MYRON ZUCKER INC.

CALMANUAL

POWER FACTOR CORRECTION APPLICATION GUIDE

CALMANUAL

HOW TO APPLY CAPACITORS TO LOW VOLTAGE POWER SYSTEMS.

SECTION INDEX

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SECTION I

POWER FACTOR

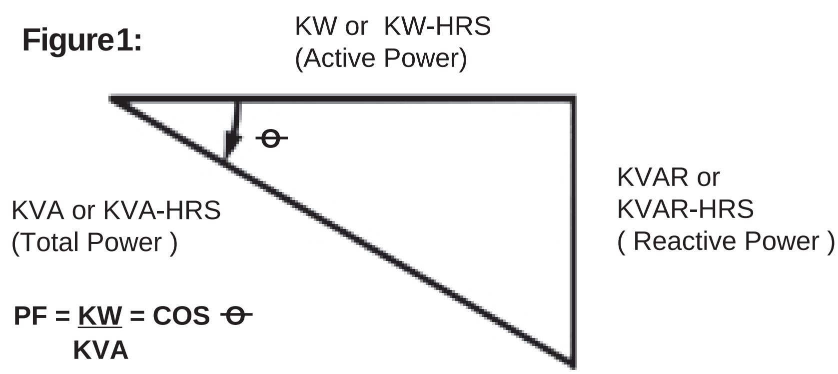
UNDERSTANDING POWER FACTOR

In most modern electrical distribution systems, the predominant loads are resistive and inductive. Resistive loads are incandescent lighting and resistance heating. Inductive loads are A.C. Motors, induction furnaces, transformers and ballast-type lighting. Inductive loads require two kinds of power: (1) active (or working) power to perform the work (motion) and (2) reactive power to create and maintain electro-magnetic fields. The vector sum of the active power and reactive power make up the total (or apparent) power used. This is the power generated by the utility for the user to perform a given amount of work.

* Active power is measured in KW (1000 Watts)
* Reactive power is measured in KVAR (1000 Volt-Amperes Reactive)
* Total Power is measured in KVA (1000 Volts-Amperes)

Power factor then is the ratio of active power to total power. We can illustrate these relationships by means of a right triangle. (See Figure 1.)

Figure1:



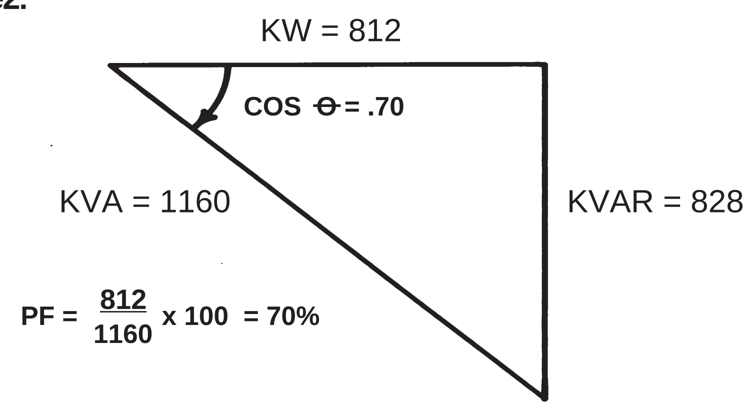
$$PF = \frac{KW}{KVA} = \cos \theta$$

Note that a low power factor requires a larger amount of KVA to accomplish a fixed amount of work (KW), whereas a high power factor would require a lesser amount of KVA to accomplish the same amount of work. Utilities provide the KVA to the user, and by means of continuous metering, they bill the user each month, and provide actual values of the components of power shown in Figure 1. If the values shown on the bill indicate a low power factor, many utilities will add a penalty to the bill. In like manner, a high power factor may result in a reduction in the over-all cost of total power consumed.

