INSULATION POWER FACTOR TESTING

OF

ROTATING MACHINERY

Oleh W. Iwanusiw
AVO International
Scarborough, Ontario, Canada

This guide is especially prepared for testing the quality of insulation of motors, generators and synchronous condenser. Although prepared especially for large, three phase machines, the information is also applicable to two phase, or even to smaller single phase machines.

The ALFA-10 is an insulation power factor test set, providing measurement of the capacitance and power factor, or dissipation factor, of the **ground wall and interphase insulation** used within the machine. The ALFA-10 is not capable of providing information on the turn-to-turn insulation of coils or windings. The turn-to-turn insulation must be evaluated using surge techniques.

1. INTRODUCTION.

The insulation within a machine consists primarily of two parts, the phase to ground insulation and the phase to phase insulation. This is shown in Figure 1.

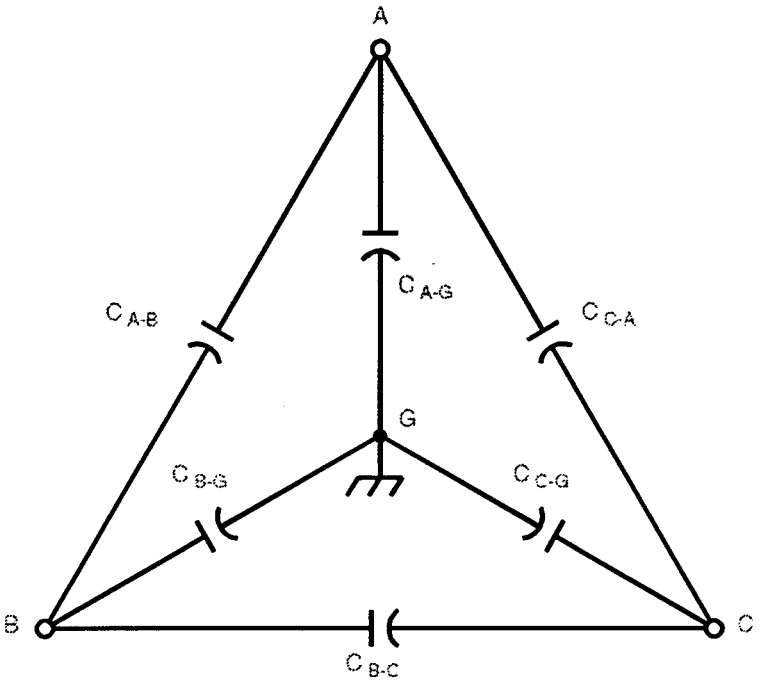

Figure 1.

In a normal situation the machine windings can be separated from each other to allow the measurement of the six components identified in Figure 1. In cases where the windings can not be separated, only one capacitance, all phases to ground, can be measured and assessed. This single measurement is usually of limited use.

2. TEST CONNECTIONS.

2.1 MACHINES WITH SIMPLE WINDINGS.

It is assumed that the machine stator winding has its star point, or its delta connection, disconnected to provide three separate windings. The diagram of capacitances to be measured is shown in Figure 1. To measure all the required quantities, three separate connections and a minimum of 6, but preferably 9 measurements should be taken. To double check every one of the measurements, it may be desirable to make a full set of 21 readings. Listing of the connections and measurements is as follows:

HIGH VOLTAGE	RED LEAD	BLUE LEAD	TESTS
Phase A	Phase B	Phase C	**1, 2, 3, 4, 5, 6, 7.**
Phase B	Phase C	Phase A	**1, 2, 3, 4, 5, 6, 7.**
Phase C	Phase A	Phase B	**1, 2, 3, 4, 5, 6, 7.**

The minimum measurements are tests #1 and 5. It is preferred to do include also #2 which duplicates interphase readings. These readings are outlined in **bold.** By conducting tests 1 to 7 on all three phases it is possible to double check every one of the readings.

2.2 MACHINES WITH PARALLEL WINDINGS.

In some instances the machine may have two parallel windings on each phase. With all of these disconnected from the star point, one will obtain six windings to test. The diagram of capacitances to be measured is shown in Figure 2. Each winding should be tested with respect to ground and with respect to the other five windings. This procedure and the number of readings is quite extensive and involved. The table below lists the connections that have to be made and readings that are to be obtained.

