Cosine (Power Factor)	Sine	Cotangent	Tangent	Angle

TABLE IV—*Continued*

Angle	Sine	Cosine (Power Factor)	Tangent	Cotangent	
36° 00′	.5878	8090	7265	1 3764	54° 00′
10	.5901	8073	7310	1 3680	50
20	.5925	8056	7355	1 3597	40
30	5948	8039	7400	1 3514	30
40	.5972	8021	.7445	1 3432	20
50	.5995	8004	7490	1.3351	10
37° 00′	6018	7986	.7536	1 3270	53° 00′
10	6041	7969	.7581	1 3190	50
20	.6065	7951	.7627	1 3111	40
30	.6088	.7934	.7673	1 3032	30
40	.6111	7916	7720	1 2954	20
50	6134	.7898	7766	1 2876	10
38° 00′	.6157	7880	.7813	1 2799	52° 00′
10	.6180	7862	.7860	1 2723	50
20	6202	7844	.7907	1 2647	40
30	6225	7826	7954	1 2572	30
40	6248	7808	.8002	1 2497	20
50	.6271	7790	.8050	1 2423	10
39° 00′	.6293	.7772	.8098	1.2349	51° 00′
10	.6316	7753	.8146	1.2276	50
20	.6338	.7735	.8195	1.2203	40
30	.6361	.7716	.8243	1 2131	30
40	.6383	.7698	.8292	1.2059	20
50	.6406	.7679	.8342	1 1988	10
40° 00′	.6428	.7660	.8391	1 1918	50° 00′
10	.6450	.7642	.8441	1.1847	50
20	.6472	.7623	.8491	1 1778	40
30	.6495	.7604	.8541	1 1708	30
40	.6517	.7585	.8591	1.1640	20
50	.6539	.7566	.8642	1.1571	10
41° 00′	.6561	.7547	.8693	1.1504	49° 00′
10	.6583	.7528	.8744	1 1436	50
20	.6604	.7509	.8796	1.1369	40
30	.6626	.7490	.8847	1.1303	30
40	.6648	.7470	.8899	1.1237	20
50	.6670	.7451	8952	1.1171	48° 10′
	Cosine (Power Factor)	Sine	Cotangent	Tangent	Angle

TABLE IV—*Continued*

Angle	Sine	Cosine (Power Factor)	Tangent	Cotangent	
42° 00′	6691	.7431	.9004	1 1106	48° 00′
10	6713	7412	.9057	1 1041	50
20	6734	.7392	9110	1 0977	40
30	6756	7373	.9163	1.0913	30
40	6777	.7353	9217	1.0850	20
50	.6799	.7333	.9271	1 0786	10
43° 00′	.6820	.7314	.9325	1.0724	47° 00′
10	.6841	.7294	.9380	1.0661	50
20	.6862	7274	9435	1 0599	40
30	6884	7254	9490	1 0538	30
40	.6905	7234	9545	1 0477	20
50	.6926	7214	9601	1 0416	10
44° 00′	.6947	7193	9657	1 0355	46° 00′
10	.6968	7173	.9713	1 0295	50
20	6988	7153	9770	1 0235	40
30	.7009	7133	9827	1 0176	30
40	.7030	.7112	.9884	1 0117	20
50	.7051	7092	9942	1 0058	10
45° 00′	7071	7071	1 0000	1 0000	45° 00′
	Cosine (Power Factor)	Sine	Cotangent	Tangent	Angle

TABLE V

MISCELLANEOUS FORMULAS

To Find	When You Know	Single-Phase	Two-Phase * (Four-Wire)	Three-Phase
Watts input to anything	Output, efficiency	$\frac{\text{Watts output}}{\text{\% efficiency}}$	$\frac{\text{Watts output}}{\text{\% efficiency}}$	$\frac{\text{Watts output}}{\text{\% efficiency}}$
Watts input to a motor	Horsepower, efficiency	$\frac{\text{hp.} \times 746 \times \text{l.f.}}{\text{\% Eff.}}$	$\frac{\text{hp.} \times 746 \times \text{l.f.}}{\text{\% Eff.}}$	$\frac{\text{hp.} \times 746 \times \text{l.f.}}{\text{\% Eff.}}$
Horsepower (output)	Current, voltage, efficiency, power factor	$\frac{E \times I \times \text{\% Eff.} \times \text{p.f.}}{746}$	$\frac{2 \times E \times I \times \text{\% Eff.} \times \text{p.f.}}{746}$	$\frac{1.73 \times E \times I \times \text{\% Eff.} \times \text{p.f.}}{746}$
Kilovolt-amperes	Current, voltage	$\frac{E \times I}{1000}$	$\frac{2 \times E \times I}{1000}$	$\frac{1.73 \times E \times I}{1000}$
Kilowatts	Current, voltage, power factor	$\frac{E \times I \times \text{p.f.}}{1000}$	$\frac{2 \times E \times I \times \text{p.f.}}{1000}$	$\frac{1.73 \times E \times I \times \text{p.f.}}{1000}$
Amperes	Horsepower, voltage, efficiency, power factor	$\frac{\text{hp.} \times 746 \times \text{l.f.}}{E \times \text{\% Eff.} \times \text{p.f.}}$	$\frac{\text{hp.} \times 746 \times \text{l.f.}}{2 \times E \times \text{\% Eff.} \times \text{p.f.}}$	$\frac{\text{hp.} \times 746 \times \text{l.f.}}{1.73 \times E \times \text{\% Eff.} \times \text{p.f.}}$
Amperes	Kilowatts, voltage, power factor	$\frac{\text{kw.} \times 1000}{E \times \text{p.f.}}$	$\frac{\text{kw.} \times 1000}{2 \times E \times \text{p.f.}}$	$\frac{\text{kw.} \times 1000}{1.73 \times E \times \text{p.f.}}$
Amperes	Kilovolt-amperes, voltage	$\frac{\text{kv-a.} \times 1000}{E}$	$\frac{\text{kv-a.} \times 1000}{2 \times E}$	$\frac{\text{kv-a.} \times 1000}{1.73 \times E}$
Power factor	Watts, voltage, current	$\frac{\text{Watts}}{E \times I}$	$\frac{\text{Watts}}{2 \times E \times I}$	$\frac{\text{Watts}}{1.73 \times E \times I}$
Power factor	Kilowatts, voltage, current	$\frac{\text{kw.} \times 1000}{E \times I}$	$\frac{\text{kw.} \times 1000}{2 \times E \times I}$	$\frac{\text{kw.} \times 1000}{1.73 \times E \times I}$

E = volts. l.f. = load factor. I = current in amperes.

* For 2-phase, 3-wire circuits the current in the common conductor is 1.41 times that in either of the other two conductors.

CHAPTER II

MOTORS

Induction Motors. The power factor of an induction motor is always less than unity. It is highest on high-speed fully loaded motors and lowest on low-speed lightly loaded motors. This is because the fields increase in size as the speeds decrease, and because the reactive or magnetizing current varies only slightly with the load while the active or effective current changes almost in proportion to the load. The power factor is the cosine of the angle the tangent of which is the reactive divided by the useful current. Therefore, as the load diminishes the

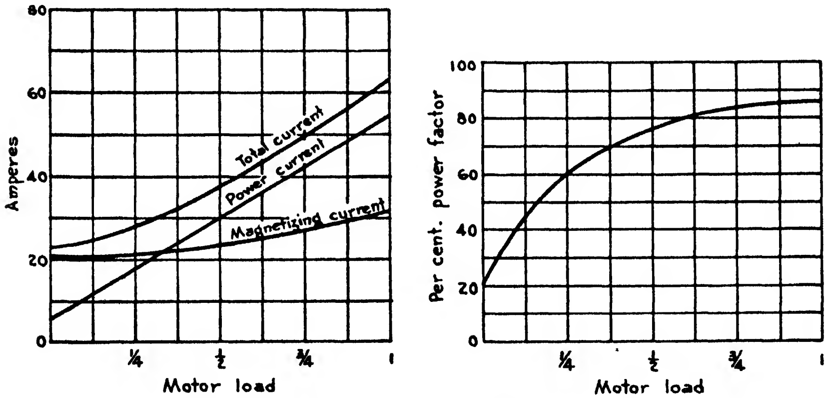

FIG. 4. Motor Currents and Power Factor

(Westinghouse Electric & Mfg. Co.)

proportion of reactive to effective current increases and the power factor decreases.

A motor is built with inherent performance characteristics, none of which can be changed by the extraneous application of a capacitor to improve power factor. The speed at which it runs, the kilowatts and amperes drawn, are dependent solely on the load and voltage. The capacitor, according to its size, will supply leading current to counteract part or all of the lagging motor current, and its effect is not on the motor but on the distribution system up to the capacitor connections. This effect, in addition to higher power factor, is decreased amperage. For any given length and size of conductor the drop in voltage is less with lower amperage; therefore, the voltage at the motor will be higher. The voltage regulation of transformers is more constant at higher power factors; therefore, the voltage at the motor will be not only higher but also more constant. The effects of voltage variation on the performance of a typical motor are shown in Fig. 5. It will be noted that increased voltage results in slightly greater speed, markedly greater starting torque (which varies as the square of the voltage), and decreased current.

Their commercial interpretations are:

1. Increased speed results in increased production—although both are slight.
2. Greater starting torque means ability to start under heavier loads, and shorter periods for acceleration of load.
3. Decreased motor current tends to reduce voltage drop still further than the decrease in line current due to the capacitor application. The combined effect results in (*a*) fewer shutdowns of the machine due to blown fuses, thereby decreasing maintenance, further increasing production, and having better satisfied piecework labor; (*b*) elimination of voltage surges causing flickering of lights and the momentary tendency of other motors to stop.

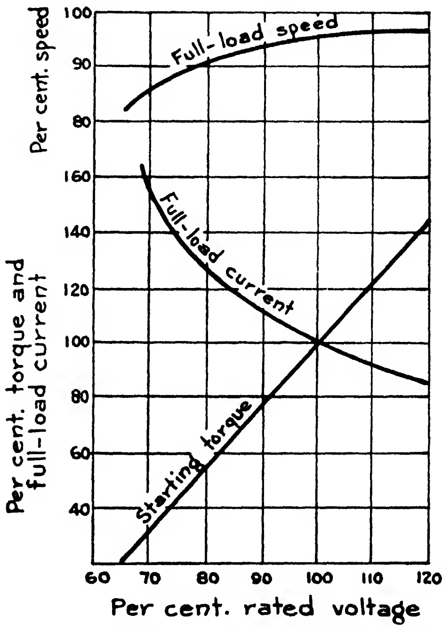

FIG. 5. Effect of Voltage on Motor Performance

(Westinghouse Electric & Mfg. Co.)

Changing Motors to Improve Power Factor. Since the power factor of induction motors increases with load and speed, improvement may be effected by:

1. Replacing motors running at partial ratings with ones whose ratings more nearly correspond with the loads.
2. Using group instead of individual drives.

3. Using individual instead of group drives.
4. Replacing low-speed motors with either geared motors or high-speed motors with V-belt drives.

Some processes require large motors for starting although smaller motors could easily thereafter carry the load. Under such conditions the use of smaller motors with high starting torque should be considered. In other processes the loads may vary with the weight of material being worked upon, or they may alter in a definite cycle. In these instances

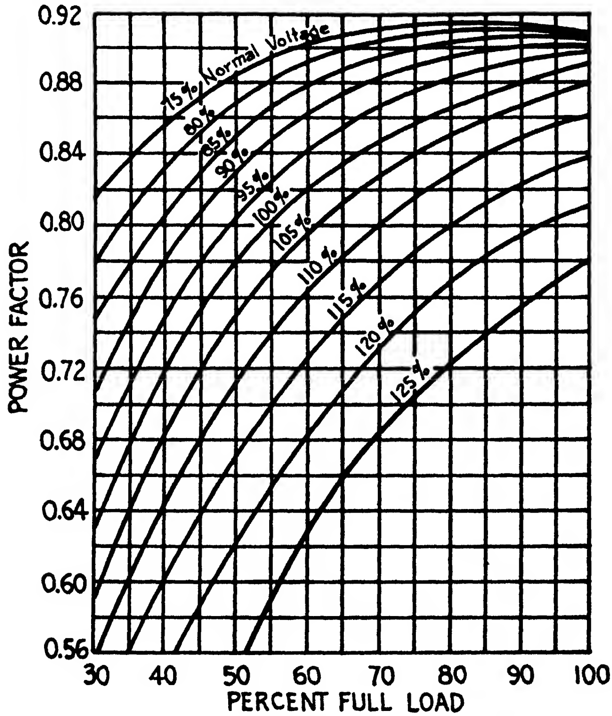

Fig. 6. Variation of Power Factor on an Average Induction Motor with Load and Voltage

(From W. W. Lewis' "Transmission Line Engineering")

changing motors may be impracticable. In any event, changing motors may involve different shaft diameters, different bolt-hole centers, and different distances from base to center of shaft. It is barely possible that shifting the motors around within a plant may give the desired results, but usually new motors must be purchased. The problem resolves itself into the desirability and economics of such changes or of using capacitors with the existing equipment. The only disadvantage of using capacitors with oversize or low-speed motors is the slight difference in efficiency due to higher friction and windage losses in these motors than in those by which they would be replaced. Some capacitors may be necessary even if all motors are fully loaded because even then the power factor may be lower than desired.

A number of individually motor-driven machines in one section of a plant may be advantageously converted to group drive if they operate continuously at partial motor rating, because the one motor just large enough to carry the combined load would have a much better power factor than the smaller motors at partial loads. Conversely, a group drive for a number of machines which operate intermittently could be profitably transformed into individual drives, because the large lightly loaded motor would have a much poorer power factor than the comparatively well-loaded smaller motors.

Because of space required and age it may be quite beneficial to replace some low-speed motors with either geared motors or high-speed motors with V-belt drives.

TABLE VI

Approximate Full-Load Amperes * of Induction-Type Squirrel-Cage and Wound-Rotor Motors

H.P.	Single-Phase			Two-Phase, 4-Wire †					Three-Phase				
	110 v.	220 v.	440 v.	110 v.	220 v.	440 v.	550 v	2200 v.	110 v.	220 v.	440 v.	550 v.	2200 v.
½	7	3 5		4.3	2.2	1.1	0.9		5	2.5	1.3	1	
¾	9.4	4.7		4.7	2.4	1.2	1.0		5.4	2.8	1.4	1.1	
1	11	5.5		5.7	2.9	1.4	1.2		6.6	3.3	1.7	1.3	
1½	15.2	7.6		7.7	4.0	2	1.6		9.4	4.7	2.4	2.0	
2	20	10		10 4	5	3	2		12	6	3	2.4	
3	28	14			8	4	3			9	4.5	4	
5	46	23			13	7	6			15	7.5	6	
7½	68	34	17		19	9	7			22	11	9	
10	86	43	21.5		24	12	10			27	14	11	
15					33	16	13			38	19	15	
20					45	23	19			52	26	21	
25					55	28	22	6		64	32	26	7
30					67	34	27	7		77	39	31	8
40					88	44	35	9		101	51	40	10
50					108	54	43	11		125	63	50	13
60					129	65	52	13		149	75	60	15
75					156	78	62	16		180	90	72	19
100					212	106	85	22		246	123	98	25
125					268	134	108	27		310	155	124	32
150					311	155	124	31		360	180	144	36
200					415	208	166	43		480	240	195	49

* Average for all speeds and frequencies.

† Values of current in common wire of 2-phase 3-wire system will be 1 41 times values given For 208 and 200-volt motors, increase 230-volt amperes by 6 and 10 per cent respectively.

TABLE VII

APPROXIMATE OPERATING CHARACTERISTICS *Normal*-TORQUE, *Normal*-STARTING-CURRENT, 3-PHASE, 60-CYCLE SQUIRREL-CAGE MOTORS, *220, 440, 550* VOLTS

Hp.	Full-Load R.P.M.	% Efficiency			% Power Factor			Kw. Input		
		Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load
½	830	68.5	69	64.5	52	45	35	0.55	0.41	0.29
	680	66	63	56	55	47	37	0.57	0.44	0.33
¾	1125	74.5	74	72	70	62	49	0.75	0.57	0.39
	855	71	68	62	61	53	42	0.79	0.62	0.45
	660	67.5	65	60	53	45	35	0.83	0.65	0.47
1	1720	78.5	79	77	80	72	61	0.95	0.71	0.48
	1135	75.5	76	74	74	66	51	0.99	0.74	0.50
	855	72.5	70	64	63	56	44	1.03	0.80	0.58
	690	75	74	68.5	63	54	42	1.00	0.76	0.54
1½	3500	78.5	79	77	80	74	61	1.43	1.06	0.73
	1740	79	79	76	82	75	62	1.42	1.06	0.74
	1125	76.5	78	78	80	74	62	1.46	1.08	0.72
	875	79.5	78	74	65	56	45	1.41	1.08	0.76
	695	77	76	71	63	55	43	1.45	1.10	0.79
2	3470	77	77	75	83	77	68	1.94	1.45	1.00
	1740	80	80	78	84	78	68	1.87	1.40	0.96
	1140	80	80	79	78	71	60	1.87	1.40	0.94
	865	79	80	77	72	65	51	1.89	1.40	0.97
	690	76	74	69	63	54	44	1.96	1.51	1.08
3	3420	78.5	79.5	78.5	85	82	73	2.85	2.11	1.43
	1720	80	81	78	87	82	71	2.80	2.07	1.43
	1160	80.5	81	79	81	72	60	2.78	2.07	1.42
	860	80.5	81	79	73.5	68	56	2.78	2.07	1.42
	690	80	79	76.5	69	62	50	2.80	2.12	1.46
5	3460	80	81	81	85	80	72	4.66	3.45	2.30
	1735	83.5	84.5	83	88	83	75	4.47	3.31	2.25
	1155	83	83	82	83	77	64	4.49	3.37	2.27
	860	83	83	81	77	71	59	4.49	3.37	2.30
	700	82	81.5	79	68	61	49	4.55	3.43	2.36
	570	78.5	79	76	57	49	33	4.75	3.54	2.45

TABLE VII—*Continued*

Hp.	Full-Load R.P.M.	% Efficiency			% Power Factor			Kw. Input		
		Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load
7½	1740	83 5	84 5	83	89	85	75	6 70	4.97	3 37
	1155	84	84 5	83	85	80	70	6.66	4.97	3 37
	865	83.5	84	82	79	72	60	6.70	4.99	3.41
	695	84	83.5	81	71	63	50	6 66	5.02	3.45
	575	81	81	78	66	57	43	6 91	5 18	3 59
10	1745	85	85 5	85	89	85	75	8.78	6.54	4.39
	1160	84.5	85	85	86	81	71	8 83	6.58	4 39
	865	85 5	85	83	81	75	63	8 73	6.58	4 49
	700	84.5	84 5	83	72	64	50	8 83	6.62	4 49
	580	85	84.5	80	73	65	51	8 78	6.62	4 67
15	1750	85	85	84.5	90 5	85	76	13.2	9.87	6 62
	1165	87.5	87.5	86	87.5	83	74	12 8	9 59	6 50
	870	86 5	85	81	82.5	76	64	12.9	9.87	6.91
	690	84 5	84.5	83	76	70	55	13 2	9 93	6.74
	580	86	86	84	72	64	50	13 0	9.76	6.66
20	1760	88	87	83	88.5	84	73	17.0	12.9	8.98
	1170	88.5	88	85.5	88.5	84	74	16 9	12.7	8.72
	880	88	87.5	85	83	76	65	17.0	12.8	8.78
	695	87.5	87.5	86	81	76	63	17.1	12.8	8.67
	580	86.5	87	86	73	66	52	17 3	12.9	8.67
25	1760	89.5	89	87	90	86.5	78	20.8	15.7	10.7
	1170	89	88	86	88.5	84	75	21.0	15.9	10 8
	880	88	88	85	85	80	70	21.2	15.9	11.0
	695	88.5	88.5	87	78	71	58	21.1	15.8	10.7
	580	86	86	84	72	63	47	21.7	16.3	11.1
30	1760	89.5	89	86	91	89	82	25.0	18.9	13.0
	1175	88.5	87.5	85	87	83	74	25.3	19.2	13.2
	880	88.5	88	86	85	80	70	25.3	19.1	13.0
	695	87	87	86	78	70	55	25.7	19.3	13.0
	580	86	86	84	75	68	54	26.0	19.5	13.3
40	1765	89.5	89	86.5	90	88	82	33.3	25.2	17.3
	1175	89.5	89	87	88	84	75	33.3	25.2	17.2
	865	89	89	88	83	77	65	33.5	25.2	17.0
	695	88	88	87	82	77	65	33.9	25.4	17.2
	580	86.5	86.5	85	79	71	59	34.5	25.9	17.6

TABLE VII—*Continued*

Hp.	Full-Load R.P.M.	% Efficiency			% Power Factor			Kw. Input		
		Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load
50	1765	90	89.5	87	91	89	82	41.4	31 3	21.4
	1160	89	89	87	90	87	80	41.9	31.4	21.4
	870	89 5	89.5	88	84	78	65	41 7	31.3	21.2
	695	88.5	88.5	87	84	77	66	42 2	31.6	21.4
	580	88	88	86	79	71	59	42 4	31 8	21.7
60	1775	90.5	90	87 5	91	88	80	49 4	37.3	25.6
	1170	90	89 5	86.5	88 5	83	70	49 7	37.5	25.9
	875	89.5	89	88	88	84	75	50 0	37.7	25.4
	700	90	90	89	84	79	68	49 7	37 3	25.2
	580	88 5	88 5	87	82	75	64	50.6	37.9	25.7
75	1775	91	90	88	91	88	80	61 4	46.7	31.8
	1175	90	89.5	87	89	85	77	62 2	46 9	32 2
	880	90.5	90 5	89	88	84	75	61.8	46 4	31 4
	700	89.5	89.5	88	85	79	68	62 5	46.9	31.8
	580	89	89	88	83	77	65	62 8	47 2	31.8
100	1775	90.5	90	88	91	88.5	80	82.4	62.2	42.4
	1175	91	90 5	88	90	86	77	82 0	61.8	42.4
	875	90.5	90	88 5	90	86	78	82.4	62 2	42.2
	705	90.5	90.5	89	85	81	70	82.4	61.8	41.9
	575	88.5	88.5	87	86	81	70	84 3	63 2	42.8
125	1775	91.5	91	89	91.5	89	81	102	76.8	52.3
	1175	91.5	91	89	90	86	77	102	76 8	52.3
	880	91.5	91	89	88	84	74	102	76.8	52.3
	700	90	89	87	86	80	65	104	78.5	53.6
	580	90	90	88	86	81	70	104	77.7	53.0
150	1780	92	91	89	91.5	89.5	83	122	92.2	62.8
	1185	93	92.5	91	91	88	80	120	90.7	61.5
	880	91 5	91	90	89	85	75	122	92 2	62 2
	695	90	89.5	88	88	83	71	124	93 8	63.6
	580	90.5	90.5	89	86 5	82	70	124	92 7	62.8
200	1775	92	91.5	89	91.5	90	84	162	122	83 8
	1190	93.5	93	92	91	88	80	160	120	81 2
	885	91 5	91.5	90.5	89	88	80	163	122	82 4
	700	91.5	91.5	90	87	83	71	163	122	82.9
	585	91.5	91.5	90	86	80	66	163	122	82.9

TABLE VIII

Approximate Operating Characteristics *Normal*-Torque, *Normal*-Starting-Current 3-Phase, 60-Cycle Squirrel-Cage Motors, 2200 Volts

Hp.	Full-Load R.P.M.	% Efficiency			% Power Factor			Kw. Input		
		Full Load	$\frac{3}{4}$ Load	$\frac{1}{2}$ Load	Full Load	$\frac{3}{4}$ Load	$\frac{1}{2}$ Load	Full Load	$\frac{3}{4}$ Load	$\frac{1}{2}$ Load
30	1170	86 5	87	85 5	82 5	77	65	25 9	19 3	13.1
	880	86	85	82	75	68	55	26 0	19 7	13 7
	575	83	83	80	72	62	50	27 0	20 2	14 0
40	1760	88 5	87 5	85	89	86	79	33 7	25 6	17.5
	1175	88	88	85	83	77	65	33 9	25 4	17 5
	865	86.5	86.5	85	83	77	65	34 5	25 9	17 5
	690	86	86	84	78	72	57	34 7	26 0	17 8
	580	85 5	85.5	84	68	59	44	34 9	26 2	17 8
50	1765	89 5	88 5	86	90	88	81	41 7	31 6	21 7
	1160	87 5	86.5	84	88.5	83.5	72	42 6	32 3	22 2
	865	87 5	87.5	86	85	80	70	42.6	32 0	21 7
	695	87 5	87.5	86	80	74	62	42.6	32 0	21.7
	580	86 5	86.5	85	81	74	62	43 2	32 3	21 9
60	1775	88	86 5	83.5	89	85	76	50 8	38 8	26.8
	1165	88	87 5	85	89	84 5	74	50 8	38 4	26 3
	865	88	87 5	86	86	80	70	50 8	38 4	26.0
	700	87.5	87 5	86	82	75	62	51 2	38.4	26 0
	580	88	87 5	85 5	77	68	55	50.8	38 4	26.2
75	1775	89	88	85	90	87	78	62 8	47.7	32.9
	1175	89	88	85	87	83	73	62 8	47 7	32.9
	870	88 5	88.5	87	87	82	75	63 2	47 4	32 2
	700	89	88 5	87	83	75	62	62 8	47 4	32 2
	585	88.5	88	86	78	70	55	63 2	47.7	32 5
100	1775	90.5	90	88	90	88	81	82 4	62 2	42 4
	1175	90	90	88	89	85	76	82 8	62 2	42 4
	875	89	88.5	87	87	83	72	83 8	63 2	42.9
	700	89 5	89	87	85	79	66	83 3	62.8	42 9
	585	89 5	89 5	87	83	77	65	83 3	62.5	42 9
125	1775	91	90 5	89	90	88.5	82	102	77.3	52.3
	1175	91	90 5	89	89	86	78	102	77.3	52.3
	880	90	90	88	88	84	74	104	77 7	53.0
	700	89	88.5	87	86	80	67	105	79 0	53.6
	585	89 5	89.5	87	83	76	64	104	78.1	53.6

TABLE VIII—*Continued*

Hp.	Full-Load R.P.M.	% Efficiency			% Power Factor			Kw. Input		
		Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load
150	1775	91	90	88	91	89 5	83	123	93 3	63 6
	1185	92	91 5	90	90	87	80	122	91 8	62 2
	880	90 5	89 5	87	85	80	68	124	93 8	64 3
	700	90	90	88 5	87	83	71	124	93 3	63 2
	585	90	90	88	86 5	82	70	124	93 3	63.6
200	1775	91	91	89	91 5	90	84	164	123	83 8
	1185	92 5	92	90 5	90	87	80	161	122	82 4
	885	91 5	91 5	90	89	86	80	163	122	82 8
	705	91 5	91 3	89 5	85	78	64	163	123	83 4
	585	91	91	89	85	79	67	164	123	83.8

TABLE IX

Approximate Operating Characteristics *Normal*-Torque, *Low*-Starting-Current, 3-Phase, 60-Cycle, Squirrel-Cage Motors, *220*, *440*, *550* Volts

Hp.	Full-Load R.P.M.	% Efficiency			% Power Factor			Kw. Input		
		Full Load	$\frac{3}{4}$ Load	$\frac{1}{2}$ Load	Full Load	$\frac{3}{4}$ Load	$\frac{1}{2}$ Load	Full Load	$\frac{3}{4}$ Load	$\frac{1}{2}$ Load
7$\frac{1}{2}$	3450	82	83	83	88	84	75	6 8	5 1	3 4
	1745	83	83	82	88	87	82	6 7	5 1	3 4
	1160	84	84 5	85	83	80	70	6 7	5 0	3 3
	865	83	85	83	76	71	58	6 7	4 9	3 4
	690	82	82	80	71	63	50	6 8	5 1	3 5
	575	81	81	78	66	57	43	6.9	5 2	3 6
10	3470	81	83	83	91	89	82	9.2	6.7	4.5
	1750	85	86	84.5	85	83	75	8.8	6.5	4.4
	1160	83	85	84.5	85	82	75	9 0	6 6	4.4
	875	86	85	82	77	71	59	8.7	6 6	4.5
	700	84.5	84.5	83	72	64	50	8.8	6.6	4.5
	580	85	84.5	80	73	65	51	8 8	6.6	4 7
15	3500	83	84	83	88	87	81	13.5	10.0	6.7
	1740	86	87	87	85	85	81	13.0	9.6	6 4
	1165	87	87 5	86	85	82	74	12.9	9.6	6.5
	875	87	87	85	77	71	60	12.9	9.6	6.6
	690	84.5	84 5	83	76	70	55	13.3	9.9	6 7
	580	86	86	84	72	64	50	13.0	9.8	6.7
20	3460	86	87	86	89	88	82	17.4	12.9	8.7
	1760	88.5	88.5	87	86	82	72	16.9	12.6	8.6
	1170	88	88	85.5	85	82	74	17:0	12.7	8.8
	875	88	88	87	78	74	63	17.0	12.7	8.6
	695	87.5	87.5	86	81	76	63	17.1	12.8	8 7
	580	86.5	87	86	73	66	52	17.3	12.9	8.7
25	3545	88	87	85	88.5	88	80	21.2	16.1	11.0
	1760	89	89	88	87	83	75	21.0	15.7	10 6
	1170	89.5	89.5	88.5	85	82	74	20.8	15.6	10 5
	880	88	88	87	81	78	69	21.2	15.9	10.7
	695	88 5	88.5	87	78	71	58	21.1	15.8	10.7
	580	84	84.5	83	69	62	48	22.2	16.6	11.2

TABLE IX—*Continued*

Hp.	Full-Load R.P.M.	% Efficiency			% Power Factor			Kw. Input		
		Full Load	$\frac{3}{4}$ Load	$\frac{1}{2}$ Load	Full Load	$\frac{3}{4}$ Load	$\frac{1}{2}$ Load	Full Load	$\frac{3}{4}$ Load	$\frac{1}{2}$ Load
30	3550	89	88	85	90	88	80	25 1	19.1	13 2
	1760	89 5	89.5	88	88 5	87	81	25 0	18 8	12.7
	1175	89	89	87 5	85	82	74	25 1	18.9	12.8
	880	88 5	88	85 5	83	79	70	25.3	19 1	13 1
	700	86	86	85	78	72	60	26.0	19.5	13.2
	585	85 5	85 5	84	73	66	52	26.2	19.6	13.3
40	3540	89	88 5	87	90	89	85	33 5	25.3	17 2
	1765	89 5	89	87	89.5	88	83	33 3	25.1	17.2
	1175	89 5	89.5	88	86	83 5	76	33 3	25 0	17.0
	875	88 5	89	88	80	75	65	33 7	25 1	17.0
	700	87 5	87.5	87	80	75	63	34 1	25 6	17.2
	580	86 5	86 5	85	79	71	59	34 5	25.9	17 6
50	3550	90	89.5	88	90	89	84	41.4	31.3	21 2
	1765	90	89.5	87	89.5	89	84	41.4	31.3	21.4
	1170	89	88	85	87	84	77	41.9	31.8	21.9
	875	89 5	89.5	88 5	82	79	70	41.7	31.3	21.1
	695	88 5	88 5	87	83	76	64	42.2	31 6	21.4
	580	88	88	86	79	71	59	42.4	31.8	21 7
60	3540	90	89.5	88	90	89	85	49.7	37.5	25 4
	1775	90.5	90	87.5	88.5	87	80	49.4	37.3	25 6
	1175	89 5	88.5	86 5	87	83	75	50 0	37.9	25.9
	875	89	89	88	83	78.5	70	50.3	37.7	25.4
	700	88 5	88.5	87	81	76	64	50.6	37.9	25.7
	580	88 5	88.5	87	82	75	64	50.6	37.9	25.7
75	3540	90.5	90	88	90	89	85	61.8	46 6	31.8
	1775	90.5	90	88.5	90	88	80	61.8	46.6	31.6
	1180	90	89	87	86	83	75	62.2	47.2	32.1
	875	89.5	89.5	87	85	82	70	62.5	46 9	32.1
	700	88	88	86.5	81	76	64	63.5	47.7	32.3
	580	89	89	88	83	77	65	62.8	47 2	31.8
100	3540	90	89	87	90	88	82	82.9	62.8	42.8
	1770	90.5	90.5	89	89	87	79	82.5	61.8	41.8
	1180	91	90.5	88	88	85	78	82.0	61.8	42.3
	870	89	89	88	86	83	71	83.8	62.8	42.3
	705	90.5	90.3	89	81	76	64	82.5	61.9	41.8
	575	88.5	88.5	87	86	81	70	84.3	63.2	42.8

TABLE IX—*Continued*

Hp.	Full-Load R.P.M.	% Efficiency			% Power Factor			Kw. Input		
		Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load
125	3555	91.5	90 5	89	90	88	81	102	77.3	52 3
	1770	91 5	91	89	89 5	88	80	102	76 8	52 3
	1180	91 5	90 5	88	88	84	75	102	77.3	52 9
	890	90	90	89	85	81	70	104	77 7	52 3
	705	90	89 5	87	83	78	66	104	78.2	53 6
	580	90	90	88	86	81	70	104	77 7	52 9
150	3555	92	91 5	89	90	88	80	122	91 8	62 8
	1770	91 5	91	89 5	90	88	81	122	92.3	62.4
	1175	92	91 5	89	89	86	78	122	91.8	62 8
	875	90	90	89	85	81	70	124	93 3	62.8
	700	90	89 5	88	83	78	66	124	93 8	63.5
	580	90 5	90 5	89	86 5	82	70	124	92.8	62 8
200	3550	92 5	92	90	90	89	85	161	122	82 8
	1770	91 5	91 5	90	90	88	80	163	122	82 8
	1180	92 5	92	89.5	89.5	86	78	161	122	83 3
	885	91 5	91 5	90 5	89	88	80	163	122	82 4
	705	91.2	91	89 5	85	81	70	164	123	83 3
	585	91 5	91 5	90	86	80	66	163	122	82 8

TABLE X

APPROXIMATE OPERATING CHARACTERISTICS, *Normal*-TORQUE. *Low*-STARTING-CURRENT, 3-PHASE, 60-CYCLE, SQUIRREL-CAGE MOTORS, *2200* VOLTS