IMPROVING POWER FACTOR

The solution is to add power factor correction capacitors to the plant power distribution system. They act as reactive power generators, and provide the needed reactive power to accomplish KW of work. This then reduces the amount of reactive power, and thus total power, generated by the utility. Let’s look at an actual case of power factor improvement to an industrial plant, and the savings that resulted. (See Figure 2)

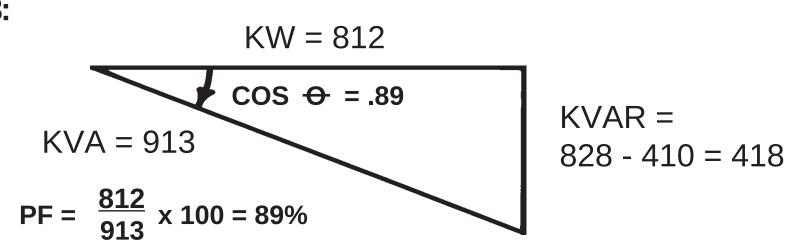
Figure2:



Because the utility applied a penalty formula when the power factor fell below 85%, this user had a penalty of $650.00 added to the bill. To accomplish 812KW of work the 1500KVA transformer was almost 78% loaded. (1160÷1500 = 77.3%)

The solution in this case was to add capacitors to the system by installing them at each of thirteen large motors. The total KVAR added was 410. This improved the power factor to 89%, and reduced the required KVA to 913, which is the vector sum of KW and KVAR. (See Figure 3)

Figure3:



The user, doing the same amount of work, but now with capacitors installed, has eliminated the $650.00 monthly penalty. This would be an annual savings of $7,800.00. The capacitors and the labor to install them cost $7,351.00, a payback of less then 12 months.

The utility has to generate 247 less KVA (1160 - 913 = 247), and the user has the 1500 KVA transformer now loaded only to 60% of capacity. This will allow the addition of more load in the future to be supplied by the transformer.

SECTION II

THE ADVANTAGES OF MAINTAINING A HIGH POWER FACTOR

ELIMINATION OF PENALTY DOLLARS

A high power factor eliminates penalty dollars imposed when operating with a low power factor. For many years, most utilities demanded a minimum of 85% power factor as an average for each monthly billing. Now many of these same utilities are demanding 95%...or else pay a penalty!

The actual wording or formula in the utility rate contract might spell out the required power factor, or it might refer to KVA billing, or it might refer to KW demand billing with power factor adjustment multipliers. Have your utility representative explain the particular rate contract used in your monthly bill. This will insure you are taking the proper steps to obtain maximum dollar savings by maintaining a proper power factor.

ADDITIONAL CAPACITY IN ELECTRICAL SYSTEM

A high power factor can help you utilize the full capacity of your electrical system. To refresh our memory, let's look again at the power triangle story, shown on Pages 3 & 4, Figures 1, 2 , and 3. Remember that KVA is a measure of the total power generated by the utility for you to accomplish your KW of work. Remember that the KVA figure is the amount of power passing through your plant transformer, and limited by its rated size: e.g. 750 KVA, 1500 KVA, 2500 KVA, etc. In the previous example, we reduced your transformer loading from 1160 to 913 KVA, thus allowing for more load to be added in the future.

REDUCTION OF I^2R LOSSES

A potential savings in billed KW-Hrs can be realized depending upon where the capacitors are located in your electrical system. When capacitors are energized they reduce the total power usage (KVA) from their location in the system up to the utility source. In other words, capacitors reduce the current in amperes that had been flowing from the utility to the capacitor location. This ampere reduction might be as high as 20%. Since watt loss generated by current passing through a conductor is expressed by the formula ... watt loss = $(\text{Ampere})^2$ x Conductor Resistance ($W=I^2R$)... it is obvious that locating the capacitors at the extremities of the feeders and branch circuits (where the loads are) can result in a sizeable reduction in total KW-Hrs usage every month.

SECTION III

HOW TO DETERMINE AMOUNT OF KVAR REQUIRED

ANALYSIS OF UTILITY BILLS

Monthly utility bills should be studied and analyzed to determine this requirement. Since loads vary from month to month, or season to season, it is well to cover the last twelve months of bills. Almost all utilities print out the average power factor for the month, and the total KW-Hrs consumed during that billing period. If this period happens to cover 30 days, then we have 30 x 24, or 720 hours. Divide the billed KW-Hrs by 720 and you will obtain the average KW for the billing period.

With this information, we can once again draw our power triangles to determine how much KVAR would be required to improve the power factor to some new desired level. Or, we can proceed to use Table 1 which simplifies the calculations. For example see below.

INSTRUCTIONS FOR USING TABLE 1:

1. Find the billing (original) power factor in column (1).
2. Read across for desired power factor.
3. Multiply number shown by average KW obtained above.

EXAMPLE:

The utility bill shows an average power factor of .72 with an average KW of 627. How much KVAR is required to improve the power factor to .95 ?