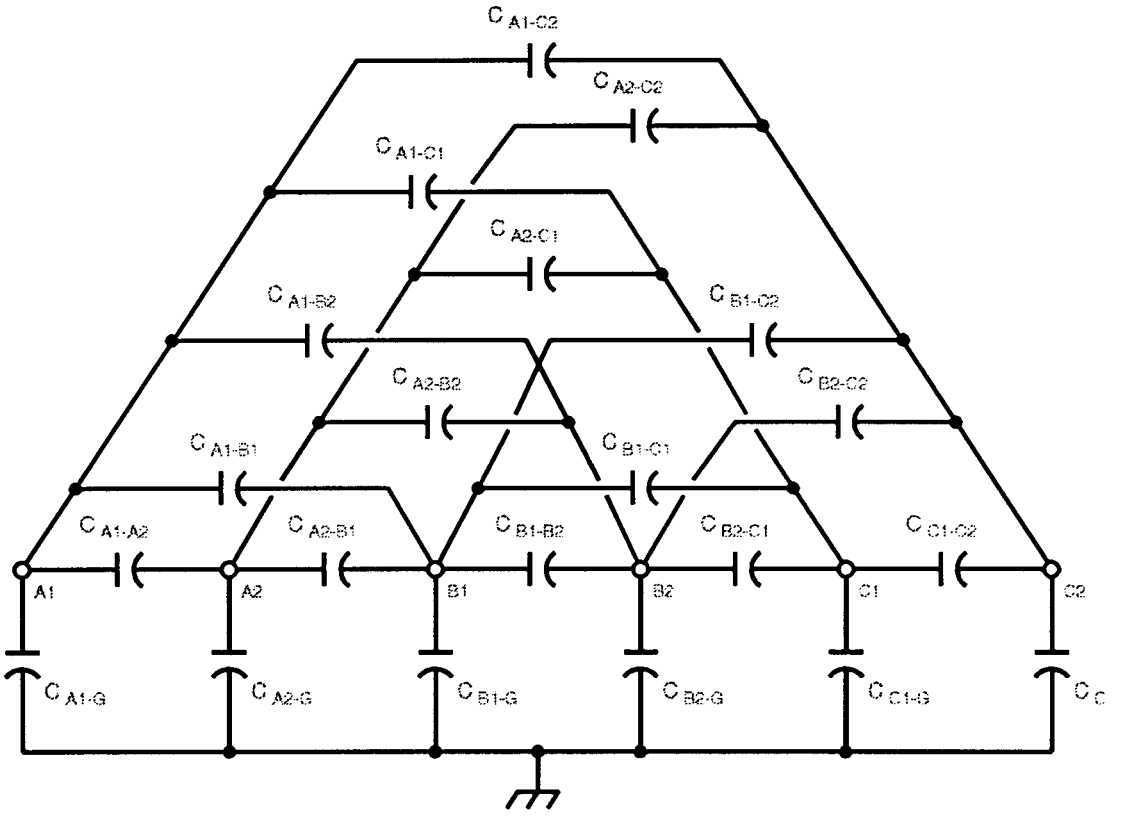

Figure 2.

Capacitances associated with winding A1 are measured with the HIGH VOLTAGE lead connected to A1. The other connections are as given below in the table.

	CAPACITANCE	RED LEAD	BLUE LEAD	TEST NUMBER
		Connect HIGH VOLTAGE to A1.		
1.	A1-G	A2	B1, B2, C1, C2	5 G[R+B]
2.	A1-A2	A2	B1, B2, C1, C2	1 R[G+B]
3.	A1-B1	B1	B2, C1, C2, A2	1 R[G+B]
4.	A1-B2	B2	C1, C2, A2, B1	1 R[G+B]
5.	A1-C1	C1	C2, A2, B1, B2	1 R[G+B]
6.	A1-C2	C2	A2, B1, B2, C1	1 R[G+B]
		Connect HIGH VOLTAGE to A2.		
7.	A2-G	A1	B1, B2, C1, C2	5 G[R+B]
8.	A2-A1	A1	B1, B2, C1, C2	1 R[G+B]
9.	A2-B1	B1	B2, C1, C2, A1	1 R[G+B]
10.	A2-B2	B2	C1, C2, A1, B1	1 R[G+B]
11.	A2-C1	C1	C2, A1, B1, B2	1 R[G+B]
12.	A2-C2	C2	A1, B1, B2, C1	1 R[G+B]
		Connect HIGH VOLTAGE to B1.		
13.	B1-G	B2	C1, C2, A1, A2	5 G[R+B]
14.	B1-B2	B2	C1, C2, A1, A2	1 R[G+B]
15.	B1-C1	C1	C2, A1, A2, B2	1 R[G+B]
16.	B1-C2	C2	A1, A2, B2, C1	1 R[G+B]
17.	B1-A1	A1	A2, B2, C1, C2	1 R[G+B]
18.	B1-A2	A2	B2, C1, C2, A1	1 R[G+B]
		Connect HIGH VOLTAGE to B2.		
19.	B2-G	B1	C1, C2, A1, A2	5 G[R+B]
20.	B2-B1	B1	C1, C2, A1, A2	1 R[G+B]
21.	B2-C1	C1	C2, A1, A2, B1	1 R[G+B]
22.	B2-C2	C2	A1, A2, B1, C1	1 R[G+B]
23.	B2-A1	A1	A2, B1, C1, C2	1 R[G+B]
24.	B2-A2	A2	B1, C1, C2, A1	1 R[G+B]
		Connect HIGH VOLTAGE to C1.		
25.	C1-G	C2	A1, A2, B1, B2	5 G[R+B]
26.	C1-C2	C2	A1, A2, B1, B2	1 R[G+B]
27.	C1-A1	A1	A2, B1, B2, C2	1 R[G+B]
28.	C1-A2	A2	B1, B2, C2, A1	1 R[G+B]
29.	C1-B1	B1	B2, C2, A1, A2	1 R[G+B]
30.	C1-B2	B2	C2, A1, A2, B1	1 R[G+B]
		Connect HIGH VOLTAGE to C2.		
31.	C2-G	C1	A1, A2, B1, B2	5 G[R+B]
32.	C2-C1	C1	A1, A2, B1, B2	1 R[G+B]
33.	C2-A1	A1	A2, B1, B2, C1	1 R[G+B]
34.	C2-A2	A2	B1, B2, C1, A1	1 R[G+B]
35.	C2-B1	B1	B2, C1, A1, A2	1 R[G+B]
36.	C2-B2	B2	C1, A1, A2, B1	1 R[G+B]

It should be pointed out that the above 36 readings provide duplication of the phase-to-phase capacitance measurements. This is a convenient method of checking the work and test results. Due to the large variety of connection that are required, the 810283 MULTI LEAD SELECTOR would be a convenient accessory to have available. The MULTI LEAD SELECTOR has eight low voltage inputs and therefore can be used for testing machines with two or three parallel windings per phase. The reading metrics for the three winding per phase machine is considerably more complex then for the two winding machine shown above.