Hp.	Full-Load R.P.M.	% Efficiency			% Power Factor			Kw. Input		
		Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load
30	1170	86.5	87	85.5	82.5	77	65	25.9	19.3	13.1
	575	83	83	80	72	62	50	27.0	20.2	14.0
40	1760	88	87.5	85	87	84	76	33.9	25.6	17.6
	1175	88	87.5	85.5	79.5	73	60	33.9	25.6	17.5
	875	85.5	85.5	83	80	75	65	34.9	26.2	18.0
	690	86	86	84	78	72	57	34.7	26.0	17.8
	580	85.5	85.5	84	68	59	44	34.9	26.2	17.8
50	1765	89.5	88.5	86	88	86	80	41.7	31.6	21.7
	1165	87.5	86.5	84	83	79	70	42.7	32.3	22.2
	865	87.5	87.5	86	81	76	67	42.7	32.0	21.7
	695	87.5	87.5	85	79	74	60	42.7	32.0	21.9
	580	86.5	86.5	85	81	74	62	43.2	32.3	21.9
60	3540	88.5	87	84	87	84	75	50.5	38.6	26.7
	1775	89.5	88.5	86	88	85	79	50.0	37.9	26.0
	1170	88	87.5	85	84	80	70	50.8	38.3	26.3
	865	87.5	87.5	86	81	76	67	51.2	38.3	26.0
	695	86	86	84	81	76	64	52.0	39.0	26.7
	580	88	87.5	85.5	77	68	55	50.8	38.3	26.2
75	3540	89	88	85.5	88	85	78	62.8	47.7	32.7
	1775	90	89	86.5	89	86	79	62.2	47.1	32.3
	1180	89	87.5	85	86	83	74	62.8	47.9	32.9
	870	88	88	86	83.5	77	65	63.6	47.7	32.5
	700	87	87	85	80.5	75	63	64.3	48.2	32.9
	585	88.5	88	86	78	70	55	63.2	47.7	32.5
100	3540	90	89	87	90	88	82	82.9	62.8	42.8
	1765	90	90	88	89	86	78	82.9	62.2	42.4
	1180	90.5	90	88	87.5	84	75	82.4	62.2	42.4
	875	88.5	88.5	86.5	84	80	66	84.3	63.2	43.2
	700	88.5	88.5	86.5	80.5	75	63	84.3	63.2	43.2
	585	89.5	89.5	87	83	77	65	83.3	62.4	42.8

TABLE X—*Continued*

Hp.	Full-Load R.P.M.	% Efficiency			% Power Factor			Kw. Input		
		Full Load	$\frac{3}{4}$ Load	$\frac{1}{2}$ Load	Full Load	$\frac{3}{4}$ Load	$\frac{1}{2}$ Load	Full Load	$\frac{3}{4}$ Load	$\frac{1}{2}$ Load
125	3555	91 5	90.5	89	90	88	81	102	77.3	52.4
	1775	91	90.5	88	89	87	79	102	77.3	53.0
	1180	91	90	87	87	83	73	102	77.7	53.6
	880	89 5	89	87	84	80	67	104	78.6	53.6
	705	90	89.5	88	82	77	65	104	78.2	53.0
	585	89.5	89.5	87	83	76	64	104	78.2	53.6
150	3555	92	91	89	90	88	80	122	92.2	62.8
	1770	91	90.5	88.5	89	87	79	123	92.8	63.2
	1175	91 5	91	88 5	88	85	75	122	92.2	63.2
	880	89 5	89 5	87	84	79	67	125	93.8	64.3
	705	89.5	90	88.5	83	78	66	125	93.3	63.2
	585	90	90	88	86.5	82	70	124	93.3	63.6
200	3550	92 5	92	90	90	88	80	161	122	82.9
	1770	91	91	89	89.5	87	79	164	123	83.8
	1180	92	91.5	89	88	85	75	162	122	83.8
	885	91.5	91 5	90	89	86	80	163	122	82.9
	705	91 5	91	89	85	80	67	163	123	83.8
	585	91	91	89	85	79	67	164	123	83.8

TABLE XI

APPROXIMATE OPERATING CHARACTERISTICS, *High*-TORQUE, *Low*-STARTING-CURRENT, 3-PHASE, 60-CYCLE, SQUIRREL-CAGE MOTORS, *220*, *440*, *550* VOLTS

Hp.	Full-Load R.P.M.	% Efficiency			% Power Factor			Kw. Input		
		Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load
3	1720	80	81	78	87	82	71	2 8	2.1	1.4
	1140	80	80.5	79	77	72	60	2.8	2.1	1.4
	855	80.5	81	79	70	63	51	2 8	2.1	1.4
5	1730	82	83	83	84	79	69	4 5	3.4	2 2
	1140	80	81	80	81	77	66	4 7	3.5	2.3
	870	80.5	81	78.5	68	62	50	4.6	3.5	2 4
7½	1730	82	83	82.5	84	81	72	6.8	5.1	3.4
	1140	82	83	83 5	81	77	68	6.8	5.1	3 4
	860	83	84	82	72	67	57	6 7	5.0	3 4
10	1750	83	85	84	83	79	72	9.0	6.6	4.4
	1150	82	83	83	85	82	75	9.1	6.7	4.5
	870	85	85	84	72	65	50	8.8	6.6	4.4
15	1735	84	86	85	85	85	80	13.3	9.8	6.6
	1160	86.5	87	86	83	79	70	12.9	9.6	6.5
	865	86	86	85	73	66	55	13.0	9.8	6.6
20	1755	88	88	87	82	78	68	17.0	12.7	8 6
	1170	88	88	87	83.5	79	70	17.0	12.7	8.6
	865	87	87	86	76	69	56	17.2	12.9	8.7
25	1765	89	89	88	82	78	68	20.9	15.7	10.6
	1170	88 5	88 5	87 5	85	82	74	21.1	15.8	10.7
	875	87.5	87.5	86	78	72	60	21.3	16.0	10.8
30	1760	89.5	89.5	88	86	82	73	25.0	18.7	12.7
	1170	88.5	88	87	85	82	74	25.3	19.1	12.9
	875	88.5	88.5	87	78	72	60	25.3	19.0	12.9
40	1765	90	89.5	88	87	84	75	33.2	24.9	17.0
	1170	89.5	89	88	85	82	74	33.3	25.0	17.0
	865	87.5	87.5	87	79	74	62	34.1	25.6	17.2

TABLE XI—*Continued*

Hp.	Full-Load R.P.M.	% Efficiency			% Power Factor			Kw. Input		
		Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load
50	1770	90 5	90	89	89	86	80	41.2	31 1	20 9
	1150	87	87 5	87	87	84	77	42 8	32.0	21.4
	865	88	88	87	79	74	63	42 4	31 8	21.4
60	1760	89	88 5	87	87 5	86	80	50 3	37.9	25 7
	1165	89	89	88	86	82	73	50 3	37.7	25 4
75	1765	90	89	87	88	86	80	62 2	47.2	32 2
2200 VOLTS										
60	1760	88 5	87.5	85	84	80	70	50.5	38.4	26.3
	1150	86 5	86	85	84	80	70	51 7	39 0	26 3
75	1755	89	88	86	85	82	70	62 8	47.7	32 5

TABLE XII

Approximate Operating Characteristics, Constant- and Adjustable-Varying-Speed, 3-Phase, 60-Cycle, *Wound-Rotor* Induction Motors, *220, 440, 550* Volts

Hp.	Full-Load R.P.M.	% Efficiency			% Power Factor			Kw. Input		
		Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load
1	1675	69	68 5	63	74	68	58	1 1	0 82	0 59
	1095	68	65 5	60	58	50	40	1 1	0 85	0 62
	835	67	65 5	60	54	46	38	1 1	0 85	0 62
1½	1675	70	69 5	65	77	71	61	1 6	1 2	0 86
	1080	71 5	68	62 5	58	50	40	1 6	1 2	0 89
	830	73	72	69	68	59	48	1 5	1 2	0 81
2	1715	71	70	66	82	77	67	2 1	1 6	1 1
	1095	72 5	72	69	64	57	47	2 1	1 6	1 1
	830	72 5	72	69	66	57	45	2 1	1 6	1 1
3	1695	76	76	72	79	73	63	2 9	2 2	1 6
	1115	74	75	75	75	67	56	3 0	2 2	1.5
	845	76	76 5	74	71	64	52	2 9	2 2	1 5
	565	75	73	65	50	40	25	3 0	2 3	1 7
5	1690	79	79	78	81	75	63	4 7	3 5	2.4
	1135	79	79	76	79	73	58	4 7	3 5	2 5
	845	80	81	79	67	62	51	4 7	3 5	2 4
	685	81	80	78	58	50	32	4 6	3 5	2 4
	565	76	75	70	60	50	30	4 9	3 7	2 7
7½	1690	82	81	79	82	76	66	6 8	5 2	3 5
	1125	79 5	80	76.5	81	75	66	7 0	5 2	3 7
	845	82	82 5	80	68	63	52	6 8	5 1	3 5
	685	80 5	80	77	63	53	37	7 0	5 2	3 6
	570	77	76	72	60	50	30	7 3	5 5	3 9
10	1705	82 5	82	81	87	82	72	9 0	6 8	4 6
	1150	84 5	84	81.5	81	77	68	8 8	6 7	4 6
	845	83	82 5	80	75	67	54	9 0	6 8	4.7
	685	83	82 5	80	70	58	42	9 0	6 8	4 7
	575	82	80	76	63	54	40	9 1	7 0	4 9
15	1705	84	85.5	85	88	85	78	13 3	9 8	6.6
	1155	85	85 5	84	83	77	65	13 2	9 8	6 7
	850	84	83 5	81	78	72	59	13 3	10 0	6 9
	690	87	86 5	85	72	69	53	12 9	9 7	6 6
	575	82.5	82	77	67	60	46	13 6	10.2	7.3

TABLE XII—*Continued*

Hp.	Full-Load R.P.M.	% Efficiency			% Power Factor			Kw. Input		
		Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load
20	1730	85 5	85 5	83	88	85	76	17.5	13.1	9 0
	1160	87	87	85	82	75	63	17 2	12 9	8.8
	855	85	85	84	79	73	58	17.6	13.2	8 9
	690	86 5	86 5	85	77	72	55	17.3	12.9	8.8
	570	83	81	77	69	58	45	18.0	13 8	9.7
25	1735	87	86	85	88 5	85	76	21 4	16 3	11 0
	1170	88	87	85	82	75	64	21.2	16 1	11 0
	870	88	88	86	84	80	70	21 2	15 9	10.9
	685	85 5	85 5	84	78	71	53	21 8	16 4	11.1
	575	84	83.5	81	71	62	47	22.2	16 8	11.5
30	1755	88	87.5	84	88 5	85	76	25.4	19.2	13.3
	1170	89	88	86	85	79	66	25.2	19.1	13.0
	870	88	88	86	82	76	62	25 4	19 1	13.0
	690	85.5	85.5	84	77	58	50	26 2	19 6	13 3
	575	84.5	84 5	82	77 5	71	58	26 5	19 9	13 7
40	1750	89	88	85	89	86	78	33 5	25 4	17 6
	1170	90	89 5	88	86	81	70	33 2	25 0	17.0
	865	87	87	85	82	74	62	34 3	25 7	17 6
	680	87	87	85	82	77	65	34 3	25 7	17.6
	575	84 5	84 5	83	74.5	67	54	35 3	26 7	18 0
50	1745	89 5	89	87	89	86	78	41 7	31 4	21 4
	1160	88 5	88	86	86	80	70	42 2	31 8	21 7
	865	87 5	87 5	86	82	74	63	42 6	32 0	21 7
	685	85 5	85 5	85	82.5	77	65	43 6	32 7	21.9
	575	86 5	86.5	85	77	70	58	43 2	32 3	21.9
60	1750	89 5	89	88	89	88	82	50 0	37.7	25 4
	1170	90	89 5	88	90	86	70	49 7	37.5	25 4
	865	87 5	87 5	86	86.5	82	72	51 2	38.4	26 0
	690	87	87	86	83.5	78.5	68	51 4	38 6	26.0
	575	87.5	87 5	86	80.5	76	65	51 2	38.4	26.0
75	1755	90	90	89	89 5	88.5	84	62.2	46 6	31.4
	1165	89	88	85	86	82	75	62 8	47 7	32.9
	870	88.5	88.5	86	87	82	71	63 2	47.3	32.5
	695	88.5	88.5	87	83	78	65	63 2	47 3	32.2
	575	88	88	86	80	74	62	63.6	47.7	32.5

TABLE XII—*Continued*

Hp.	Full-Load R.P.M.	% Efficiency			% Power Factor			Kw. Input		
		Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load
100	1755	89 5	89	87	91	89	84	83 3	62 8	42 8
	1170	90 5	90	88	88	84	75	82 5	62 2	42 3
	875	89	89	87	87	82	71	83 8	62.8	42 8
	695	89 5	89.5	88	86	80	65	83 3	62 5	42 3
	575	88	88	86 5	86	82	71	84 8	63 6	43 1
125	1755	90 5	89 5	86 5	92	90	85	103	78 2	53 9
	1170	90 5	90	88	88 5	84	75	103	77 7	53 0
	870	90	90	87	85	80	67	104	77 7	53 6
	700	89.5	89	87	85	79	63	104	78 5	53 6
	575	89	89	87	84.5	80	70	105	78.5	53 6
150	1755	90.5	90	88	92	90	85	124	93 3	63 6
	1170	91.5	91	90	90	87	80	122	92.2	62 2
	875	90 5	90	88	86	81	73	124	93.3	63.6
	695	90	89 5	88	86	80	65	124	93 8	63.6
	580	90	89 5	88	85	81	70	124	93 8	63 6
200	1760	91	90 5	89	89	87	80	164	124	83 8
	1170	92 5	92	91	90	87	80	161	122	82 0
	880	91	91	90	88	85	79	164	123	82 9
	700	91	90 5	89	85	80	65	164	124	83 8
	585	91	91	89	84	79	70	164	123	83 8

TABLE XIII

APPROXIMATE OPERATING CHARACTERISTICS, CONSTANT- AND ADJUSTABLE-VARYING-SPEED, 3-PHASE, 60-CYCLE, *Wound-Rotor* INDUCTION MOTORS, *2200* VOLTS

Hp.	Full-Load R.P.M.	% Efficiency			% Power Factor			Kw Input		
		Full Load	3/4 Load	1/2 Load	Full Load	3/4 Load	1/2 Load	Full Load	3/4 Load	1/2 Load
30	1155	84 5	84	81	86	81 5	70	26 5	20 0	13 7
	570	82	82	80	70	64	50	27 3	20 5	14 0
40	1735	87	86	84	87 5	84	75	34 3	26 0	17 8
	1155	86	86	83	87	80	72	34 7	26 0	18 0
	860	85 5	85	84	78	70	55	34 9	26 3	17 8
	685	84 5	84 5	82	77	71	59	35.3	26 5	18 2
	570	83	83	81	74	67	55	35.9	27 0	18 4
50	1735	88	87	85	88	85	78	42.3	32 2	21 9
	1155	87	86	83	88	84	75	42.8	32 5	22 5
	865	86 5	86	85	80	72	58	43.1	32 5	21 9
	685	85 5	85.5	83	78	71	60	43.6	32 7	22 5
	575	84.5	85	84.5	72	65	51	44 1	33 1	22 1
60	1750	89	88	85	85	80	71	50 3	38 1	26 3
	1160	88	87	85	88	84	75	50 8	38 6	26 3
	860	86.5	86	84	85	82	72	51 8	39 0	26 6
	695	86.5	86.5	84	80	71	55	51 8	38 8	26 6
	580	86 5	86	85	77	71	58	51 8	39 0	26 3
75	1755	89.5	89	86.5	87	84	76	62 5	47 2	32 3
	1165	88	87	83	85	80	70	63 6	48 2	33 7
	870	87.5	87	84	84	78	66	63 9	48 2	33 3
	695	87.5	87.5	85	81	72	58	63 9	47 9	32 9
	580	87	87	85	75	67	54	64 3	48 2	32 9
100	1755	89	88	86	89.5	86	78	83 8	63 6	43 3
	1170	89.5	88.5	85	87	83	74	83.3	63 2	43 8
	875	88	87.5	86	84	80	69	84 8	63 9	43 3
	695	88	88	86	85	80	70	84 8	63 6	43 3
	575	87.5	87	84	82	76	66	85 2	64 3	44.4
125	1755	90	89	85.5	89.5	86	78	104	78 5	54 5
	1170	89.5	89 5	88	87	83	74	104	78.1	52 9
	880	89	88 5	87	86.5	82	70	105	79 0	53.6
	700	89	88 5	86	87	83	74	105	79 0	54 2
	580	88	87 5	86	82	76	66	106	79.8	54 2

TABLE XIII—*Continued*

Hp.	Full-Load R.P.M.	% Efficiency			% Power Factor			Kw. Input		
		Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load
150	1755	90 5	90	88	90	87 5	80	124	93 2	63 6
	1165	91	90 5	89	89	87	80	123	92 7	62 8
	880	90	89 5	88	87	82	70	124	93 8	63 6
	700	90 5	90 5	88 5	87	83	73	124	92 7	63 2
	575	88 5	88 5	86 5	82	77	66	127	94 8	64 7
200	1760	90 5	90	88	90	87 5	80	165	124	84 8
	1170	91 5	91	90	89 5	88	80	163	123	82 9
	880	91	90 5	89	87	82	70	164	124	83 8
	705	91	90	88	87	82	73	164	124	84 8
	580	90	89 5	88	82	77	66	166	125	84 8

TABLE XIV

MANUFACTURERS' POLYPHASE MOTOR DESIGNATIONS

Manufacturer	Squirrel-Cage, Constant-Speed			Wound-rotor
	Normal-Torque, Normal-Starting-Current	Normal-Torque, Low-Starting-Current	High-Torque, Low-Starting-Current	Constant- and Adjustable-Varying Speed
Allis-Chalmers	AR, AN	ARX, ANX	ART, ANT	ARY, ANY
Louis Allis, old	......	X	A	V
new	S	X	A	H
American	SBO, BE, TE, HR, PV, PK, BBO	. .	BBL	......
Burke	S, E, SE, EB, EM	S	S	V, EBV, EMV
Century, old	SC	DSCN, SCN	DSCH	SR
new	SC	SCN	SCH	SR
Continental	A, N, AF, NF, AP, NP	AL, N	AH	SA
Crocker-Wheeler, old	P, Y	PLS, YLS	PHDC, YHDC	......
new	A	ALS	AHDC	ASR
large	Y, Q, R	YLS, QLS, RLS		YSR, QSR, RSR
Delco	SSC	...	DSC	......
Diehl	ID, IS	. ...	IDX	IDM
Electric Dynamic	BA, A	.. .	..	BA, A
Emerson	P	...	..	......
General Electric, old	KT, KQ	FT, FQ	FTR, FQR	MT, MQ
new	K	KF	KQ	M
large	KT, KQ	FT, FQ	FTR, FQR	MT, MQ
Harnishfeger	H	HOL	HO	......
Howell	T, SC, K, SCV, NV	N	H	SR, QSR, SRV
Ideal	A, AC, AF, ATE	AT	AEH, AAH	AVE, AV
Imperial	E	EN	EH	W
Leland	P	....	. . .	......
Lincoln	D, FD, ED, DD	DS, ES	DL, DR, ER, DSS	DX
Master	PA	...	. ... .	SR
Marble Card	SC, TE, FN	SCL, FN	SCH, FN	......
Fairbanks Morse, old	H	HS	HA, HO	HV
new	Q	QS	QO	QV
large	H	HS	HO	HV
Peerless	P	......	......	......
Reliance, old	AA	AL	......	......
new	AA—Form O	AA—Form OL	AA—Form OLH	AW—Form O
Robbins & Myers	L, PS	L	L	......
Star	NL, A, N, FN, FM, FNLT, NLT	NLT		S, AS
Sterling	KF	. ....	.....	......
United States	CF, FC, FRB, STB, FR, ST	SAJ, SA, SC	CF, FC, PRB, STB, FR, ST	Slip Ring
Wagner, old	RP	RX	RY	RS
new	RP-1	RP-2	RP-4, RP-5	RS-1
Westinghouse	CS—Gen. Purp.	CS—Class I	CS—Class II	CW

TABLE XV

APPROXIMATE FULL-LOAD AMPERES * OF UNITY-POWER-FACTOR SYNCHRONOUS MOTORS

Hp.	Two-phase, 4-Wire †				Three-phase			
	220 v.	440 v.	550 v.	2200 v.	220 v.	440 v.	550 v.	2200 v.
25	47	24	19	4 7	54	27	22	5 4
30	56	29	23	5 7	65	33	26	6 5
40	75	37	31	7 5	86	43	35	8 6
50	94	47	38	9.4	108	54	44	10.8
60	111	56	44	11.3	128	64	51	13
75	140	70	57	14	161	81	65	16
100	182	93	74	18	211	106	85	21
125	228	114	93	23	264	132	106	26
150		137	110	28	.	158	127	32
200	.	182	145	37	.	210	168	42

* Average for all speeds and frequencies.
† Values of current in common wire of 2-phase, 3-wire system will be 1 41 times values given.
For 208- and 200-volt motors, increase 230-volt amperes by 6 and 10 per cent, respectively.
For 90- and 80-per-cent-power-factor motors the amperes should be multiplied by 1 1 and 1.25 respectively.

Synchronous Motors. Synchronous motors are usually designed to operate at either unity or 80 per cent leading power factor. When operating at a leading power factor, their effect is similar to that of a group of capacitors connected to the system. The leading reactive current supplied by synchronous motors of both types depends on their loads and can be computed from the chart, Fig. 7. The leading power factor is shown in Fig. 8.

A synchronous motor operating without load is, in effect, a synchronous condenser.

Synchronous Condensers. Synchronous condensers are seldom used for power-factor improvement because their losses are comparatively high, they cannot be properly placed in relation to the load, and they require the attention inherent to rotating machines. Compared with capacitors, they cost about 15 per cent less, but their losses are in the ratio of 4.5 to 0.33 per cent.

If 500 kv-a. of capacitance at 2300 volts is required for a plant operating 200 hours per month and paying $1.50 per kw. of demand and $0.006

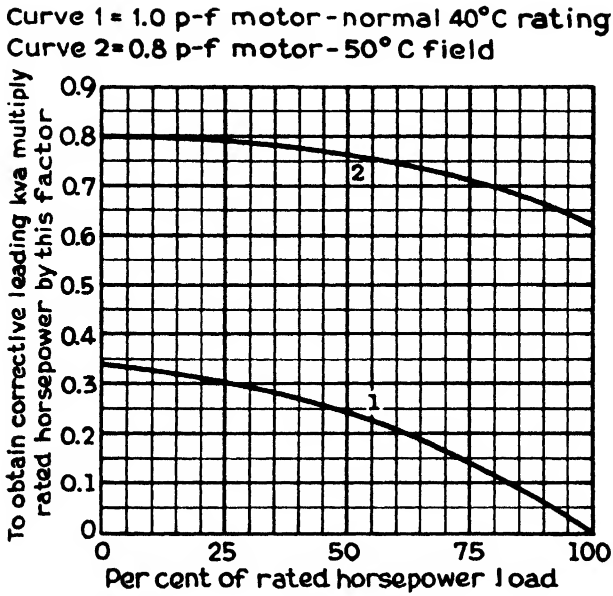

Fig. 7. Leading Reactive Current Supplied by Synchronous Motors

(General Electric Co.)

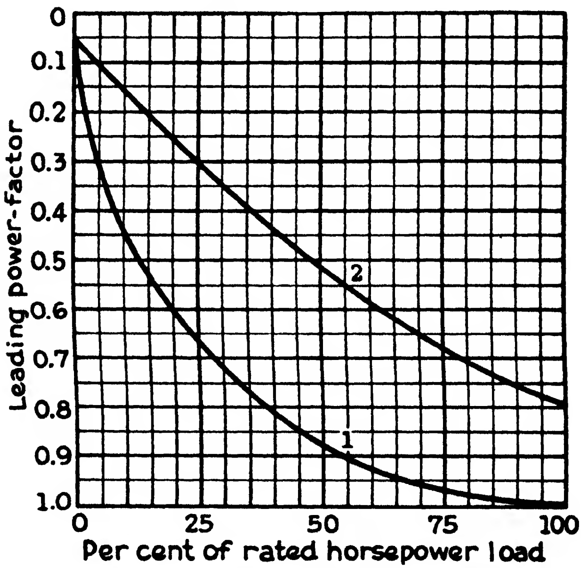

Fig. 8. Effect of Load on Power Factor of Synchronous Motors

(General Electric Co.)

per kw-hr., a comparison of synchronous condenser and capacitor would be as follows:

Cost of synchronous condenser, exciter, and control panel	$3200
Cost of capacitor equipment	3830

Input to synchronous condenser = 0 045 × 500	= 22 5 kw
Input to capacitor = 0 0033 × 500	= 1 65 kw

Cost of operating synchronous condenser (ignoring maintenance) would be:

22 5 kw. × $1 50	=	$33 75	
200 × 22 5 kw-hr. × 0 006	=	27 00	
		$60 75	per month
		12	
		$729 00	per year

Cost of using capacitor would be.

1 65 kw. × $1 50	=	$2 48	
200 × 1 65 kw-hr. × 0 006	=	1 98	
		$4.46	per month
		12	
		$53 52	per year

Annual saving in operating expense in favor of capacitors = $675

In this example the saving would make up for the difference in cost in one year and amortize the entire investment in less than six years.

If the plant instead of purchasing power generated its own at a cost of $0.01 per kw-hr., the comparison would be:

Cost of operating synchronous condenser:

4500 kw-hr. × $0 01 = $45 per month or $540 per year

Cost of using capacitor:

330 kw-hr. × $0 01 = $3.30 per mo. or $39.60 per year

Annual saving in favor of capacitors = $500

Synchronous Motors *vs.* Induction Motors and Capacitors. Synchronous motors have a lower starting torque than induction motors, are not available in sizes less than 25 hp., cost considerably more, improve plant power factor only when in operation, and have higher maintenance and repair costs. Induction motors and capacitors may cost less and give better service.

The first points to be settled in considering which type to use are:

1. Will the motor run whenever the plant is in operation?
2. Are synchronous motors available in that size?

3. Will a synchronous motor have sufficient starting torque for that particular application?

If the answers are yes, prices should be obtained on the synchronous motor and on an induction motor accompanied by capacitors equal in size to the reactance of the induction motor plus whatever leading reactance would be supplied by the synchronous motor. The decision can then be made on the basis of economics.

For example, a 50-hp., 870-r.p.m., 440-volt motor, which will operate at full load, is required in a plant where 50 leading rkv-a. would be required to improve the power factor to 95 per cent, the desired point. A synchronous motor would fulfill the three conditions to be considered first. From Table XXVI, page 72, the capacity required to improve the power factor of the induction motor to 95 per cent is found to be 13 kv-a., and to 100 per cent, 27 kv-a. From Fig. 7, page 42, it is seen that a unity-power-factor synchronous motor would supply no leading reactive kilovolt-amperes at full load, and that an 0.8-power-factor motor would supply $0.62 \times 50 = 31$ leading rkv-a. However, the unity-power-factor synchronous motor would supply $27 - 13$ or 14 kv-a. in excess of requirements. The prices obtained are:

Induction motor	$496
100% p.f. synchronous motor	748
80% p.f. synchronous motor	796
Control panel for synchronous motor	150
Capacitors, per kv-a.	8

The cost of power-factor improvement using the induction motor would be:

Capacitors, $50 + 13 = 63$ kv-a. $\times$ $8	$504
Motor	496
Total	$1000

The cost of power-factor improvement using the unity-power-factor synchronous motor would be:

Capacitors, $50 - 14 = 36$ kv-a. $\times$ $8	$288
Motor	748
Control panel	150
Total	$1186

The cost of power-factor improvement using the 0.8-power-factor synchronous motor would be:

Capacitors, $50 - 31 - 14 = 5$ kv-a. $\times$ $8 =	$40
Motor	796
Control panel	150
Total	$986

The analysis definitely eliminates the unity-power-factor synchronous motor. If the lines to other motors where 50 kv-a. in capacitors could be placed are not long or overloaded, the 0.8-power-factor synchronous motor could be used. If they are overloaded and long, capacitors could be placed at the motor terminals, and the small difference in cost between the induction-motor, capacitor combination, and the 0.8-power-factor synchronous motor may be more than offset either by obviating the necessity of replacing with larger copper, or by decreasing the losses from the lines.

Had the voltage been 230 instead of 460, the price of the motors would have been the same, but the capacitors would have cost $16 per kv-a. instead of $8, and the 80-percent-power-factor synchronous motor would have been the best solution.

Noel Capacitor Motors. These motors are available in both the squirrel-cage and wound-rotor type, and for unity or 0.8 leading power factor. They are similar to the ordinary induction motors except that two windings are employed in the stator—the usual main-line winding placed in the upper section of the coil slots and an auxiliary winding placed in the bottom of the slots and connected to an external capacitor. The two windings function like a transformer to permit the use of a 660-volt capacitor on lower line voltages.

They show no saving in cost over induction motors and capacitors except when the line voltage is 230 and then not in the smaller sizes. The saving in cost increases with the size of the motor. The disadvantage of their use, instead of induction motors and capacitors, would be the increased cost of rewinding if that were ever necessary. Characteristic performance curves for unity- and 80-percent-leading-power-factor motors are given in Figs. 9 and 10, pages 46 and 47.

Fynn-Weichsel Motors. These motors are a combination of the wound-rotor-induction and self-exciting synchronous types and are available in sizes from 7.5 to 200 hp. and for 230, 460, and 575 volts, either two- or three-phase.

The rotors carry a polyphase winding corresponding to the number of phases of the supply line. This winding is connected to slip-rings which are contacted by brushes connected to the supply line. The rotors also carry a very small direct-current winding which is connected to a commutator and which under normal running conditions generates the necessary exciting current for the synchronous operation of the machine.

The stators in all cases are provided with a two-phase winding. During normal running operation, one phase is short-circuited and thus acts as a damping winding, preventing hunting; the other phase is connected to the brushes of the direct-current commutator and carries the exciting current.

The starting characteristics are very similar to those of wound-rotor induction motors, thus giving very high starting torque with small starting current. The starting current required for full-load starting torque

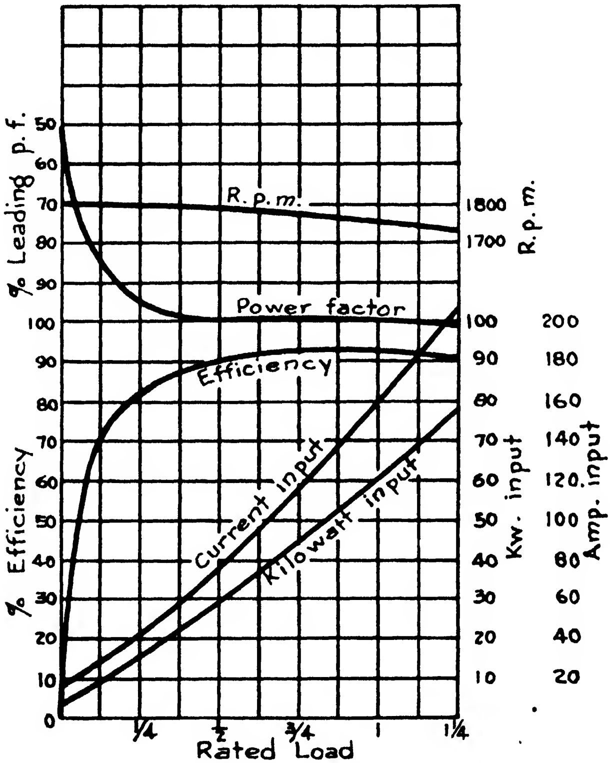

FIG. 9. Characteristic Curves of Noel Capacitor Motor Rated 75 hp., 220 volts, 1800 r.p.m., 100% Power Factor, Normal Torque, Normal Starting Current

(Ideal Electric & Mfg Co)

is approximately equal to the full-load running current, and for 250 per cent starting torque is about 2.5 times the normal running current.

During the starting period, resistances, which are connected in series with each of the two-phase windings of the stator, are gradually cut out, either manually or automatically, and are short-circuited just before synchronous speed is reached. At this time the machine automatically falls into synchronism, developing a very powerful synchronizing torque which is equal to the running torque. Consequently these motors are capable of pulling into synchronism much heavier loads than conventional synchronous motors.

Heavy overloads stall synchronous motors, but, if Fynn-Weichsel motors are pulled out of step by heavy overloads (160 per cent or more of normal), they continue to operate as induction motors until the load

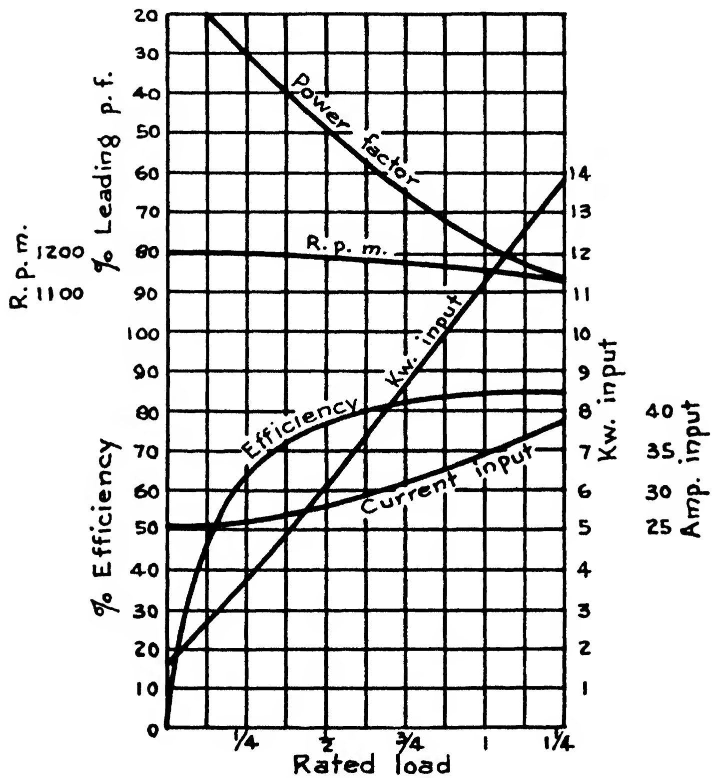

FIG. 10. Characteristic Curves of Noel Capacitor Motor Rated 12½ hp., 220 volts, 1200 r.p.m., 80% Leading Power Factor, Normal Torque, Low Starting Current

(Ideal Electric & Mfg Co.)

returns to values equal to or less than the maximum torque of the motors when operating as synchronous machines, at which time they automatically return to synchronism.

These motors are particularly suitable for loads which are difficult to start or which fluctuate rapidly, such as rock crushers and beaters in paper mills. They are also advantageous where both constant and reduced speeds may be required, for example, on wire-drawing machines. In this case, during adjustment of dies, the motors operate with resistance in the secondary and thus run at a speed materially below normal. After completion of adjustment, the resistances are short-circuited and the machines synchronize.