STEPS:

1. Locate .72 (original power factor) in column (1).
2. Read across desired power factor to .95 column. We find .635 multiplier
3. Multiply 627 (average KW) by .635 = 398 KVAR.
4. Install 400 KVAR to improve power factor to 95%.

Now that we have determined that capacitors totaling 400 KVAR must be installed, we must decide where to locate them.

TABLE 1: MULTIPLIERS TO DETERMINE CAPACITOR KVAR REQUIRED FOR POWER FACTOR CORRECTION

Original Power Factor	Desired Power Factor																				
	0.80	**0.81**	**0.82**	**0.83**	**0.84**	**0.85**	**0.86**	**0.87**	**0.88**	**0.89**	**0.90**	**0.91**	**0.92**	**0.93**	**0.94**	**0.95**	**0.96**	**0.97**	**0.98**	**0.99**	**1.0**
0.50	0.982	1.008	1.034	1.060	1.086	1.112	1.139	1.165	1.192	1.220	1.248	1.276	1.306	1.337	1.369	1.403	1.440	1.481	1.529	1.589	1.732
0.51	0.937	0.962	0.989	1.015	1.041	1.067	1.094	1.120	1.147	1.175	1.203	1.231	1.261	1.292	1.324	1.358	1.395	1.436	1.484	1.544	1.687
0.52	0.893	0.919	0.945	0.971	0.997	1.023	1.050	1.076	1.103	1.131	1.159	1.187	1.217	1.248	1.280	1.314	1.351	1.392	1.440	1.500	1.643
0.53	0.850	0.876	0.902	0.928	0.954	0.980	1.007	1.033	1.060	1.088	1.116	1.144	1.174	1.205	1.237	1.271	1.308	1.349	1.397	1.457	1.600
0.54	0.809	0.835	0.861	0.887	0.913	0.939	0.966	0.992	1.019	1.047	1.075	1.103	1.133	1.164	1.196	1.230	1.267	1.308	1.356	1.416	1.559
0.55	0.769	0.795	0.821	0.847	0.873	0.899	0.926	0.952	0.979	1.007	1.035	1.063	1.093	1.124	1.156	1.190	1.227	1.268	1.316	1.376	1.519
0.56	0.730	0.756	0.782	0.808	0.834	0.860	0.887	0.913	0.940	0.968	0.996	1.024	1.054	1.085	1.117	1.151	1.188	1.229	1.277	1.337	1.480
0.57	0.692	0.718	0.744	0.770	0.796	0.822	0.849	0.875	0.902	0.930	0.958	0.986	1.016	1.047	1.079	1.113	1.150	1.191	1.239	1.299	1.442
0.58	0.655	0.681	0.707	0.733	0.759	0.785	0.812	0.838	0.865	0.893	0.921	0.949	0.979	1.010	1.042	1.076	1.113	1.154	1.202	1.262	1.405
0.59	0.619	0.645	0.671	0.697	0.723	0.749	0.776	0.802	0.829	0.857	0.885	0.913	0.943	0.974	1.006	1.040	1.077	1.118	1.166	1.226	1.369
0.60	0.583	0.609	0.635	0.661	0.687	0.713	0.740	0.766	0.793	0.821	0.849	0.877	0.907	0.938	0.970	1.004	1.041	1.082	1.130	1.190	1.333
0.61	0.549	0.575	0.601	0.627	0.653	0.679	0.706	0.732	0.759	0.787	0.815	0.843	0.873	0.904	0.936	0.970	1.007	1.048	1.096	1.156	1.299
0.62	0.516	0.542	0.568	0.594	0.620	0.646	0.673	0.699	0.726	0.754	0.782	0.810	0.840	0.871	0.903	0.937	0.974	1.015	1.063	1.123	1.266
0.63	0.483	0.509	0.535	0.561	0.587	0.613	0.640	0.666	0.693	0.721	0.749	0.777	0.807	0.838	0.870	0.904	0.941	0.982	1.030	1.090	1.233
0.64	0.451	0.474	0.503	0.529	0.555	0.581	0.608	0.634	0.661	0.689	0.717	0.745	0.775	0.806	0.838	0.872	0.909	0.950	0.998	1.068	1.201
0.65	0.419	0.445	0.471	0.497	0.523	0.549	0.576	0.602	0.629	0.657	0.685	0.713	0.743	0.774	0.806	0.840	0.877	0.918	0.966	1.026	1.169
0.66	0.388	0.414	0.440	0.466	0.492	0.518	0.545	0.571	0.598	0.626	0.654	0.682	0.712	0.743	0.775	0.809	0.846	0.887	0.935	0.995	1.138
0.67	0.358	0.384	0.410	0.436	0.462	0.488	0.515	0.541	0.568	0.596	0.624	0.652	0.682	0.713	0.745	0.779	0.816	0.857	0.905	0.965	1.108
0.68	0.328	0.354	0.380	0.406	0.432	0.458	0.485	0.511	0.538	0.566	0.594	0.622	0.652	0.683	0.715	0.749	0.786	0.827	0.875	0.935	1.078
