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Validating Capacitor Design Values

There are hundreds of thousands of power factor correction capacitors (PFCC for short) installed throughout the United States. In most cases, the capacitors have little or no indication whether or not they are performing to their designed output power. When capacitors degrade, they are not performing their intended function – improving the efficiency of power from the point of installation back to the Users metering point. Simply put, the degradation of a capacitor means the User is very likely to see their utility bills increase over time.

This document will briefly address common causes of PFCC failures and how to determine if a capacitor is performing within its designed output power range.

Factors That Affect Capacitor Life Expectancy

Power factor correction capacitors are typically designed to last about 20 years when operating within their design parameters. Unfortunately, most installations expose the capacitors to one or more factors that cause their design limitations to be exceeded and therefore significantly reduce the capacitors life expectancy. Many different external factors can cause capacitors to fail. However, there are four common factors that have the most impact – voltage, frequency, temperature, and harmonics. Each of these factors are discussed briefly below. As will be seen, some of the factors by themselves should not cause too much of a concern. In most cases, it is a combination of the four factors that cause the most damage to capacitors.

<u>Voltage</u>
Capacitors are designed for a specific operating voltage. All UL listed capacitors must indicate the intended operating voltage on their nameplate. A voltage applied to a capacitor that is *lower* than the intended operating voltage will not damage the capacitor. The only impact to the user is the loss of intended power factor correction. A voltage applied to a capacitor that is higher than the intended operating voltage may cause damage to the capacitor since the design limits may be exceeded. When the voltage design limits are exceeded, the capacitor will start losing its capacitance and therefore will eventually become ineffective in correcting power factor.

Frequency

Like voltage, capacitors are designed to operate at a specific frequency. Fortunately, in the United States, the output frequency, 60HZ, in most parts of the country is very stable. As a result, variations in frequency alone do not have a large impact on capacitor failures. However, if the input frequency is above the rated frequency AND the output voltage exceeds the rated operating voltage, the effects of frequency can further accelerate the rate of capacitor failures. Like voltage, a lower than rated frequency will not damage the capacitor. The lower frequency will simply produce less power factor correction than intended. If frequency is above the intended operating value, the output power will increase by the same proportional percent as the frequency. Again, frequency is normally well controlled within one percent of intended output, so alone the increase is not too concerning. It is the compounding affect with increased voltage that causes further capacitor degradation.

Temperature

Like most electrical devices, capacitors are designed to operating within a specified ambient temperature range. Ambient temperature means the temperature surrounding the capacitor. For power factor correction capacitors, the maximum operating voltage is typically 40^{o}C or 104^{o}F. Higher than rated temperatures surrounding the equipment can cause the unit to heat up excessively inside the enclosure and therefore cause premature degradation or failure of internal electrical conducting material. When this happens, the capacitor, once again, no longer produces the intended power factor correction. It is important to note that even though the room temperature may be reasonable, say 80^{o}F, if a capacitor is installed directly next to a heat generating device, the temperature surrounding the capacitor can quickly exceed its design temperature rating. This is important because all too often a user will say “my room temperature is only 80^{o}F so the temperature cannot be a problem”, only to find out later the capacitor was installed next to the heat exhaust of another piece of equipment….ooops! It is always best to obtain as much information as possible about the capacitors installation location and process/equipment surrounding the capacitor.

Harmonics

Harmonics can be very complicated. In simple terms, harmonics are high frequency electrical noise that are added to the intended operating voltage and currents of electrical equipment. These extra voltages and currents are not normally accounted for when the distribution system is designed. As a result, when an electrical device is subjected to these extra currents and voltages, they begin to degrade and become damaged, often to the point of complete breakdown and failure. Capacitors are especially susceptible to these high frequency noises because by nature, the capacitors tend to ‘absorb’ higher frequencies. When capacitors absorb these higher frequencies, they quickly become overloaded and can fail very rapidly. Harmonics are the most detrimental factor in causing power factor correction capacitor failures. There are many common electrical devices that cause harmonics including electronic lighting ballasts, computers, and uninterruptible power supplies. Electronic motor starters such as softstarters and variable frequency drives (more commonly referred to as VFD's), cause the most havoc with capacitors. The reason softstarters and VFD's cause the most problems is simply because there are normally a much larger part of the system load in an industrial facility than any of the other devices. This means they contribute much more and much larger magnitudes of frequency noise than all the other device combined.