The power factor during the starting period is approximately equal to that of wound-rotor induction motors of equal rating. Over normal working range the power factor is leading, and for normal direct-current

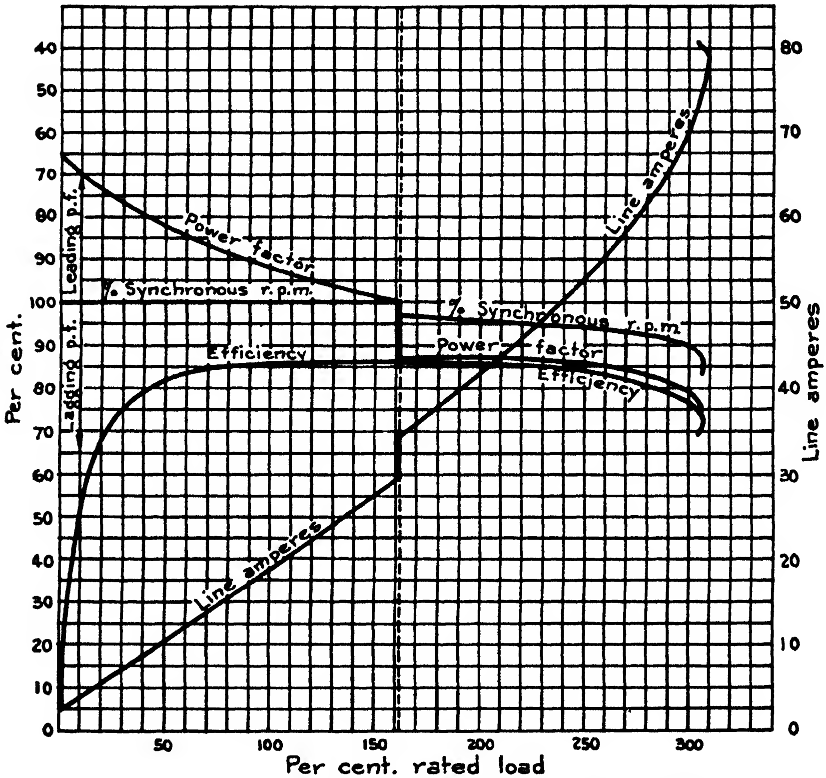

FIG. 11. Performance Curves of a Typical Fynn-Weichsel Motor

(Wagner Electric Corporation)

brush setting the leading reactive kilovolt-amperage is frequently just about sufficient to counteract the lagging reactive kilovolt-amperage of an induction motor having the same horsepower rating. If, however, the direct-current brushes are shifted in the direction of rotation, the leading reactive kilovolt-amperage is increased. In order to prevent overheating in this case, the mechanical load on the motors must be decreased below their normal horsepower rating until the exciting current reaches the value stamped on the name plate.

Fynn-Weichsel motors will probably cost considerably more than synchronous motors or induction motors and capacitors, and their application will therefore be limited to services for which they are particularly adapted. Any necessary repairs would cost more than for motors of simpler construction, and the manufacturer prefers to make them in his own plant.

CHAPTER III

TRANSFORMERS

Capacity. The most important effect of power factor on transformers is on their capacity. Transformers are rated in kilovolt-amperes, and, since kilovolt-amperes is kilowatts divided by power factor, they would have to be twice as large, and the investment therein twice as great, for a 50-per-cent-power-factor load as for a load having unity power factor.

A typical example would be a plant desiring to install additional motor equipment and now having a load of 200 kw. at 65 per cent power factor, and using current reduced from 2300 to 230 volts through its own substation, which cost \$3000 and consists of three 100-kv-a. transformers. The load on the transformers is 200 kw. 0.65 = 308 kv-a.; therefore no substantial load could be added unless larger transformers are purchased or the power factor improved on the secondary side of the present bank. If the power factor is so improved to 95 per cent, the load on the transformers would be 200 kw. 0.95 = 211 kv-a., a reduction of 97 kv-a. This would liberate 89 kv-a. for additional load, and 89 kv-a. is about 30 per cent of the transformer capacity. The size capacitors required to improve the power factor would be determined by multiplying the load in kilowatts by the difference in tangents corresponding to the power factors, from Table II, page 5.

tan 65% = 1.1692
tan 95% = 0.3287

0.8405 × 200 kw. = 168 kv-a. required

At \$16 per kv-a. the capacitors would cost \$2688. Since 30 per cent of the \$3000 value of the substation is \$900, the cost of improving the power factor would amortize itself in \$2688/\$900 = 3 years, and the annual return on the investment would be \$900/\$2688 = 33.5 per cent. There would be an additional saving due to decreased transformer losses and, in all probability, substantially reduced billing from the utility supplying the electricity.

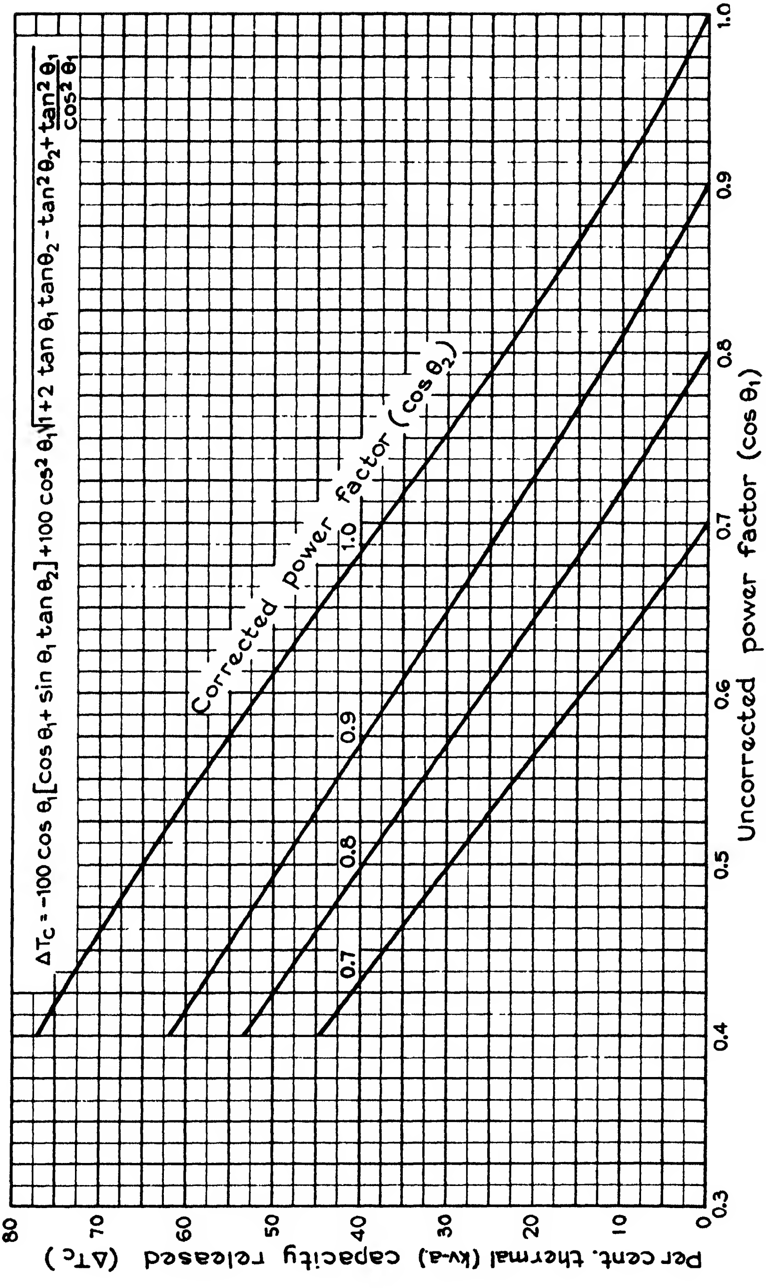

FIG. 12. Per Cent Thermal Capacity (Kv-a. at Original Power Factor) Released by Improving Power Factor

(General Electric Co.)

Reactance. The reactive kilovolt-amperes of a transformer consist of the sum of two components. The first is the magnetizing current, which is practically constant from no load to full load; and the second the reactance which varies about in direct proportion to the load. Voltages above or below nominal affect these values considerably, the effect being dependent on the design point of the core saturation curve. No definite figures, therefore, can be given, but it may be assumed that the percentage effect is about double the percentage variation in voltage.

TABLE XVI

APPROXIMATE MAGNETIZING CURRENT OF TRANSFORMERS
Reactance at No Load

These data are approximate for single-phase, 60-cycle, oil-immersed, self-cooled distribution transformers having nominal high voltages of either 2300/4000Y or 6600/11,000Y.

Kv-a.	%	Rkv-a.
15	5 08	0.76
25	4.75	1.19
37.5	4.65	1.74
50	4 62	2.31
75	4 55	3.41
100	4 48	4.48
150	4.36	6.54
200	4 23	8 46
250	4.10	10 25
333	3.90	13 00
500	3.49	17 45

Reactance in Ohms. The delta reactance per phase of a three-phase transformer or bank of transformers may be determined from

$$X_t = \frac{10\,kv^2 \times p}{kv\text{-}a} \qquad (2)$$

in which X_t = reactance in ohms.
kv = kilovolts between phases on low-voltage side.
p = per cent reactance.
$kv\text{-}a$ = transformer rating per phase.

The equivalent Y reactance would be one-third of the value obtained from the above formula.

The reactance at partial loads would be approximately in proportion to the load.

TABLE XVII

Transformer Reactance

The data are approximate for single-phase, 60-cycle, oil-immersed, self-cooled distribution transformers at full load and rated voltage. The voltages are nominal. The reactance at any other load may be found by multiplying the load in kilovolt-amperes by the per cent reactance. The total reactances of transformers are these values plus the magnetizing current.

High Voltage . . Low Voltage. . .	2300/4000Y 120/240, 240/480		6600/11,000Y 115/230, 240/480		6600/11,000Y 2300	
Kv-a.	%	Rkv-a.	%	Rkv-a.	%	Rkv-a.
15	2.20	0.33	2.35	0.35	4.12	0.62
25	2.32	0.58	2.51	0.63	4.77	1.19
37.5	2.56	0.96	2.64	0.99	4.85	1.82
50	2.62	1.31	2.68	1.34	5.35	2.68
75	3.28	2.46	4.85	3.63	4.86	3.64
100	3.29	3.29	4.84	4.84	4.86	4.86
150	3.29	4.95	4.87	7.30	4.88	7.32
200	3.32	6.66	4.86	9.72	4.37	8.74
250	4.67	11.67	4.88	12.20	4.90	12.24
333	4.70	15.63	4.98	16.57	4.90	16.30
500	4.80	24.00	5.10	25.50	5.00	25.00

The information in Table XVIII on page 54 is useful in determining the effect of installing transformers on the over-all power factor, and in determining the amount of leading reactance necessary to counteract the lagging reactance of transformers.

For example, a plant has a load of 75 kw. at 70 per cent power factor, and in order to secure a better contract with the utility is considering the installation of three 37.5-kv-a. transformers, primary metering, and improving the power factor to 90 per cent. The first step is to determine the present reactance. This is done by multiplying the tangent corresponding to 70 per cent power factor by the load in kilowatts. The transformer kilowatts and reactive kilovolt-amperes, obtained from Tables XIX and XVIII, are then added to obtain future conditions.

Present conditions ..	75 kw.	1.0202 × 75 = 76.5 rkv-a.	70% p.f.
Transformers .	2	7.0	
Future conditions .	77 kw.	83.5 rkv-a.	67.8% p.f.

The power factor would therefore have to be improved from 67.8 instead of 70 per cent.

If a plant has a substation consisting of three 100-kv-a. transformers and the utility uses reactive metering, the transformers at no load would be responsible for 3 × 4.48 rkv-a. × 720 hr. = 9680 rkv-a-hr. per month. The condenser capacity required to counteract their effect would be 14 kv-a.

TABLE XVIII

Kv-a. in Capacitors Necessary to Counteract Reactance of Transformers

These data are approximate for single-phase, 60-cycle, oil-immersed, self-cooled distribution transformers. The voltages are nominal

High Voltage Low Voltage	2300/4000Y 120/240, 240/480				6600/11,000Y 115/230, 240/480			
Loading	100%	75%	50%	0	100%	75%	50%	0
Substation Kv-a								
75	5	5	5	4	7	6	5	4
100	7	7	6	5	10	9	7	5
112.5	8	7	7	6	11	9	8	6
150	11	10	9	7	15	13	11	7
225	18	16	14	11	21	18	16	11
300	23	21	18	14	28	24	21	14
450	34	31	27	20	42	36	31	20
600	45	40	35	26	55	47	40	26
750	66	57	48	31	67	58	49	31
1000	86	74	62	39	89	76	64	39
1500	124	106	88	53	129	110	91	53

Losses. Power factor affects the losses from transformers, since for a given length and size of conductor the loss therefrom will vary as the square of the amperage. See Power Losses, page 113. As an example, if three 150-kv-a., 2300/230-volt, single-phase transformers carry a three-phase load of 300 kw. at 65 per cent power factor, and the power factor is improved on the secondary side to 90 per cent, what will be the reduction in losses, and their value, if the demand charge is $1.50 per kw.

TABLE XIX

TRANSFORMER LOSSES

These data are approximate for single-phase, 60-cycle, oil-immersed, self-cooled distribution transformers. The voltages are nominal.

Loss in Watts

High Voltage / Low Voltage	2300/4000Y			6600/11,000Y			6600/11,000Y			13,200		
	120/240, 240/480			115/230, 240/480			2300			115/230, 240/480		
Kv-a.	No Load	Copper	Total	No Load	Copper	Total	No Load	Copper	Total	No Load	Copper	Total
15	77	261	338	92	280	372	106	270	376	118	285	403
25	115	388	503	140	410	550	158	380	538	168	385	553
37.5	148	512	660	200	540	740	220	470	690	225	530	755
50	186	617	803	270	670	940	275	650	925	295	670	965
75	280	930	1210	385	900	1285	400	850	1250	415	960	1375
100	370	1200	1570	460	1230	1690	510	1130	1640	528	1230	1758
150	550	1790	2340	725	1720	2445	740	1635	2375	750	1840	2590
200	800	2210	3010	920	2340	3260	900	2200	3100	960	2370	3330
250	1115	2830	3945	1115	2830	3945	1115	2575	3690			..
333	1310	3525	4835	1310	3515	4825	1310	3195	4505			..
500	1675	4870	6545	1675	4870	6545	1675	4430	6105			.

and the cost per kilowatt-hour in the lowest block is 1 cent? The plant operates 191 hours per month.

From Table XIX the copper loss per transformer is found to be 1.79 kw.; $3 \times 1.79 = 5.37$ kw. total.

The load carried before power-factor improvement

$$= \frac{300}{0.65} = 462 \text{ kv-a.}$$

The load carried after power-factor improvement

$$= \frac{300}{0.9} = 334 \text{ kv-a.}$$

The copper loss before power-factor improvement

$$= \left(\frac{462}{450}\right)^2 \times 5.37 = 5.65 \text{ kw.}$$

The copper loss after power-factor improvement

$$\left(\frac{334}{450}\right)^2 \times 5.37 = 2.96 \text{ kw.}$$

5.65 kw.
2.96
—
2.69 kw. reduction in loss

$1.50 × 2.69 kw. = $4.03 per month reduction in demand charge

$0.01 × 2.69 kw. × 191 hr. = $5.14 per month reduction in energy charge

$4.03
5.14

$9.17 per mo. × 12 mo. = $110.04 per yr.

Voltage Regulation. The percentage voltage regulation of transformers decreases as the power factor increases; therefore, a high-power factor contributes to a more constant voltage.

TABLE XX

PERCENTAGE VOLTAGE REGULATION OF TRANSFORMERS

Percentage voltage regulation means the percentage increase in secondary voltage from full load to no load, the primary voltage remaining constant. For single-phase, 60-cycle, oil-immersed, self-cooled transformers having a primary voltage of 2300/4000Y and a secondary voltage of 120 240 the values are approximately as given below

Kv-a.	Power Factor						
	100%	95%	90%	80%	70%	60%	50%
37.5	1.4	2.1	2.3	2.6	2.8	2.8	2.9
50	1.2	2.0	2.2	2.6	2.7	2.8	2.9
75	1.2	2.2	2.5	3.0	3.2	3.3	3.4
100	1.2	2.1	2.5	2.9	3.2	3.3	3.4
150	1.2	2.1	2.5	2.9	3.2	3.3	3.4
200	1.1	2.1	2.4	2.9	3.1	3.3	3.4
250	1.1	2.4	3.0	3.6	4.1	4.4	4.6
333	1.1	2.4	3.0	3.6	4.1	4.4	4.6
500	1.0	2.4	3.0	3.6	4.1	4.4	4.6

CHAPTER IV

CAPACITORS

Construction. A capacitor is a static condenser, and is used to supply leading current to an alternating-current circuit. Modern capacitors for power-factor improvement consist of windings of aluminum foil and paper immersed in oil or an inert gas contained in hermetically sealed vessels.

The characteristics of the paper are exceedingly important, for the normal life of a capacitor depends largely on this item. Perfect paper

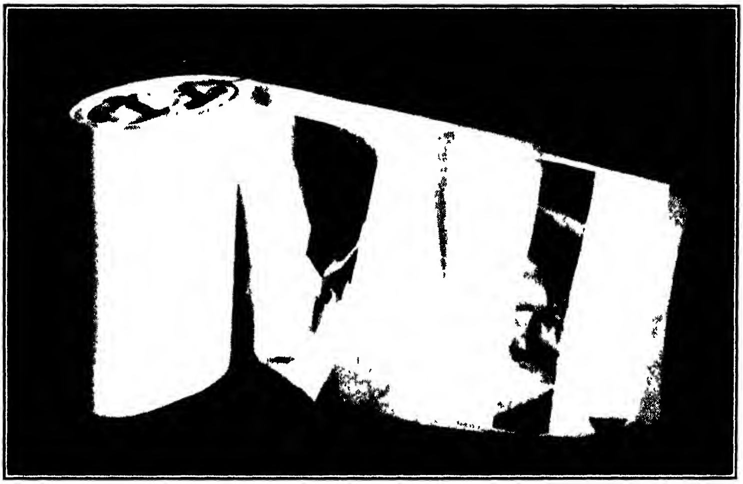

Fig. 13. Small Unit of a Capacitor

(National Electric Condenser Co.)

would be absolutely dry before impregnation, contain no conducting particles, and show no deterioration in the liquid or gas used for impregnation. Moisture or conducting particles would contribute to short-circuiting, and since conductor-free paper is not commerically obtainable, the general practice is to use a number of layers between the foil, dependent upon the voltage, so that the conducting particles will not become superimposed.

One manufacturer uses nitrogen for impregnation. All others use mineral oil, vegetable oil, or a synthetic oil bearing various trade names.

The gas is usually under a pressure of several hundred pounds, and the possibilities of leakage and breakdown are therefore greater than in oil-impregnated capacitors under no pressure. Such equipment, however, is very compact and can be readily installed indoors or out-of-doors. Because of mass construction, replacement cost would be high.

Vegetable oils are considered inferior to mineral or synthetic oils because of a relatively high and unstable power factor, which increases the losses and shortens the life of the equipment.

Mineral oil, of the type used in transformers, is a very satisfactory impregnating medium but, because its dielectric constant is about half

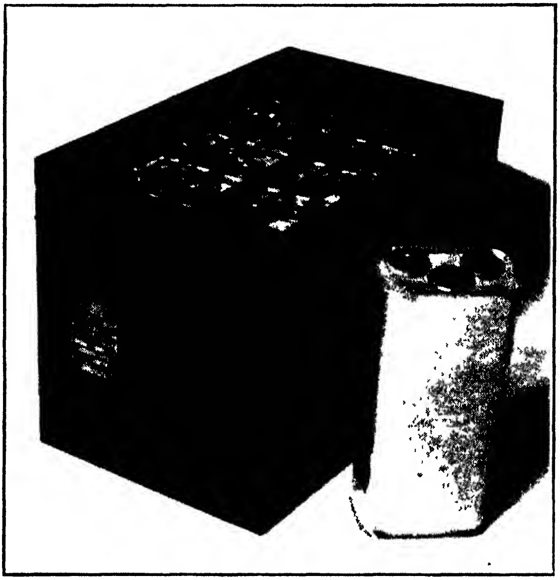

FIG. 14. A Unit and Capacitor Assembly

(National Electric Condenser Co.)

that of the synthetic oil, equipment using it is bulkier and heavier, although assemblies of such capacitors are not necessarily larger. The fact that mineral oil is combustible and the synthetic oil is not is a theoretical rather than practical disadvantage if the capacitors are properly installed.

Life. Only a negligible percentage of 230-volt, wax-impregnated capacitors installed seventeen years ago have failed. They were not hermetically sealed, and the wax is unstable at high ambient temperatures. High-voltage, mineral-oil-impregnated capacitors, used in conjunction with step-up transformers, have given satisfactory service for more than twenty years. Capacitors impregnated with synthetic oil are comparatively new, but their life record is almost perfect. There is every reason to believe that obsolescence only will determine the desirability of using the capacitors now being marketed.

Application. Capacitors improve power factor from the point of application back to the generator. Therefore, to obtain the maximum benefits they should be connected as near as practicable to the equipment causing the low power factor. The determining factors are:

1. Use factor of equipment.
2. Distance from generator, metering point, or distribution panel.
3. Adequacy of wiring.
4. Adequacy of substation or generator.
5. Cost.

Capacitors can be economically applied to terminals of motors or the load side of their controlling switches only if the number of hours they operate at least equals the number of hours the plant operates. A group of motors operating intermittently should have the power factor improved by capacitors at the distribution center.

If the distance from generator, metering point, or distribution panel to the load is comparatively short, the location of the capacitor is immaterial. If the lines are amply large and short, the reduction in losses and increase in voltage due to placing the capacitor at the load will be inconsequential. If the substation has sufficient capacity, there is a choice of using low- or high-voltage capacitors.

Cost is discussed under "Frequency and Voltage," page 61.

High- *vs.* Low-Voltage Capacitors. In an industrial plant purchasing electricity at 2300/4000 volts and using it at 230 volts, capacitors applied on the secondary side of the transformers will probably cost approximately twice as much as 2300-volt capacitors. If the secondary voltage were 460 or 575, the secondary capacitors installed would very likely cost less than primary equipment. The primary capacitors would improve the power factor for billing purposes only while the low-voltage capacitors would have the additional advantages:

(*a*) Reduction in load on lines, permitting useful load to be added without enlarging the copper; and reduction in line losses, which are measured in kilowatts and kilowatt-hours.

(*b*) Reduction in load on transformers, obviating replacement of overloaded with larger ones; or allowing greater load to be carried on the existing bank; and reduction in transformer losses. The value of liberated transformer capacity and reduced losses must be added to the cost of primary capacitors in comparing it with that of secondary equipment. See pages 50 and 54.

(*c*) Improvement in voltage because of better voltage regulation of transformers, reduced voltage drop in lines, and decreased motor current. This improvement results in slightly higher motor speeds

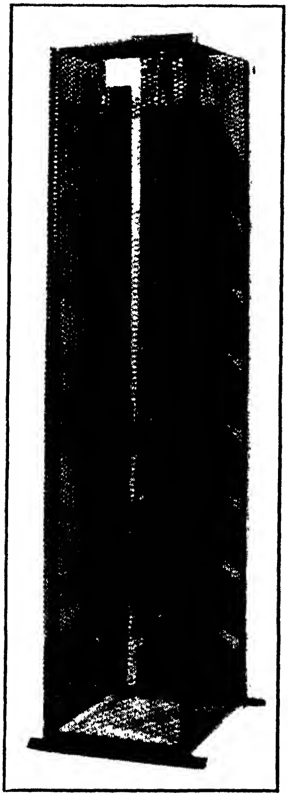

FIG. 15. Indoor Low-voltage Rack-type Capacitor

(General Electric Co.)

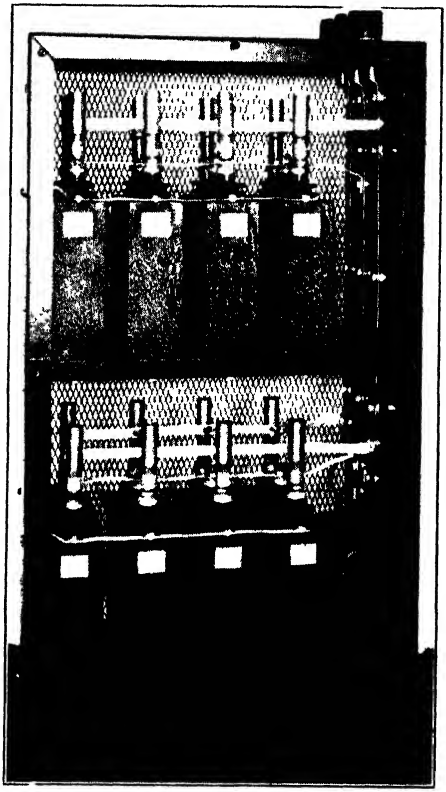

FIG. 16. Indoor Capacitor for Primary Voltages

(Westinghouse Electric & Mfg. Co.)

and greater starting torque. Lights will also operate at greater brilliancy and with less flickering.

(*d*) Reduction in maintenance of fuses, starting devices, etc.

(*e*) Much lower replacement cost, because the units are smaller.

Rating. Capacitors are rated in kilovolt-amperes (kv-a.) for operation on 60-cycle current. The unit of capacitance is the microfarad,

TABLE XXI

Capacity of Condensers in Microfarads per Kv-a

Volts	μf
230	50.14
460	12.54
575	8.02
2300	0.5014

and the number of microfarads per kilovolt-ampere at various voltages is given in Table XXI. For any other frequency or voltage the capacity in microfarads per kilovolt-ampere may be computed from the formula

$$C = \frac{1000}{2\pi f E^2} (10)^6 \tag{3}$$

in which f = frequency and E = voltage.

Frequency and Voltage. The capacity of a condenser varies directly with the frequency. Therefore, a standard 60-cycle, 10-kv-a. capacitor would be rated $(25 \times 10)/60 = 4.17$ at 25 cycles. Capacitors for 25 cycles would cost $60/25 = 2.4$ as much as for 60 cycles and would be correspondingly larger.

The capacity of a condenser also varies as the square of the voltage. A 460-volt capacitor operating at 440 volts would give $(440/460)^2$ or 0.917 its rated leading kilovolt-amperes. See Fig. 17, page 63.

Reactance in Ohms. The delta reactance per phase of a capacitor may be determined from the formula

$$X_c = \frac{1}{6.28 \times f \times \dfrac{c \times kv\text{-}a}{1{,}000{,}000}} \tag{4}$$

in which X_c = capacitive reactance in ohms.
f = frequency in cycles per second.
c = capacitance in microfarads per kilovolt-ampere.
$kv\text{-}a$ = capacitor kilovolt-amperes per phase.

The equivalent Y reactance would be one-third of the value obtained from the formula. Capacitive reactance varies as the square of the voltage and inversely as the kilovolt-amperes.

TABLE XXII

MAXIMUM PERMISSIBLE WORKING VOLTAGES OF CAPACITORS

Standard Capacitor Voltage Rating	Range of Circuit Voltages *		Maximum Permissible Working Voltage
	For Delta	For Y	
230	230 240	. .	264
460	460–480		528
575	575–600	.. .	660
2,300	2,300-2,400	4,000–4,150	2,640
4,000	4,000–4,150	6,900–7,200	4,565
4,600	4,600–4,800	....	5,280
6,900	6,900–7,200	11,950–12,470	7,920
7,620	7,620–7,950	13,200-13,800	8,745
11,950	11,950-12,470	.	13,720
13,200	13,200–13,800		15,150

* Line to line, not line to neutral.

TABLE XXIII

RELATIONS OF KV-A. AND AMPERES

	230 v.	460 v.	2300 v.
1-Phase			
1 amp. =	0 23 kv-a.	0 46 kv-a.	2 3 kv-a.
1 kv-a. =	4 348 amp.	2 174 amp	0 435 amp.
2-Phase *			
1 amp. =	0 46 kv-a.	0.92 kv-a.	4.6 kv-a.
1 kv-a. =	2 174 amp.	1 087 amp.	0 217 amp
3-Phase			
1 amp. =	0 398 kv-a.	0 796 kv-a.	3 979 kv-a.
1 kv-a. =	2 513 amp	1 257 amp.	0 251 amp.

* Current in common conductor of 2-phase, 3-wire circuit = 1 41 that in other conductors.

Losses. The losses in watts in modern capacitors are guaranteed by the manufacturer not to exceed one-third of one per cent of their rating. At this amount the losses would be as shown in Table XXIV.

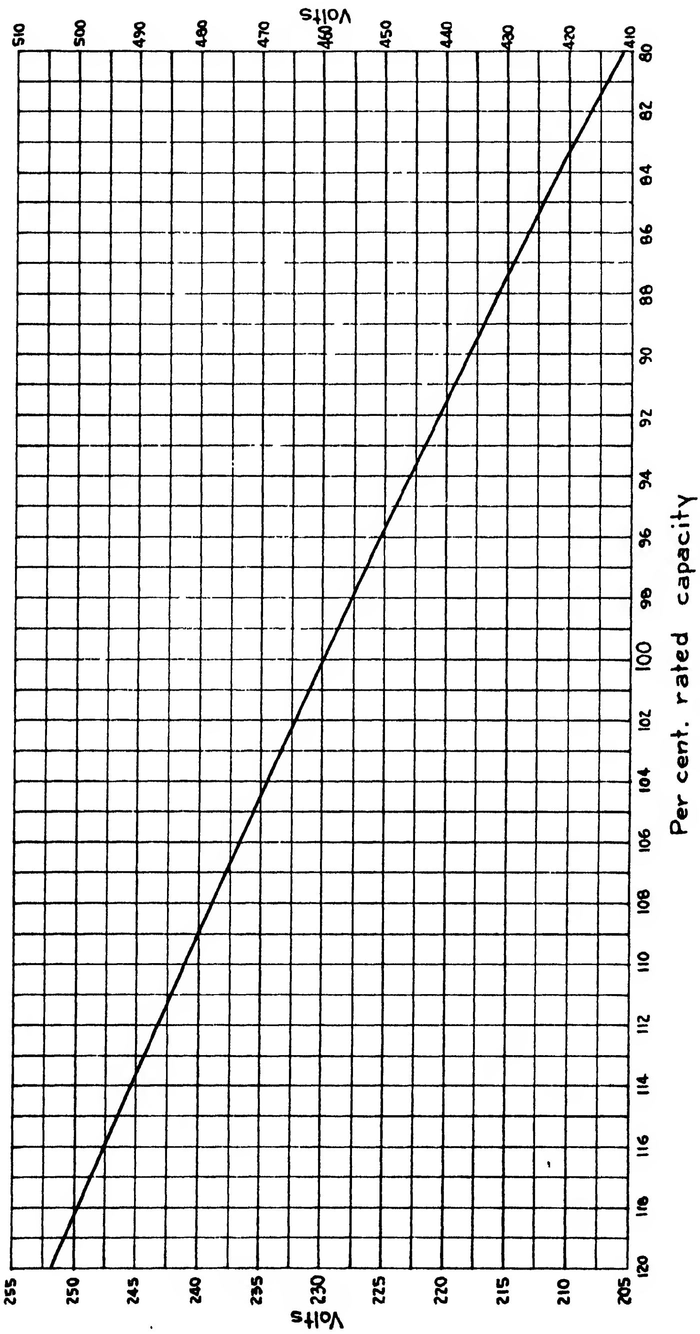

FIG. 17. Effect of Voltage Variation on Capacitor Output

TABLE XXIV

CAPACITOR LOSSES

Kv-a.	Loss in Watts	Kv-a.	Loss in Watts
15	50	70	233
20	66	80	266
25	83	90	300
30	100	100	333
35	116	120	400
40	133	150	500
45	150	180	600
50	166	200	666
60	200	240	800

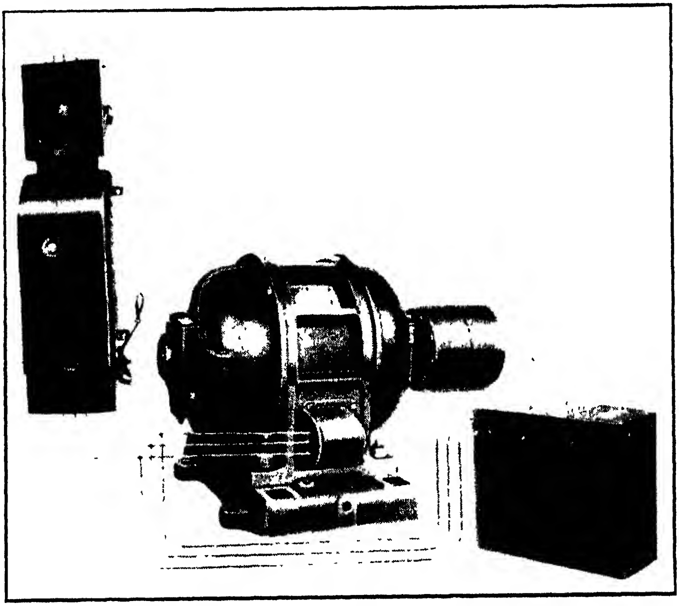

FIG. 18. Schematic Diagram of Capacitor Connected to Motor Terminals

(General Electric Co.)

Connections. Capacitors for power-factor improvement are always connected in parallel with the equipment they serve. Connecting them in series greatly decreases their output, as is shown by the following formula, in which C equals total capacity of any number of individual capacities C_1, C_2, C_3, etc.

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \tag{5}$$

Therefore, if two capacitors each rated at 2 kv-a. are connected in series the total capacity would be $\frac{1}{C} = \frac{1}{2} + \frac{1}{2} = 1$ kv-a.

Protection. Where a capacitor is connected to the motor terminals or the load side of the motor safety switch, it will be protected by the motor fuses, and the motor winding will act as a discharger. Where

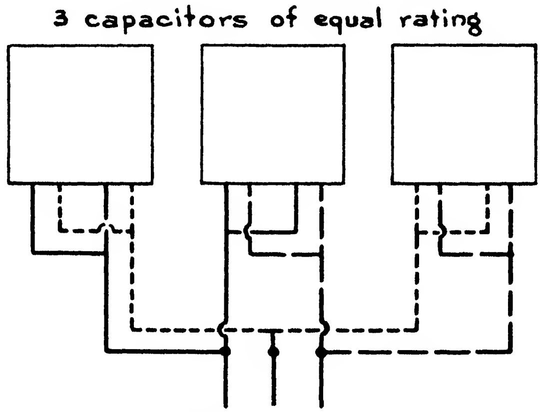

Fig. 19. Diagram for Connecting Two-phase, Four-wire Capacitors to a Three-phase Circuit

capacitors are connected to the distribution system, they should be provided with dischargers, and they require a fused safety switch if of the low-voltage type, and a non-automatic oil circuit breaker and expulsion-type primary cutouts if used on primary voltages. Discharge devices furnished with the equipment by manufacturers will drain the stored charge to 50 volts or less within one minute after the capacitor is disconnected from the source of supply.

A capacitor with exposed terminals should never be handled before ascertaining that it is discharged. It may be discharged by shorting the terminals or grounding them.

The capacitor equipment, where placed at an outdoor substation, will also be protected by the lightning arresters for the substation.

Testing. The instruments necessary to determine whether a capacitor is up to rating are a voltmeter and an ammeter—for convenience, one of the clip-on type. While the capacitor is in circuit, read the two instruments. If the voltage is the same as on the name plate, the amperage should correspond with that given in Tables XXXIII, XXXIV, and XXXV, pages 83, 84, and 85. If the voltage is not the same, the amperage should be that taken from these tables multiplied by the percentage of rated capacity obtained from Fig. 17, page 63.