3. TEST VOLTAGE.

The maximum test voltage for a rotating machine depends on the age of the machine and the maintenance practices of the utility. Insulation of **new machines** is typically tested for power factor up to the high pot voltage, which is twice the line-to-line rating. Power factor measurements on such machine insulation would be made at least at four test voltages, namely $2xV_{rated}$, $1.5xV_{rated}$, V_{rated} and $0.5xV_{rated}$. In many cases the power factor would be measured at many more voltage test points, typically every 5 or 10% of the machine voltage rating. The difference between the power factor at rated voltage and that at half the rated voltage is referred to as TIP-UP.

For **used machines**, the test voltage seldom exceeds the voltage rating, and in many instances is limited to the phase voltage of the machine. Similarly as for new equipment, a minimum of 4 test points are taken.

In summary, the following are the typical test points:

New Equipment: Max. Test voltage = $2xV_{rated}$

Used Equipment: Max. Test voltage = V_{rated} or $0.6xV_{rated}$

The number of test points should not be fewer then 4. When doing the minimum 4 test points, they should be 100, 50, 25 and 12% of the maximum test voltage. When doing tests at 10 to 20 voltages, these should be evenly distribute at every 5 or 10 % of the maximum test voltage.

4. TEST PROCEDURES.

The test procedure depends on the size of capacitance and the required test voltage. Figure 5A through 5D show the capability of the ALFA-10 and its power supply by itself and with one or two 810287 INDUCTORS. Figure 3 or the listing below can be used to determine if the ALFA-10 can be used directly.

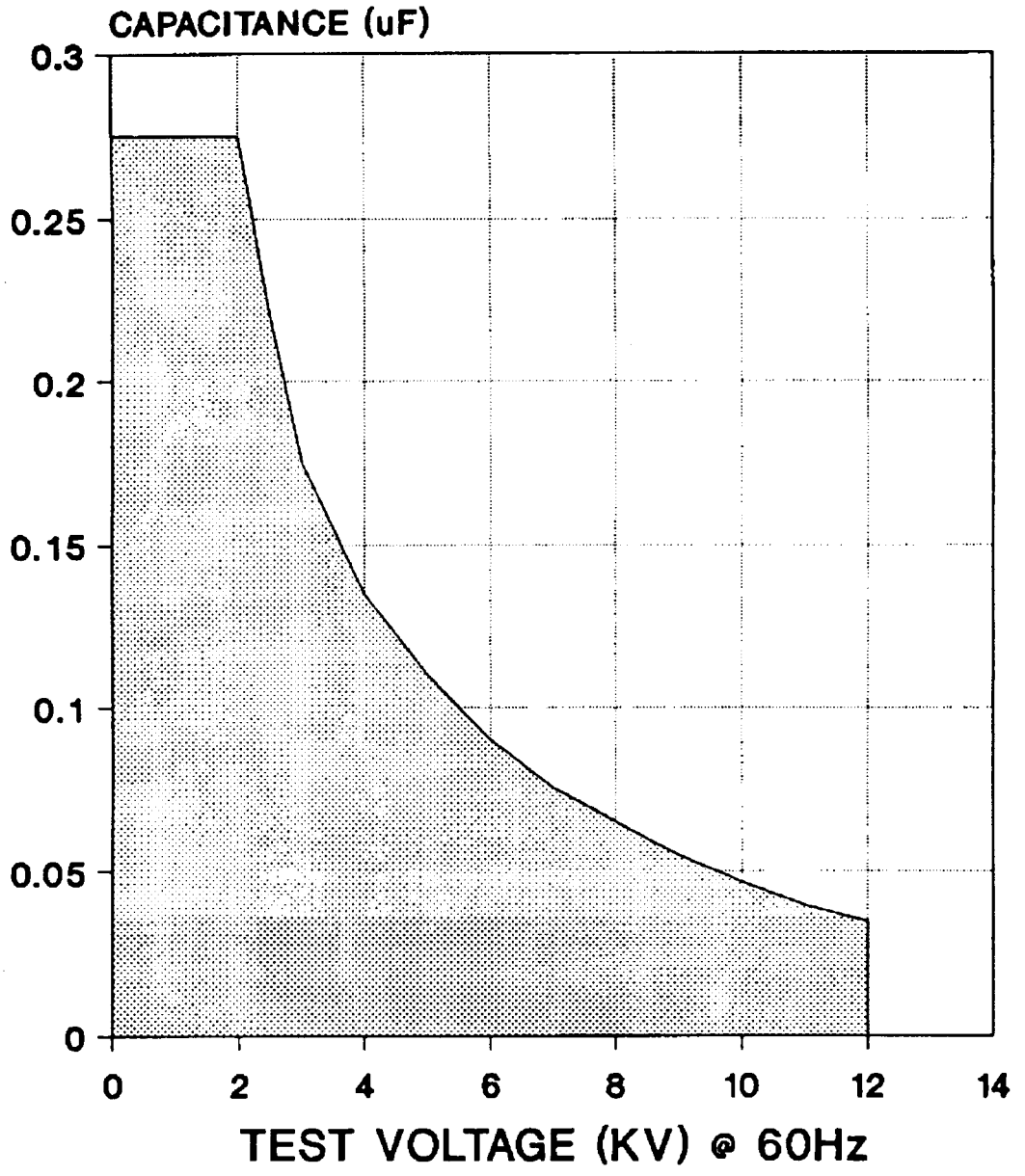
CAPACITANCE (uF)
0.3
0.25
0.2
0.15
0.1
0.05
0
0
2
4
6
8
10
12
14
TEST VOLTAGE (KV) @ 60Hz