0.69	0.299	0.325	0.351	0.377	0.403	0.429	0.456	0.482	0.509	0.537	0.565	0.593	0.623	0.654	0.686	0.720	0.757	0.798	0.846	0.906	1.049
0.70	0.270	0.296	0.322	0.348	0.374	0.400	0.427	0.453	0.480	0.508	0.536	0.564	0.594	0.625	0.657	0.691	0.728	0.769	0.817	0.877	1.020
0.71	0.242	0.268	0.294	0.320	0.346	0.372	0.399	0.425	0.452	0.480	0.508	0.536	0.566	0.597	0.629	0.663	0.700	0.741	0.789	0.849	0.992
0.72	0.214	0.240	0.266	0.292	0.318	0.344	0.371	0.397	0.424	0.452	0.480	0.508	0.538	0.569	0.601	0.635	0.672	0.713	0.761	0.821	0.964
0.73	0.186	0.212	0.238	0.264	0.290	0.316	0.343	0.369	0.396	0.424	0.452	0.480	0.510	0.541	0.573	0.607	0.644	0.685	0.733	0.793	0.936
0.74	0.159	0.185	0.211	0.237	0.263	0.289	0.316	0.342	0.369	0.397	0.425	0.453	0.483	0.514	0.546	0.580	0.617	0.658	0.706	0.766	0.909
0.75	0.132	0.158	0.184	0.210	0.236	0.262	0.289	0.315	0.342	0.370	0.398	0.426	0.456	0.487	0.519	0.553	0.590	0.631	0.679	0.739	0.882
0.76	0.105	0.131	0.157	0.183	0.209	0.235	0.262	0.288	0.315	0.343	0.371	0.399	0.429	0.460	0.492	0.526	0.563	0.604	0.652	0.712	0.855
0.77	0.079	0.105	0.131	0.157	0.183	0.209	0.236	0.262	0.289	0.317	0.345	0.373	0.403	0.434	0.466	0.500	0.537	0.578	0.626	0.685	0.829
0.78	0.052	0.078	0.104	0.130	0.156	0.182	0.209	0.235	0.262	0.290	0.318	0.346	0.376	0.407	0.439	0.473	0.510	0.551	0.599	0.659	0.802
0.79	0.026	0.052	0.078	0.104	0.130	0.156	0.183	0.209	0.236	0.264	0.292	0.320	0.350	0.381	0.413	0.447	0.484	0.525	0.573	0.633	0.776
0.80	0.000	0.026	0.052	0.078	0.104	0.130	0.157	0.183	0.210	0.238	0.266	0.294	0.324	0.355	0.387	0.421	0.458	0.499	0.547	0.609	0.750
0.81		0.000	0.026	0.052	0.078	0.104	0.131	0.157	0.184	0.212	0.240	0.268	0.298	0.329	0.361	0.395	0.432	0.473	0.521	0.581	0.724
0.82			0.000	0.026	0.052	0.078	0.105	0.131	0.158	0.186	0.214	0.242	0.272	0.303	0.335	0.369	0.406	0.447	0.495	0.555	0.698
0.83				0.000	0.026	0.052	0.079	0.105	0.132	0.160	0.188	0.216	0.246	0.277	0.309	0.343	0.380	0.421	0.469	0.529	0.672
0.84					0.000	0.026	0.053	0.079	0.106	0.134	0.162	0.190	0.220	0.251	0.283	0.317	0.354	0.395	0.443	0.503	0.646
0.85						0.000	0.027	0.053	0.080	0.108	0.136	0.164	0.194	0.225	0.257	0.291	0.328	0.369	0.417	0.477	0.620
0.86							0.000	0.026	0.053	0.081	0.109	0.137	0.167	0.198	0.230	0.264	0.301	0.342	0.390	0.450	0.593
0.87								0.000	0.027	0.055	0.083	0.111	0.141	0.172	0.204	0.238	0.275	0.316	0.364	0.424	0.567
0.88									0.000	0.028	0.056	0.084	0.114	0.145	0.177	0.211	0.248	0.289	0.337	0.397	0.540
0.89										0.000	0.028	0.056	0.086	0.117	0.149	0.183	0.220	0.261	0.309	0.369	0.512
0.90											0.000	0.028	0.058	0.089	0.121	0.155	0.192	0.233	0.281	0.341	0.484
0.91												0.000	0.030	0.061	0.093	0.127	0.164	0.205	0.253	0.313	0.456
0.92													0.000	0.031	0.063	0.097	0.134	0.175	0.223	0.283	0.426
0.93														0.000	0.032	0.066	0.103	0.144	0.192	0.252	0.395
0.94															0.000	0.034	0.071	0.112	0.160	0.220	0.363
0.95																0.000	0.037	0.079	0.126	0.186	0.329
0.96																	0.000	0.041	0.089	0.149	0.292
0.97																		0.000	0.048	0.108	0.251
0.98																			0.000	0.060	0.203
0.99																				0.000	0.143
																					0.000