Measurement Techniques

Now that you have an understanding of the primary causes of PFCC failures, let's look at the two primary methods for checking whether or not a PFCC is operating within its designed operating range, current measurements and/or capacitance measurements.

Either method is just as effective but since harmonics can have an effect on true RMS current measurements, it is recommended that both methods be used for validity. Measurements should be taken by qualified personnel only!

<u>Current Measurements</u>

Measured capacitor current can be compared to the chart in Appendix A. It is important to use the correct voltage chart based on the voltage listed on the capacitor nameplate. The charts include expected current measurements for common KVAR ratings at 208, 240, 480, and 600V all 60Hz. These are the most common three phase voltages in North America.

The electrician should measure and record the primary current of each phase of the capacitor. If multiple capacitors exist in the design, the current measurement should be made at the main power distribution device so that the total current of each phase is measured. The intent is to measure the total design current not individual currents of each capacitor element. See Figure 1 for proper measurement locations.

If the current measurement for any phase is lower than the range shown in the charts in Appendix A, the capacitor has experienced degradation and should be replaced.

If the current measurement for any phase is higher than the range shown in the charts in Appendix A, the capacitor should be disconnected and the capacitance should be checked as described below. If the capacitance is within the range listed in Appendix B and the current exceeds the values in Appendix A , it will soon begin to lose capacitance and/or could experience detrimental failure if it is allowed to continue to operate in this kind of environment. This would be a good time to contact the manufacturer or other knowledgeable source such as NUCO Controls to assist with recommended solutions.

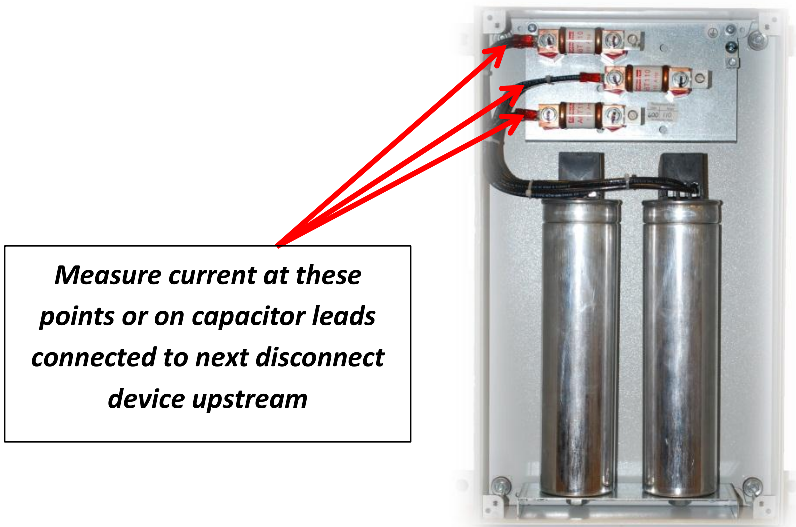

Figure 1 – Current Measurement Location

<u>Capacitance Measurements</u>

Capacitance measurements can be made by most modern day multimeters. *Capacitors must be disconnected from power before measuring capacitance.* The meter must have the ability to read capacitance up to 2500 uF as a minimum. The electrician should make three capacitance measurements, A-B, A-C, and B-C, at the main power distribution device so that the total capacitance is measured. The intent is to measure the total design capacitance not individual capacitance of each capacitor element. See Figure 2 for proper measurement locations.

The measurements can be compared to the range listed on the charts listed in Appendix B. Again, it is important to use the correct voltage chart since capacitance for the same output power will vary depending on voltage.

IEEE Std. 18 is one of several electrical standards that address PFCC designs. IEEE Std. 18 limits designed capacitance for each KVAR to the ranges listed in the charts. The electrician should never see a reading greater than those listed. If the readings are higher, then the capacitor nameplate data is wrong or was misread.