Figure 3.

Capacitance charging capacity of ALFA-10 power supply:

0.066 μF @ 8 kV 60 Hz (0.08 @ 50 Hz),
0.088 μF @ 6 kV 60 Hz (0.106 @ 50 Hz),
0.13 μF @ 4 kV 60 Hz (0.16 @ 50 Hz),
0.26 μF @ 2 kV 60 Hz (0.32 @ 50 Hz), and
0.52 μF @ 1 kV 60 Hz (0.64 @ 50 Hz).

As can be seen that at low voltage, the power supply can provide charging current to a larger capacitance then can be measured by the ALFA-10, as the instrument's range is limited to 0.26 ALFA-10.

4.1 Preliminary Measurements.

The purpose of these measurements is to determine if the ALFA-10 can test the machine directly, or if auxiliary equipment is required.

If the capacitance values and test voltages for the machine are known, this preliminary test can be omitted and the operator should proceed directly to SECTION 4.2 to determine if he should follow TEST PROCEDURE #1, 2 or 3 in SECTION 5, 6 or 7.

To determine the values of the capacitance to be measured, connect the ALFA-10 as shown in Figure 4 and conduct test #1, 2 and 5. The test should be conducted at low voltage, 250 - 1000 volts. The ALFA-10 will provide readings of the capacitances even if they are much higher then 0.26 ALFA-10, but with reduced accuracy. Only one phase of the machine need be tested, as the other phases should be of approximately the same value.

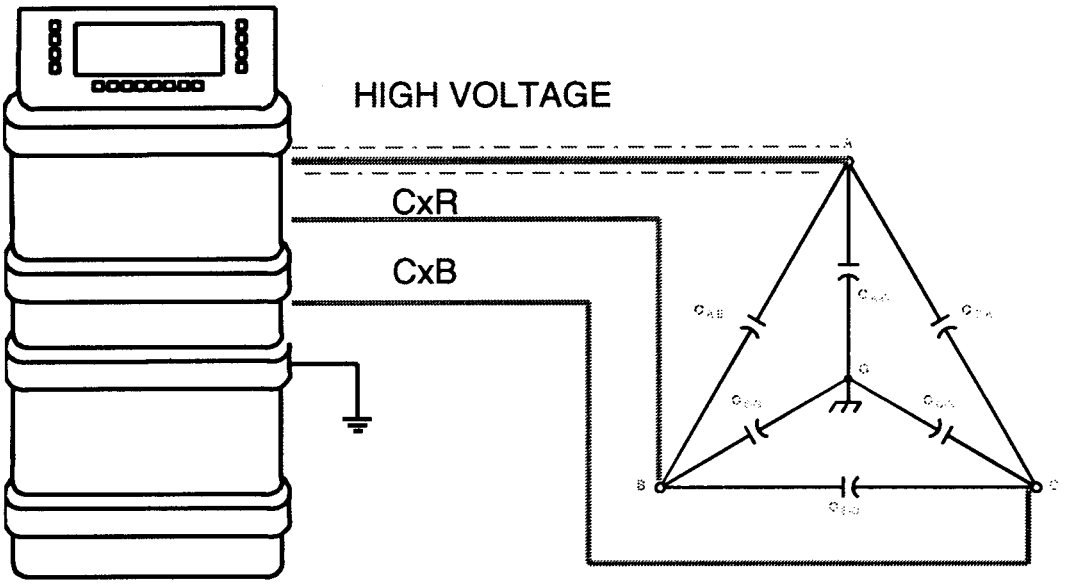

Figure 4.

4.2 Observations and Determination.

From the measurement above, determine the **largest capacitance** to be measured and the **SUM of the capacitances** to be supplied by the power supply.

A. If the largest capacitance is less then 0.26 ALFA-10 proceed to C.

B. If the largest capacitance is more then 0.27 ALFA-10 proceed to ITEM 7 - TEST PROCEDURE #3.

C. If the SUM of the capacitances is less then the capacity of the power supply, at the highest desired test voltage, proceed to ITEM 5 - TEST PROCEDURE #1.

If the SUM of the capacitances is more then the capacity of the power supply at the highest desired test voltage, proceed to ITEM 6 - TEST PROCEDURE #2.

5. TEST PROCEDURE #1.

ALFA-10 without auxiliary accessories.

This procedure is for conditions where the maximum capacitance to be measured is less then 0.27 ALFA-10 and the charging capacitance is within the limitations of the power supply at the maximum test voltage. No additional equipment is required for this procedure.