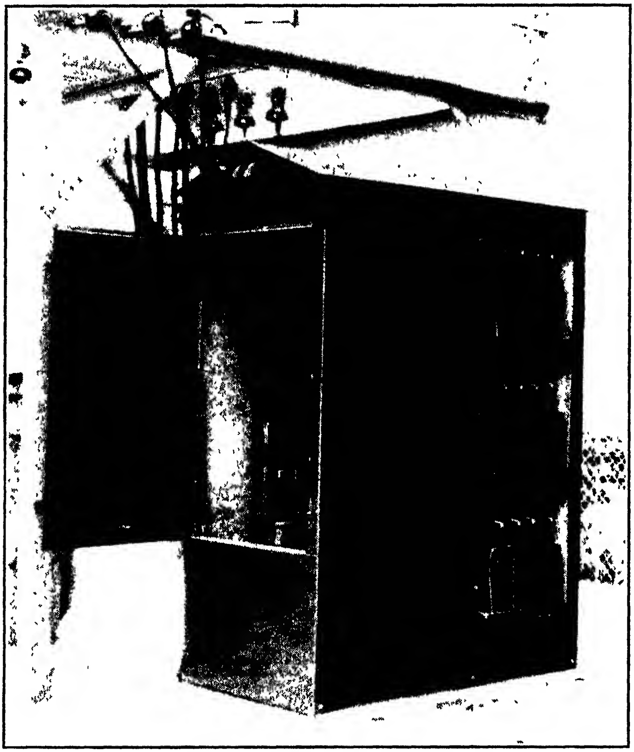

Fig. 20. Outdoor Capacitor

(General Electric Co.)

Capacitors seldom develop open circuits, but they sometimes short-circuit. If the capacitors are connected in their normal circuit and the fuses blow when the switch is closed, of course one or more units has developed a short circuit. If the fuses do not blow and an ammeter reads zero or less than normal, there is an open circuit. Switches for capacitors should be of rugged construction because the load on them is constant. If the fuse clips are of light construction and not very resilient, the fuses may be destroyed by the heat generated by poor contact and not because of a short-circuited capacitor. Solid rather than renewable fuses are recommended for this service because of the possibility of poor contacts in the renewable ones.

A plant electrician may try to test the equipment with a magneto or Megger. A magneto test set is a manually operated alternating-current generator in series with a polarized bell. The bell would ring whether the capacitor were short-circuited or in good condition and would not ring if it were open-circuited. Therefore it would be of little use. A Megger is a combination of a direct-current generator and an ohmmeter. Two types are available—those which deliver variable pressure, depending on the speed at which the handle is rotated, and those which deliver a constant pressure by means of a slip clutch. Either type would give a zero reading if the capacitor were short-circuited. The constant-pressure instrument would read infinity if the capacitor were open-circuited between the internal assembly and the terminals but would not indicate an open circuit in the assembly itself. The constant-pressure Megger would give an intermediate scale reading if the capacitor were in good condition. The indicator of a variable-pressure Megger would oscillate from an intermediate position to infinity if the capacitor were in good condition because of the alternate charging and discharging of the capacitor due to fluctuation in current. In using a Megger sufficient time must be allowed for the capacitors to take a charge before any readings are taken.

Capacitors Used with Auto Transformers. For 230-volt service it is possible to use 460-volt capacitors connected to the line through 230- to 460-volt dry-type auto-transformers. The reason for considering such a combination is possible decrease in initial cost. The disadvantages are increased reactive kilovolt-amperes, increased kilowatt demand, and increased kilowatt-hours. The following tabulation gives a comparison of prices for equipment in three sizes.

	60 kv-a.	90 kv-a.	120 kv-a.
230-volt capacitors . .	$988 00	$1482 00	$1976 00
460-volt capacitors.	$464 50	$689 00	$910 00
Auto transformers	596 40	701 93	924.00
Total..............	$1060 90	$1390 93	$1834 00

Auto-transformers and transformers supplying capacitors should be suitable for operation at the maximum permissible working voltage of the capacitors, and should have a minimum kilovolt-ampere rating of 135 per cent of the capacitor rating.

TABLE XXV

AUTO-TRANSFORMER LOSSES

The approximate losses of 230/460-volt auto-transformers to which capacitors are connected are

Capacitor kv-a.	Kw. Loss
30	0 362
45	0 500
60	0 635
75	0 765
90	0 900
105	1 030
120	1.162

If the demand charge is $2.00 per kw., and the energy charge in the lowest block applying $0.006, the annual cost of losses in the auto-transformers would be

Capacitor kv-a.	Annual Cost
60	$52 62
90	69 80
120	87 96

The use of capacitors with auto-transformers, therefore, cannot be economically justified and is not recommended.

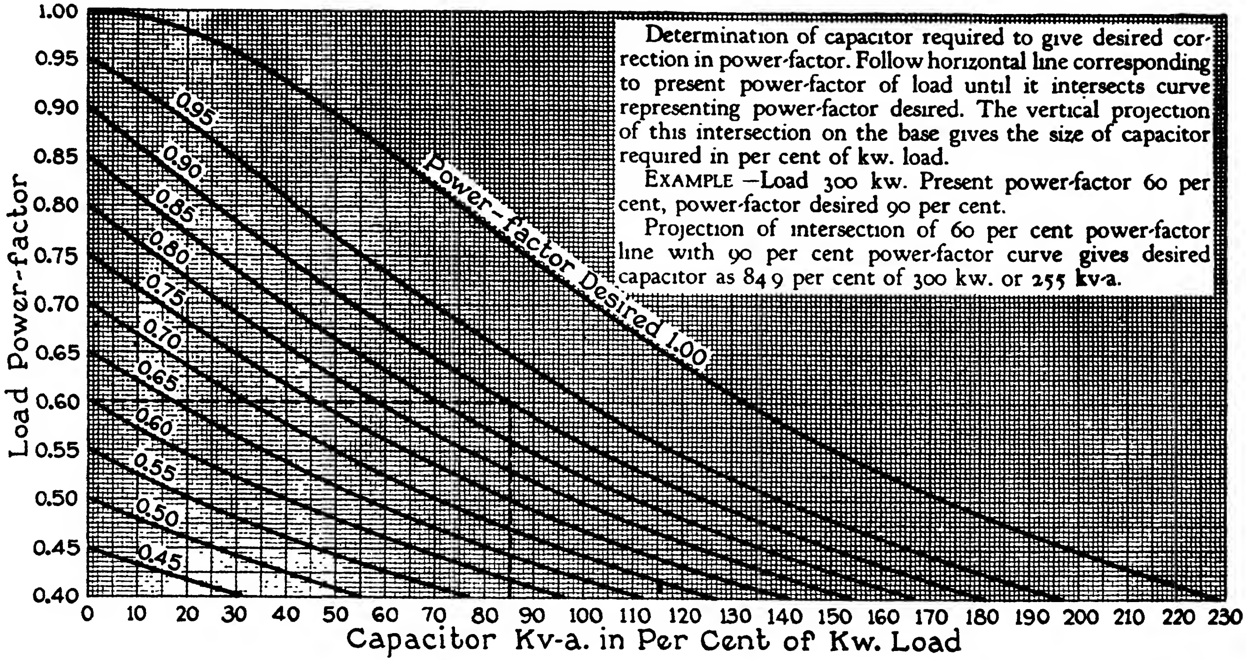

FIG. 21. Capacitor Kv-a. Required to Improve Power Factor

(General Electric Co)

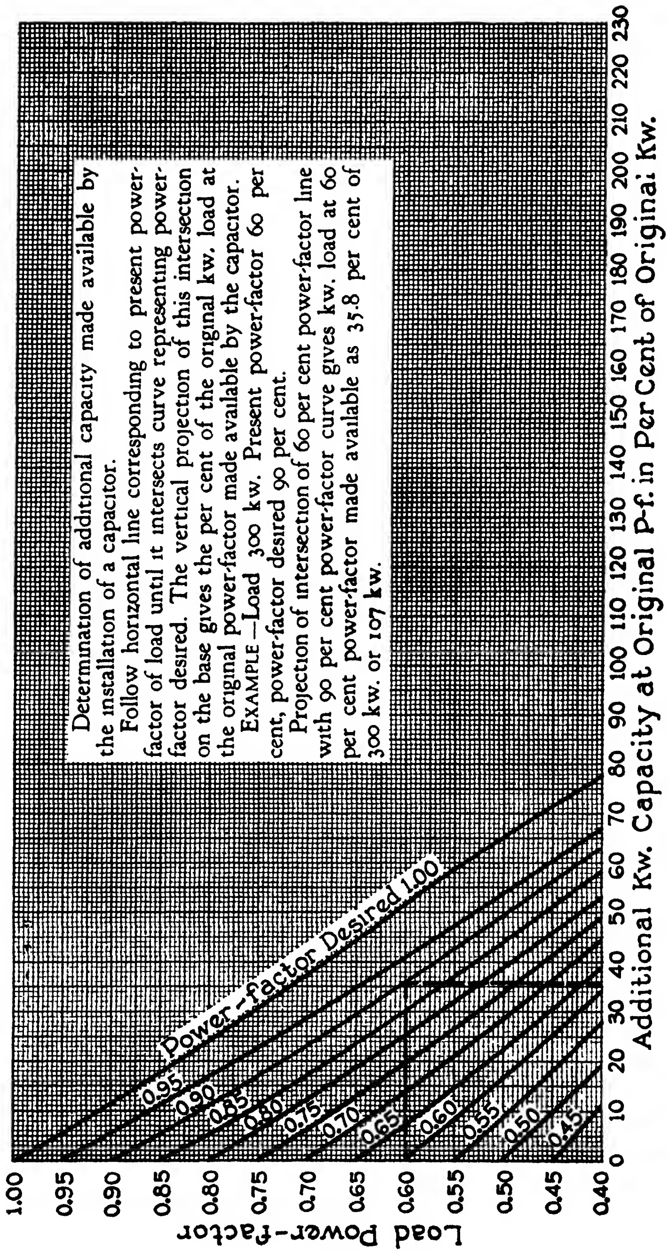

FIG. 22. Kw. Capacity Made Available by Capacitor Installation

(General Electric Co.)

TABLE XXVI

Approximate Kv-A. in Capacitors Needed to Improve the Power Factor of *Normal*-Torque, *Normal*-Starting Current, 3-Phase, 60-Cycle Squirrel-Cage Motors, *220, 440, 550* Volts

Hp.	Full-Load R P M	Full Load				3/4 Load				1/2 Load			
		85%	90%	95%	100%	85%	90%	95%	100%	85%	90%	95%	100%
½	830	0 56	0 64	0 72	0 90	0 56	0 62	0 68	0 81	0 60	0 64	0 68	0 78
	680	0 51	0 59	0 68	0 86	0 55	0 61	0 68	0 83	0 62	0 67	0 72	0 83
¾	1125	0 30	0 40	0 52	0 77	0 37	0 44	0 53	0 72	0 45	0 50	0.57	0 69
	855	0 54	0 64	0 77	1 0	0 61	0 69	0 79	0 99	0 69	0 75	0 82	0 97
	660	0 81	0 93	1 1	1 3	0 89	0 98	1 1	1 3	0 96	1 0	1.1	1 2
1	1720	0 12	0 25	0 40	0 71	0 24	0 34	0 45	0 68	0 33	0 39	0 47	0 62
	1135	0 29	0 42	0 57	0 91	0 38	0 48	0 60	0 84	0 53	0 60	0 68	0 84
	855	0 63	0 77	0 93	1 3	0 69	0 80	0 92	1 2	0 83	0 90	0.96	1 2
	690	0 61	0 75	0 90	1 2	0 71	0 82	0 94	1 2	0 83	0 91	0 99	1.2
1½	3500	0 19	0 38	0 60	1 1	0 31	0 45	0 62	0 96	0 50	0 59	0.71	0 95
	1740	0 11	0 32	0 52	0 99	0 28	0 42	0 59	0 93	0 48	0 58	0.69	0 94
	1125	0 19	0 39	0 61	1 1	0 31	0 46	0 63	0 98	0 46	0 56	0 67	0 91
	875	0 78	0 97	1 2	1 6	0 93	1 1	1 2	1 6	1 0	1 1	1 3	1 5
	695	0 89	1 1	1 3	1 8	0 99	1 1	1 3	1 7	1 2	1 3	1 4	1 7
2	3470	0 10	0 36	0 67	1 3	0 30	0 50	0 72	1 2	0 46	0 59	0 75	1 1
	1740	0 05	0 30	0 59	1 2	0 26	0 45	0 66	1 1	0 41	0 57	0 72	1 0
	1140	0 34	0 59	0 89	1 5	0 52	0 71	0 93	1 4	0 67	0 80	0 94	1 3
	865	0 65	0 91	1 2	1 8	0 77	0 96	1 2	1 6	1 0	1 2	1 3	1 6
	690	1 2	1 5	1 8	2 4	1 4	1 6	1 9	2 4	1 5	1 7	1 9	2 2
3	3420		0 39	0 83	1 8	0 17	0 45	0 78	1 5	0 45	0 65	0 87	1 3
	1720		0 23	0 67	1 6	0 16	0 44	0 77	1 4	0 53	0 73	0 95	1 4
	1160	0 29	0 62	1 1	2 0	0 71	0 99	1 3	2 0	1 0	1 2	1 4	1 9
	860	0 84	1 2	1 7	2 6	0 95	1 2	1 6	2 2	1 2	1 4	1 6	2 1
	690	1 2	1 6	2 0	2 9	1 4	1 7	2 0	2 7	1 6	1 8	2 1	2 5
5	3460		0 63	1 4	2 9	0 45	0 92	1 5	2 6	0 79	1 1	1 5	2 2
	1735	.	0 25	0 94	2 4	0 17	0 62	1 1	2 2	0 59	0 90	1.2	2 0
	1155	0 23	0 84	1 5	3 0	0 70	1 2	1 7	2 8	1 3	1 6	1 7	2 7
	860	0 94	1 5	2 2	3.7	1 3	1 7	2 2	3 3	1 7	2 0	2 4	3 1
	700	2 1	2.7	3 4	4 9	2 3	2 8	3 3	4.5	2 7	3 1	3 4	4 2
	570	3 9	4 5	5 3	6 8	4.1	4 6	5.1	6 3	5 5	5 8	6 2	7 0
7½	1740	.	0 19	1 2	3 4	. . .	0.67	1 4	3 1	0 88	1 3	1.9	3 0
	1155	. .	0 90	1 9	4 1	0 65	1 3	2 1	3.7	1.3	1 8	2.3	3 4
	865	1 0	2 0	3 0	5 2	1.7	2.3	3 2	4.8	2 4	2.9	3 4	4 5
	695	2 5	3 4	4 4	6 6	3 1	3 8	4 5	6.2	3 8	4 3	4 8	6 0
	575	3 6	4 5	5.6	7 9	4.3	5 0	5.8	7 5	5.3	5 8	6.4	7 5

TABLE XXVI—*Continued*

Hp.	Full-Load R.P.M	Full Load				3/4 Load				1/2 Load			
		85%	90%	95%	100%	85%	90%	95%	100%	85%	90%	95%	100%
10	1745		0.25	1.6	4.5	.	0.89	1.9	4.1	1.2	1.7	2.4	3.9
	1160	.	0.96	2.3	5.2	0.69	1.6	2.6	4.8	1.6	2.2	2.9	4.4
	865	0.91	2.1	3.5	6.3	1.7	2.6	3.6	5.8	2.8	3.4	4.1	5.5
	700	3.0	4.2	5.6	8.5	3.8	4.7	5.8	7.9	5.1	5.6	6.3	7.8
	580	2.8	4.0	5.3	8.2	3.6	4.5	5.6	7.7	5.0	5.6	6.3	7.9
15	1750	...		1.9	6.2	...	1.3	2.9	6.1	1.6	2.5	3.5	5.7
	1165	...	0.88	2.9	7.1	0.50	1.8	3.3	6.4	1.9	2.8	3.8	5.9
	870	0.84	2.6	4.6	8.8	2.2	3.7	5.2	8.4	4.0	4.9	6.0	8.3
	690	3.1	4.9	7.0	11.3	4.0	5.3	6.9	10.1	6.1	7.0	8.0	10.2
	580	4.5	6.2	8.3	12.5	5.7	7.0	8.5	11.7	7.4	8.3	9.4	11.5
20	1760	....	0.71	3.4	8.9	0.34	2.1	4.1	8.3	2.8	4.1	5.5	8.4
	1170	....	0.71	3.3	8.9	0.33	2.1	4.0	8.2	2.5	3.7	5.1	7.9
	880	0.89	3.2	5.8	11.4	3.0	4.7	6.7	10.9	4.8	6.0	7.4	10.3
	695	1.8	4.1	6.8	12.4	3.0	4.7	6.7	10.9	5.3	6.5	7.8	10.7
	580	5.4	7.8	10.5	16.2	6.7	8.4	10.4	14.7	8.9	10.0	11.4	14.2
25	1760	. ..	..	3.2	10.1	....	1.5	3.9	9.1	2.0	3.4	5.1	8.6
	1170	.	0.88	4.1	11.0	0.41	2.6	5.0	10.3	2.8	4.3	6.0	9.5
	880	..	2.9	6.2	13.1	2.1	4.2	6.7	11.9	4.4	5.9	7.6	11.2
	695	3.9	6.7	10.0	16.9	5.9	8.0	10.5	15.7	8.3	9.8	11.5	15.0
	580	7.5	10.4	13.8	20.9	10.0	12.2	14.7	19.9	14.0	15.5	17.2	20.8
30	1760	.		3.2	11.4	..	0.53	3.5	9.7	1.0	2.8	4.8	9.1
	1175	...	2.1	6.0	14.3	1.0	3.6	6.6	12.9	3.8	5.6	7.7	12.0
	880	.	3.4	7.4	15.7	2.5	5.1	8.0	14.3	5.2	7.0	9.0	13.3
	695	4.7	8.2	12.2	20.6	7.7	10.3	13.3	19.7	11.7	13.4	15.5	19.7
	580	6.8	10.3	14.4	22.9	8.9	11.6	14.6	21.0	12.5	14.3	16.4	20.7
40	1765	..		5.2	16.1	..	1.4	5.3	13.6	1.4	3.7	6.4	12.1
	1175	..	1.8	7.0	18.0	0.66	4.1	8.0	16.3	4.5	6.8	9.5	15.1
	865	1.8	6.3	11.5	22.5	5.3	8.7	12.6	20.9	9.3	11.6	14.3	19.9
	695	2.7	7.2	12.5	23.6	5.3	8.7	12.7	21.0	9.5	11.8	14.4	20.1
	580	5.4	10.1	15.4	26.7	9.6	13.1	17.2	25.7	13.2	15.6	18.3	24.1
50	1765	...	.	5.3	18.9	.	0.88	5.7	16.0	1.7	4.6	7.9	14.9
	1160	.		6.5	20.3	. .	2.6	7.5	17.8	2.8	5.7	9.0	16.0
	870	1.1	6.7	13.2	26.9	5.7	10.0	14.8	25.1	11.7	14.5	17.8	24.8
	695	1.1	6.8	13.4	27.2	6.6	10.9	15.8	26.2	11.1	14.0	17.3	24.4
	580	6.6	12.4	19.0	32.9	11.8	16.1	21.1	31.5	16.3	19.2	22.5	29.7
60	1775		.. .	6.3	22.5	..	2.1	7.9	20.1	3.3	6.8	10.8	19.2
	1170	...	2.1	9.8	26.1	2.0	7.1	12.9	25.2	10.4	13.9	17.9	26.4
	875	....	2.8	10.6	27.0	1.0	6.1	11.9	24.3	6.7	10.1	14.0	22.4
	700	1.3	8.0	15.8	32.1	5.8	10.9	16.7	28.9	11.6	15.0	18.9	27.2
	580	4.0	10.8	18.7	35.3	9.9	15.1	21.0	33.4	14.9	18.4	22.4	30.8

TABLE XXVI—*Continued*

Hp.	Full-Load R.P.M.	Full Load				3/4 Load				1/2 Load			
		85%	90%	95%	100%	85%	90%	95%	100%	85%	90%	95%	100%
75	1775			7.8	28 0	.....	2 6	9.9	25 2	4.1	8 5	13 4	23 8
	1175		1 7	11.4	31 9	. ...	6 4	13.7	29.1	6.2	11.1	16 1	26.7
	880		3 4	13 0	33 4	1.2	7 5	14.7	29.9	8.2	12 5	17 4	27 7
	700		8 5	18.2	38.7	7.3	13 7	21.0	36.4	14.6	18.9	23 8	34 3
	580	3 3	11.8	21 6	42.2	9.9	16.2	23.6	39.1	17.5	21 8	26 4	37.2
100	1775	.		10 5	37.5	.....	2.6	12.3	32.7	5.5	11.3	17 9	31 8
	1175	.	.	12 8	39.7	....	6.7	16.4	36.7	8.9	14 6	21 2	35 1
	875	.	.	12 8	39 9	.....	6.8	16.5	36.9	7.7	13 4	20 4	33.8
	705	..	11 2	24 0	51.1	6 5	14.8	24.4	44.8	16.8	22.4	29 0	42 8
	575		9 2	22 3	50.0	6.6	15 2	24.9	45.7	17.1	22 9	29 6	43 7
125	1775	.	.	11.5	44.9	.....	2.2	14.1	39.4	5 5	12 5	20 6	37 8
	1175		..	15 9	49.4	.....	8.4	20.3	45.6	10 9	18 0	26 2	43.3
	880		5 7	21 5	55.1	2.0	12 4	24.4	49.5	15 1	22 2	30 3	47.6
	700		11 4	27 5	61.7	10 2	20.8	33.0	58 8	29 4	36 7	45 0	62.7
	580		11 4	27 5	61 7	8 1	18.6	30.7	56 2	21 2	28 4	36 6	54.1
150	1780	...	. .	13 7	53 7	.....	1.3	15.6	45.9	3.3	11.8	21 6	42.2
	1185	.....	....	15.2	54 7	. ..	5.0	19.1	48.9	8.0	16 3	25 9	46.1
	880	.	3 4	22.4	62 5	. ..	12.5	26.8	57.1	16 3	24.7	34.4	54 8
	695	.....	6 9	26 2	68 2	4 9	17.6	32 2	63 0	23 6	32 2	42.1	63.0
	580		11 9	31 2	71 9	7 3	19 8	34 2	64 7	25 1	33 6	43 3	64.1
200	1775	...	.	18 2	71 3	.		19 0	59.1	2 2	13.5	26.6	54.1
	1190	.	...	20 3	72 8		6 7	25.3	64 8	10.6	21.5	34.2	60 8
	885	. .	4 6	29.9	83 5		6 8	25.8	65.9	10.7	21 9	34.7	61.8
	700	. .	13 4	38 8	92 3	6 4	22.9	41 8	81.9	30.8	42.1	54.9	82.2
	585	....	17.8	43.2	96 7	15 9	32.4	51 3	91.5	43.0	54.2	67.2	94.3

TABLE XXVII

Approximate Kv-A. in Capacitors Needed to Improve the Power Factor of *Normal*-Torque, *Normal*-Starting-Current, 3-Phase, 60-Cycle, Squirrel-Cage Motors, *2200* Volts

Hp	Full-Load R P M	Full Load				3/4 Load				1/2 Load			
		85%	90%	95%	100%	85%	90%	95%	100%	85%	90%	95%	100%
30	1170	1.7	5.2	9.2	17.7	4.0	6.6	9.6	16.0	7.2	9.0	11.0	15.3
	880	6.8	10.3	14.4	22.9	9.0	11.7	14.8	21.2	12.3	14.2	16.3	20.8
	575	9.3	12.9	17.1	26.0	13.0	15.8	18.9	25.6	15.6	17.5	19.6	24.2
40	1760		0.9	6.2	17.3		2.8	6.8	17.7	2.7	5.1	7.8	13.6
	1175	1.8	6.4	11.6	22.8	5.3	8.7	12.7	21.0	9.6	12.0	14.7	20.5
	865	1.8	6.5	11.8	23.2	5.4	8.9	12.9	21.4	9.6	12.0	14.7	20.5
	690	6.3	11.0	16.4	27.8	9.0	12.5	16.5	25.0	14.6	17.0	19.8	25.7
	580	16.0	20.7	26.2	37.7	19.6	23.1	27.2	35.8	25.3	27.7	30.3	36.3
50	1765			6.5	20.2		1.8	6.7	17.1	2.3	5.2	8.6	15.7
	1160		1.8	8.4	22.4	1.3	5.6	10.7	21.3	7.6	10.7	14.1	19.2
	865		5.8	12.4	26.4	4.2	8.5	13.5	24.0	8.7	11.6	15.0	22.1
	695	5.6	11.3	17.9	31.9	9.3	13.6	18.6	29.1	14.0	16.9	20.3	27.5
	580	4.5	10.4	17.1	31.3	9.3	13.7	18.7	29.3	14.1	17.1	20.5	27.7
60	1775		1.4	9.3	26.0		5.3	11.3	24.0	6.3	9.9	14.1	22.9
	1165		1.4	9.3	26.0	0.51	5.7	11.7	24.3	7.6	11.2	15.3	23.9
	865		5.5	13.5	30.1	5.0	10.2	16.2	28.8	10.4	13.9	18.0	26.5
	700	4.0	10.9	18.9	35.7	10.1	15.3	21.2	33.8	16.8	20.3	24.3	32.9
	580	10.6	17.5	25.4	42.2	17.6	22.8	28.8	41.4	23.5	27.1	31.2	39.8
75	1775	..	. .	9.8	30.4	.	3.9	11.3	27.0	6.0	10.5	15.5	26.4
	1175	..	5.2	14.9	35.5	2.5	9.0	16.4	32.0	10.4	14.9	20.0	30.8
	870	..	5.2	15.0	35.8	3.7	10.1	17.5	33.1	8.4	12.8	17.8	28.4
	700	3.3	11.8	21.5	42.2	12.4	18.9	26.2	41.8	20.8	25.1	30.1	40.7
	585	11.5	20.1	29.8	50.7	19.1	25.5	32.9	48.6	29.2	33.6	38.7	49.3
100	1775	..	..	12.8	39.9	...	3.5	13.1	33.6	4.4	10.2	16.8	30.7
	1175	...	2.3	15.2	42.4	...	8.4	18.1	38.5	10.0	15.7	22.3	36.3
	875	...	6.9	19.9	47.4	3.3	11.9	21.7	42.4	14.8	20.6	27.3	41.3
	700	....	11.3	24.2	51.7	9.8	18.3	28.1	48.7	22.3	28.1	34.7	48.8
	585	4.4	15.6	28.6	56.0	13.1	21.5	31.3	51.8	23.6	29.4	36.0	50.2
125	1775	....	....	15.9	49.4	....	3.2	15.3	40.7	4.1	11.2	19.3	36.5
	1175	....	2.9	18.7	52.2	....	8.4	20.5	45.8	9.6	16.6	24.8	41.9
	880	....	5.8	21.9	56.2	2.0	12.6	24.6	50.1	15.3	22.5	30.7	48.2
	700	....	11.5	27.8	62.3	10.3	21.0	33.3	59.2	26.2	33.4	41.8	59.4
	585	5.4	19.5	35.7	69.8	18.4	28.9	41.1	66.7	31.1	38.3	46.7	64.4
150	1775	...	...	15.6	56.0	....	1.3	15.8	46.5	3.3	11.9	21.8	42.7
	1185	.....	....	19.0	59.1	...	7.6	21.8	52.0	8.1	16.5	26.1	46.5
	880	...	16.8	36.1	76.8	12.2	24.9	39.5	70.3	29.5	38.2	48.2	69.3
	700	....	10.2	29.5	70.2	4.9	17.5	32.0	62.6	23.5	32.1	41.8	62.7
	585	....	11.9	31.2	72.0	7.3	19.9	34.5	65.1	25.4	34.0	43.9	64.9
200	1775	....	....	18.4	72.2	.....	....	19.1	59.6	2.2	13.5	26.6	54.1
	1185	.....	.....	25.0	78.0	.....	10.1	29.0	69.1	10.7	21.9	34.7	61.8
	885	....	4.6	29.8	83.5	.....	13.3	32.3	72.4	10.7	22.0	34.9	62.1
	705	....	22.1	47.4	101.0	22.5	39.1	58.3	98.7	48.4	59.7	72.7	100.0
	585	.....	22.2	47.7	102.0	19.2	35.8	55.0	95.4	40.9	52.2	65.3	93.0

TABLE XXVIII

Approximate Kv-A. in Capacitors Needed to Improve the Power Factor of *Normal*-Torque, *Low*-Starting-Current, 3-Phase, 60-Cycle, Squirrel-Cage Motors, *220, 440, 550* Volts

Hp	Full-Load R P M	Full Load				3/4 Load				1/2 Load			
		85%	90%	95%	100%	85%	90%	95%	100%	85%	90%	95%	100%
7½	3450		0.38	1.4	3.7	0.13	0.82	1.6	3.3	0.89	1.4	1.9	3.0
	1745	.	0.37	1.4	3.6		0.42	1.2	2.9	0.27	0.73	1.3	2.4
	1160	0.35	1.3	2.3	4.5	0.65	1.3	2.1	3.8	1.3	1.8	2.3	3.4
	865	1.6	2.5	3.5	5.7	1.8	2.5	3.3	4.9	2.7	3.1	3.7	4.8
	690	2.5	3.5	4.5	6.7	3.1	3.8	4.6	6.3	3.9	4.4	4.9	6.1
	575	3.6	4.5	5.6	7.9	4.3	5.0	5.8	7.5	5.3	5.8	6.4	7.6
10	3470			1.2	4.2		0.19	1.2	3.4	0.35	0.96	1.7	3.1
	1750		1.2	2.6	5.5	0.34	1.2	2.2	4.4	1.2	1.8	2.4	3.9
	1160		1.2	2.6	5.6	0.52	1.4	2.4	4.6	1.2	1.8	2.4	3.9
	875	1.8	3.0	4.3	7.2	2.5	3.4	4.4	6.5	3.4	4.0	4.7	6.2
	700	3.0	4.2	5.6	8.5	3.8	4.7	5.8	7.9	5.0	5.6	6.3	7.8
	580	2.8	4.0	5.3	8.2	3.6	4.5	5.5	7.7	5.0	5.7	6.4	7.9
15	3500		0.75	2.9	7.3		0.82	2.4	5.7	0.70	1.6	2.6	4.9
	1740		1.8	3.8	8.1		1.3	2.8	5.9	0.67	1.5	2.5	4.6
	1165		1.7	3.8	8.0	0.75	2.1	3.5	6.7	1.9	2.8	3.8	5.9
	875	2.7	4.4	6.5	10.7	3.6	4.9	6.4	9.5	4.7	5.6	6.6	8.8
	690	3.1	4.9	7.0	11.4	4.0	5.3	6.8	10.1	6.0	6.9	8.0	10.2
	580	4.5	6.2	8.3	12.5	5.7	7.0	8.5	11.8	7.5	8.4	9.4	11.6
20	3460	.	0.49	3.2	8.9		0.72	2.7	7.0	0.68	1.9	3.2	6.1
	1760	.	1.8	4.5	10.0	0.99	2.7	4.7	8.8	3.0	4.1	5.5	8.3
	1170	..	2.3	4.9	10.5	0.99	2.7	4.7	8.9	2.5	3.7	5.1	8.0
	875	3.1	5.4	8.1	13.6	3.7	5.4	7.4	11.5	5.3	6.4	7.8	10.6
	695	1.8	4.1	6.8	12.4	3.0	4.7	6.7	10.9	5.3	6.5	7.9	10.7
	580	5.4	7.8	10.5	16.2	6.7	8.4	10.4	14.7	8.9	10.1	11.4	14.3
25	3545	..	0.89	4.2	11.1	....	0.89	3.4	8.7	1.4	2.9	4.6	8.3
	1760		1.7	5.0	11.9	0.82	2.9	5.4	10.5	2.8	4.2	5.9	9.3
	1170		2.8	6.1	12.9	1.2	3.3	5.8	10.9	3.0	4.5	6.1	9.5
	880	2.2	5.1	8.4	15.3	2.9	5.1	7.4	12.8	4.6	6.0	7.7	11.2
	695	3.9	6.7	10.0	16.9	5.9	8.0	10.5	15.7	8.4	9.8	11.5	15.0
	580	9.5	12.5	16.0	23.3	10.7	13.0	15.5	21.0	13.5	15.0	16.8	20.5
30	3550	...	..	3.9	12.2	..	1.1	4.0	10.3	1.7	3.5	5.6	9.9
	1760	..	1.0	4.9	13.1	..	1.5	4.5	10.7	1.3	3.0	5.0	9.2
	1175	...	3.4	7.3	15.5	1.5	4.0	7.0	13.2	3.7	5.4	7.4	11.6
	880	1.3	4.7	8.7	17.0	3.0	5.6	8.5	14.8	5.2	7.0	9.1	13.4
	700	4.7	8.3	12.3	20.8	6.7	9.4	12.4	18.8	9.4	11.2	13.2	17.6
	585	8.3	11.8	15.9	24.5	10.2	12.8	15.9	22.3	13.6	15.4	17.5	21.8
40	3540	....	....	5.2	16.1	.	0.71	4.6	13.0	...	2.3	5.0	10.7
	1765	..	0.47	5.6	16.6	.	1.4	5.3	13.6	0.90	3.2	5.9	11.5
	1175		3.6	8.8	19.8	0.98	4.4	8.3	16.5	4.0	6.3	8.9	14.5
	875	4.4	9.0	14.2	25.3	6.6	10.0	13.9	22.1	9.3	11.6	14.3	19.9
	700	4.4	9.1	14.4	25.5	6.7	10.2	14.1	22.6	10.5	12.9	15.6	21.2
	580	5.4	10.1	15.4	26.8	9.6	13.1	17.2	25.7	13.2	15.6	18.3	24.1