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If the capacitance measurements are lower than shown in the charts in Appendix B, the PFCC has degraded and should be replaced.

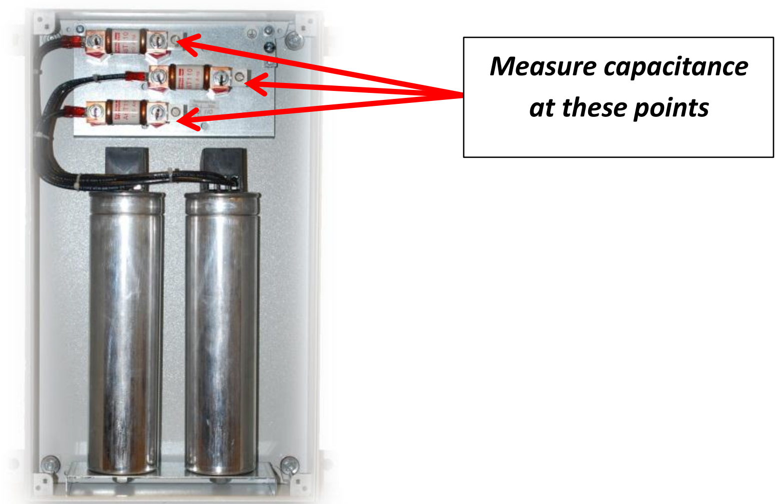

Figure 2 – Capacitance Measurement Location

In either case, low current measurements or low capacitance, the capacitor is likely experiencing high voltage, high frequency, high harmonics, high temperature or a combination of all of these. When a facility experiences the loss of multiple capacitors, there is a very high probability that one or more of these four conditions are present. Before the capacitors are replaced, the operating conditions should be further investigated to ensure it is safe to add capacitors back to the customers electrical system. In many cases where these conditions exist, customized power quality solutions can be developed to solve the issues creating the capacitor failures while allowing the capacitors to perform their intended function.

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APPENDIX A

Power Factor Correction Capacitors
Current Measurements

Current Measurements

	208V		240V		480V		600V	
KVAR	Min	Max	Min	Max	Min	Max	Min	Max
0.5	1.4	1.6	1.2	1.4	0.6	0.7	0.5	0.6
1.0	2.8	3.2	2.4	2.8	1.2	1.4	1.0	1.1
1.5	4.2	4.8	3.6	4.1	1.8	2.1	1.4	1.7
2.0	5.6	6.4	4.8	5.5	2.4	2.8	1.9	2.2
3.0	8.3	9.6	7.2	8.3	3.6	4.1	2.9	3.3
4.0	11.1	12.8	9.6	11.1	4.8	5.5	3.8	4.4
5.0	13.9	16.0	12.0	13.8	6.0	6.9	4.8	5.5
7.5	20.8	23.9	18.0	20.7	9.0	10.4	7.2	8.3
10.0	27.8	31.9	24.1	27.7	12.0	13.8	9.6	11.1
12.5	34.7	39.9	30.1	34.6	15.0	17.3	12.0	13.8
15.0	41.6	47.9	36.1	41.5	18.0	20.7	14.4	16.6
17.5	48.6	55.9	42.1	48.4	21.0	24.2	16.8	19.4
20.0	55.5	63.8	48.1	55.3	24.1	27.7	19.2	22.1
22.5	62.5	71.8	54.1	62.2	27.1	31.1	21.7	24.9
25.0	69.4	79.8	60.1	69.2	30.1	34.6	24.1	27.7
27.5	76.3	87.8	66.2	76.1	33.1	38.0	26.5	30.4
30.0	83.3	95.8	72.2	83.0	36.1	41.5	28.9	33.2
35.0	97.2	111.7	84.2	96.8	42.1	48.4	33.7	38.7
40.0	111.0	127.7	96.2	110.7	48.1	55.3	38.5	44.3
45.0	124.9	143.6	108.3	124.5	54.1	62.2	43.3	49.8
50.0	138.8	159.6	120.3	138.3	60.1	69.2	48.1	55.3
55.0	152.7	175.6	132.3	152.2	66.2	76.1	52.9	60.9
60.0	166.5	191.5	144.3	166.0	72.2	83.0	57.7	66.4
65.0	180.4	207.5	156.4	179.8	78.2	89.9	62.5	71.9
70.0	194.3	223.4	168.4	193.7	84.2	96.8	67.4	77.5
75.0	208.2	239.4	180.4	207.5	90.2	103.7	72.2	83.0
80.0	222.1	255.4	192.5	221.3	96.2	110.7	77.0	88.5
85.0	235.9	271.3	204.5	235.1	102.2	117.6	81.8	94.1
90.0	249.8	287.3	216.5	249.0	108.3	124.5	86.6	99.6
95.0	263.7	303.2	228.5	262.8	114.3	131.4	91.4	105.1
100.0	277.6	319.2	240.6	276.6	120.3	138.3	96.2	110.7