Connect the ALFA-10 according to the table in SECTION 2.1 or 2.2, whichever is appropriate, and conduct the measurements at the decided test voltages.

Refer to section 8 for assistance in interpreting the test results.

6. TEST PROCEDURE #2.

ALFA-10 with 810287 Fixed Inductors.

This procedure is for conditions where the maximum capacitance is less then 0.27 ALFA-10, but the power supply is not capable of delivering the charging current.

This test procedure requires one or more 810287 Fixed Inductors (810287-1 for 50 Hz).

PROCEDURE.

1. Examine Figure 5A through 5D to determine if one or two inductors are required.

2. Once the use of one or two inductors have been determined, proceed to test the machine at the desired test voltages using connections from SECTION 2.1 or 2.2, as appropriate.

3. Refer to section 8 for assistance in interpreting the test results.

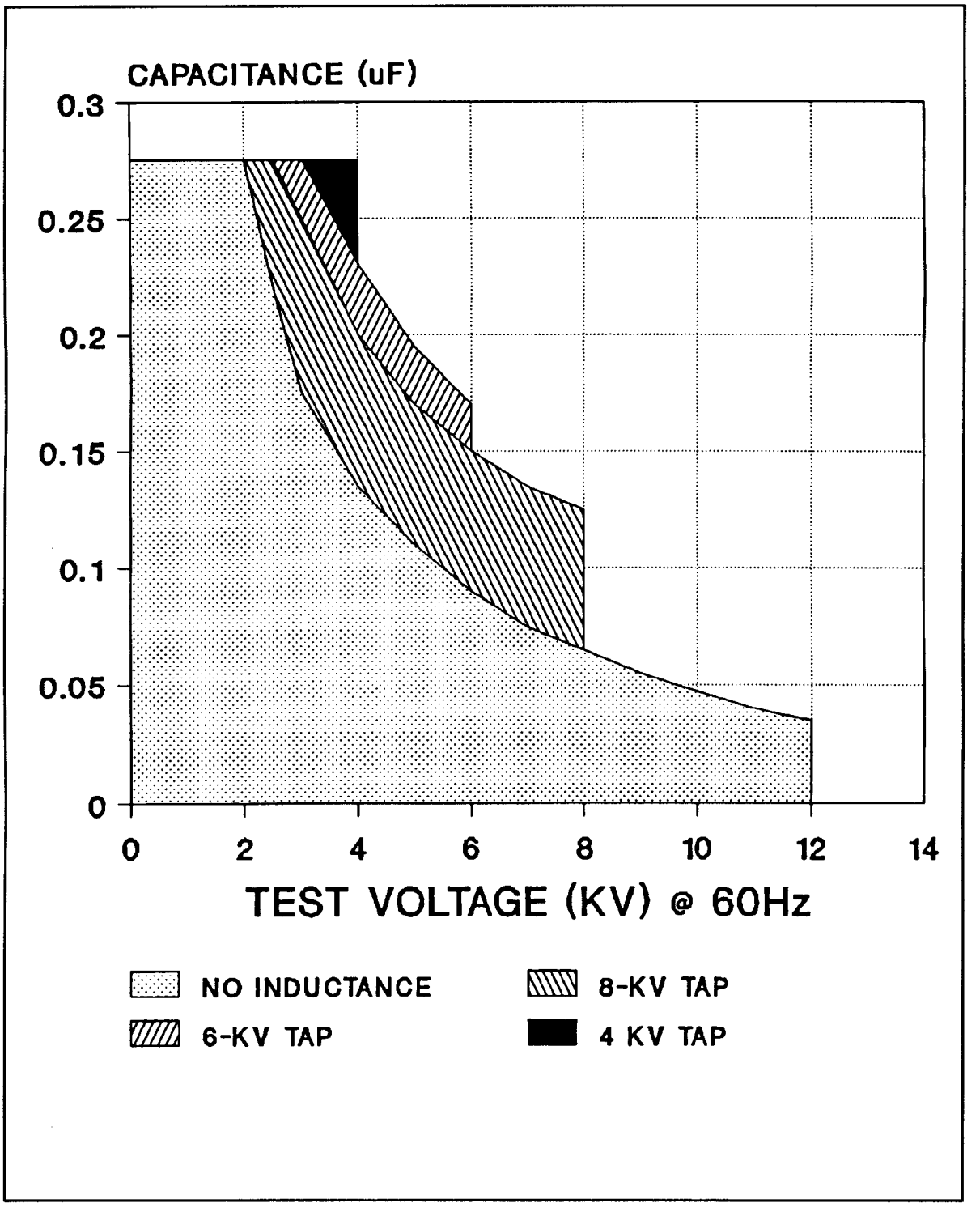

FIGURE 5A. USING ONE COMPENSATING INDUCTOR @ 60 Hz

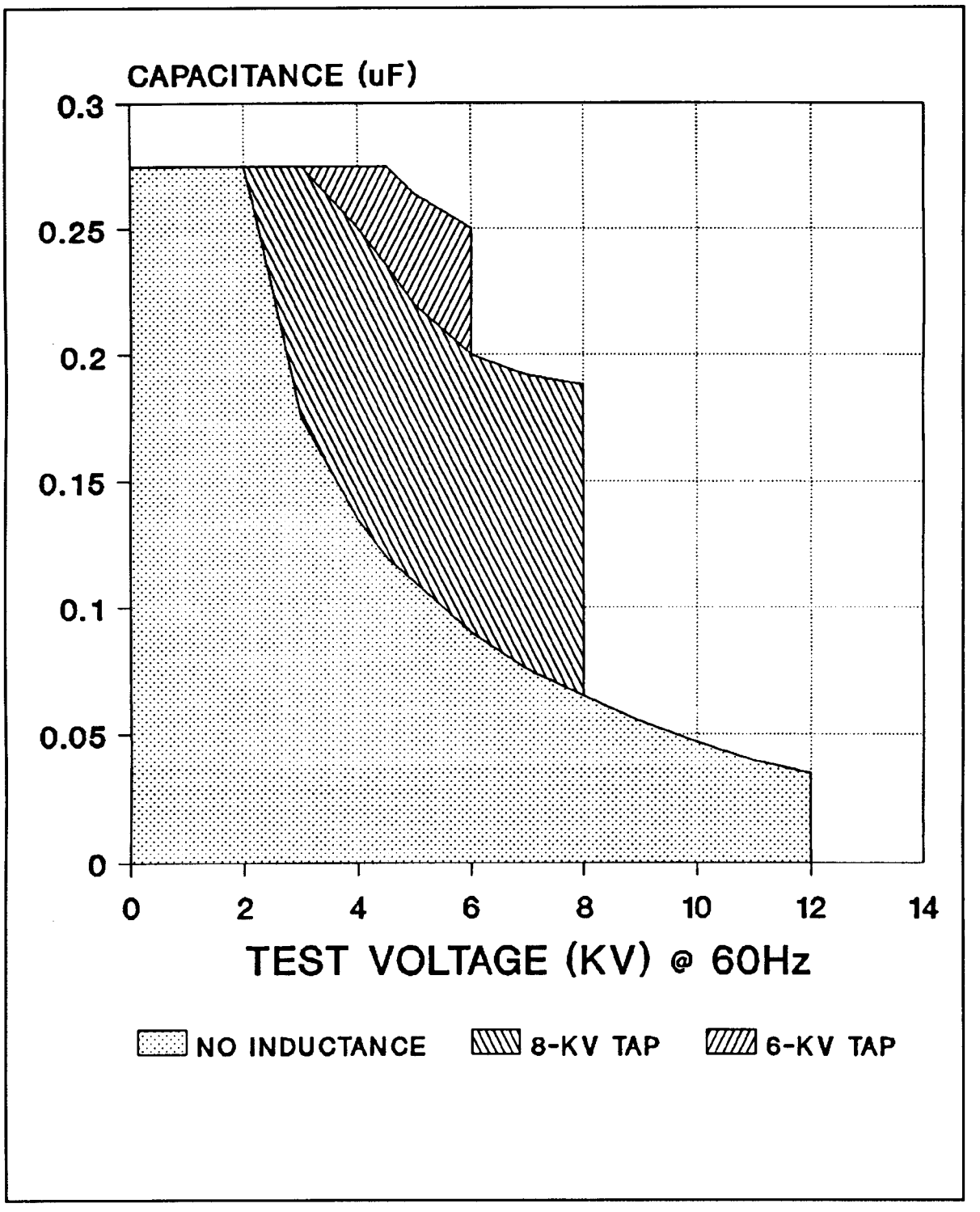

FIGURE 5B. USING TWO COMPENSATING INDUCTOR @ 60 Hz

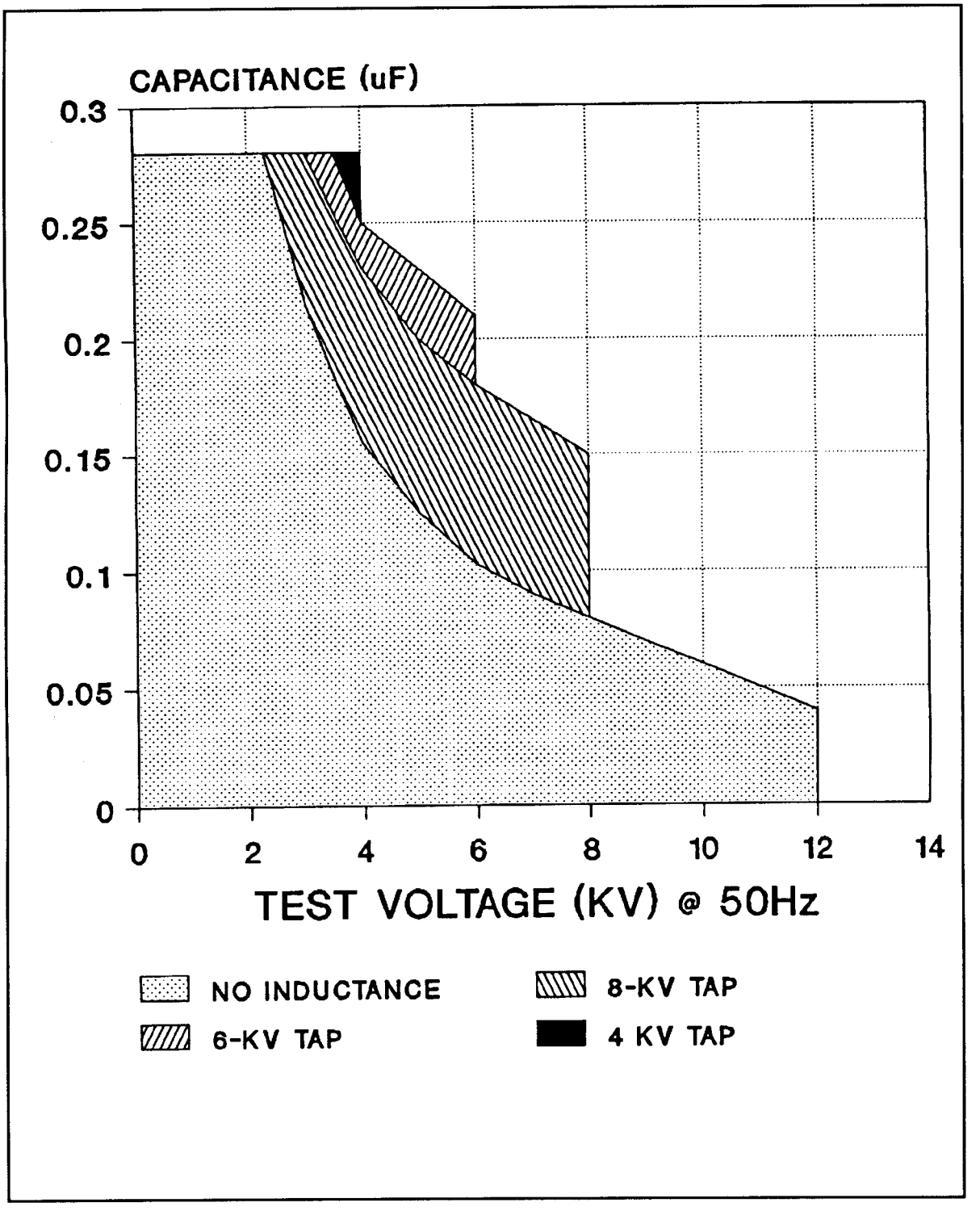

FIGURE 5C. USING ONE COMPENSATING INDUCTOR @ 50 Hz

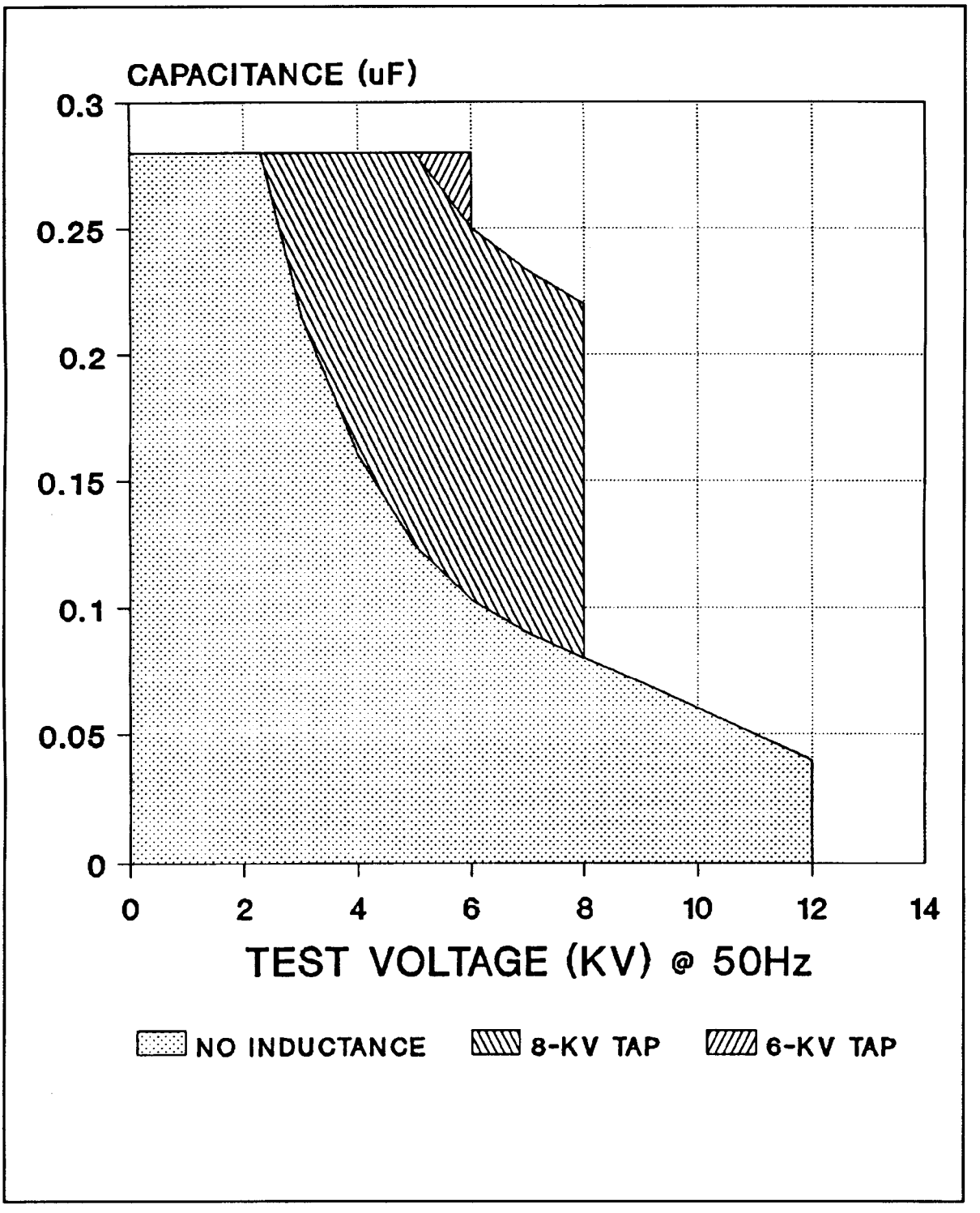

FIGURE 5D. USING TWO COMPENSATING INDUCTOR @ 50 Hz

7. TEST PROCEDURE #3.

ALFA-10 with 670600 Resonating Inductor.