TABLE XXVIII—*Continued*

Hp.	Full-Load R.P.M.	Full Load				3/4 Load				1/2 Load			
		85%	90%	95%	100%	85%	90%	95%	100%	85%	90%	95%	100%
50	3550	.....	....	6.4	20 1	....	0 88	5 7	16 0	0 56	3.4	6.7	13.7
	1765	.....	0.58	7 0	20.6	.	0 88	5.7	16 0	0 56	3.5	6.8	13 8
	1170	....	3.5	10 0	23 7	0 83	5 1	10 1	20 5	4 6	7.6	10 9	18 2
	875	3 3	8 9	15 4	29 1	4 9	9 1	14 0	24 3	8 4	11 3	14 6	21 5
	695	2.2	7 9	14 5	28 4	7 4	11 7	16 6	27 0	12 4	15 3	18.7	25 7
	580	6 6	12 4	19 0	32 9	11 8	16 1	21.1	31 5	16 3	19 2	22 6	29 7
60	3540	.....	....	7 7	24 1	.	1 0	6 9	19 2	.. .	3 4	7 4	15 7
	1775	.. .	2 1	9 8	26 0	.	3 1	8 9	21 1	3 3	6 8	10 8	19 2
	1175	...	4 1	11.9	28 3	2 0	7 1	13 0	25.4	6 8	10 3	14 3	22 8
	875	2 6	9 5	17 3	33 8	6 4	11 5	17 4	29 7	10 2	13 6	17.6	25 9
	700	5 3	12 1	20 0	36 6	8 9	14.1	19 9	32 4	14 9	18 4	22 4	30 8
	580	4 0	10 8	18 7	35.3	9 9	15 1	20 9	33 4	14 9	18 4	22.4	30 8
75	3540	.....	....	9.6	30.0	...	1 3	8 6	23 9	....	4 3	9 3	19 7
	1775	....	....	9.6	30.0	.....	2 6	9 8	25 1	4.1	8 4	13 3	23 7
	1180	.....	6 8	16 5	36 9	2.5	8 9	16 2	31 7	8 4	12 8	17 7	28 3
	875	.....	8.5	18.2	38 7	3 7	10 0	17 3	32 7	12 8	17 2	22 2	32 8
	700	6.6	15.2	25.1	46.0	11.2	17.7	25 1	40 8	18 7	23 1	28 1	38 8
	580	3.3	11 8	21.6	42.2	9.9	16.2	23 6	39 1	17 5	21 8	26 7	37 2
100	3540	.....	....	12.9	40.2	....	3.5	13 3	33 9	3 4	9 2	15.8	29 9
	1770	....	2.3	15.1	42.3	... .	5.1	14 7	35 0	6 5	12 2	18 7	32 4
	1180	.....	4.6	17.3	44.3	....	8 4	18 0	38 3	7 7	13 5	20 0	33 9
	870	.....	9.1	22.2	49.8	3.3	11 8	21.6	42.2	15 7	21 5	28 0	41 9
	705	9.0	19.8	32 6	59 7	14.6	22 9	32.6	52 9	24 3	29 9	36 4	50 2
	575	....	9.2	22.3	50.0	6 6	15.1	24 9	45 7	17 1	22 9	29 5	43 7
125	3555	....	.....	15.9	49.4	....	4.3	16 3	41.7	5.5	12 5	20 7	37.9
	1770	...	1.4	17 3	50.8	....	4.3	16 2	41.5	6.8	13 9	22 0	39.2
	1180	...	5 7	21.5	55.1	2.0	12 6	24 6	50 2	13 9	21.0	29 3	46.7
	890	....	14 1	30.3	64 5	8.1	18 7	30 7	56 2	20.9	28.0	36 1	53 4
	705	5 4	19 5	35 7	69 8	14 3	24 9	37.0	62.7	27.8	35.0	43 3	61.0
	580	...	11 4	27 5	61.7	8 1	18 7	30 7	56.2	21 2	28.3	36.6	54 0
150	3555	...	... .	19.0	59 1	..	5 1	19.4	49.6	8.2	16 7	26.4	47.1
	1770	...	....	19 0	59 1	.	5 1	19.5	49.8	6 5	15.0	24.7	45.2
	1175	...	3.4	22 4	62 5	....	10.0	24 3	54.4	11 5	20.0	29.7	50.4
	875	..	16 8	36.1	71.8	9 7	22 4	36.9	67.6	25.1	33.6	43.4	64.1
	700	6.5	23.3	42.6	83.3	17.1	29 8	44 4	75.3	32.9	41 5	51.4	72.3
	580	...	11.9	31 2	72.0	7 3	19.8	34.3	64.8	25 1	33.6	43.4	64.1
200	3550	....	....	25.1	78.0	....	3.4	22.4	62.5	.....	11.2	24.1	51.3
	1770	....	.....	25.3	79.0	....	6.8	25.7	65 8	10.8	22.0	34.9	62 1
	1180	....	2.3	27.3	80.3	....	13 3	32 3	72.4	15.2	26.5	39.4	66 8
	885	..	4.6	29.8	83.5	....	6 8	25.7	65.8	10.7	21 9	34.7	61 8
	705	....	22 2	47.7	102.0	12.8	29 5	48.6	89.1	33.3	44.6	57.5	85 0
	585	...	17.8	43.2	96.8	15.9	32 4	51 3	91.5	43.0	54.2	67.1	94 4

TABLE XXIX

APPROXIMATE KV-A. IN CAPACITORS NEEDED TO IMPROVE THE POWER FACTOR OF *Normal*-TORQUE, *Low*-STARTING-CURRENT, 3-PHASE, 60-CYCLE, SQUIRREL-CAGE MOTORS, *2200* VOLTS

Hp.	Full-Load R.P.M.	Full Load				3/4 Load				1/2 Load			
		85%	90%	95%	100%	85%	90%	95%	100%	85%	90%	95%	100%
30	1170	1.7	5.2	9.2	17.7	4.0	6.6	9.7	16.0	7.2	9.0	11.0	15.3
	575	9.3	13.0	17.1	26.0	13.0	15.8	18.9	25.5	15.6	17.5	19.6	24.2
40	1760	.	2.8	8.1	19.2	0.67	4.1	8.1	16.5	4.1	6.5	9.3	15.1
	1175	4.9	9.4	14.7	25.9	8.1	11.5	15.5	23.9	12.5	14.9	17.5	23.3
	875	4.5	9.3	14.7	26.2	6.9	10.4	14.5	23.1	9.9	12.3	15.1	21.1
	690	6.3	11.0	16.4	27.8	8.9	12.5	16.5	25.1	14.6	17.0	19.8	25.7
	580	16.0	20.7	26.2	37.6	19.6	23.1	27.3	35.8	25.3	27.7	30.5	36.3
50	1765	....	2.3	8.8	22.5	....	3.4	8.4	18.7	2.8	5.8	9.1	16.3
	1165	2.2	8.0	14.7	28.7	5.1	9.4	14.4	25.1	8.9	11.9	15.3	22.6
	865	4.5	10.2	16.9	30.9	7.5	11.9	16.8	27.4	10.6	13.5	16.9	24.1
	695	6.7	12.5	19.1	33.1	9.2	13.6	18.5	29.1	15.6	18.6	21.9	29.2
	580	4.5	10.4	17.1	31.2	9.3	13.7	18.7	29.4	14.1	17.1	20.5	27.7
60	3540	...	4.2	12.0	28.6	1.0	6.2	12.2	24.9	7.0	10.6	14.8	23.5
	1775	...	2.8	10.5	27.0	...	5.1	11.0	23.5	4.1	7.6	11.6	20.2
	1170	1.3	8.2	16.1	32.8	5.0	10.2	16.1	28.7	10.5	14.1	18.2	26.8
	865	5.3	12.3	20.2	37.1	9.0	14.2	20.1	32.7	12.7	16.2	20.3	28.8
	695	5.4	12.5	20.5	37.7	9.2	14.5	20.5	33.3	15.5	19.1	23.3	32.0
	580	10.6	17.5	25.4	42.2	17.6	22.7	28.7	41.3	23.5	27.1	31.2	39.8
75	3540	....	3.5	13.3	33.9		6.5	13.9	29.6	6.0	10.4	15.5	26.2
	1775	....	1.7	11.4	31.9	...	5.1	12.5	27.9	5.1	9.4	14.5	25.0
	1180	...	6.9	16.6	37.3	2.5	9.0	16.5	32.2	9.5	14.0	19.1	29.9
	870	2.5	11.1	21.0	41.9	10.0	16.4	23.8	39.5	17.9	22.2	27.3	38.0
	700	7.6	16.3	26.3	47.4	12.6	19.2	26.6	42.4	20.2	24.6	29.7	40.6
	585	11.5	20.1	29.9	50.7	19.1	25.5	32.9	48.7	29.2	33.6	38.6	49.4
100	3540	.....	....	12.9	40.2	...	3.5	13.3	33.9	3.4	9.2	15.8	29.9
	1765	.....	2.3	15.2	42.5	.....	6.8	16.5	36.9	7.7	13.5	20.1	34.0
	1180	....	5.7	18.5	45.6	1.6	10.0	19.7	40.1	11.1	16.9	23.5	37.4
	875	2.2	13.6	26.7	54.4	8.2	16.8	26.6	47.3	22.4	28.2	35.0	49.3
	700	9.9	21.3	34.4	62.1	16.6	25.1	34.9	55.7	26.5	32.3	39.0	53.3
	585	4.4	15.6	28.6	56.0	13.1	21.5	31.2	51.8	23.5	29.3	35.9	50.0
125	3555	.....	.....	15.9	49.4	.....	4.3	16.3	41.7	5.5	12.6	20.7	37.9
	1775	.....	2.9	18.7	52.2	.....	6.4	18.4	43.7	8.3	15.5	23.7	41.1
	1180	.....	8.4	24.3	57.8	4.1	14.6	26.7	52.2	17.0	24.2	32.5	50.1
	880	2.7	16.8	33.0	67.2	10.2	20.9	33.1	58.9	26.2	33.4	41.8	59.4
	705	8.1	22.2	38.4	72.7	16.3	26.9	39.1	64.8	29.1	36.3	44.5	62.0
	585	5.4	19.5	35.7	69.8	18.4	29.0	41.1	66.8	31.1	38.3	46.7	64.3

TABLE XXIX—*Continued*

Hp	Full-Load R.P.M.	Full Load				3/4 Load				1/2 Load			
		85%	90%	95%	100%	85%	90%	95%	100%	85%	90%	95%	100%
150	3555			19 0	59 1		5 1	19 5	49 7	8 2	16 7	26 5	47 1
	1770		3 4	22 6	63 0		7 6	22 1	52 6	9 9	18 4	28 3	49 0
	1175		6 8	25 7	65 8		12 5	26 8	57 1	16 5	25 1	34 9	55 7
	880	3 3	20 2	39 6	80 7	14 7	27 4	12 0	72 8	31 4	40 1	50 2	71 3
	705	6 5	23 5	12 8	84 0	17 0	29 7	44 2	74 9	32 8	41 3	51 2	71 9
	585		11 9	31 2	72 0	7 3	19 9	34 5	65 2	25 4	34 0	43 9	64 9
200	3550		.	25 1	78 0		6 8	25 7	65 8	10 7	22 0	34 9	62 2
	1770		2 3	27 8	81 8		10 1	29 3	69 7	13 1	24 5	37 5	65 0
	1180		9 0	34 2	87 4		16 5	35 5	75 6	22 0	33 3	46 4	73 9
	885		4 6	29 9	83 5		13 3	32 3	72 4	10 8	22 0	34 9	62 2
	705		22 1	47 4	101 0	16 0	32 7	51 8	92 3	41 0	52 2	65 3	92 9
	585		22 2	47 7	102 0	19 2	35 9	55 0	95 4	41 0	52 2	65 3	92 9

TABLE XXX

Approximate Kv-A. in Capacitors Needed to Improve the Power Factor of *High*-Torque, *Low*-Starting-Current, 3-Phase, 60-Cycle, Squirrel-Cage Motors, *220, 440, 550* Volts

Hp.	Full-Load R P.M	Full Load				3/4 Load				1/2 Load			
		85%	90%	95%	100%	85%	90%	95%	100%	85%	90%	95%	100%
3	1720		0 23	0 67	1 6	0 16	0 45	0 78	1 4	0 52	0 71	0 93	1 4
	1140	0 59	0 96	1 4	2 3	0 72	1 0	1 3	2 0	1 0	1 2	1 4	1 9
	855	1 1	1 5	1 9	2 9	1 3	1 6	1 9	2 6	1 5	1 7	1 9	2 4
5	1730	0 12	0 73	1 4	2 9	0 53	0 99	1 5	2 6	0 95	1 2	1 6	2 3
	1140	0 49	1 1	1 9	3 4	0 73	1 2	1 7	2 9	1 2	1 5	1 9	2 6
	870	2 1	2 7	3 4	5 0	2 3	2 7	3 3	4 4	2 7	3 0	3 4	4 2
7½	1730	0 18	1 1	2 2	4 4	0 53	1 2	2 0	3 7	1 2	1 6	2 2	3 3
	1140	0 71	1 6	2 7	4 9	1 1	1 8	2 6	4 2	1 6	2 0	2 6	3 7
	860	2 3	3 2	4 3	6 5	2 4	3 1	3 9	5 5	2 8	3.3	3 8	4 9
10	1750	0 47	1 7	3 1	6 0	1 0	1 9	3 0	5 1	1 5	2 1	2 8	4 2
	1150		1 2	2 6	5 6	0 52	1 4	2 5	4 7	1 2	1 8	2 5	4 0
	870	3 0	4 2	5 6	8 5	3 6	4 5	5 5	7 7	4 9	5 5	6 2	7 6
15	1735	..	1 8	3 9	8 2		1 3	2 9	6 1	0 86	1 8	2 8	4 9
	1160	0 68	2 4	4 4	8.7	1 5	2 8	4 3	7 4	2 6	3 5	4 5	6 6
	865	4 1	5 9	7.9	12 2	5 1	6 4	7 9	11 1	5 9	6 8	7 9	10 0
20	1755	1 3	3 6	6 3	11 9	2 3	4 0	6 0	10 2	3 9	5 1	6 4	9 3
	1170	67	3.0	5 6	11 2	2 0	3 7	5 7	9 9	3 4	4 6	5 9	8 8
	865	4 0	6 4	9 1	14 7	5 5	7 3	9 3	13 5	7 5	8 7	10 0	12 9
25	1765	1 6	4 5	7 7	14 6	2 9	5 0	7 4	12 6	4 9	6 3	8 0	11 4
	1170	.	2 9	6 1	13 1	1 2	3 4	5 8	11 0	3 1	4 5	6 2	9 7
	875	3 9	6 8	10 1	17 1	5 5	7 7	10 2	15 4	7 7	9 2	10 8	14 4
30	1760		2 7	6 6	14 8	1 5	4 0	6 9	13 1	4 0	5 7	7 7	11 9
	1170	.	3 3	7 1	15 0	1 5	4 1	7 1	13.3	3 7	5 5	7 5	11 7
	875	4 6	8 0	12 0	20 3	6 5	9 1	12 1	18 3	9 2	10 9	12 9	17.2
40	1765		2 7	7 9	18 8	0 65	4 0	7 9	16.1	4 5	6 8	9 4	15 0
	1170		4 5	9 7	20 6	2 0	5 3	9 2	17 4	4 9	7 2	9 9	15 5
	865	5 3	10 0	15 3	26 4	7 4	10 9	14 8	23 3	11 1	13 4	16 1	21 8
50	1770		1.2	7 6	21 1		3 4	8 2	18 4	2 7	5 6	8 8	15 7
	1150		3 5	10 2	24 3	0 84	5 2	10 1	20 7	4 5	7 4	10 7	17 7
	865	6 6	12 4	19 0	32 9	9 2	13 5	18 4	28 9	13 1	16 0	19.4	26 4
60	1760		3 5	11 3	27.8		4 1	10 0	22 5	3 4	6 8	10 8	19 3
	1165		5 5	13 3	29.8	3 0	8 1	13 9	26 3	8 0	11 5	15 4	23 7
75	1765		3 5	13 1	33 6	.	5 2	12 5	28 0	4 2	8 6	13 6	24 1

2200 Volts

60	1760	1.3	8 2	16 0	32 6	5 0	10 2	16 2	28.8	10 5	14 1	18 2	26 8
	1150	1.4	8 4	16 4	33 4	5 1	10 4	16 4	29 2	10 5	14 1	18 2	26 8
70	1755	.....	8 5	18 3	38 9	3 7	10 2	17 6	33.3	13 0	17.4	22 5	33 2

TABLE XXXI

APPROXIMATE KV-A. IN CAPACITORS NEEDED TO IMPROVE THE POWER FACTOR OF CONSTANT- AND ADJUSTABLE-VARYING-SPEED, 3-PHASE, 60-CYCLE, *Wound-Rotor* INDUCTION MOTORS, *220, 440, 550* VOLTS

Hp.	Full-Load R.P M.	Full Load				3/4 Load				1/2 Load			
		85%	90%	95%	100%	85%	90%	95%	100%	85%	90%	95%	100%
1	1675	0.32	0 47	0 64	1 0	0 38	0 49	0 61	0 88	0 46	0 54	0 62	0 83
	1095	0 86	1 0	1 2	1 5	0 95	1 1	1 2	1 5	1 0	1 1	1 2	1 4
	835	1 0	1 2	1 4	1.7	1 1	1 2	1 4	1 6	1 1	1 2	1 3	1 5
1½	1675	0 33	0 55	0 80	1 3	0 45	0 61	0 80	1 2	0.58	0 70	0 83	1 1
	1080	1 3	1 5	1 7	2 2	1 3	1 5	1 7	2 1	1.5	1 6	1 7	2 0
	830	0 69	0 89	1 1	1 6	0 90	1 1	1 2	1 6	0 98	1 1	1 2	1 5
2	1715	0 16	0 45	0 78	1 5	0 32	0 55	0 80	1 3	0 54	0 68	0 86	1 2
	1095	1 2	1 5	1 8	2 5	1 3	1 5	1 8	2 3	1 4	1 5	1 7	2 1
	830	1.1	1 4	1 7	2 4	1 3	1 5	1 8	2 3	1 5	1 7	1 8	2 2
3	1695	0.45	0.85	1 3	2 3	0 70	0 99	1 3	2 1	0 98	1 2	1 4	2 0
	1115	0.78	1 2	1 7	2 6	1 1	1 4	1 7	2 4	1 3	1 5	1 7	2 2
	845	1 1	1 5	1 9	2 9	1 3	1 6	1 9	2 6	1 5	1 7	2 0	2 5
	565	3 3	3 7	4 2	5 2	3 8	4 2	4 5	5 3	5 5	5 8	6 0	6 6
5	1690	0 49	1 1	1 9	3 4	0 92	1 4	1 9	3 1	1 5	1 8	2 2	3 0
	1135	0 73	1 4	2 1	3 6	1 1	1 6	2 1	3 3	2 0	2 3	2 7	3 5
	845	2 3	2 9	3 7	5 2	2 3	2 7	3 3	4 1	2 6	2 9	3 3	4 1
	685	3 6	4 2	5 0	6 5	3 9	4 4	4 9	6 1	5 6	5 9	6 3	7 1
	565	3 5	4 2	4 9	6 5	4 1	4 6	5.2	6 4	6 8	7 3	7 7	8 6
7½	1690	0 53	1 5	2 5	4 7	1 2	1 9	2 7	4 4	1 8	2 3	2 8	4 0
	1125	0 73	1 7	2 8	5 1	1 4	2 1	2 9	4 6	1 9	2 4	3 0	4 2
	845	3 1	4 0	5 1	7 3	3 1	3 8	4 6	6 3	3 6	4 1	4.6	5 8
	685	4 3	5 2	6 3	8 6	5 1	5 8	6 6	8 3	6 8	7 3	7 9	9 0
	570	5 2	6 2	7 3	9 7	6 1	6 9	7 7	9 5	10 0	10 5	11 1	12 4
10	1705	.	0.74	2 1	5 1	0 53	1 5	2 5	4 7	1 6	2 2	2 9	4 4
	1150	0 92	2.1	3 5	6 4	1 4	2 3	3 3	5 6	2 1	2 7	3 4	5 0
	845	2 4	3 6	5 0	7 9	3 3	4 2	5 3	7 5	4 4	5 1	5 8	7 3
	685	3 6	4.8	6 2	9 2	5 3	6 3	7 3	9 6	7 2	7 9	8 6	10 2
	575	5 6	6 8	8 2	11 2	6 6	7 5	8 6	10 9	8 2	8 9	9 6	11.2
15	1705		0 74	2 8	7 2		1 3	2 9	6 1	1 2	2 1	3 1	5 3
	1155	0 69	2 5	4 5	8 9	2 1	3 4	4 9	8 1	3 7	4 6	5 6	7 8
	850	2 4	4 2	6 3	10 7	3 4	4 8	6 4	9 6	5 2	6 1	7 2	9 4
	690	4 4	6 2	8 2	12 4	4 2	5 5	7 0	10 2	6 5	7 4	8 4	10 6
	575	6 6	8 5	10 6	15 1	7 3	8 7	10 2	13 6	9 6	10 6	11 7	14 1
20	1730	..	0 97	3 7	9 4		1 8	3 8	8 1	2 1	3 3	4 7	7 7
	1160	1 3	3 7	6 4	12 0	3 4	5 1	7 1	11 4	5 4	6 6	8 0	10 9
	855	2 8	5 1	7 9	13 7	4 2	6 0	8 0	12 3	7 0	8 2	9.6	12 5
	690	3 6	6 0	8 6	14 3	4 4	6 2	8 2	12 4	7 9	9 1	10 5	13 4
	570	7 7	10 2	13 0	18 9	10 8	12 7	14 8	19 4	13 2	14 6	16 1	19 3
25	1735	....	0 89	4 2	11 2	...	2 2	4 7	10 1	2 6	4.1	5 8	9 5
	1170	1 7	4 5	7 8	14 8	4 2	6.4	8 9	14 2	6.4	7.9	9 6	13.2
	870	0 56	3 4	6 7	13 7	2 1	4 2	6 7	11 9	4 4	5 8	7 5	11 1
	685	4 0	6 9	10 3	17 5	6 1	8 3	10 9	16 3	10 9	12 4	14 1	17 8
	575	8 3	11.3	14.7	22 0	10 8	13 1	15 7	21 2	14 5	16 0	17.8	21.6

TABLE XXXI—*Continued*

Hp.	Full-Load R.P.M.	Full Load 85%	Full Load 90%	Full Load 95%	Full Load 100%	3/4 Load 85%	3/4 Load 90%	3/4 Load 95%	3/4 Load 100%	1/2 Load 85%	1/2 Load 90%	1/2 Load 95%	1/2 Load 100%
30	1755	....	1 1	5 0	13 4	....	2 6	5.6	11 9	3 1	4.9	7 0	11.4
	1170	.....	3 4	7.3	15 6	3 0	5 6	8 5	14 8	6 8	8 5	10 5	14 8
	870	2.0	5.4	9 4	17.7	4 5	7 1	10 0	16 3	8 4	10 1	12 2	16 5
	690	5.5	9 0	13 1	21 7	9 0	11.6	14.7	21 1	14 8	16 6	18 7	23 0
	575	5 2	8 8	12 9	21 6	7 4	10 1	13 2	19 7	10 7	12 6	14 7	19 2
40	1750	..	0 94	6 1	17 2	..	2 8	6 7	15 1	3 2	5 6	8 3	14.1
	1170		3 6	8 5	19 7	2 6	6 0	9 9	18 1	6 8	9 1	11 7	17.4
	865	2 7	7 3	12 7	23 9	7 4	10 9	14 9	23 3	11 4	13 7	16 5	22 3
	680	2 7	7 3	12 7	23 9	5 3	8 8	12 9	21 3	9 7	12 1	14 8	20 6
	575	9 7	14 5	20 0	31 6	13 0	16 7	20 8	29 6	16 9	19 3	22 2	28 1
50	1745		1 2	7 7	21 3	..	3 4	8 3	18 6	3 9	6 8	10 3	17 2
	1160	.	4 6	11 2	25.0	4 1	8 5	13 4	23 9	8 7	11 6	15 0	22 1
	865	3 3	9 1	15 7	29 7	9 3	13 6	18 6	29 1	13 3	16 2	19 6	26 8
	685	2 8	8 6	15 2	29 2	6 8	11 3	16 4	27 1	12 0	15 0	18.4	25.6
	575	9 0	14 9	21 6	35 8	12 9	17 3	22 3	33 0	17 2	20 1	23 6	30 8
60	1750	..	1 4	9 2	25 6		2 1	8 0	20 3	2 0	5 4	9 4	17 7
	1170			7 7	24 1	.	4 1	9 9	22 2	10.2	13.6	17 5	25 9
	865		4 9	12 9	29 7	3 0	8.2	14 2	26 8	8.9	12 5	16 5	25 1
	690	2 0	9 0	17 0	33 9	6 5	11 8	17 8	30 5	11 9	15 4	19 5	28 0
	575	6 0	12 9	20 9	37.7	9 0	13 5	20 2	32 8	14 3	17 8	21.8	30 4
75	1755		0 88	10.5	31 0	..	1.9	9 2	24 5	0 82	5.1	10 0	20 3
	1165	.	6 9	16 6	37.3	3 7	10 2	17 6	33 3	8 6	13 1	18 2	29 0
	870		5 2	15 0	35 7	3 7	10.1	17 5	33 0	12 1	16 5	21.5	32 2
	695	3 3	11 9	21 7	42 4	8 6	15 0	22 4	37 9	17 7	22.1	27.1	37 7
	575	8 3	16 9	26 8	47 7	13 8	20 3	27.7	43 3	20 9	25 3	30.4	41.1
100	1755		...	10 6	37 9	. .	1.8	11 5	32 2	1 1	6 9	13.6	27 6
	1170		4 6	17.4	44.5	1.6	10 0	19 7	40 1	11 1	16.8	23 4	37 3
	875		6 9	20.0	47 4	4.9	13 4	23.2	43 8	15 9	21.7	28.4	42 4
	695		9.1	22 1	49 4	8 1	16 6	26 3	46 8	23 3	33.2	35.5	49 5
	575		9 3	22 4	50 3	5 0	13 6	23.5	44 3	16 0	21 9	28.5	42 7
125	1755	.	.....	10 0	43.8	.....	...	12.2	37 8	...	7.3	15 7	33.4
	1170		4.2	20.3	54 2	2 0	12 6	24 6	50.2	13 9	21 1	29.3	46.7
	870	.	14.1	30 3	64 4	10 1	20 6	32 7	58 2	26 2	33 4	41 8	59 4
	700		14 1	30 3	64 4	12 3	22 9	35 1	60 9	32 8	40 1	48.4	66 1
	575	1 4	15 6	31 9	66 4	10 2	20 8	33.1	58 8	21.4	28.7	37.0	54.7
150	1755		....	12 1	52 8	.....	....	14 5	45 2	.. .	8 6	18 5	39.4
	1170	..	.....	19.0	59 1	....	7.6	21.9	52.2	8.1	16 5	26 2	46 6
	875	....	13.5	32.8	73.5	9.7	22.4	36.9	62.5	20 1	28.7	38 6	59 4
	695	.....	13.5	32.8	73.5	12 2	24 9	39.5	70 3	34.9	43.5	53.3	74.3
	580	.....	16.8	36.1	76.8	9 8	22 5	37 1	67.9	25.4	34 0	43 9	64.9
200	1760	....	4 6	30.1	84.0	... .	10.2	29 5	70.2	10 9	22.2	35.3	62.8
	1170	.....	.....	25.0	78.0	....	10.1	29 0	69.1	10.7	21 8	34.5	61 5
	880	....	9 1	34.6	88 5	.....	16 7	35 8	76.2	13.0	24.2	37.1	64.3
	700	....	22.2	47.7	102.0	16.2	32.9	52.2	93.0	46.1	57.3	70.4	98.0
	585	4 3	26.5	52.0	106.0	19.3	35.9	55.0	95.4	33.5	44.8	57.8	85.6

TABLE XXXII

APPROXIMATE KV-A. IN CAPACITORS NEEDED TO IMPROVE THE POWER FACTOR OF CONTANT- AND ADJUSTABLE-VARYING-SPEED, 3-PHASE, 60-CYCLE, *Wound-Rotor* INDUCTION MOTORS, *2200* VOLTS

Hp	Full-Load R P M.	Full Load				3/4 Load				1/2 Load			
		85%	90%	95%	100%	85%	90%	95%	100%	85%	90%	95%	100%
30	1155		2 9	7 0	15 7	1 8	4 5	7 6	14 2	5 5	7 3	9 5	14 0
	570	10 9	14 6	18 9	27 9	11 9	14 7	17 9	24 6	15 6	17 5	19 7	24 3
40	1735		2 4	7 7	19 0	0 68	4 2	8 2	16 8	4 7	7 1	9 8	15 7
	1155		2 9	8 3	19 7	3 4	6 9	10 9	19 5	6 2	8 6	11 4	17 3
	860	6 4	11 1	16 5	28 0	10 5	14 1	18 2	26 9	16 0	18 4	21 2	27 0
	685	7 4	12 2	17 6	29 3	9 8	13 4	17 6	26 3	13 6	16 1	18 9	24 9
	570	10 4	15 2	20 8	32 6	13 2	16 9	21 0	29 9	16 6	19 0	21 9	28 0
50	1735		2 3	8 9	22 8		4 4	9 4	19 9	4 0	7 0	10 4	17 6
	1155		2 4	9 0	23 1	0 85	5 3	10 3	21 0	5 9	8 9	12 4	19 8
	865	5 6	11 4	18 1	32 3	11 2	15 6	20 6	31 3	17 2	20 1	23 6	30 8
	685	8 0	13 9	20 6	35 0	12 2	16 6	21 7	32 4	16 0	19 1	22 5	29 8
	575	15 2	21 1	28 0	42 5	18 2	22 7	27 8	38 7	23 6	26 6	30 0	37 3
60	1750		6 8	14 6	31 2	5 0	10 1	16 0	28 6	9 8	13 3	17 4	26 1
	1160	. .	2 8	10 7	27 4	1 0	6 2	12 2	24 9	6 9	10 5	14 5	23 2
	860	..	7 0	15 1	32 1	3 1	8 3	14 4	27 2	9 2	12 8	16 9	25 6
	695	6 8	13 8	21 8	38 8	14 4	19 7	25 7	38 5	23 9	27 5	31 6	40 4
	580	10 8	17 8	25 9	42 9	14 5	19 8	25 9	38 7	20 6	24 4	28 3	36 9
75	1755	.	5 2	14 9	35 4	1 2	7 6	15 0	30 4	7 6	12 0	17 0	27 6
	1165		8 6	18 5	39 4	6 3	12 8	20 3	36 1	13 5	18 0	23 3	34 4
	870	1 7	10 3	20 3	41 2	8 8	15 3	22 8	38 7	17 3	21 8	27 0	37 9
	695	6 7	15 3	25 2	46 3	16 5	23 0	30 4	46 2	25 8	30 2	35 4	46 2
	580	16 9	25 6	35 5	56 6	23 5	30 0	37 6	53 4	30 9	35 4	20 4	51 2
100	1755	..	1 2	14 2	41 8	.	6 9	16 8	37 7	7 9	13.8	20 5	34 7
	1170	..	6 9	19 8	47 2	3.3	11 9	21 7	42 4	12 7	18 6	25 4	39 8
	875	2 2	13 7	26 9	54 8	8 3	17 0	26 9	47 9	18 6	24 4	31 2	45 5
	695	..	11 5	24 7	52 6	8 3	16 9	26 8	47 7	17 3	23 2	29 9	44 2
	575	6 7	18 2	31 4	59 4	15 1	23 8	33 8	55 0	23 1	29 1	35 9	50 6
125	1755	..	1 5	17 7	51 8	. ..	8 6	20 8	46.6	9 9	17 3	25 8	43 7
	1170	..	8 6	24 8	58 9	4.1	14 7	26 8	52 4	15 3	22 5	30 7	48 1
	880	..	10 1	26 4	60 9	6 2	16 9	29 2	55 2	21 4	28 7	37 0	54 7
	700	..	8 7	25 0	59 5	4 1	14 8	27 1	53.1	15 7	23 0	31.4	49.2
	580	8 3	22 6	39 1	74 0	18 7	29 6	42 0	68 2	28 1	35 4	43 8	61.7
150	1755	....	...	19 3	60 1	....	6 4	20 9	51 5	8 3	16 9	26 8	47 7
	1165	. .	3 4	22 6	63 0	.....	7 6	22 0	52 4	8 2	16 7	26 4	47 1
	880	. .	10 2	29 5	70 2	7 3	20 0	34 6	65 5	25 4	34 0	43 9	64 9
	700	.	10 2	29 5	70 2	4.9	17 4	31 8	62 2	20 0	28 6	38 4	59 1
	575	9 9	27 1	46 8	88.7	19 8	32.6	47.3	78.6	33 5	42 3	52 4	73 7
200	1760	...	....	25.7	79.9	.....	8 6	27 9	68.7	11 0	22 5	35.7	63 6
	1170	.	2 3	27.7	81 3	.....	6.8	26 0	66 4	10 7	22 0	34.9	62 2
	880	...	13 5	39 0	92 8	9.7	26.5	45 8	86.6	33 5	44 8	57.9	85 5
	705	. .	13 5	39 0	92.8	9 7	26.5	45.8	86 6	26.8	38 3	51 5	79.3
	580	13 0	35 5	61 3	116.0	26 1	43 1	62.5	103.6	44 0	55.5	68.7	96 6

TABLE XXXIII

WIRE, SWITCH AND FUSE SIZES FOR 230-VOLT CAPACITORS

Kv-A.	2-Phase, 4-Wire *				3-Phase			
	Amp	Wire	Switch	Fuses	Amp.	Wire	Switch	Fuses
5	11	No 12	30-a.	20-a.	13	No. 10	30-a.	20-a.
10	22	8	60	35	25	6	60	40
15	33	6	60	50	38	4	60	60
20	44	4	100	70	50	2	100	75
25	54	2	100	80	63	1	100	95
30	65	1	100	100	75	0	200	120
35	76	0	200	120	88	00	200	150
40	87	00	200	150	100	00	200	150
45	98	00	200	150	113	000	200	175
50	109	000	200	175	126	200,000	200	200
55	120	200,000	200	200	138	0000	400	225
60	130	200,000	200	200	151	250,000	400	225
65	141	0000	400	225	163	250,000	400	250
70	152	250,000	400	225	176	300,000	400	275
75	163	250,000	400	250	188	350,000	400	300
80	174	300,000	400	275	201	350,000	400	300
85	185	350,000	400	275	214	400,000	400	325
90	196	350,000	400	300	226	500,000	400	350
95	206	400,000	400	325	239	500,000	400	375
100	217	400,000	400	325	251	500,000	400	375

* Current in common conductor of 3-wire circuit = 1 41 times values given.

TABLE XXXIV

Wire, Switch and Fuse Sizes for 460-Volt Capacitors

Kv-A.	2-Phase, 4-Wire *				3-Phase			
	Amp.	Wire	Switch	Fuses	Amp.	Wire	Switch	Fuses
5	5	No. 12	30-a.	8-a.	6	No. 12	30-a.	10-a.
10	11	12	30	20	13	12	30	20
15	16	10	30	25	19	8	30	30
20	22	8	60	35	25	6	60	40
25	27	6	60	40	31	6	60	50
30	33	6	60	50	38	4	60	60
35	38	4	60	60	44	4	100	70
40	43	4	100	65	50	2	100	75
45	49	2	100	75	57	2	100	85
50	54	2	100	80	63	1	100	95
55	60	2	100	90	69	0	200	110
60	65	1	100	100	75	0	200	120
65	71	0	200	110	82	0	200	125
70	76	0	200	120	88	00	200	150
75	82	0	200	125	94	00	200	150
80	87	00	200	150	101	000	200	150
85	92	00	200	150	107	000	200	175
90	98	00	200	150	113	000	200	175
95	103	000	200	150	119	200,000	200	200
100	109	000	200	175	126	200,000	200	200

* Current in common conductor of 3-wire circuit = 1.41 times values given.

TABLE XXXV

WIRE AND FUSE SIZES FOR 2300/4000-VOLT CAPACITORS

Kv-A.	2-Phase, 2300-Volt 4-Wire			2-Phase, 2300-Volt 3-Wire Common Conductor			3-Phase 2300-Volt			3-Phase, 4000-Volt		
	Amp.	Fuses (amp	Wire No	Amp	Fuses (amp)	Wire No	Amp.	Fuses (amp)	Wire No.	Amp.	Fuses 'amp)	Wire No.
20	4	10	8	6	10	8	5	10	8	3	5	8
30	7	15	8	9	15	8	8	15	8	4	10	8
40	9	15	8	12	20	8	10	15	8	6	10	8
50	11	20	8	15	25	8	13	20	8	7	15	8
60	13	20	8	18	30	8	15	25	8	9	15	8
70	15	25	8	21	40	8	18	30	8	10	15	8
80	17	25	8	25	40	6	20	30	8	12	20	8
90	20	30	8	28	50	6	23	40	6	13	20	8
100	22	40	8	31	50	6	25	40	6	15	25	8
110	24	40	6	34	60	4	28	50	6	16	25	8
120	26	40	6	37	60	4	30	50	6	17	30	8
130	28	50	6	40	60	4	33	50	6	19	30	8
140	30	50	6	43	75	4	35	60	4	20	30	8
150	33	50	6	46	75	4	38	60	4	22	40	8
160	35	60	4	49	75	2	40	60	4	23	40	6
170	37	60	4	52	100	2	43	75	4	25	40	6
180	39	60	4	55	100	2	45	75	4	26	40	6
190	41	75	4	58	100	2	48	75	2	28	50	6
200	43	75	4	61	100	1	50	75	2	29	50	6
210	46	75	4	64	100	1	53	100	2	30	50	6
220	48	75	2	67	100	1	55	100	2	32	50	6
230	50	75	2	71	125	0	58	100	2	33	50	6
240	52	100	2	74	125	0	60	100	1	35	75	4
250	54	100	2	77	125	0	63	100	1	36	75	4

Expulsion-type primary cutouts, only, may be used wherever the capacitors are to be in constant service. Where the capacitor service will be intermittent or where required by the Underwriters, a non-automatic oil switch should be used in conjunction with the expulsion-type cutouts. In every case it will be necessary to consult the utility to learn what the short-circuit capacity of the equipment should be. Also consult utility about connections of 4000-volt equipment. Fuses are not required but may be used in the common conductor of a 2-phase, 3-wire circuit.