Note: All measurements are in amps.

APPENDIX B

Power Factor Correction Capacitors
Capacitance Measurements

Capacitance Measurements

	208V		240V		480V		600V	
KVAR	Min	Max	Min	Max	Min	Max	Min	Max
0.5	15.3	17.6	11.5	13.2	2.9	3.3	1.8	2.1
1.0	30.7	35.3	23.0	26.5	5.8	6.6	3.7	4.2
1.5	46.0	52.9	34.5	39.7	8.6	9.9	5.5	6.4
2.0	61.3	70.5	46.1	53.0	11.5	13.2	7.4	8.5
3.0	92.0	105.8	69.1	79.4	17.3	19.9	11.1	12.7
4.0	122.6	141.0	92.1	105.9	23.0	26.5	14.7	16.9
5.0	153.3	176.3	115.1	132.4	28.8	33.1	18.4	21.2
7.5	229.9	264.4	172.7	198.6	43.2	49.6	27.6	31.8
10.0	306.6	352.5	230.3	264.8	57.6	66.2	36.8	42.4
12.5	383.2	440.7	287.8	331.0	72.0	82.7	46.1	53.0
15.0	459.8	528.8	345.4	397.2	86.3	99.3	55.3	63.6
17.5	536.5	616.9	403.0	463.4	100.7	115.8	64.5	74.1
20.0	613.1	705.1	460.5	529.6	115.1	132.4	73.7	84.7
22.5	689.8	793.2	518.1	595.8	129.5	148.9	82.9	95.3
25.0	766.4	881.4	575.6	662.0	143.9	165.5	92.1	105.9
27.5	843.0	969.5	633.2	728.2	158.3	182.0	101.3	116.5
30.0	919.7	1,057.6	690.8	794.4	172.7	198.6	110.5	127.1
35.0	1,073.0	1,233.9	805.9	926.8	201.5	231.7	128.9	148.3
40.0	1,226.2	1,410.2	921.0	1,059.2	230.3	264.8	147.4	169.5
45.0	1,379.5	1,586.4	1,036.2	1,191.6	259.0	297.9	165.8	190.7
50.0	1,532.8	1,762.7	1,151.3	1,324.0	287.8	331.0	184.2	211.8
55.0	1,686.1	1,939.0	1,266.4	1,456.4	316.6	364.1	202.6	233.0
60.0	1,839.3	2,115.2	1,381.6	1,588.8	345.4	397.2	221.0	254.2
65.0	1,992.6	2,291.5	1,496.7	1,721.2	374.2	430.3	239.5	275.4
70.0	2,145.9	2,467.8	1,611.8	1,853.6	403.0	463.4	257.9	296.6
75.0	2,299.2	2,644.1	1,726.9	1,986.0	431.7	496.5	276.3	317.8
80.0	2,452.5	2,820.3	1,842.1	2,118.4	460.5	529.6	294.7	338.9
85.0	2,605.7	2,996.6	1,957.2	2,250.8	489.3	562.7	313.2	360.1
90.0	2,759.0	3,172.9	2,072.3	2,383.2	518.1	595.8	331.6	381.3
95.0	2,912.3	3,349.1	2,187.5	2,515.6	546.9	628.9	350.0	402.5
100.0	3,065.6	3,525.4	2,302.6	2,648.0	575.6	662.0	368.4	423.7

Note: All measurements are in uF.