SECTION IV

LOCATION OF REQUIRED CAPACITORS

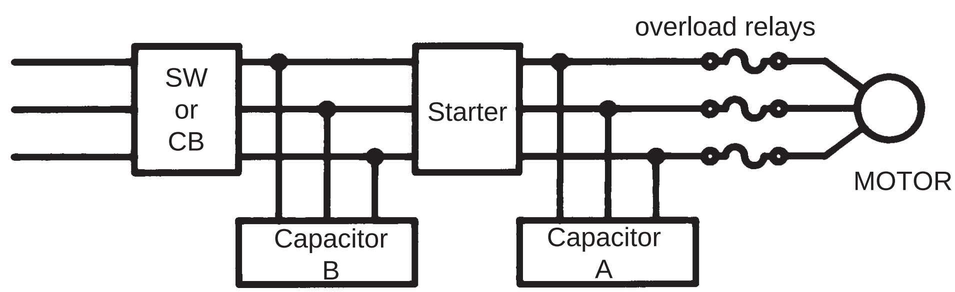
HERE ARE 4 METHODS USED IN LOCATING CAPACITORS WITHIN AN ELECTRICAL SYSTEM.

Method #1: CAPACITOR AT LOAD (CALMOUNT*® *brand capacitor)

Install a single capacitor at each sizeable motor and energize it whenever the motor is in operation. We refer to this as ***Calmount*** ® brand capacitor (Capacitor At Load). Tables 2 and 3 show suggested KVAR ratings to be selected.

This method usually offers the greatest advantages of all, and the capacitors could be connected either in location (A) or (B) in Figure 4 below:

Figure4:



Location A - Normally used for most motor applications.

Location B - Used when motors are jogged, plugged, reversed; for multi-speed motors, or reduced-voltage start motors.

The advantages of method #1 are many:

(A) Corrects PF, unloads the transformer, reduces losses in conductors (KW-Hrs) from source to motor location.

(B) Voltage drop to motor is reduced - thus optimizing motor performance.

(C) Installation simple - no new switches or circuit breakers required.

TABLE 2: SUGGESTED MAXIMUM CAPACITOR RATINGS USED FOR HIGH EFFICIENCY MOTORS AND OLDER DESIGN (PRE "T-FRAMES") MOTORS*

Induction Motor Horsepower Rating	No. of Poles and Nominal Motor Speed in RPM											
	2 3600 RPM		4 1800 RPM		6 1200 RPM		8 900 RPM		10 720 RPM		12 600 RPM	
	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %
3	1.5	14	1.5	15	1.5	20	2	27	2.5	35	3	41
5	2	12	2	13	2	17	3	25	4	32	4	37
7.5	2.5	11	2.5	12	3	15	4	22	5	30	6	34
10	3	10	3	11	3	14	5	21	6	27	7.5	31
15	4	9	4	10	5	13	6	18	8	23	9	27
20	5	9	5	10	6	12	7.5	16	9	21	12.5	25
25	6	9	6	10	7.5	11	9	15	10	20	15	23
30	7	8	7	9	9	11	10	14	12.5	18	17.5	22
40	9	8	9	9	10	10	12.5	13	15	16	20	20
50	12.5	8	10	9	12.5	10	15	12	20	15	25	19
60	15	8	15	8	15	10	17.5	11	22.5	15	27.5	19
75	17.5	8	17.5	8	17.5	10	20	10	25	14	35	18
100	22.5	8	20	8	25	9	27.5	10	35	13	40	17
125	27.5	8	25	8	30	9	30	10	40	13	50	16
150	30	8	30	8	35	9	37.5	10	50	12	50	15
200	40	8	37.5	8	40	9	50	10	60	12	60	14
250	50	8	45	7	50	8	60	9	70	11	75	13
300	60	8	50	7	60	8	60	9	80	11	90	12
350	60	8	60	7	75	8	75	9	90	10	95	11
400	75	8	60	6	75	8	85	9	95	10	100	11
450	75	8	75	6	80	8	90	9	100	9	110	11
500	75	8	75	6	85	8	100	9	100	9	120	10