TABLE XXXVI

ALLOWABLE CARRYING CAPACITY OF CONDUCTORS*

Gage No.	Area in Circular Mils	Rubber Insulation, Amperes	Varnished Cambric Insulation, Amperes	Other Insulation and Bare Conductors, Amperes
14	4,107	15	18	20
12	6,530	20	25	30
10	10,380	25	30	35
8	16,510	35	40	50
6	26,250	50	60	70
5	33,100	55	65	80
4	41,740	70	85	90
3	52,630	80	95	100
2	66,370	90	110	125
1	83,690	100	120	150
0	105,500	125	150	200
00	133,100	150	180	225
000	167,800	175	210	275
	200,000	200	240	300
0000	211,600	225	270	325
	250,000	250	300	350
	300,000	275	330	400
	350,000	300	360	450
	400,000	325	390	500
	500,000	400	480	600
	600,000	450	540	680
	700,000	500	600	760
	750,000	525	630	800
	800,000	550	660	840
	900,000	600	720	920
	1,000,000	650	780	1000
	1,100,000	690	830	1080
	1,200,000	730	880	1150
	1,300,000	770	920	1220
	1,400,000	810	970	1290
	1,500,000	850	1020	1360
	1,600,000	890	1070	1430
	1,700,000	930	1120	1490
	1,800,000	970	1160	1550
	1,900,000	1010	1210	1610
	2,000,000	1050	1260	1670

1 mil = 0.001 inch

* For copper wires and cables of 98 per cent conductivity. For aluminum conductors the capacities are 84 per cent of those given.

TABLE XXXVII

Number of Conductors in Conduit or Tubing

Size of Conductor	Number of Conductors in One Conduit or Tubing					
	1	2	3	4	5	6
No. 14	½	½	½	½	¾	¾
12	½	½	½	¾	¾	1
10	½	¾	¾	¾	1	1
8	½	¾	1	1	1¼	1¼
6	½	1	1¼*	1¼	1½	1½
5	¾	1¼	1¼	1¼	1½	2
4	¾	1¼	1¼	1½	2	2
3	¾	1¼	1¼	1½	2	2
2	¾	1¼	1½	1½	2	2
1	¾	1½	1½	2	2	2½
0	1	1½	2	2	2½	2½
00	1	2	2	2½	2½	3
000	1	2	2	2½	3	3
0000	1¼	2	2½	2½	3	3
200,000 C.M	1¼	2	2½	2½	3	3
250,000	1¼	2½	2½	3	3	3½
300,000	1¼	2½	3	3	3½	3½
350,000	1¼	2½	3	3½	3½	4
400,000	1¼	3	3	3½	4	4
500,000	1½	3	3	3½	4	4½
600,000	2	3	3½	4	4½	5
700,000	2	3½	3½	4½		
750,000	2	3½	3½	4½		
800,000	2	3½	4	4½		
900,000	2	3½	4	4½		
1,000,000	2	4	4	5		
1,100,000	2½	4	4½	6		
1,200,000	2½	4½	4½	6		
1,300,000	2½	4½	5	6		
1,400,000	2½	4½	5	6		
1,500,000	2½	4½	5	6		
1,600,000	2½	5	5	6		
1,700,000	3	5	5	6		
1,800,000	3	5	6	6		
1,900,000	3	5	6			
2,000,000	3	5	6			

* Where a run of conduit or tubing does not exceed 50 ft and does not contain more than the equivalent of two quarter-bends from end to end, three No. 6 stranded conductors may be installed in 1-in. conduit.

CHAPTER V

PROBLEMS AND THEIR SOLUTION

The solutions of problems typical of those encountered in considering the application of equipment for improvement of power factor are here offered as a guide to the solution of similar problems. The following index is intended to increase their availability.

Problem	Description
1	Capacity required to improve power factor of load
2	Capacity required to improve average power factor of load with secondary metering
3	Capacity required to improve average power factor of load with primary metering
4	Capacity required to improve power factor of miscellaneous power-factor load
5	Substitution of synchronous for induction motor
6	Addition of 0.80 leading-power-factor synchronous motor to plant load
7	Improve power factor and add as much motor load as possible without increasing kv-a. load
8	Operating a synchronous motor as such and as a condenser
9	Grouping of circuits to obtain approximately equal loads and power factors
10	Proportion of synchronous-motor load to be unity and 0.80 leading power factor to produce required plant power factor
11	Effect of adding to an inductive load (*a*) more inductive load, (*b*) unity-power-factor synchronous motor, (*c*) 0.80-power-factor synchronous motor; and (*d*) operating synchronous motor as a condenser.

Problem 1. What size capacitor is required to improve the power factor of a 200-kw. load from 0.70 to 0.90?

$$\begin{aligned} \text{Tan } 70\% &= 1.0202 \text{ (from Table II, page 5)} \\ \text{Tan } 90\% &= \underline{0.4843} \\ & \quad 0.5359 \times 200 \text{ kw.} = 107 \text{ kv-a.} \end{aligned}$$

Or the difference in tangents could have been obtained directly from Table III, page 7.

Problem 2. What size capacitor is required to improve the average power factor of a plant to 95 per cent if the monthly difference in the registration of the kilowatt-hour meter is 30,000 and the reactive kilovolt-ampere-hour meter 32,000? The electrical equipment operates 190 hours a month, and the metering is on the secondary side of the transformers.

$$\frac{32{,}000 \text{ rkv-a-hr.}}{30{,}000 \text{ kw-hr.}} = 1.0660$$
$$\text{Tan } 95\% = \underline{0.3287}$$
$$0.7373 \times 30{,}000 \text{ kw-hr.} = 22{,}100 \text{ rkv-a-hr. to be eliminated}$$
$$\frac{22{,}100}{190} = 117 \text{ kv-a.}$$

Problem 3. What size capacitor would have been required in Problem 2 had the metering been on the primary side of three 75-kv-a. transformers?

From Table XVI, page 52, the magnetizing current of a 75-kv-a. transformer is found to be 3.41 rkv-a.

$$3 \times 3.41 = 10\ 23 \text{ rkv-a.} \times 720 \text{ hr. per mo.} = 7370 \text{ rkv-a-hr.}$$

22,100 rkv-a-hr. to be eliminated
7,370 rkv-a-hr. transformers (at no load)

14,730 rkv-a-hr. motors*

$$\frac{14{,}730}{190} = 77.6 + 10.23 = 88 \text{ kv-a. total}$$

* In reality, motors and loaded transformers.

Problem 4. What size capacitor is required to improve the power factor to 0.90 lagging of a load now consisting of 220 kw. at 0.55 lagging power factor, to which will be added 80 kw. at unity power factor and 40 kw. at 0.80 leading power factor?

Tan 55% = 1.5185 ×	220 kw.	=	334 rkv-a.
	80 kw.		0 rkv-a.
Tan 80% = 0.7500 ×	40 kw.	= −	30 rkv-a.
	340 kw.		304 rkv-a.

$$\frac{304}{340} = 0.8950 = 74.5\% \text{ power factor}$$
$$\text{Tan } 90\% = \underline{0.4843}$$
$$0.4107 \times 340 \text{ kw.} = 140 \text{ kv-a.}$$

Problem 5. A plant has a load of 75 kw. at 70 per cent power factor. If a 25 hp., 1160-r.p.m. squirrel-cage induction motor driving an air compressor, and having an average load of 50 percent, is replaced by a unity-power-factor synchronous motor, what would be the power factor?

From Table VII, page 24, it is seen that the operating characteristics of the present motor are:

% power factor.... 75
Kw. input......... 10.8

The rkv-a. would be:

$$\text{Tan } 75\% = 0.8819 \times 10.8 = 9.5$$

From Fig. 7, page 42, it is seen that the synchronous motor would supply 0.24 × 25 = 6 leading rkv-a. Changing motors would, therefore, reduce the plant reactance by 9.5 + 6 = 15.5 rkv-a.

The original reactance was: tan 70% = 1.0202 × 75 kw. = 76.7. The new reactance would be 76.7 − 15.5 = 61.2. The new power factor 61.2/75 = 0.817 = 77.4%. If the reactance is metered, the reduction in monthly reactive kilovolt-ampere-hours will be 15.5 × number of hours per month the motor operates.

Problem 6. What will be the resultant power factor if 200 kw. at 0.80 leading power factor is added to a 750-kw. load at 0.70 lagging power factor?

$$\begin{aligned} \text{Tan } 70\% &= 1.0202 \times 750 \text{ kw.} = 765 \text{ rkv-a.} \\ \text{Tan } 80\% &= 0.7500 \times 200 \text{ kw.} = -150 \text{ rkv-a.} \\ &\qquad\qquad\quad 950 \text{ kw.} \qquad 615 \text{ rkv-a.} \end{aligned}$$

$$\frac{615}{950} = 0.648 = 83.9\% \text{ lagging power factor}$$

Problem 7. How much load at what leading power factor can be added, without increasing the kilovolt-amperes to a circuit carrying 500 kw. at 0.66 lagging power factor, the combined load to have a power factor of 90 per cent?

$$\frac{500 \text{ kw.}}{0.66} = 758 \text{ kv-a.}$$

$$\begin{aligned} \text{Tan } 66\% &= 1.1383 \times 500 \text{ kw.} = 569 \text{ rkv-a.} \\ \text{Future kw.} &= 0.9 \times 758 \text{ kv-a.} = 682 \\ \text{Future rkv-a.} &= \tan 90\% = 0.4843 \times 682 \text{ kw.} = 330 \\ 569 - 330 &= 269 \text{ leading rkv-a. to be supplied} \\ 682 - 500 &= 182 \text{ kw.} \end{aligned}$$

$$\frac{269}{182} = 1.477 = 56.1\% \text{ leading power factor}$$

Therefore 182 kw. at 56.1 per cent leading power factor can be added without increasing the amperage of the circuit, and the power factor of the combined load will be 90 per cent.

Problem 8. What is the day and night power factor of a plant-circuit load consisting of 400 kw. at 0.66 lagging power factor and a 250-hp., 0.80-leading-power-factor synchronous motor which is operated at full load during the day and as a condenser at night? Its kilowatt input as a motor is 205; as a condenser 10.

From the graph, Fig. 7, page 42, it is seen that the leading reactive kilovolt-amperes supplied by the synchronous motor at full load is 0.62 × 250 hp. = 155, and at no load 0.8 × 250 = 200.

Tan 66% = 1.1383 × 400 kw. = 456 rkv-a.

205	−155
605	301

$$\frac{301}{605} = 0.498 = 89.5\% \text{ p.f. during day}$$

400 kw.	456 rkv-a.
10	−200
410	256

$$\frac{256}{410} = 0.625 = 84.8\% \text{ p.f. during night}$$

Problem 9. A mill will have the following loads which must be grouped into three circuits as nearly equal as possible in kilowatts load and power factor:

Load	Power Factor	Load	Power Factor
500 kw.	0.93 lagging	275 kw.	0.75 lagging
325	0.72 "	325	0.87 "
250	1.0 "	200	0.74 "
200	0.92 leading	350	0.83 "

	Kw.	Tan	Rkv-a	Group
	500	0 3952	198	2
	325	0 9639	313	1
	250	0	0	3
	200	0 4260	−85	1
	275	0 8819	242	2
	325	0 5667	184	1
	200	0 9089	182	3
	350	0 6720	235	3
Total,	2425		1269	

$$\frac{2425 \text{ kw.}}{3} = 808 \qquad \frac{1269 \text{ rkv-a.}}{3} = 423$$

By comparison of kilowatts and reactive kilovolt-amperes, we arrive at the grouping given above and below.

Circuit	Kw.	Rkv-a.
1	325	313
	200	−85
	325	184
	850	412
2	500	198
	275	242
	775	440
3	250	0
	200	182
	350	235
	800	417

$$\frac{412}{850} = 0.485 = 90\% \text{ p.f.}$$

$$\frac{440}{775} = 0.568 = 87\% \text{ p.f.}$$

$$\frac{417}{800} = 0.522 = 88.6\% \text{ p.f.}$$

Problem 10. A plant is to have 330 kw. at 0.60 lagging power factor and 400 kw. in synchronous motors. What part of the synchronous-motor load should be 0.80 leading power factor to obtain an over-all power factor of 0.90 lagging?

Tan 60% = 1.3333 × 330 kw. = 440 rkv-a.
Tan 90% = 0.4843 × 730 kw. = 353 rkv-a.

Difference = 87 rkv-a.

Tan 80% = 0.7500

$$\frac{87}{0.75} = 116 \text{ kw.}$$

Problem 11. A load of 500 kw. at 0.75 power factor is to be supplemented by a 250-kw. load. What will be the respective power-factor results: (*a*) with an induction-motor addition at 0.90 lagging power factor; (*b*) with a synchronous-motor addition at unity power factor; (*c*) and with a synchronous-motor addition at 0.80 leading power factor? (*d*) What will be the effect of operating the 0.80-leading-power-factor synchronous motor as a condenser?

(*a*)

Tan 75% = 0.8819 × 500 kw. = 441 rkv-a.
Tan 90% = 0.4843 × 250 kw. = 121 rkv-a.

750 kw. 562 rkv-a.

$$\frac{562}{750} = 0.749 = 80\% \text{ power factor}$$

(*b*)

500 kw. 441 rkv-a.
250 kw. 0 rkv-a.

750 kw. 441 rkv-a.

$$\frac{441}{750} = 0.5875 = 86.2\% \text{ power factor}$$

(*c*)

500 kw. 441 rkv-a.
Tan 80% = 0.7500 × 250 kw. = − 188 rkv-a.

750 kw. 253 rkv-a.

$$\frac{253}{750} = 0.3375 = 94.7\% \text{ power factor}$$

(*d*) The kilowatt input of a synchronous motor without load is approximately 5 per cent of the full-load input. From Fig. 7, page 42, it is seen that the no-load, full-load reactive-kilovolt-ampere ratio is 80/62 = 1.29. Therefore, the leading reactive kilovolt-amperes supplied will be 188 × 1.29 = 242; the kilowatt input 0.05 × 250 = 12.5.

500.0 kw. 441 rkv-a.
12.5 kw. −242 rkv-a.

512.5 kw. 199 rkv-a.

$$\frac{199}{512.5} = 0.389 = 93.2\%$$

CHAPTER VI

INDUSTRIAL POWER-FACTOR STUDIES

In this chapter are given actual studies of power-factor improvement in several industrial plants to determine what savings could be made in purchasing electricity. They will serve to illustrate the most common utility rate structures and the procedure to be followed. Cost of installation has not been taken into consideration, the assumption being made that material costs would be negligible and that labor is available.

STUDY 1

The utility supplying this plant bills on monthly average power factor determined by registration of kilowatt-hour and reactive-kilovolt-ampere-hour meters ratcheted to prevent backward rotation. The metering is on the primary side of the transformers, and the energy blocking is partially dependent upon contract kilowatts.

The principal plant load consists of air-compressor motors near the service entrance.

Synopsis of Schedule Under Which Electricity is Purchased

Rate.

$130.00 for the first 50 kw., or fraction thereof, of the contract kilowatts.
2.60 per kw. for the next 50 kw. of the contract kilowatts.
1.60 per kw. for the next 100 kw. of the contract kilowatts.
1.40 per kw. for all additional kilowatts of the contract kilowatts.
The above charges entitle consumer to use 50 kw-hr. for each kilowatt of the contract kilowatts.
1.5 cents per kw-hr. for the next 50 kw-hr. per kw. of the contract kilowatts or for the next 5000 kw-hr., whichever is the greater.
1.0 cents per kw-hr. for the next 150 kw-hr. per kw. of the contract kilowatts but not more than 150,000 kw-hr.
0.8 cent per kw-hr. for the next 150 kw-hr. per kw. of the contract kilowatts but not more than 150,000 kw-hr.
0.6 cent per kw-hr. for all additional kilowatt-hours.

Contract Kilowatts. The contract kilowatts shall be the average kilowatts, corrected for power factor but not less than 70 per cent of the highest during any of the preceding 11 months.

Power Factor. Whenever the power factor during any month is greater than 85 per cent, the average kilowatts shall be decreased by $\frac{1}{2}$ per cent of itself for each whole

1 per cent by which the said power factor is greater than 85 per cent. In case the said power factor is less than 85 per cent, the said average kilowatts shall be similarly increased for each whole 1 per cent less than 85 per cent.

Billing Data.

Date	Contract Kw.	Average Kw.	P. F.	Kw-Hr	Rkv-A-Hr.	Cost
Jan. 21	95	81 6	51 8%	8,300	13,700	$322 25
Feb. 23	91	81 0	59 7	14,600	19,600	419 20
Mar. 23	89	79 8	61 2	13,000	16,800	390 80
Apr. 23	85	77 4	64 3	16,800	20,000	406 33
May 24	87	78 0	60 1	16,400	21,800	371 70
June 22	86	75 6	56 3	11,600	17,000	321 60
July 22	91	79 2	53 9	10,500	16,400	321 10
Aug. 23	92	83 4	63 6	18,500	22,500	403 20
Sept. 23	97	85 8	60 0	16,300	21,700	391 70
Oct. 22	107	94 8	58 1	14,200	19,900	386 45
Total ...	920	816 6	589 0	140,200	189,400	$3744 33
Average .	92	82 0	58 9	14,020	18,940	$ 374 43

Plant Operation. 44 hours per week × $4\frac{1}{3}$ weeks = 191 hours per month.

Transformer Reactance.

3 × 50 = 150 kv-a. = 7 rkv-a. × 720 hr. = 5040 rkv-a-hr. per month.

Capacitance Required.

For 97% average power factor:

Tan 97% = 0.2506 × 14,020 kw-hr. = 3510 rkv-a-hr. permissible

18,940 rkv-a-hr. total
 3,510 rkv-a-hr. permissible

15,430 rkv-a-hr. to be eliminated

15,430 rkv-a-hr.
 5,040 rkv-a-hr. at no load

10,390 rkv-a-hr. under load

$$\frac{10,390}{191} = 55 + 7 = 62 \text{ kv-a.}$$

Effect on Billing.

Date	Rkv-A-Hr.	Power Factor	Contract Kw.
Jan. 21	0	100 0%	75
Feb. 23	4100	96 3	76
Mar. 23	1300	99 5	74
Apr. 23	4500	96 6	73
May 24	6300	93 4	75
June 22	1500	99 2	70
July 22	900	99 6	73
Aug. 23	7000	93 5	80
Sept. 23	6200	93 5	82
Oct. 22	4400	95 5	90
Total		967 1	768
Average		96 7	76 8

Value of a Contract Kw.

1. Below 100:

$$\$2.60 - 0.50 = \$2.10$$

2. Above 100:

$$\$1.60 - 0.50 = \$1.10$$

Savings Effected.

1. *In Billing:*

Contract kw. for 10 mo. at 58.9% power factor = 920
" " " 10 " " 96.7% " " = 768

Difference = 152

Average = 15.2
12

For 12 months = 182.4

Of this 182 kw., 7 is above 100.

$1.10	$2.10	$367.50
7	175	7.70
$7.70	$367.50	$375.20 total

2. *In Transformer Losses:*

0.617 kw. × 3 = 1.851 total copper loss

The power factor of the plant load is:

18,940	rkv-a-hr. total
5,040	rkv-a-hr. transformers
13,900	rkv-a-hr. plant

14,020 kw-hr. × 0.98 × 13,730 kw-hr. plant

$$\frac{13{,}900}{13{,}730} = 1.011 = 70.3\%$$

The power factor of the plant load after 62 kv-a. of capacitors is installed will be:

15,700	rkv-a-hr.
11,830	rkv-a-hr. eliminated (62 × 191 hr.)
3,870	rkv-a-hr. remaining

$$\frac{3{,}870}{13{,}730} = 0.2815 = 96.3\%$$

The load carried before p-f. improvement $= \dfrac{82 \text{ kw.} \times .98}{0.703} = 114$ kv-a.

The load carried after p-f. improvement $= \dfrac{82 \text{ kw.} \times .98}{0.963} = 83$ "

The copper loss before p-f. improvement $= \left(\dfrac{114}{150}\right)^2 \times 1.851 = 1.070$ kw.

The copper loss after p-f. improvement $= \left(\dfrac{83}{150}\right)^2 \times 1.851 = 0.567$ "

Reduction = 0.503 "

Savings:

(a) In demand:	(b) In consumption:	(c) Total:
$2.10	0.503 kw.	$1.05
0.503	191 hr. per mo.	.96
$1.05 per mo.	96 kw-hr. per mo.	$2.01
	$0.01	12
	$0.96	$24.12 per yr.

3. *Total:*

$367.50	per yr. in billing
24.12	per yr. in transformer losses
$391.62	per yr.

Summary.

Improved average power factor	96.7%
Capacitance required (kv-a.)	62
Cost of capacitors (65 kv-a., 230-volt, rack-type)	$1160.00
Annual saving	$391.62
Saving equals investment in	3 yr.
Annual return on investment	33.7%

STUDY 2

The utility supplying this plant bills on monthly average power factor determined by registration of kilowatt-hour and reactive kilovolt-ampere-hour meters ratcheted to prevent reverse rotation. The metering is on the secondary side of the transformers, and the energy blocking does not depend on the billing demand.

Synopsis of Service Classification on Which Electricity is Purchased

Rate per Month:

Use of capacity charge:

$2.00 per kw. for the first 20 kw.
1.25 per kw. for all in excess of 20 kw.

Use of energy charge:

2.2 cents per kw-hr. for the first 2,500 kw-hr.
2.0 cents per kw-hr. for the next 2,500 kw-hr.
1.6 cents per kw-hr. for the next 5,000 kw-hr.
1.4 cents per kw-hr. for the next 10,000 kw-hr.
1.0 cents per kw-hr. for the next 50,000 kw-hr.

When measured, the use of capacity shall be the highest average number of kilowatts taken during any 15-minute period of the month increased or decreased in the ratio that 85 per cent bears to the power factor.

Billing Data.

Date	Billed Kw.	Meas. Kw.	P. F.	Kw-Hr.	Rkv-A-Hr.	Cost
Jan. 16....	89	70	67%	15,170	16,800	$406 63
Feb. 15....	98	78	68	13,370	14,400	392 68
Mar. 15....	99	78	67	12,370	13,700	379 93
Apr. 15....	104	82	67	17,080	18,900	452 12
May 17....	110	84	65	19,360	22,600	491 54
June 15...	105	80	65	16,290	19,100	442 31
July 16....	100	74	63	14,490	17,900	410 86
Aug. 16 .	104	76	62	12,460	15,800	387 44
Sept. 16 .	100	73	62	12,750	16,100	386 50
Oct. 15	111	86	66	15,490	17,700	438 61
Nov. 15 ...	100	78	66	14,090	16,100	405 26
Total .	1120	859	718	162,820	189,100	$4593 88
Average .	102	78	65 3	14,802	17,191	$ 417 63

Plant Operation.

$$\frac{14{,}802 \text{ kw-hr.}}{78 \text{ kw.}} = 190 \text{ hr. per mo. at peak, probably 217 hr. total}$$

Capacitance Required.

For 95 per cent average power factor:

Tan 95% = 0.3288 × 14,802 kw-hr. = 4870 rkv-a-hr. permissible

17,191 rkv-a-hr. total
4,870 rkv-a-hr. permissible

12,321 rkv-a-hr. to be eliminated

$$\frac{12{,}321}{217} = 57 \text{ kv-a.}$$

Effect on Billing.

Date	Rkv-A-Hr.	Power Factor	Billing Kw.
Jan. 16	4,500	95 9%	62
Feb. 15	2,100	98 8	67
Mar. 15	1,400	99 4	67
Apr. 15	6,600	93 3	75
May 17	10,300	88 3	81
June 15	6,800	92 3	74
July 16	5,600	93 3	67
Aug. 16	3,500	96 3	67
Sept. 16	3,800	95 8	65
Oct. 15	5,400	94 4	77
Nov. 15	3,800	96 6	69
Total		1054 4	771
Average		95 9	70

Saving Effected

Average billing demand at 65.3% average power factor = 102
Average billing demand at 95.9% average power factor = 70

Monthly difference = 32
12

Annual difference = 384

$1.25 = value of a billing kw.
384

$480.00 per year in billing
56.62 per year in power loss*

$536.62 per year total

* Assuming that the loss before improvement was 0.03 × 14,802 kw-hr., or 444 kw-hr., the reduction would be

$$\left(1 - \frac{65.3^2}{95.9^2}\right) 444 = 238 \text{ kw-hr.}$$

238/217 = 1.1 kw. × $1.25 = $1.38
238 kw-hr. × 0.014 = 3.33

$4.71 per mo.
12

$56.62 per yr.

Summary.

Improved average power factor	95.9%
Capacitance required (kv-a.)	57
Cost of capacitors (230-volt, box-type)	$971.00
Annual saving	$536.62
Saving equals investment in	1.8 yr.
Annual return on investment	55.3%

STUDY 3

The utility supplying this plant bills on monthly average power factor determined by registration of kilowatt-hour and unratcheted reactive-kilovolt-ampere-hour meters. Capacitors will therefore be in service for metering purposes 24 hours a day.

Excerpt from Rate on Which Electricity is Purchased

Power Factor Adjustment. When the power factor of the customer's load varies from 90 per cent lagging the bill as computed under the rate table shall be decreased 1 per cent for each 1 per cent that the actual power factor is in excess of the above standards and increased $\frac{1}{2}$ of 1 per cent for each 1 per cent that the actual power factor is below the above standards.

Billing Data.

Date	P. F.	Kw-Hr.	Rkv-A-Hr.	Bill	Additional P-F. Charge
4–5 to 5–7	83 1	13,600	9,100	$360.00	$12.24
6–6	88.2	10,300	5,500	294.00	2.65
7–8	80.9	4,400	3,190	176 00	7 92
8–7	68.2	2,800	3,000	144.00	15.90
9–6	81 7	3,400	2,400	156 00	2.50
10–8	86.5	10,000	5,801	288.00	4.90
11–6	89 4	14,000	7,000	368.00	1.10
12–6	85.4	19,000	11,580	468.00	10.76
1–6	84.5	19,600	12,400	480.00	13.44
2–4	79.5	28,600	21,800	660.00	34.32
3–5	81 6	25,400	18,000	596.00	25.03
4–6	84.3	22,400	14,300	536.00	15.01
Total....	......	....	......	$4526.00	$145.77

Capacitance Required for Unity Power Factor.

$$\frac{21{,}800 \text{ rkv-a-hr.}}{720 \text{ hr. per mo.}} = 30.3 \text{ kv-a.} \quad \text{(30 will be sufficient)}$$

Annual Savings.

1. By eliminating power-factor charge	$145.77
2. By reducing bill 10%	452.60
	$598.37

Summary.

Improved average power factor	100%
Capacitance required (kv-a.)	30
Cost of capacitors (230-volt, rack-type)	$530.00
Annual saving	$598.37
Saving equals investment in	11 mo.
Annual return on investment	113%

STUDY 4

The metering is on the secondary side of the transformers, although there are small transformers for lighting, making it advisable to have some capacitors on the line at all times. Energy charge is dependent on billing demand. This plant was billed at 75 per cent power factor determined by spot test. The utility then installed a ratcheted reactive-kilovolt-ampere-hour meter, and the monthly average power factor was found to be 70.3 per cent. Because the demand and usage varied only slightly, averages were used instead of computing the effect on each bill.

Synopsis of Service Classification on Which Electricity Is Purchased

Demand Charge:

First	10 kw. of billing demand	$25.00
Next	15 kw. of billing demand	@ $ 2.00 per kw.
Next	25 kw. of billing demand	@ $ 1.50 per kw.
Next	100 kw. of billing demand	@ $ 1.25 per kw.
All over	150 kw. of billing demand	@ $ 1.00 per kw.

Energy Charge:

First	40 hours' use of billing demand	@ 2.0¢ per kw-hr.
Next	60 hours' use of billing demand	@ 1.5¢ per kw-hr.
Next	100 hours' use of billing demand	@ 1.2¢ per kw-hr.
Next	100 hours' use of billing demand	@ 1.0¢ per kw-hr.
All over	300 hours' use of billing demand	@ 0.8¢ per kw-hr.

Power Factor and Billing Demand. The power factor of the customer's installation shall be determined from time to time at the option of the company by suitable instruments furnished by the company.

Whenever the power factor of the customer's installation is above or below 85 per cent lagging, the billing demand shall be determined in accordance with the formula:

$$\text{Billing demand} = \frac{\text{Measured demand} \times 85}{\text{Power factor in percentage as determined}}$$

Discount. Bills are gross at the foregoing rates. A discount of 1 per cent will be allowed on all bills if paid on or before the last day for payment as specified on bill.

Billing Data.

Month	Kw. Billed	Kw. Measured	Billed P.F.	Average P.F.	Kw-Hr	Rkv-A-Hr.	Amount
June	56 5	50 0	75	69 7	9,600	9,888	$241 64
July .	54 7	48 4	75	69 1	8,160	8,544	221 41
Aug.	56 5	50 0	75	68 1	12,096	12,192	268 53
Sept.	57 6	51 0	75	70 4	8,736	8,832	232 42
Oct.	58 5	51 8	75	71 4	10,752	10,560	257.74
Nov.	63 2	55 9	75	73 3	10,368	9,600	260 80
Total	347 0	307 1		422 0	59,712	59,616	$1482 54
Average	57 8	51 2	75	70 3	9,952	9,936	$ 247 09

Average Bill at 70.3 Per Cent Power Factor.

$$\text{Billing demand} = \frac{51.2 \times 85}{70.3} = 62 \text{ kw.}$$

10 kw.		=	$ 25.00
15 kw.	@ $2.00	=	30.00
25 kw.	@ 1.50	=	37.50
12 kw.	@ 1.25	=	15.00
2480 kw-hr.	@ 0.02	=	49.60
3720 kw-hr.	@ 0.015	=	55.80
3752 kw-hr.	@ 0.012	=	45.02
			$257.92
1% cash discount			2.58
			$255.34

Average Bill at 90 Per Cent Power Factor.

$$\text{Billing demand} = \frac{51.2 \times 85}{90} = 48 \text{ kw.}$$

10 kw.		=	$ 25.00
15 kw.	@ $2.00	=	30.00
23 kw	@ 1.50	=	34.50
1920 kw-hr.	@ 0.02	=	38.40
2880 kw-hr.	@ 0.015	=	43.20
4800 kw-hr.	@ 0.012	=	57.60
352 kw-hr.	@ 0.010	=	3.52
			$232.22
1% cash discount			2.32
			$229.90

Average Bill at 98 Per Cent Power Factor.

$$\text{Billing demand} = \frac{51.2 \times 85}{98} = 44 \text{ kw.}$$

10 kw.			=	$ 25.00
15 kw.	@	$2.00	=	30.00
19 kw.	@	1.50	=	28.50
1760 kw-hr.	@	0.02	=	35.20
2640 kw-hr.	@	0.015	=	39.60
4400 kw-hr.	@	0.012	=	52.80
1152 kw-hr.	@	0.010	=	11.52
				$222.62
1% cash discount				2.23
				$220.39

Savings Effected.

1. At 90% power factor:

   $255.34
   229.90
   ———
   $ 25.44 per month
   12
   ———
   $305.28 per year

2. At 98% power factor:

   $255.34
   220.39
   ———
   $ 34.95 per month
   12
   ———
   $419.40 per year

Capacitance Required.

1. For 90% power factor

   Tan 90% = 0.4843 × 9952 kw-hr. = 4820 rkv-a-hr. permissible
   9936 rkv-a-hr. total
   4820 rkv-a-hr. permissible
   ———
   5116 rkv-a-hr. to be eliminated
   From motor data 26 kv-a. will be required (kv-a. × hours per day)

2. For 98% power factor:

   Tan 98% = 0.2031 × 9952 = 2020 rkv-a-hr. permissible
   9936
   2020
   ———
   7916 rkv-a-hr. to be eliminated
   From motor data 41 kv-a. will be required (kv-a. × hours per day)

Distribution of Capacitors.

Hp.	R.P.M.	Application	Load Factor	Hours per Day	Kv-A.	
					90% P.F.	98% P.F.
15	1160	Filling Dep't	50	10	6	6
15	1160	Slitting "	66	9	5	7
15	1160	Gumming "	66	9		7
5	1160	Elevator	50	9		3
30	865	Calender	90	9	15	15
5	1160	Machine shop	65	9		3
					—	—
					26	41

If power factor is improved to 90 per cent, connect 5-kv-a. capacitor to line side of motor switch through a 30-amp. type C switch, having 10-amp. fuses.

If power factor is improved to 98 per cent, connect the 3-kv-a. capacitor nearer the metering point to the line side of the motor switch through a 30-amp. switch, having 6-amp. fuses.

Summary.

Improved average power factor	90%	98%
Capacitance required (kv-a.)	26	41
Cost of capacitors (460-volt, box-type)	$211.90	$334.15
Annual saving (copper losses not included)	$305.28	$419.40
Saving equals investment in	8 mo.	9.5 mo.
Annual return on investment	144%	125%

STUDY 5

In this instance the utility determines power factor by spot test, and 90 per cent is required to avoid having the measured demand increased for billing purposes in the ratio that 90 per cent bears to the power factor. No credit is given for power factors in excess of 90 per cent. The billing was based upon a rate having secondary metering, and, for economy, it was decided to purchase transformers and change to a rate having primary metering.

Synopsis of Rate.

Rate Table:

Capacity charge: Per kilowatt of billing demand per month:

$2.25 for any part of the first 50 kw.
1.30 for any part of the next 150 kw.
1.15 for the excess over 200 kw.

Energy charge: Per kilowatt-hour per month:

1 5¢ for any part of the first 5000 kw-hr.
0 8¢ for any part of the next 100 kw-hr. per kw. of billing demand
0 6¢ for any part of the next 200 kw-hr. per kw. of billing demand

Power-Factor Adjustment. Where the power factor is less than 90 per cent for an installation having a measured demand in excess of 50 kw., such demand shall be increased for billing purposes in the ratio that 90 per cent bears to the power factor.

Billing Data.

Date	Kw. Billed	Kw. Measured	P.F.	Kw-Hr.	Cost*
9–12 to 10–15	217	158 4	65 6%	31,400	$817 77
11–13	221	160.8	65 6	26,900	784.78
12–12	201	146 4	65 6	24,790	731 03
1–10	250	182 4	65 6	27,820	843.71
2–8	286	208.8	65.6	37,560	997.52
3–12	303	220 8	65 6	41,980	1065 58
4–11	313	228 0	65 6	44,030	1101.31
5–13	286	208 8	65 6	42,500	1040.47
6–12	270	196 8	65.6	36,490	959 02
7–12	207	151 2	65.6	29,450	786 16
8–13	214	156 0	65 6	30,060	804 87
9–12	254	184.8	65 6	31,250	885 49
Total.	3022	2203 2	.	404,230	$10,817.71
Average	252	184 0	. . . .	33,686	$901.48

* These amounts include $34 50 for rental of 69 sub-meters

Size of Required Transformers (2-phase).

$$\frac{184 \text{ kw.}}{0.656} = 281 \text{ kv-a., use two } 150 \text{ kv-a.}$$

Transformer Losses.

2 × 150 kv-a. = 300 kv-a. = 23 rkv-a. (Table XVIII, page 54.)
2 × 2.34 = 4.68 kw. (Table XIX, page 55.)

Power-Factor Test.

8–3	Power..............	112.4 kw.	217.2 rkv-a.	46.0% p.f.
	Light..............	68.3	9.6	99
		180.7	223.8	62.4

If no changes were made, future billing would be at this power factor.

Effect of Transformers on Power Factor.

180.7 kw.	223.8 rkv-a.
4.7	23
185.4	246.8

$$\frac{246.8}{185.4} = 1.331 = 60.1\% \text{ p.f.}$$

Capacitance Required.

$$\frac{246.8}{185.4} = 1.3310$$

$$\text{Tan } 90\% = 0.4843$$

$$0.8467 \times 185.4 \text{ kw.} = 160 \text{ kv-a.}$$

Value of a Billing Kw.

Above 200—$1.15 + 0.20 = $1.35
Below 200—$1.30 + 0.20 = $1.50

Saving Effected.

Average billing demand at 60.1% p.f. $= \dfrac{185.4 \times 90}{60.1} = 278$

Average billing demand at 90.0% p.f. = 185

Difference = 93

$1.35	$1.50	$105.30
78	15	22.50
$105.30	$22.50	$127.80 per month
		12
		$1533.60 per year

Summary.

Improved power factor	90%
Capacitance required (kv-a.)	160
Cost of capacitors (2300-volt, rack-type)	$1248
Annual saving	$1534
Saving equals investment in	10 mo.
Annual return on investment	123%

CHAPTER VII

CONDUCTOR LOSSES

POWER LOSS

In Transmission. Heat is developed in any conductor through which electricity flows, and the temperature of the conductor is raised thereby. Often the amount of heat developed is so small that it is not noticeable, but it is present nevertheless. The heat represents the loss due to the overcoming of the resistance by the current, is measured in watts, and is commonly referred to as the I^2R loss since it varies with the square of the amperage. Ninety-eight per cent hard-drawn copper wire at 70° F. has a resistance of 10.7 ohms per circular-mil-foot. The resistance of copper conductors per 1000 ft. is given in Table XXXIX, page 111.

Formulas. The power loss due to load, and the reduction in this loss effected by power-factor improvement, may be computed from the following formulas, in which:

d = length of line one way.
I = amperes, corresponding to phase of circuit.
I_1 = amperes, corresponding to phase of circuit, at original power factor.
I_2 = amperes, corresponding to phase of circuit, at improved power factor.
K_1 = 1 divided by the square of the original power factor. See Table XXXVIII, page 108.
K_2 = 1 divided by the square of the improved power factor. See Table XXXVIII, page 108.
kv = kilovolts between phase wires.
kw = kilowatts, corresponding to phase of circuit.
P = power loss, in kilowatts.
P_r = reduction in power loss, in kilowatts.
R = resistance in ohms per unit of length used.
R_c = resistance in ohms in common conductor per unit of length used.

R_o = resistance in ohms in outside conductor per unit of length used.

θ = power-factor angle.

TABLE XXXVIII

VALUES OF $\left(\frac{1}{PF}\right)^2$

P. F.	K	P. F.	K	P. F.	K
1.00	1.00	0.80	1.56	0.60	2.78
0.99	1.02	0.79	1.60	0.59	2.87
0.98	1.04	0.78	1.65	0.58	2.98
0.97	1.06	0.77	1.69	0.57	3.08
0.96	1.09	0.76	1.73	0.56	3.19
0.95	1.11	0.75	1.78	0.55	3.31
0.94	1.13	0.74	1.83	0.54	3.43
0.93	1.16	0.73	1.88	0.53	3.56
0.92	1.18	0.72	1.93	0.52	3.70
0.91	1.21	0.71	1.99	0.51	3.85
0.90	1.23	0.70	2.04	0.50	4.00
0.89	1.26	0.69	2.10	0.49	4.17
0.88	1.29	0.68	2.16	0.48	4.34
0.87	1.32	0.67	2.23	0.47	4.53
0.86	1.35	0.66	2.30	0.46	4.73
0.85	1.39	0.65	2.37	0.45	4.94
0.84	1.42	0.64	2.44	0.44	5.17
0.83	1.45	0.63	2.52	0.43	5.42
0.82	1.49	0.62	2.60	0.42	5.67
0.81	1.53	0.61	2.69	0.41	5.95

For single-phase, two-wire circuits:

$$P = \frac{I^2 \times R \times d}{500} \tag{6}$$

$$P = \frac{kw^2 \times R \times d}{500\ kv^2 \times \cos^2\theta} \tag{7}$$

$$P_r = \frac{(I_1^2 - I_2^2)R \times d}{500} \tag{8}$$

$$P_r = \frac{kw^2 \times R \times d(K_1 - K_2)}{500\ kv^2} \tag{9}$$

For two-phase, four-wire circuits:

$$P = \frac{I^2 \times R \times d}{250} \tag{10}$$

$$P = \frac{kw^2 \times R \times d}{1000\ kv^2 \times \cos^2 \theta} \tag{11}$$

$$P_r = \frac{(I_1^2 - I_2^2)R \times d}{250} \tag{12}$$

$$P_r = \frac{kw^2 \times R \times d(K_1 - K_2)}{1000\ kv^2} \tag{13}$$

For two-phase, three-wire circuits:

(*a*) When common conductor is larger than outside conductors:

$$P = \frac{2\ I^2(R_o + R_c)d}{1000} \tag{14}$$

$$P = \frac{kw^2(R_o + R_c)d}{2000\ kv^2 \times \cos^2 \theta} \tag{15}$$

$$P_r = \frac{2(I_1 - I_2)(R_o + R_c)d}{1000} \tag{16}$$

$$P_r = \frac{kw^2(R_o + R_c)(K_1 - K_2)d}{2000\ kv^2} \tag{17}$$

(*b*) When all wires are of the same size: Use formulas 10, 11, 12, and 13.

For three-phase circuits:

$$P = \frac{3\ I^2 \times R \times d}{1000} \tag{18}$$

$$P = \frac{kw^2 \times R \times d}{1000\ kv^2 \times \cos^2 \theta} \tag{19}$$

$$P_r = \frac{3(I_1^2 - I_2^2)Rd}{1000} \tag{20}$$

$$P_r = \frac{kw^2 \times R \times d(K_1 - K_2)}{1000\ kv^2} \tag{21}$$

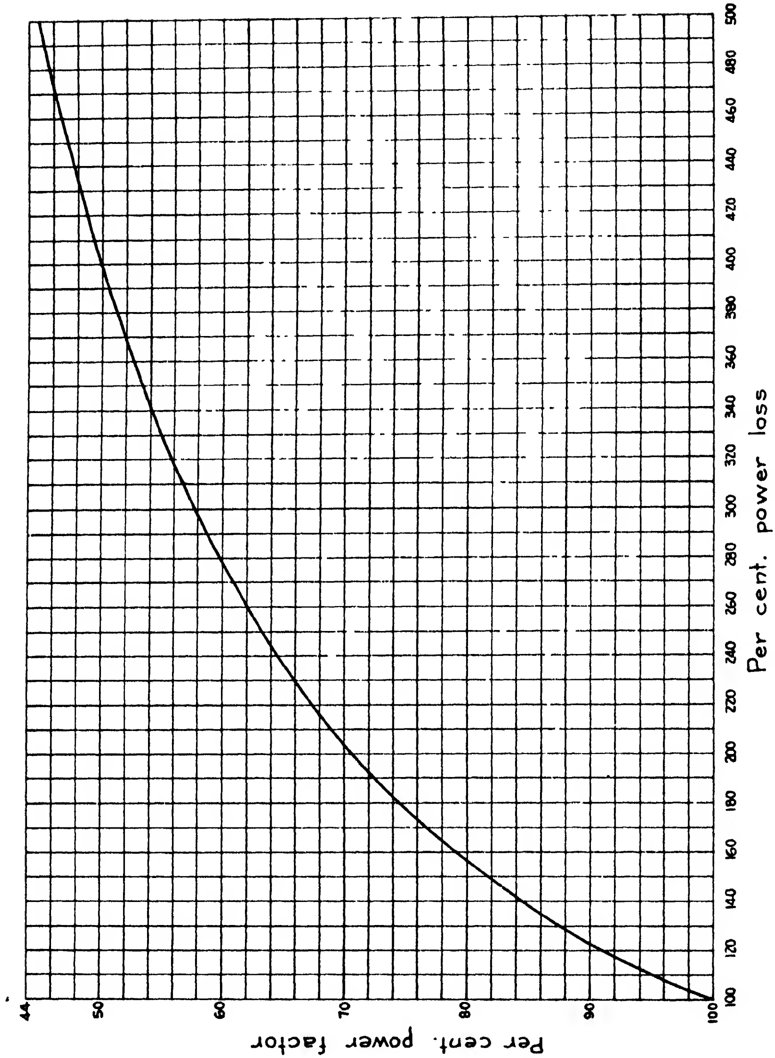

FIG. 23. Variation of Power Loss with Power Factor

TABLE XXXIX

Resistance and Reactance of Copper Conductors

Ohms per 1000 Ft. 60 Cycles

Gage No.†	Resistance (R)	Reactance (X)* Equivalent Spacing in Inches											
		1 2	1	2	3	4	5	6	8	10	12	18	24
14	2 67835	0688	0848	1008	1101	1167	1218	1260	1326	1377	1420	1512	1579
12	1 68453	0635	0795	0955	1048	1114	1165	1207	1273	1324	1366	1460	1525
10	1 05973	0582	0742	0902	0994	1060	1111	1153	1219	1270	1313	1406	1472
8	66626	0515	0674	0833	0926	0992	1043	1084	1150	1203	1243	1336	1402
6	41905	0462	0620	0780	0873	0939	0990	1031	1097	1149	1190	1283	1349
5	33233	0435	0594	0753	0846	0912	0963	1005	1071	1122	1163	1257	1323
4	26354	0409	0568	0726	0819	0886	0937	0978	1044	1096	1137	1230	1296
3	20901	0382	0541	0700	0793	0859	0910	0951	1017	1069	1110	1203	1269
2	16574	0356	0515	0673	0766	0832	0883	0925	0991	1042	1084	1177	1243
1	13144	0330	0488	0647	0740	0806	0857	0898	0964	1016	1057	1150	1216
0	10427		0464	0623	0716	0782	0833	0874	0940	0993	1033	1126	1192
00	08264		0437	0596	0689	0755	0806	0847	0913	0966	1006	1099	1165
000	06555	.	0411	0570	0663	0729	0780	0821	0887	0940	0980	1073	1139
0000	05198		0384	0543	0636	0702	0753	0794	0860	0913	0953	1048	1112
Circular Mils	(R)												
250,000	04400		0365	0524	0617	0683	0734	0775	0841	0894	0934	1027	1093
300,000	03667		0344	0503	0596	0662	0713	0754	0820	0873	0913	1006	1072
350,000	03143		0326	0485	0578	0644	0695	0736	0802	0853	0895	0988	1054
400,000	02750		0311	0470	0563	0629	0680	0721	0787	0840	.0880	0973	1039
500,000	02200	...	0286	0445	0538	0604	0655	0696	0762	0815	0855	0948	1014
600,000	01833	..		0435	0528	0591	0642	0685	0751	0802	0845	0935	1000
700,000	01571	.		0415	0508	0573	0625	0665	0731	0782	0825	0920	0985
800,000	01375	..		0400	0495	0560	0610	0650	0716	0767	0810	0905	0970
900,000	01222	.	.	0385	0480	0545	0595	0635	0701	0752	0795	0890	0955
1,000,000	01100		.	0377	0470	0534	0585	0628	0693	0746	0787	0881	0947

* The reactance at any other frequency than 60 cycles is $f/60$ times the table values.

† All wires larger than No. 8 are considered as being stranded.

The reactance X' at any spacing D' not given in the table is equal to the reactance X at the next smaller spacing D given in the table plus the quantity 0 053 ($\log_{10} D'/D$). Thus $X' = X + 0.053 (\log_{10} D'/D)$. Or the reactance in ohms to be added to that at the next smaller spacing may be taken from the table below.

D'/D $X+$	1.01 0.0002	1.02 0.0005	1 03 0 0007	1 04 0 0009	1 05 0 0011	1 06 0 0013	1 07 0 0016	1 08 0 0018	1 09 0 0020	1.10 0.0022
D'/D $X+$	1.11 0 0024	1.12 0 0026	1.13 0 0028	1 14 0 0030	1 15 0 0032	1 16 0 0034	1 17 0 0036	1 18 0.0038	1 19 0 0040	1.20 0 0042
D'/D $X+$	1 21 0.0044	1.22 0 0046	1 23 0 0048	1.24 0 0050	1 25 0 0051	1.28 0 0057	1 33 0 0066	1.42 0.0081	1 50 0 0093	

Example Using Formulas. Conditions: Load of 10 kw. at 0.6 power factor is improved to 0.9 power factor. The length of line, one way, is 200 ft., and the voltage at source is 230.

If circuit is single phase:

$$I_1 = \frac{10 \times 1000}{230 \times 0.6} = 72.5 \text{ amp.} \qquad I_2 = \frac{10 \times 1000}{230 \times 0.9} = 48.3 \text{ amp.}$$

No. 4 wire, R per 1000 ft. = 0.26354

If circuit is two-phase, four-wire:

$$I_1 = \frac{10 \times 1000}{2 \times 230 \times 0.6} = 36.2 \text{ amp.}$$

$$I_2 = \frac{10 \times 1000}{2 \times 230 \times 0.9} = 24.2 \text{ amp.}$$

No. 8 wire, R per 1000 ft. = 0.66626

If circuit is two-phase, three-wire:

$$I_1 = \frac{10 \times 1000}{2 \times 230 \times 0.6} = 36.2 \text{ amp.}$$

$$I_2 = \frac{10 \times 1000}{2 \times 230 \times 0.9} = 24.2 \text{ amp.}$$

$36.2 \times 1.41 = 51$ amp. in common conductor
Outside wire = No. 8, R per 1000 ft. = 0.66626
Common wire = No. 6, R per 1000 ft. = 0.419

If circuit is three-phase:

$$I_1 = \frac{10 \times 1000}{1.73 \times 230 \times 0.6} = 42 \text{ amp.}$$

$$I_2 = \frac{10 \times 1000}{1.73 \times 230 \times 0.9} = 28 \text{ amp.}$$

No. 6 wire, R per 1000 ft. = 0.419

Formula 8

$$\frac{(72.5^2 - 48.3^2) \times 0.26354 \times 0.2}{500} = 0.307 \text{ kw.}$$

Formula 9

$$\frac{10^2 + 0.26354 \times 0.2(2.78 - 1.23)}{500 \times 0.23^2} = 0.309 \text{ kw.}$$

Formula 12

$$\frac{(36.2^2 - 24.2^2)0.66626 \times 0.2}{250} = 0.386 \text{ kw.}$$

Formula 13

$$\frac{10^2 \times 0.66626 \times 0.2(2.78 - 1.23)}{1000 \times 0.23^2} = 0.37 \text{ kw.}$$

Formula 16

$$\frac{2(36.2 - 24.2)(0.66626 + 0.419)0.2}{1000} = 0.314 \text{ kw.}$$

Formula 17

$$\frac{10^2(0.66626 + 0.419)(2.78 - 1.23)0.2}{2000 \times 0.23^2} = 0.318 \text{ kw.}$$

Formula 20

$$\frac{3(42^2 - 28^2)0.419 \times 0.2}{1000} = 0.246 \text{ kw.}$$

Formula 21

$$\frac{10^2 \times 0.419 \times 0.2(2.78 - 1.23)}{1000 \times 0.23^2} = 0.246 \text{ kw.}$$

In Transformation. Transformers consist essentially of coils of wire wound around an iron core. Hysteresis and circulating currents induced in the core cause a loss, termed "core loss," "iron loss," or "no-load loss," which is practically constant regardless of the load carried but which increases rapidly if the rated voltage is exceeded. The passage of load current through the resistance of the windings causes a "copper loss" which varies as the square of the load carried (I^2R). These losses are given in Table XIX, page 55.

Reducing the load on transformers by improving the power factor of the load effects a saving in losses which is determined by subtracting the copper losses after improvement from the copper losses before improvement.

Example. If three 100 kv-a., 2300/230-volt single-phase transformers carry a three-phase load of 200 kw. at 70 per cent power factor, and the power factor is improved on the secondary side to 95 per cent, what will be the reduction in losses?

From Table XIX, page 55, the copper loss per transformer is found to be 1.20 kw. per transformer × 3 = 3.60 total copper loss.

The load carried before power-factor improvement is $\frac{200 \text{ kw.}}{0.70} = 286$ kv-a.

The load carried after power-factor improvement is $\frac{200 \text{ kw.}}{0.95} = 211$ kv-a.

The copper loss before power-factor improvement is $\left(\frac{286}{300}\right)^2 \times 3.6 = 3.27$ kw.

The copper loss after power-factor improvement is $\left(\frac{211}{300}\right)^2 \times 3.6 = 1.78$ kw.

3.27 kw.
1.78 kw.

Reduction in loss = 1.49 kw.

Approximation of Power Loss. To determine the reduction in power loss due to power-factor improvement in a whole plant, it would be necessary to know the size and length of every conductor affected, as well as the loads on each before and after improvement. Such a study may be unwarranted, but still some value of the reduction desired. In such instances the best procedure is to assume that the losses before improvement were a certain percentage of the kilowatt-hours used, and multiply the kilowatt-hours loss so determined by

$$\left(1 - \frac{\cos^2 \theta_1}{\cos^2 \theta_2}\right) \tag{22}$$

or

$$\left(1 - \frac{K_2}{K_1}\right) \tag{23}$$

In these formulas:

θ_1 = power-factor angle before improvement.
θ_2 = power-factor angle after improvement.
K_1 = 1 divided by the square of the original power factor, from Table XXXVIII, page 108.
K_2 = 1 divided by the square of the improved power factor, from Table XXXVIII, page 108.

The accuracy of the result will depend entirely on the correctness of the percentage assumed, and in making the assumption the method of improvement, original power factor, and the length of lines must be considered. Obviously, the loss from short lines is less than from long ones, so that the proportion of power loss to kilowatt-hours used would be less. The power loss in kilowatt-hours per month having been approximated, the reduction in demand may be determined by dividing the kilowatt-hours by the number of hours the plant operated.

Example. A plant operating 240 hours per month has a demand of 100 kw., a power factor of 60 per cent, and uses 20,000 kw-hr. Assuming that the power loss before power-factor improvement was 4 per cent of 20,000 kw-hr., or 800 kw-hr., the reduction in loss by improvement to 95 per cent would be

$$800\left(1 - \frac{0.60^2}{0.95^2}\right) = 480 \text{ kw-hr.}$$

or

$$800\left(1 - \frac{1.11}{2.78}\right) = 480 \text{ kw-hr.}$$

The reduction in demand would be

$$\frac{480 \text{ kw-hr.}}{240 \text{ hr.}} = 2 \text{ kw.}$$

Evaluation of Reduction in Power Loss. Reduction in power loss results in diminished electricity bills. The billing is usually divided into two parts, a capacity or demand charge, and an energy charge. If a kilowatt of billing demand is worth $1.50, a kilowatt-hour $0.01, and the reduction in loss is 5 kw. and 1000 kw-hr., the saving will be

5 kw.	×	$1.50	=	$ 7.50
1000 kw-hr.	×	0.01	=	10.00
		Total	=	$17.50

VOLTAGE DROP

The flow of current through wires is hindered by the resistance of the wires and the currents induced in each wire by the currents flowing through the wires near it. The latter is called inductive reactance, is designated X, and varies with the spacing of the conductors. The resistance, R, is constant regardless of spacing. The total resistance or reactance of a conductor is that per unit length multiplied by the length of the conductor.

The equivalent spacing of conductors is:

In a single-phase, two-wire circuit, the distance between centers of wires.

In a two-phase circuit of any number of wires, the distance between centers of wires of the same phase.

In a three-wire circuit, see Fig. 27, page 127.

The resistance and reactance of copper conductors per 1000 ft. is given in Table XXXIX, page 111. In using this table to compute voltage drop for small wires in a conduit, use $\frac{1}{2}$ in. equivalent spacing. Voltage drop is usually expressed in percentage of the voltage at the source of the circuit.

Formulas. The drop in voltage due to load, and the voltage rise effected by power-factor improvement, may be computed from the following formulas. The currents in polyphase circuits are assumed to be balanced. In the formulas:

ckv-a = capacitor kilovolt-amperes, corresponding to phase of circuit.

d = length of line one way.

E = volts between phase wires.

e = voltage drop, in percentage.
e_r = voltage rise, in percentage.
I = amperes, corresponding to phase of circuit.
I_1 = amperes, corresponding to phase of circuit, at original power factor.
I_2 = amperes, corresponding to phase of circuit, at improved power factor.
I_c = amperes in common conductor.
I_{c1} = amperes in common conductor at original power factor.
I_{c2} = amperes in common conductor at improved power factor.
I_o = amperes in outside conductor.
I_{o1} = amperes in outside conductor at original power factor.
I_{o2} = amperes in outside conductor at improved power factor.
kv = kilovolts between phase wires.
kw = kilowatts, corresponding to phase of circuit.
R = resistance in ohms per unit of length used.
R_c = resistance in ohms in common conductor per unit of length used.
R_o = resistance in ohms in outside conductor per unit of length used.
θ = power-factor angle.
θ_1 = original power-factor angle.
θ_2 = improved power-factor angle.
X = reactance in ohms per unit of length used.
X_c = reactance in ohms of common conductor per unit of length used.
X_o = reactance in ohms of outside conductor per unit of length used.

For single-phase, two-wire circuits:

$$e = \frac{200\, I(R \cos \theta + X \sin \theta)d}{E} \tag{24}$$

$$e_r = \frac{200\, d[I_1(R \cos \theta_1 + X \sin \theta_1) - I_2(R \cos \theta_2 + X \sin \theta_2)]}{E} \tag{25}$$

$$e_r = \frac{d \times X \times kw(\tan \theta_1 - \tan \theta_2)}{5\, kv^2} \tag{26}$$

$$e_r = \frac{d \times X \times ckv\text{-}a}{5\, kv^2} \tag{27}$$

For two-phase, four-wire circuits:

$$e = \frac{200\, I(R \cos \theta + X \sin \theta)d}{E} \tag{28}$$

$$e_r = \frac{200\, d\,[I_1(R \cos \theta_1 + X \sin \theta_1) - I_2\,(R \cos \theta_2 + X \sin \theta_2)]}{E} \tag{29}$$

$$e_r = \frac{d \times X \times kw(\tan \theta_1 - \tan \theta_2)}{10\, kv^2} \tag{30}$$

$$e_r = \frac{d \times X \times ckv\text{-}a}{10\, kv^2} \tag{31}$$

For two-phase, three-wire circuits:

(*a*) When common conductor is larger than outside conductors:

$$e = \frac{100\, d\, I_o[(R_o + R_c) \cos \theta + (X_o + X_c) \sin \theta]}{E} \tag{32}$$

$$e_r = \frac{\begin{cases} 100\, d\{I_{o1}[(R_o + R_c) \cos \theta_1 + (X_o + X_c) \sin \theta_1]\\ -I_{o2}[(R_o + R_c) \cos \theta_2 + (X_o + X_c) \sin \theta_2]\}\end{cases}}{E} \tag{33}$$

$$e_r = \frac{d(X_o + X_c)kw\,(\tan \theta_1 - \tan \theta_2)}{20\, kv^2} \tag{34}$$

$$e_r = \frac{d(X_o + X_c)ckv\text{-}a}{20\, kv^2} \tag{35}$$

(*b*) When all wires are of the same size: use formulas 28, 29, 30, and 31.

For three-phase circuits:

$$e = \frac{1.73 \times 100\, I(R \cos \theta + X \sin \theta)d}{E} \tag{36}$$

$$e_r = \frac{1.73\, d\,[I_1(R \cos \theta_1 + X \sin \theta_1) - I_2(R \cos \theta_2 + X \sin \theta_2)]}{E} \tag{37}$$

$$e_r = \frac{d \times X \times kw(\tan \theta_1 - \tan \theta_2)}{10\, kv^2} \tag{38}$$

$$e_r = \frac{d \times X \times ckv\text{-}a}{10\, kv^2} \tag{39}$$

Example Using Formulas. Conditions: Load of 10 kw. at 0.6 power factor is to be improved to 0.9 power factor. The length of line, one way, is 200 ft.; the voltage at source is 230; the wires are in conduit; and 8.5 kv-a. in capacitors is required.

$\cos\theta_1 = 0.6 \qquad \sin\theta_1 = 0.8$

$\cos\theta_2 = 0.9 \qquad \sin\theta_2 = 0.4358$

$\tan\theta_1 = 1.3333 \qquad \tan\theta_2 = 0.4843$

If circuit is single-phase:

$$I_1 = \frac{10 \times 1000}{230 \times 0.6} = 72.5 \text{ amp.}$$

$$I_2 = \frac{10 \times 1000}{230 \times 0.9} = 48.3 \text{ amp.}$$

No. 4 wire, R per 1000 ft. = 0.26354
X per 1000 ft. = 0.0409

If circuit is two-phase, four-wire:

$$I_1 = \frac{10 \times 1000}{2 \times 230 \times 0.6} = 36.2 \text{ amp.}$$

$$I_2 = \frac{10 \times 1000}{2 \times 230 \times 0.9} = 24.2 \text{ amp.}$$

No. 8 wire, R per 1000 ft. = 0.66626
X per 1000 ft. = 0.0515

If circuit is two-phase, three-wire:

$$I_{o1} = \frac{10 \times 1000}{2 \times 230 \times 0.6} = 36.2 \text{ amp.}$$

$$I_{o2} = \frac{10 \times 1000}{2 \times 230 \times 0.9} = 24.2 \text{ amp.}$$

$$I_{c1} = 1.41 \times 36.2 = 51 \text{ amp.}$$

$$I_{c2} = 1.41 \times 24.2 = 34.1 \text{ amp.}$$

Outside wires = No. 8, R per 1000 ft. = 0.66626
X per 1000 ft. = 0.0515

Center wire = No. 6, R per 1000 ft. = 0.419
X per 1000 ft. = 0.0462

If circuit is three-phase:

$$I_1 = \frac{10 \times 1000}{1.73 \times 230 \times 0.6} = 42 \text{ amp.}$$

$$I_2 = \frac{10 \times 1000}{1.73 \times 230 \times 0.9} = 28 \text{ amp.}$$

No. 6 wire, R per 1000 ft. = 0.419
X per 1000 ft. = 0.0462

Formula 25

$$\frac{\left\{\begin{matrix}200 \times 0.2\,[72.5(0.26354 \times 0.6 + 0.0409 \times 0.8) \\ -48.3(0.26354 \times 0.9 + 0.0409 \times 0.4358)]\end{matrix}\right\}}{230} = 0.2537$$

Formula 26

$$\frac{0.2 \times 0.0409 \times 10(1.3333 - 0.4843)}{5 \times 0.23^2} = 0.263$$

Formula 27

$$\frac{0.2 \times 0.0409 \times 8.5}{5 \times 0.23^2} = 0.263$$

Formula 29

$$\frac{\left\{\begin{matrix}200 \times 0.2\,[36.2(0.66626 \times 0.6 + 0.0515 \times 0.8) \\ -24.2(0.66626 \times 0.9 + 0.0515 \times 0.4358)]\end{matrix}\right\}}{230} = 0.167$$

Formula 30

$$\frac{0.2 \times 0.0515 \times 10(1.3333 - 0.4843)}{10 \times 0.23^2} = 0.166$$

Formula 31

$$\frac{0.2 \times 0.0515 \times 8.5}{10 \times 0.23^2} = 0.166$$

Formula 33

$$\frac{\left\{\begin{matrix}100 \times 0.2\{36.2\,[(0.66626 + 0.419)0.6 + (0.0515 + 0.0462)0.8] \\ -24.2\,[(0.66626 + 0.419)0.9 + (0.0515 + 0.0462)0.4358]\}\end{matrix}\right\}}{230} = 0.16$$

Formula 34

$$\frac{0.2(0.0515 + 0.0462)10(1.3333 - 0.4843)}{20 \times 0.23^2} = 0.16$$

Formula 35

$$\frac{0.2(0.0515 + 0.0462)8.5}{20 \times 0.23^2} = 0.16$$

Formula 37

$$\frac{\left\{\begin{matrix}1.73 \times 0.2\,[42(0.419 \times 0.6 + 0.0462 \times 0.8) \\ -28(0.419 \times 0.9 + 0.0462 \times 0.4358)]\end{matrix}\right\}}{230} = 0.15$$

Formula 38

$$\frac{0.2 \times 0.0462 \times 10(1.3333 - 0.4843)}{10 \times 0.23^2} = 0.15$$

Formula 39

$$\frac{0.2 \times 0.0462 \times 8.5}{10 \times 0.23^2} = 0.15$$

PART II

UTILITIES' DISTRIBUTION SYSTEMS

CHAPTER VIII

UTILITIES' DISTRIBUTION SYSTEMS

Present Conditions. The power factor of commercial and residential feeders has been reduced considerably during recent years by the increased use of small-motor-driven appliances such as refrigerators, air-conditioning and unit-heating apparatus, water pumps, oil-burners, and fans. The ever-growing number of gaseous signs with their essential transformers has also contributed to this condition. With power fac-

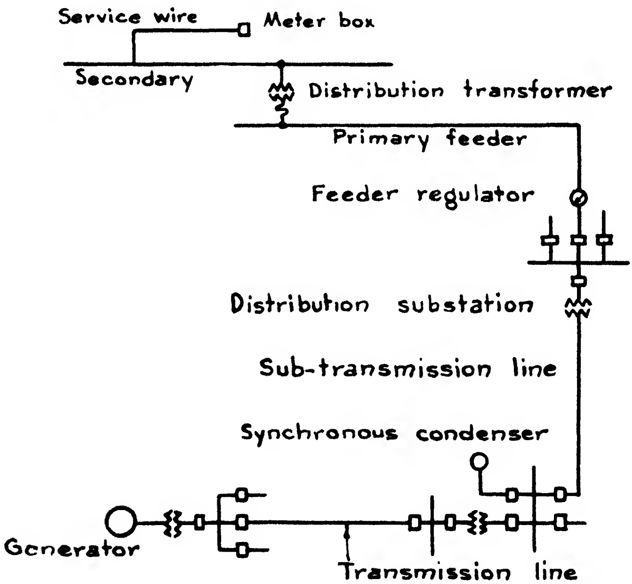

FIG. 24. Typical Power System

tors varying from 50 to 80 per cent, generation, transmission, and substation equipment has become fully loaded or overloaded, and the voltage drop on feeders has increased or become excessive.

A large percentage of the total system cost is invested in equipment whose rating is determined by heating, principally generators and transformers. If generators are operated at lower than rated power factor, their outputs are limited by the field. Improving the power factor up to the generator rating releases capacity faster than would be indicated by consideration of load current only, since a relatively large reduction in field current may be made with a small reduction in armature or load current.

Voltage drop is usually the limiting feature of the kilowatt carrying capacity of distribution feeders, and reactive current causes a greater drop than active or power current. A substantial share of the entire range of voltage-regulating equipment is consumed by compensation necessary for the voltage drop produced by reactive current.

Improvement of system power factor has for many years been accomplished by the use of large synchronous condensers at the subtransmission bus in the step-down substation, although the primary purpose of the condensers has been to control the transmission-line voltage. From the standpoint of decreasing reactive current on the system, this method is only partly effective, since the subtransmission and distribution systems are not helped. Synchronous condensers cannot be practically applied in small kilovolt-ampere ratings; therefore, they cannot be placed much closer to the load.

Use of Capacitors. Because capacitors are manufactured in small units, their losses are less than one-third of one per cent, and the maintenance required by them is negligible, they can be advantageously used if improvement on the distribution system is desired. Their proper application results in removal of reactive current from the entire system and generators, thereby liberating carrying capacity of generators, transformers, feeders, and regulators; reducing the losses in this equipment; decreasing the voltage drop and consequently increasing the revenue; and deferring expense of major system changes.

Losses are inversely proportional to the square of the power factor, so that, if the power factor is improved from 75 to 98 per cent, the losses will be reduced to 58 per cent of their original value. For any given circuit and power factor, 1 kv-a. of capacitor will improve the kilowatt carrying capacity a constant amount regardless of how high the power-factor improvement is taken. Therefore, as far as economic return is concerned, it is entirely practical to go to unity power factor.

The question then arises as to just where on the distribution system capacitors can be best applied. The possibilities are: on the secondary side of the distribution transformers, on the primary feeders, and at the distribution substation. Because conditions vary considerably, it is absolutely necessary to make studies of each specific case in order to evaluate the comparative economies properly.

The cost per kilovolt-ampere of capacitors varies with the voltage and kilovolt-ampere rating of the individual unit; therefore, the capacitor application offering the maximum savings may not produce the greatest over-all return on the investment. At present 2300- and 4000-volt individual pole-type capacitors cost least per kilovolt-ampere; 460- and 575-volt, about 11 per cent more; 4600- to 11,950-volt, approximately 24 per cent more; and 230-volt, 2.4 times as much.

Secondary Capacitors. Since the meter box is closest to the source of reactive current, it would seem the ideal location for capacitors. Theoretically, the next best place is the secondary side of the distribution transformers. Both applications are subject to the following operating limitations.

1. The size capacitors required to produce maximum benefits on the feeder may cause excessive overvoltages at times, owing to the wide diversity between feeder and transformer loading.

2. If, in order to avoid this condition, the size is reduced, there is a corresponding reduction in released feeder capacity at other times, and the released transformer capacity may likewise be lowered to an unimportant amount.

Secondary capacitors, in addition to releasing transformer capacity, effect a voltage rise through the transformers which augments that on the feeder, and is usually greater than the additional voltage rise obtainable on the secondary lines when capacitors are placed at their ends.

Despite the advantages over primary capacitors, the use of secondary capacitors, excluding industrial applications, will be relatively limited by their present costs, which in most cases substantially exceed their additional benefits.

Distribution Substation Capacitors. Capacitors installed at the distribution substation bus would be ahead of feeder regulators and, unless the bus itself is regulated, the substation would probably be subjected to excessive voltages at light loads. Therefore, such capacitors must usually be switched out of service during light-load periods; and this automatically controlled switching equipment greatly increases the cost per kilovolt-ampere of the installation.