*For use with 3-phase, 60 hertz NEMA Classification B Motors to raise full load power factor to approximately 95%

TABLE 3: SUGGESTED MAXIMUM CAPACITOR RATINGS "T-FRAME" NEMA "DESIGN B" MOTORS*

Induction Motor Horsepower Rating	No. of Poles and Nominal Motor Speed in RPM											
	2 3600 RPM		4 1800 RPM		6 1200 RPM		8 900 RPM		10 720 RPM		12 600 RPM	
	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %
2	1	14	1	24	1.5	30	2	42	2	40	3	50
3	1.5	14	1.5	23	2	28	3	38	3	40	4	49
5	2	14	2.5	22	3	26	4	31	4	40	5	49
7.5	2.5	14	3	20	4	21	5	28	5	38	6	45
10	4	14	4	18	5	21	6	27	7.5	36	8	38
15	5	12	5	18	6	20	7.5	24	8	32	10	34
20	6	12	6	17	7.5	19	9	23	10	29	12.5	30
25	7.5	12	7.5	17	8	19	10	23	12.5	25	17.5	30
30	8	11	8	16	10	19	15	22	15	24	20	30
40	12.5	12	15	16	15	19	17.5	21	20	24	25	30
50	15	12	17.5	15	20	19	22.5	21	22.5	24	30	30
60	17.5	12	20	15	22.5	17	25	20	30	22	35	28
75	20	12	25	14	25	15	30	17	35	21	40	19
100	22.5	11	30	14	30	12	35	16	40	15	45	17
125	25	10	35	12	35	12	40	14	45	15	50	17
150	30	10	40	12	40	12	50	14	50	13	60	17
200	35	10	50	11	50	11	70	14	70	13	90	17
250	40	11	60	10	60	10	80	13	90	13	100	17
300	45	11	70	10	75	12	100	14	100	13	120	17
350	50	12	75	8	90	12	120	13	120	13	135	15
400	75	10	80	8	100	12	130	13	140	13	150	15
450	80	8	90	8	120	10	140	12	160	14	160	15
500	100	8	120	9	150	12	160	12	180	13	180	15

*For use with 3-phase, 60 hertz NEMA Classification B Motors to raise full load power factor to approximately 95%

Method #2: FIXED CAPACITOR BANK
***(CAPACIBANK** ® brand capacitor)*

Install a fixed quantity of KVAR electrically connected at one or more locations in the plant's electrical distribution system, and energized at all times.

This method is often used when the facility has few motors of any sizeable horsepower to which capacitors can economically be added. A fixed amount of KVAR can easily be added to an existing run of plug-in bus by installing a ***Busmount***™ brand capacitor. A fixed amount can be added to the main buses in a motor control center. In most cases, however, the fixed bank (***Capacibank***™ brand capacitor) is usually located near the service entrance switchboard. In all cases, a separate fused switch, or circuit breaker, must be provided ahead of the capacitor bank.

There is one most important fact to remember whenever you install a fixed bank. When the system is lightly loaded (perhaps on Sundays or holidays), and you have too large a bank of KVAR energized, the voltage can be so great that motors, lamps, and controls can burn out. Unbalanced load or other similar conditions can aggravate the trouble with harmonics. Our research indicates that KVAR equal to 20% of the transformer KVA is the maximum size of a fixed KVAR bank that should be installed. Values larger then this can result in a large resonant current, potentially harmful to the system.

Remember, that while the fixed bank can unload the transformer, and show an improved power factor on your monthly bill, it does nothing to reduce the conductor watt loss (and thus billed KW-Hrs).