If the feeders are unregulated, automatic bus-type capacitors may be used advantageously, not only to improve power factor, but also to provide voltage regulation. However, primary-feeder capacitors, especially on regulated lines, produce appreciably better results at lower cost.

Primary-Feeder Capacitors. These cost less than either secondary or bus-type and usually prove to be the most satisfactory type.

Determination of Capacitor Requirements. 1. *To reduce voltage drop a given amount.* The capacitor kilovolt-amperes for this purpose may be readily computed by using formula 44, page 128. Since one component of the denominator of this formula is distance, it is obvious that, as this item increases, the required capacitance decreases, and, therefore, the farther out on the line capacitors are placed, the smaller they need be. However, this saving in capacitor cost is obtained at the expense of energy losses, and is recommended only if energy losses have no value.

2. *To produce maximum benefits.* The capacitor kilovolt-amperes for this purpose should be equal to the average daily reactive load and should

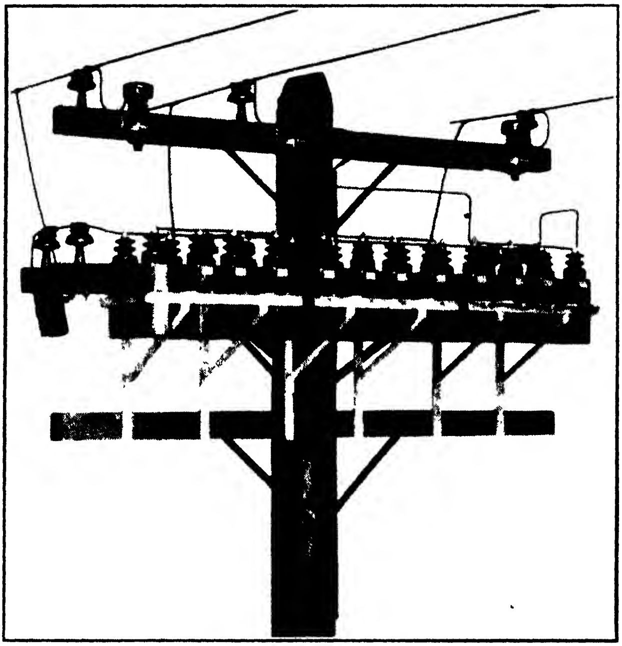

FIG. 25. Group of Individual Distribution Capacitors

(General Electric Co.)

be distributed along the feeder in proportion to this load. Since the load will vary, the improved power factor will also, but its average will be unity. This method will produce the maximum increase in kilowatt carrying capacity of the line and maximum reduction in energy losses.

Spacing of Conductors. For any three-phase arrangement of conductors, the equivalent spacing $D = \sqrt[3]{ABC}$. This resolves itself into $D = A$, B, or C for symmetrical triangular spacing and into $D = 1.26$ A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

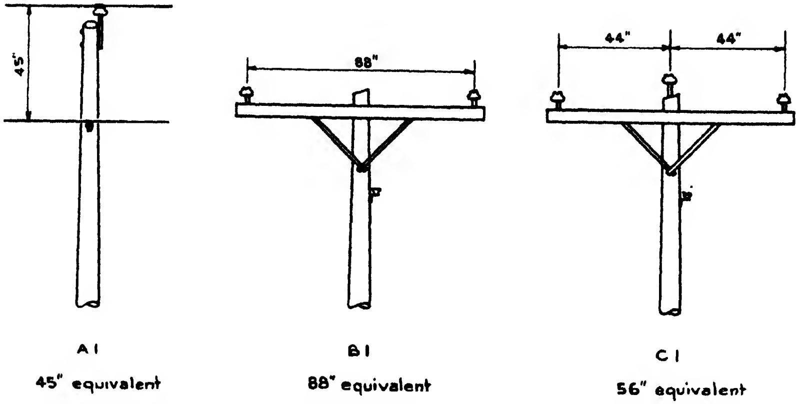

FIG. 26. Line Configurations Used by Rural Electrification Administration

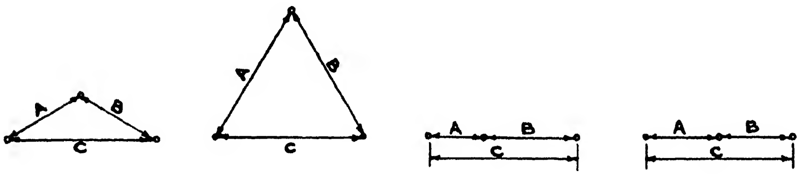

FIG. 27

Unsymmetrical Triangular Spacing	Symmetrical Triangular Spacing	Irregular Flat Spacing	Regular Flat Spacing

$D = 1.26$ A or 1.26 B

Formulas for Applying Shunt Capacitors.

d = length of line one way, in miles or thousands of feet.
e = voltage drop, in percentage.
e_r = voltage rise, in percentage.
kv = kilovolts between phase wires.
$kv\text{-}a$ = load corresponding to phase of circuit, in kilovolt-amperes.
$kv\text{-}a_1$ = load corresponding to phase of circuit, in kilovolt-amperes at original power factor.
$kv\text{-}a_2$ = load corresponding to phase of circuit, in kilovolt-amperes at improved power factor.
$ckv\text{-}a$ = capacitor kilovolt-amperes, corresponding to phase of circuit.
kw = kilowatts, corresponding to phase of circuit.
$kw\text{-}hr_1$ = kilowatt-hour consumption before voltage improvement.
R = resistance in ohms per unit of length used.
θ_1 = original power-factor angle.

θ_2 = improved power-factor angle.
V_1 = per cent voltage before power-factor improvement.
V_2 = per cent voltage after power-factor improvement.
X = reactance in ohms per unit of length used.

Voltage. The voltage drop, in percentage, caused by load is equal to

$$\text{3-phase circuits} \quad e = \frac{d \times kv\text{-}a\ (R \cos \theta_1 + X \sin \theta_1)}{10\ kv^2} \tag{40}$$

$$\text{1-phase circuits} \quad e = \frac{d \times kv\text{-}a\ (R \cos \theta_1 + X \sin \theta_1)}{5\ kv^2} \tag{41}$$

The voltage rise, in percentage, caused by capacitor application is equal to

$$\text{3-phase circuits} \quad e_r = \frac{d \times X \times ckv\text{-}a}{10\ kv^2} \tag{42}$$

$$\text{1-phase circuits} \quad e_r = \frac{d \times X \times ckv\text{-}a}{5\ kv^2} \tag{43}$$

The capacitor kilovolt-amperes, corresponding to phase of circuit, necessary to reduce voltage drop a given amount, or to produce a specified voltage rise, is equal to

$$\text{3-phase circuits} \quad ckv\text{-}a = \frac{e_r\ 10\ kv^2}{d \times X} \tag{44}$$

$$\text{1-phase circuits} \quad ckv\text{-}a = \frac{e_r\ 5\ kv^2}{d \times X} \tag{45}$$

Line Carrying Capacity. The kilowatt carrying capacity where voltage drop is the limiting factor is equal to

$$\text{3-phase circuits} \quad \frac{e \times 10\ kv^2}{d\ (R + X \tan \theta_1)} \tag{46}$$

$$\text{1-phase circuits} \quad \frac{e \times 5\ kv^2}{d\ (R + X \tan \theta_1)} \tag{47}$$

The kilowatt carrying capacity after the application of a capacitor is equal to

$$\text{3-phase circuits} \quad \frac{(e + e_r)\ 10\ kv^2}{d\ (R + X \tan \theta_1)} \tag{48}$$

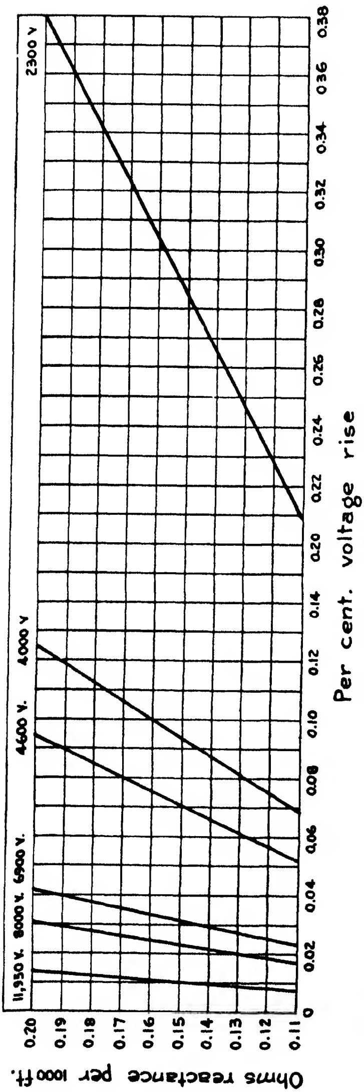

FIG. 28. Per Cent Voltage Rise (line to line) per 100 Capacitor Kv-a. per 1000 Feet of Three-phase Line
(General Electric Co.)

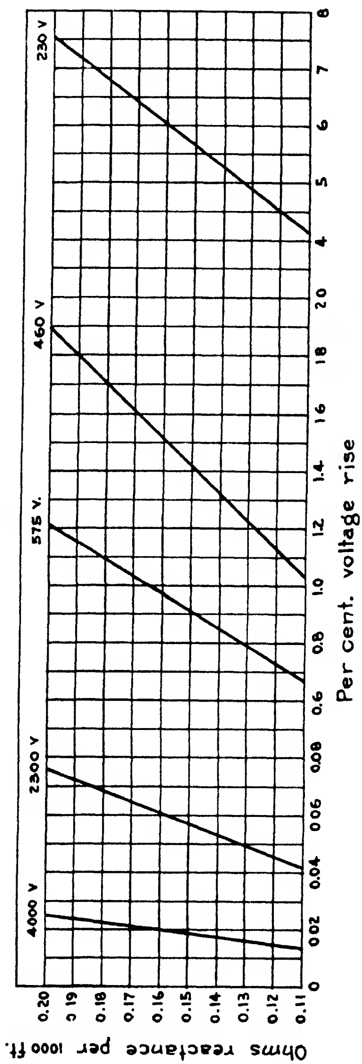

FIG. 29. Per Cent Voltage Rise (line to line) per 10 Capacitor Kv-a. per 1000 Feet of Single-phase Line

or

$$\frac{d \times X \times ckv\text{-}a + e \times 10\ kv^2}{d\ (R + X \tan \theta_1)} \tag{49}$$

1-phase circuits $$\frac{(e + e_r)\ 5\ kv^2}{d\ (R + X \tan \theta_1)} \tag{50}$$

or

$$\frac{d \times X \times ckv\text{-}a + e \times 5\ kv^2}{d\ (R + X \tan \theta_1)} \tag{51}$$

The kilowatt carrying capacity released by the application of a capacitor is equal to

1- or 3-phase circuits $$\frac{ckv\text{-}a}{R/X + \tan \theta_1} \tag{52}$$

The per cent kilowatt carrying capacity released by power-factor improvement is equal to

1- or 3-phase circuits $$\frac{100\ (\tan \theta_1 - \tan \theta_2)}{R/X + \tan \theta_1} \tag{53}$$

The ratio of capacitor kilovolt-amperes to kilowatts increase in carrying capacity is equal to

1- or 3-phase circuits $$R/X + \tan \theta_1 \tag{54}$$

Energy Losses. The formulas for voltage drop and carrying capacity were necessarily based on peak-load conditions. The quantities used in formulas for energy losses, however, must be based on the daily average load conditions. To obtain these conditions from charts, secure the r.m.s. value by extracting the square root of the average squared ordinate.

The energy losses after power-factor improvement, in percentage of losses before improvement, are equal to

1- or 3-phase circuits $$100 \left(\frac{\cos^2 \theta_1}{\cos^2 \theta_2}\right) \tag{55}$$

The percentage reduction in losses if the power factor is improved is equal to

1- or 3-phase circuits $$100 \left(1 - \frac{\cos^2 \theta_1}{\cos^2 \theta_2}\right) \tag{56}$$

The kilowatt line loss at any power factor, in percentage of kilowatts transmitted, is equal to

$$\text{3-phase circuits} \quad \frac{kv\text{-}a^2 \times R \times d}{10\, kv^2 \times kw} \tag{57}$$

$$\text{1-phase circuits} \quad \frac{kv\text{-}a^2 \times R \times d}{5\, kv^2 \times kw} \tag{58}$$

The ratio of capacitor kilovolt-amperes to the kilowatt reduction in losses is equal to

$$\text{3-phase circuits} \quad \frac{1000\, ckv\text{-}a \times kv^2}{R \times d\,(kv\text{-}a_1^2 - kv\text{-}a_2^2)} \tag{59}$$

$$\text{1-phase circuits} \quad \frac{500\, ckv\text{-}a \times kv^2}{R \times d\,(kv\text{-}a_1^2 - kv\text{-}a_2^2)} \tag{60}$$

Note: $kw\,(\tan\theta_1 - \tan\theta_2)$ may be substituted for $ckv\text{-}a$.

The annual kilowatt-hour reduction in losses due to power-factor improvement is equal to

$$\text{3-phase circuits} \quad \frac{8.76\,(kv\text{-}a_1^2 - kv\text{-}a_2^2)\, R \times d}{kv^2} \tag{61}$$

$$\text{1-phase circuits} \quad \frac{17.52\,(kv\text{-}a_1^2 - kv\text{-}a_2^2)\, R \times d}{kv^2} \tag{62}$$

Increase in Kv-a. Capacity. The additional load, in kilovolt-amperes, at original power factor, which may be added to the corrected kilovolt-amperes to give a total kilovolt-amperage equal to that before power-factor improvement, or the released thermal capacity, at the original power factor, where the limiting factor is kilovolt-ampere demand, such as at substations and generators, is equal to

1- or 3-phase circuits

$$kv\text{-}a\left(\frac{\sin\theta_1 \times ckv\text{-}a}{kv\text{-}a} - 1 + \sqrt{1 - \cos^2\theta_1 \times \frac{ckv\text{-}a^2}{kv\text{-}a^2}}\right) \tag{63}$$

The additional load which may be added, or the thermal capacity released, expressed in percentage of the kilovolt-amperes before power-factor improvement, is equal to

1- or 3-phase circuits

$$\frac{\sin\theta_1 \times ckv\text{-}a}{kv\text{-}a} - 1 + \sqrt{1 - \cos^2\theta_1 \times \frac{ckv\text{-}a^2}{kv\text{-}a^2}} \tag{64}$$

TABLE XL

Resistance and Reactance of Conductors

Ohms per 1000 ft.

Conductor	Resistance (R)	Reactance (X)* Equivalent Spacing in Inches										
		30	36	42	45	48	56	60	72	84	88	96
Solid copper												
No. 8	.6485	.1466	.1508	.1544	.1560	.1574	.1609	.1625	.1667	.1703	1713	.1733
6	4068	.1413	.1455	.1491	1507	.1521	.1556	1572	1614	.1649	.1659	1680
4	2566	.1360	.1402	1437	.1453	.1468	.1503	1519	.1561	.1596	.1606	1627
3	2034	.1334	.1375	.1411	1427	.1441	.1476	.1492	.1534	.1570	.1580	1600
Stranded copper												
No. 2	1644	.1294	.1335	.1371	.1387	.1401	.1436	.1453	.1495	1530	.1540	.1561
1	1304	.1267	.1309	.1345	.1361	.1375	.1410	1426	1468	1503	1513	.1534
0	1034	.1243	.1285	.1321	.1337	.1351	.1386	.1403	.1445	.1480	1490	.1510
2/0	0820	1216	.1258	.1294	1310	.1324	.1359	.1376	.1418	.1453	.1563	.1483
3/0	0650	.1190	.1232	1268	.1284	.1298	.1333	.1350	.1392	.1427	1437	.1457
4/0	0516	.1163	.1205	.1241	.1257	.1271	.1306	.1323	.1365	1400	.1410	.1430
A.C.S.R.†												
No. 4	4242	1383	1424	.1458	.1474	.1490	.1525	.1542	.1583	.1618	1628	.1650
3	.3371	.1362	.1403	.1438	.1454	.1470	1505	1521	1562	1597	.1607	.1629
2	2670	.1341	.1383	.1419	.1435	.1450	.1485	1500	1542	1578	.1588	.1608
1	2121	.1322	.1364	.1398	1414	.1428	.1463	1481	1523	1557	1567	.1587
0	1691	.1300	.1341	1377	.1393	.1407	.1442	1458	1502	1536	.1546	.1566
2/0	1360	.1280	1322	.1356	.1372	1388	1423	.1440	1481	.1515	1525	.1547
3/0	1097	.1260	.1301	.1337	.1353	1367	1402	1420	1460	1496	.1506	.1527
4/0	0879	.1241	.1282	1318	.1334	.1348	1383	1400	1441	.1477	.1487	.1508
Copper-weld-copper‡												
No. 2A	1641	142	.147	151	152	.153	.157	.158	163	166	167	.169
4A	2610	.148	.152	.156	157	.159	163	164	168	.171	.172	.175
6A	4150	.153	157	161	.162	.164	.168	.169	173	177	.178	.180
8A	6598	158	162	165	166	167	171	.172	.176	.180	.181	.183
3 No. 8	5383	158	.162	166	167	169	.173	.174	.178	.182	.183	.185
3 No. 10	8559	.163	167	.171	.172	174	.178	.179	.183	.187	.188	.190
3 No. 12	1.3610	169	173	177	178	179	183	185	189	.192	.193	.195

* The reactance at any other frequency than 60 cycles is $f/60$ times the table values.

The reactance X' at any spacing D' not given in the table is equal to the reactance X at the next smaller spacing D given in the table plus the quantity 0.053 ($\log_{10} D'/D$). Thus $X' = X + 0.053 (\log_{10} D'/D)$. Or the reactance in ohms to be added to that at the next smaller spacing may be taken from the table below.

D'/D	1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.08	1.09	1.10
$X+$	0.0002	0.0005	0.0007	0.0009	0 0011	0.0013	0.0016	0 0018	0.0020	0.0022
D'/D	1.11	1.12	1.13	1.14	1.15	1.16	1.17	1.18	1.19	1.20
$X+$	0 0024	0.0026	0.0028	0 0030	0.0032	0.0034	0.0036	0.0038	0.0040	0 0042
D'/D	1.21	1.22	1.23	1.24	1.25					
$X+$	0.0044	0 0046	0.0048	0.0050	0.0051					

† Single-layer conductors, current density 600 amp. per sq. in. Based on Aluminum Company of America data.

‡ Based on data supplied by Copperweld Steel Company; 40 per cent conductivity.

TABLE XLI

Resistance and Reactance of Conductors

Ohms per mile

Conductor	Resistance (*R*)	Reactance (*X*)* Equivalent Spacing in Inches 30	36	42	45	48	56	60	72	84	88	96
Solid copper												
No. 8	3 42	774	796	815	823	.831	850	858	880	.899	905	915
6	2 15	746	768	787	795	.803	822	830	852	871	877	.887
4	1 35	718	740	.759	.767	.775	.794	.802	824	843	.849	859
3	1 07	704	726	.745	.753	.761	780	.788	810	.829	.835	845
Stranded copper												
No. 2	0 868	683	705	.724	.732	.740	759	.767	.789	808	.814	.824
1	0 689	669	691	710	718	726	745	753	.775	.794	.800	.810
0	0 546	656	678	697	705	713	732	741	763	781	.787	797
2/0	0 433	642	664	683	691	699	718	727	749	767	773	783
3/0	0 343	628	650	669	677	685	704	.713	735	753	759	769
4/0	0 272	614	636	655	663	671	690	699	.721	.739	745	755
A.C.S.R †												
No. 4	2 24	730	752	770	.778	786	805	.814	836	854	860	871
3	1 78	719	741	759	767	776	795	.803	825	843	849	.860
2	1 41	708	730	749	757	765	784	792	814	.833	839	.849
1	1 12	698	720	738	746	754	773	782	804	822	828	838
0	0 893	686	708	727	735	743	762	.770	793	811	.817	827
2/0	0 718	676	698	716	724	733	752	.760	.782	800	806	.817
3/0	0 579	665	687	706	714	722	741	749	771	790	796	.806
4/0	0 464	655	677	696	704	712	731	.739	761	.780	786	.796
Copperweld-copper‡												
No. 2A	0 866	750	776	797	803	.808	829	834	861	876	.882	.892
4A	1 378	781	803	824	829	.840	.861	.866	887	903	.908	.924
6A	2 191	808	829	850	855	866	887	.892	913	.935	.940	.950
8A	3 484	834	855	871	876	.882	903	908	.929	.950	956	.966
3 No. 8	2 842	834	855	876	882	892	.913	919	940	.961	.966	.977
3 No. 10	4 519	861	882	903	908	.919	.940	945	966	987	993	1.003
3 No. 12	7 186	892	913	935	940	945	.966	.977	998	1.014	1 019	1.030

* The reactance at any other frequency than 60 cycles is $f/60$ times the table values.

The reactance X' at any spacing D' not given in the table is equal to the reactance X at the next smaller spacing D given in the table plus the quantity 0 2794 ($\log_{10} D'/D$). Thus $X' = X + 0.2794 (\log_{11} D'/D)$. Or the reactance in ohms to be added to that at the next smaller spacing may be taken from the table below.

D'/D	1 01	1 02	1 03	1.04	1.05	1 06	1.07	1 08	1 09	1.10
$X+$	0 001	0 002	0 004	0.005	0 006	0 007	0 008	0 009	0 011	0.012
D'/D	1 11	1.12	1.13	1 14	1.15	1.16	1.17	1.18	1.19	1 20
$X+$	0 013	0 014	0 015	0 016	0 017	0 018	0 019	0 020	0 021	0 022
D'/D	1 21	1 22	1 23	1 24	1.25					
$X+$	0 023	0 024	0 025	0 026	0.027					

† Single-layer conductors, current density 600 amp. per sq. in. From Aluminum Company of America data.

‡ Based on data supplied by Copperweld Steel Company; 40 per cent conductivity.

Increase in Kilowatt-Hour Consumption. The increase in kilowatt-hour consumption resulting from improved voltage is approximately equal to

$$\text{3-phase circuits} \quad kw\text{-}hr_1 \left[\left(\frac{V_2}{V_1} \right)^{1.6} - 1 \right] \tag{65}$$

Example of Applying Formulas to a Three-Phase Feeder. Assume a 4000-volt, three-phase, 60-cycle circuit of No. 0 copper wires, having an equivalent spacing of 56 in., and carrying a peak load of 1250-kv-a. at 80 per cent power factor and a daily average load of 750 kv-a. The distance from the transformer bank, which consists of three 333-kv-a. transformers, to the load is 5000 ft. Five hundred kilovolt-amperes in capacitors is placed at the load because that quantity corresponds to the average daily reactive kilovolt-amperes. If the feeder had branches and loads taken off at various points, the capacitor kilovolt-amperes would equal the average reactive kilovolt-amperes for the whole circuit, and capacitors would be distributed along the line in proportion to the reactive loads. The effect on each section would be computed separately and added to obtain the total.

Voltage. Percentage voltage drop caused by load =

$$\frac{5 \times 1250(0.1034 \times 0.8 + 0.1386 \times .06)}{10 \times 4^2} = 6.48$$

Volts drop = 0.0648 × 4000 = 267.2

Percentage voltage rise caused by application of shunt capacitor =

$$\frac{5 \times 0.1386 \times 500}{10 \times 4^2} = 2.17$$

Three-phase capacitor kilovolt-amperes required to reduce voltage drop 2.17 per cent =

$$\frac{2.17 \times 10 \times 4^2}{5 \times 0.1386} = 500$$

Line Carrying Capacity. Kilowatt carrying capacity for a specified voltage drop =

$$\frac{6.48 \times 10 \times 4^2}{5(0.1034 + 0.1386 \times 0.75)} = 1000$$

The carrying capacity after application of the capacitor =

$$\frac{(6.48 + 2.17)10 \times 4^2}{5(0.1034 + 0.1386 \times 0.75)} = 1335 \text{ kw.}$$

or

$$\frac{5 \times 0.1386 \times 500 + 6.48 \times 10 \times 4^2}{5(0.1034 + 0.1386 \times 0.75)} = 1335 \text{ kw.}$$

The capacity released by applying the capacitor =

$$\frac{500}{\dfrac{0.1034}{0.1386} + 0.75} = 335 \text{ kw.}$$

The percentage kilowatt capacity released by capacitor application =

$$\frac{100(0.75 - 0.25)}{\dfrac{0.1034}{0.1386} + 0.75} = 33.5\%$$

The ratio of capacitor kilovolt-amperes to kilowatts increase in carrying capacity =

$$\frac{0.1034}{0.1386} + 0.75 = 1.496$$

Energy Losses. In the example under consideration the average daily load is 750 kv-a. with 500 rkv-a. The average power factor before improvement is therefore 74.6 per cent, and the kilowatts 560. The power factor after application of 500 kv-a. in capacitors would be unity and the load 560 kv-a. The losses after power-factor improvement in percentage of losses before improvement =

$$100\left(\frac{0.746^2}{1.000^2}\right) = 55.7$$

The reduction in losses due to power-factor improvement =

$$100\left(1 - \frac{0.746^2}{1.000^2}\right) = 44.3\%$$

The loss at original power factor in percentage of kilowatts =

$$\frac{750^2 \times 0.1034 \times 5}{10 \times 4^2 \times 560} = 3.25$$

$$0.0325 \times 560 \text{ kw.} = 18.2 \text{ kw.}$$

The loss at improved power factor in percentage of kilowatts =

$$\frac{560^2 \times 0.1034 \times 5}{10 \times 4^2 \times 560} = 1.81$$

$$0.0181 \times 560 \text{ kw.} = 10.1 \text{ kw.}$$

The kilowatt saving = 8.1

The ratio of capacitor kilovolt-amperes to kilowatt reduction in losses =

$$\frac{1000 \times 500 \times 4^2}{0.1034 \times 5(750^2 - 560^2)} = 62.2$$

The annual kilowatt-hour reduction in losses =

$$\frac{8.76(kv\text{-}a_1^2 - kv\text{-}a_2^2)R \times d}{kv^2} = 70{,}440$$

Increase in Kilovolt-Ampere Capacity. Since the transformers carried a load of 1250 kv-a., this will have to be considered their capacity rather than their rated capacity of 1000 kv-a.

The released thermal capacity (kilovolt-amperes at original power factor) of the transformer bank =

$$1250\left(0.6 \times \frac{500}{1250} - 1 + \sqrt{1 - 0.8^2 \times \frac{500^2}{1250^2}}\right) = 237.5$$

The released thermal capacity (kilovolt-amperes at original power factor) of the transformer bank, in percentage of kilovolt-amperes before improvement =

$$0.6 \times \frac{500}{1250} - 1 + \sqrt{1 - 0.8^2 \times \frac{500^2}{1250^2}} = 19$$

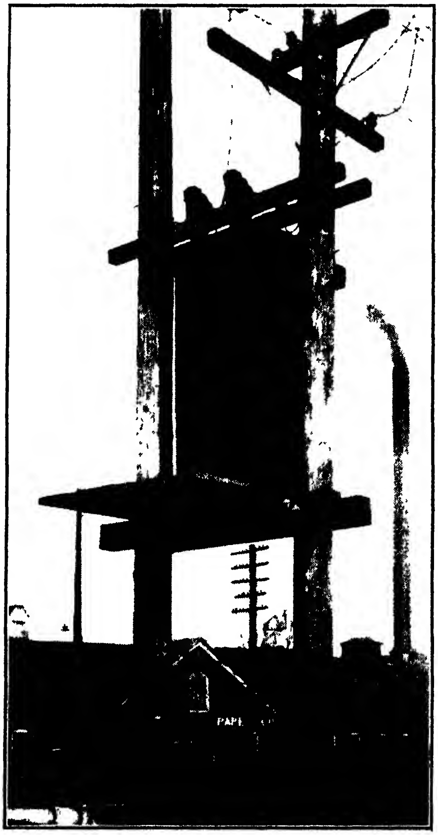

Fig. 30. Pole-type Capacitor

(Westinghouse Electric & Mfg. Co.)

Increase in Kilowatt-Hour Consumption. The average voltages before and after power-factor improvement must first be determined by using formula 40.

Per cent drop before improvement =

$$\frac{5 \times 750(0.1386 \times 0.666 + 0.1034 \times 0.746)}{10 \times 4^2} = 4$$

Per cent drop after improvement =

$$\frac{5 \times 560(0.1386 \times 0 + 0.1034 \times 1)}{10 \times 4^2} = 1.8$$

If the annual kilowatt-hour consumption before improvement is unknown, it may be approximated by multiplying the average kilowatt demand by 8760 hours.

$$560 \times 8760 = 4{,}905{,}600 \text{ kw-hr.}$$

The increase in kilowatt-hour consumption due to voltage improvement will be approximately

$$4{,}905{,}600 \left[\left(\frac{98.2}{96.0} \right)^{1.6} - 1 \right] = 181{,}507$$

Evaluation of Capacitor Effects. The increased line capacity usually has a value of \$25 per kv-a., which, at 12.5 per cent carrying charge, has an annual worth of \$25 $\times$ 0.125 = \$3.125.

Energy losses are usually evaluated at 1 cent per kw-hr.

Substation capacity is worth about \$15 per kv-a., which, carried at 12.5 per cent, has an annual value of \$15 $\times$ 0.125 = \$1.90.

Generating capacity usually costs a minimum of \$180 per kv-a., which, carried at 12.5 per cent, has an annual value of \$180 $\times$ 0.125 = \$22.50.

Increased consumer revenue averages about 2 cents per kw-hr.

Operating Problems. *Overvoltage at Light Load.* The voltage rise caused by shunt capacitors is practically constant regardless of load conditions. If the feeder is unregulated, this rise plus the overvoltages characteristic of light loads may produce an excessive overvoltage. Therefore, feeder regulators should always be used in conjunction with capacitors to give satisfactory voltage control. If they are not used it may be necessary to switch the capacitors out of service at such times, thereby decreasing their period of usefulness.

Harmonic Resonance. This condition will occur in only comparatively rare cases where the inductive reactance of the circuit, usually during light-load periods, is equal to, and hence neutralizes, the capacitive reactance. The usual possibilities of trouble are a fifth- or seventh-harmonic voltage on a system coincident with a resonant condition at these frequencies. Under such conditions, the current in the circuit is limited only by the resistance and may consequently attain enormous values, damaging the capacitors or transformers. Standard capacitors are designed for 35 per cent increase in kilovolt-amperes as an overload rating.

If trouble occurs, it is obviously necessary only to upset the balance existing between the inductive and capacitive reactance. The simplest and most economical way of doing so is to redistribute or relocate the capacitors; or they may be switched out of service at light loads, or small series reactors may be placed at the capacitor terminals.

Formulas for Harmonic Resonance.* When capacitors are installed at a substation or in a building near the entrance of service from a substation, there is a slight possibility of harmonic resonance under light-load conditions. Since the fifth harmonic is usually the cause, and because resonance can occur only when the inductive and capacitive reactances are equal, the equation, ignoring resistance and the system impedance on the primary side of the transformers, would be

$$25(X_l + X_t) = X_c \tag{66}$$

wherein X_l = reactance of line from transformers to capacitor.
X_t = reactance of transformers.
X_c = reactance of capacitor.

For analysis it is convenient to reduce all values to an equivalent Y circuit. To give the same percentage voltage drop in a Y and a delta circuit, the equivalent Y reactance of delta-connected transformers and capacitors would be one-third of the reactance of the kilovolt-amperes across one phase.

A 100-kv-a., 230-volt, 60-cycle delta-connected capacitor would have 33.33 kv-a. in each phase. Using formula 3, page 61, the microfarads per kilovolt-ampere is found to be

$$C = \frac{1000}{6.28 \times 60 \times 230^2}(10)^6 = 50.14$$

which value may also be found in Table XXI, page 61.

Substituting values in formula 4, page 61, the delta capacitive reactance per phase is ascertained to be

$$X_c = \frac{1}{6.28 \times 60 \times \dfrac{33.33 \times 50.14}{1{,}000{,}000}} = 1.5883$$

* Based upon "Equation Yields Kv-a. for Resonance" by F. I. Woltz in *Electrical World*, August 27, 1938.

and the equivalent Y reactance 1.588/3 = 0.5294. Since X_c varies as the square of the voltage and inversely as the kilovolt-amperes, the proportionality expression for a capacitor of any kilovolt-ampere rating operating at any other voltage E than 230 would be

$$\frac{X_c}{0.5294} = \frac{100}{kv\text{-}a} \times \left(\frac{E}{230}\right)^2$$

$$X_c = \frac{0.5294 \times 100}{kv\text{-}a} \times \left(\frac{E}{230}\right)^2$$

$$X_c = \frac{52.94}{kv\text{-}a} \times \left(\frac{E}{230}\right)^2 \qquad (67)$$

Substituting this value of X_c and the equivalent Y transformer reactance $X_t/3 = X_t$ in equation 66, for the condition of 300-cycle resonance the formula becomes

$$25\left(X_l + \frac{X_t}{3}\right) = \frac{52.94}{kv\text{-}a} \times \left(\frac{E}{230}\right)^2$$

from which

$$kv\text{-}a = \frac{6.36}{3X_l + X_t}\left(\frac{E}{230}\right)^2 \qquad (68)$$

wherein X_l = reactance of one conductor of three-phase line from substation to capacitor.

X_t = total reactance of one transformer of three-phase delta bank.

E = transformer voltage (delta connection) or voltage rating of capacitor.

$kv\text{-}a$ = total three-phase condenser capacity at voltage E.

It is suggested that if resonance is to be avoided the capacitance installed should not exceed 60 per cent of the critical value given. The reactance of transformers may be computed from formula 2, page 52, and line reactance obtained from Table XXXIX, page 111.

Example Using Formula 68. What size capacitor may be placed at the service entrance of a building without fear of harmonic resonance at no load if the substation 500 ft. distant consists of three 150-kv-a. transformers 4000/460 volts, and the service is 500,000 circular mils copper wire having an equivalent delta spacing of 3 ft.?

The transformer reactance would be

$$X_t = \frac{10 \times 0.46^2 \times 4.36}{150} = 0.0615$$

The line reactance is found to be 0.0538/2 = 0.0269

$$kv\text{-}a = \frac{6.36}{3 \times 0.0269 + 0.0615} \left(\frac{460}{230}\right)^2 = 179$$

$$0.6 \times 179 = 107 \text{ kv-a. suggested maximum}$$

Testing for Harmonic Resonance. If trouble is experienced with a group capacitor installation and harmonic resonance is suspected as its cause, a recording voltmeter and ammeter should be connected in the capacitor circuit. The amperes that should be drawn for various sizes of capacitors at the usual voltages are given in Tables XXXIII, XXXIV, and XXXV, pages 83, 84, and 85. Output of capacitors varies as the square of the voltage, and for low-voltage equipment is shown graphically in Fig. 17, page 63.

Standard capacitors are designed to take 35 per cent increase in kilovolt-amperes as an overload rating. This quantity may be composed of harmonics superimposed on the 60-cycle fundamental. If the ammeter record shows current in excess of the capacitor rating at the observed voltage, it will usually be due to harmonics, and if the current exceeds 135 per cent of rating will probably cause failure of the capacitor.

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