Method #3: AUTOMATIC CAPACITOR BANK
***(AUTOCAPACIBANK** ™ brand capacitor)*

Install an automatically controlled capacitor bank (***Autocapacibank***™ brand capacitor) that will closely maintain a pre-selected value of power factor. This is accomplished by having a controller switch steps of KVAR on, or off, as needed. This type of bank eliminates the concern of having too much KVAR energized at light load periods.

This method would seem to have much appeal, but it also has a real disadvantage. Since it is usually located near the incoming service entrance switchboard, we find that like the fixed bank this automatic bank does nothing to reduce the conductor losses (and thus billed KW-Hrs). Remember that the reduction in conductor losses using ***Calmount*** ® brand capacitor (method #1) can be sizeable.

Method #4: COMBINATION OF METHODS

Since no two electrical distribution systems are identical, each must be carefully analyzed to arrive at the most cost-effective solution, using one or more of the methods.

SECTION V

HARMONIC DISTORTION PROBLEMS

Starting in the late 1970's commercial, institutional, and industrial plants have experienced a tremendous growth in the use of equipment that can generate “harmonic” distortion in power systems. Some examples of such equipment will include DC drives, AC variable frequency drives, rectifiers, induction furnaces, and UPS systems. This harmonic distortion develops a current wave shape which results in higher than normal RMS amperes (and heat) which will result in nuisance fuse-blowing, circuit-breaker tripping, over-heated transformers, and premature capacitor failure.

If a facility has but a few pieces of the above-mentioned equipment in use, Myron Zucker, Inc. can pinpoint the harmonic number and amplitude present in the system. If the facility is a large one with many sources of harmonic distortion, then a complete audit of the total electrical system with a harmonic analysis must be made. We can provide such services.

The solution to all of the above is the installation of harmonic filters that not only correct or improve the power factor, but also prevent harmonics from damaging existing equipment on line. We have developed the ***Caltrap***™ brand harmonic filters for application to the actual harmonic source equipment. We also have the larger ***Capacitrap***™ brand harmonic filters (large filter banks) to provide overall system correction when many types of harmonic-producing equipment exist. This has become quite a specialized field, and we consider ourselves as leaders in low-voltage filter application. We are ready to help you eliminate your “Dirty Power” problems! Let us furnish you our new application guide for solving harmonic distortion problems.

CAPACITOR DEFINITION & APPLICATION DATA

DEFINITIONS

C: Capacitance (farads)
KW: Kilowatts, measure of active power
KVA: Kilovolt-amperes, measure of apparent power
KVAR: Kilovolt-amperes reactive
μF: Microfarads, measure of capacitance (farads x 10^{-6})
f: Frequency of voltage or current in Hz
I_c: Capacitor current in amperes
W: Dissipated power, in watts
V: Voltage (Volts)
I or A: Current (Amperes)
R: Resistance (ohms)

BASIC RELATIONS

$$PF = \frac{KW}{KVA} = \cos \theta$$

$$KVAR = \sqrt{KVA^2 - KW^2}$$

$$C \text{ in } \mu F = \frac{KVAR \times 10^3}{(2 \pi f) \times (KV)^2}$$

$$W = I^2 R$$

$$KVA = \frac{\sqrt{3} \times V \times A}{10^3} \text{ (3-phase)}$$

$$I_c = \frac{KVAR \times 10^3}{\sqrt{3} \times V} \text{ (3-phase)}$$

Applied Voltage	208V	240V	480V	600V
Amps / KVAR	2.78	2.41	1.20	0.96

RECOMMENDED WIRE SIZES, SWITCHES AND FUSES

FOR 3-Phase 60 Hz CAPACITORS

(These wire sizes are based on 135% of rated current in accordance with the 1999 National Electrical Code. Article 460)

	240 VOLTS				480 VOLTS				600 VOLTS				
KVAR	Current* (Amps)	Wire Size 90°C-Type THHN XHHW* or Equiv.†	Fuse (Amps)	C.B. or Switch (Amps)	Current* (Amps)	Wire Size 90°C-Type THHN XHHW* or Equiv.†	Fuse (Amps)	C.B. or Switch (Amps)	Current* (Amps)	Wire Size 90°C-Type THHN XHHW* or Equiv.†	Fuse (Amps)	C.B. or Switch (Amps)	KVAR
1	2.4	14	5	30	1.2	14	3	30	1	14	3	30	1
1.5	3.6	14	6	30	1.8	14	3	30	1.4	14	3	30	1.5
2	4.8	14	10	30	2.4	14	5	30	1.9	14	3	30	2
2.5	6	14	10	30	3.0	14	6	30	2.4	14	5	30	2.5
3	7.2	14	I5	30	3.6	14	6	30	2.9	14	5	30	3
4	9.6	12	20	30	4.8	14	10	30	3.8	14	6	30	4
5	12	12	20	30	6	14	10	30	4.8	14	10	30	5
6	14	10	25	30	7.2	14	15	30	5.8	14	10	30	6
7.5	18	10	30	30	9	14	15	30	7.2	14	15	30	7.5
10	24	8	40	60	12	12	20	30	9.6	12	20	30	10
12.5	30	8	50	60	15	10	25	30	12	12	20	30	12.5
15	36	6	60	60	18	10	30	30	14	10	25	30	15
17.5	42	6	70	100	21	8	35	60	16	10	30	30	17.5
20	48	4	80	100	24	8	40	60	19	8	35	60	20
22.5	54	4	90	100	27	8	50	60	22	8	35	60	22.5
25	60	2	100	100	30	8	50	60	24	8	40	60	25
27.5	66	2	125	200	33	6	60	60	26	8	45	60	27.5
30	72	2	125	200	36	6	60	60	29	8	50	60	30
32.5	78	1/0	150	200	39	6	65	100	31	8	50	60	32.5
35	84	1/0	150	200	42	6	70	100	34	6	60	60	35
37.5	90	1/0	150	200	45	6	75	100	36	6	60	60	37.5
40	96	2/0	175	200	48	4	80	100	38	6	65	100	40
42.5	102	2/0	175	200	51	4	90	100	41	6	70	100	42.5
45	108	3/0	200	200	54	4	90	100	43	6	75	100	45
50	120	3/0	200	200	60	2	100	100	48	4	80	100	50
52.5	126	3/0	200	200	63	2	110	200	50	4	80	100	52.5
55	132	4/0	250	400	66	2	125	200	53	4	90	100	55
60	144	4/0	250	400	72	2	125	200	58	2	100	100	60
65	156	4/0	250	400	78	1/0	150	200	62	2	110	200	65
70	168	300M	300	400	84	1/0	150	200	67	2	125	200	70
75	180	300M	300	400	90	1/0	150	200	72	2	125	200	75
80	192	350M	350	400	96	2/0	175	200	77	1/0	150	200	80
90	216	500M	400	400	108	3/0	200	200	86	1/0	150	200	90
100	240	500M	400	400	120	3/0	200	200	96	2/0	175	200	100
125	300	(2)4/0	500	600	150	4/0	250	400	120	3/0	200	200	125
150	360	(2)300M	600	600	180	300M	300	400	144	4/0	250	400	150
200	480	(2)500M	800	800	240	500M	400	400	192	350M	350	400	200
225	540	(3)300M	900	1200	270	(2)4/0	500	600	216	500M	400	400	225
250	600	(3)350M	1000	1200	300	(2)4/0	500	600	240	500M	400	400	250
300	720	(3)500M	1200	1200	360	(2)300M	600	600	288	(2)4/0	500	600	300
350					420	(2)350M	700	800	336	(2)300M	600	600	350
400					480	(2)500M	800	800	384	(2)350M	700	800	400
450					540	(3)300M	900	1200	432	(2)400M	750	800	450
500					600	(3)350M	1000	1200	480	(2)500M	800	800	500
550					660	(3)500M	1100	1200	528	(3)300M	900	1200	550
600					720	(3)500M	1200	1200	576	(3)350M	1000	1200	600

* RATED CURRENT BASED ON OPERATION AT RATED VOLTAGE, FREQUENCY, AND KVAR
† CONSULT NATIONAL ELECTRICAL CODE FOR OTHER WIRE TYPES. ABOVE SIZE BASED ON 35ºC AMBIENT OPERATION. (REFER TO NEC TABLE 310-16.)
NOTE: FUSES FURNISHED WITHIN CAPACITOR ASSEMBLY MAY BE RATED AT HIGHER VALUE THAN SHOWN IN THIS TABLE. THE TABLE IS CORRECT FOR FIELD INSTALLATIONS AND REFLECTS THE MANUFACTURER'S SUGGESTED RATING FOR OVERCURRENT PROTECTION AND DISCONNECT MEANS IN COMPLIANCE WITH THE NATIONAL ELECTRICAL CODE.