This procedure is for conditions when the largest capacitor to be measured is more then 0.27 ALFA-10 and the power supply can not supply the required charging current at the maximum test voltage. Please refer to figures 6A and 6B.

Additional equipment required includes:

A. 670600 RESONATING INDUCTOR, and
B. 810288 INTERFACE MODULE.

PROCEDURE:

1. Connect the RESONATING INDUCTOR and the INTERFACE MODULE to the ALFA-10 as per instructions in their manuals.

2. Conduct the tests as per connections specified in SECTION 2.1 or 2.2, whichever is appropriate.

3 Note that the capacitance of each connection should be approximately the same, therefore once the RESONATING INDUCTOR is adjusted for one phase, little adjustment should be required as the connections are switched from phase to phase.

4. Refer to section 8 for assistance in interpreting the test results.

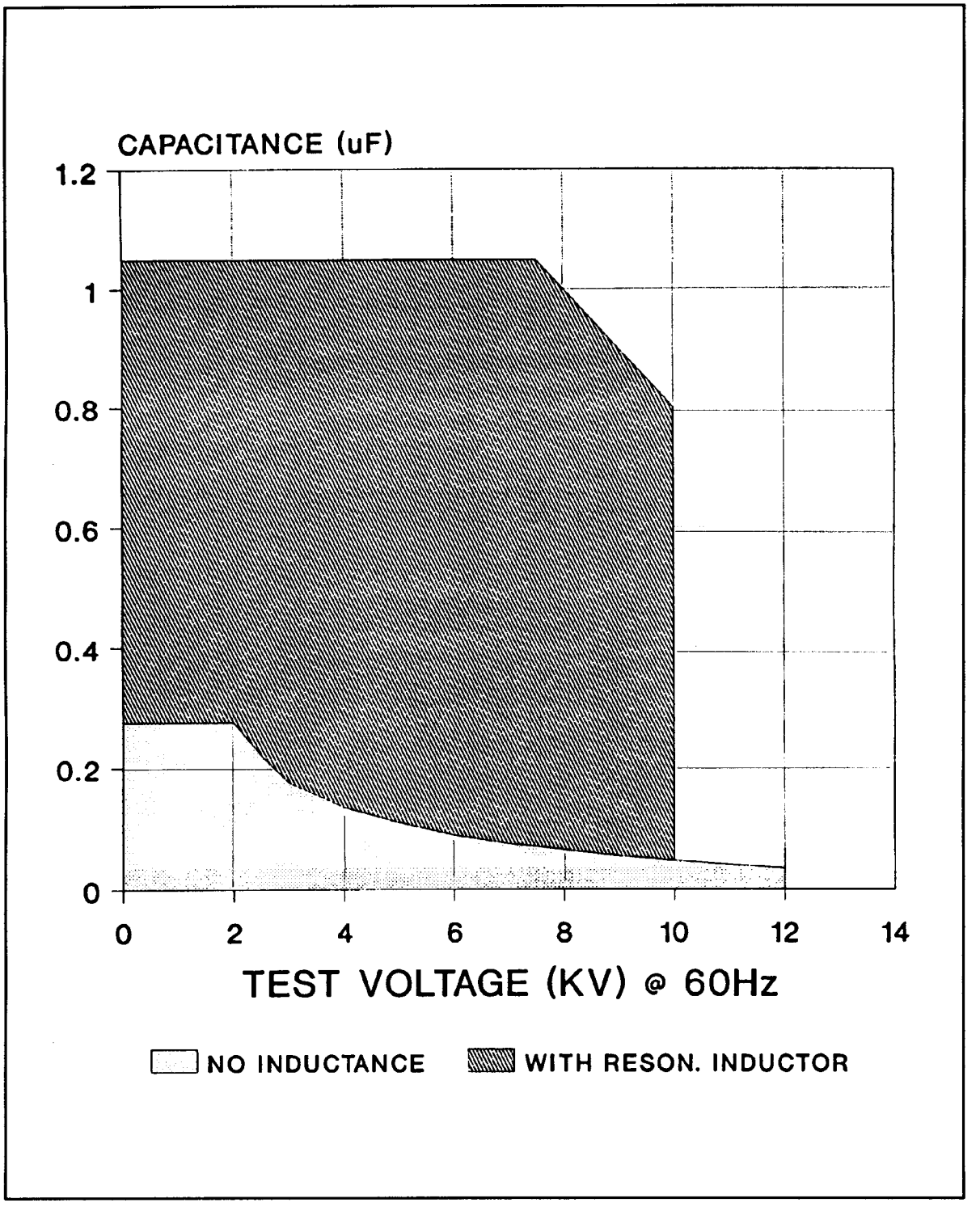

FIGURE 6A. USING THE RESONATING INDUCTOR @ 60 Hz

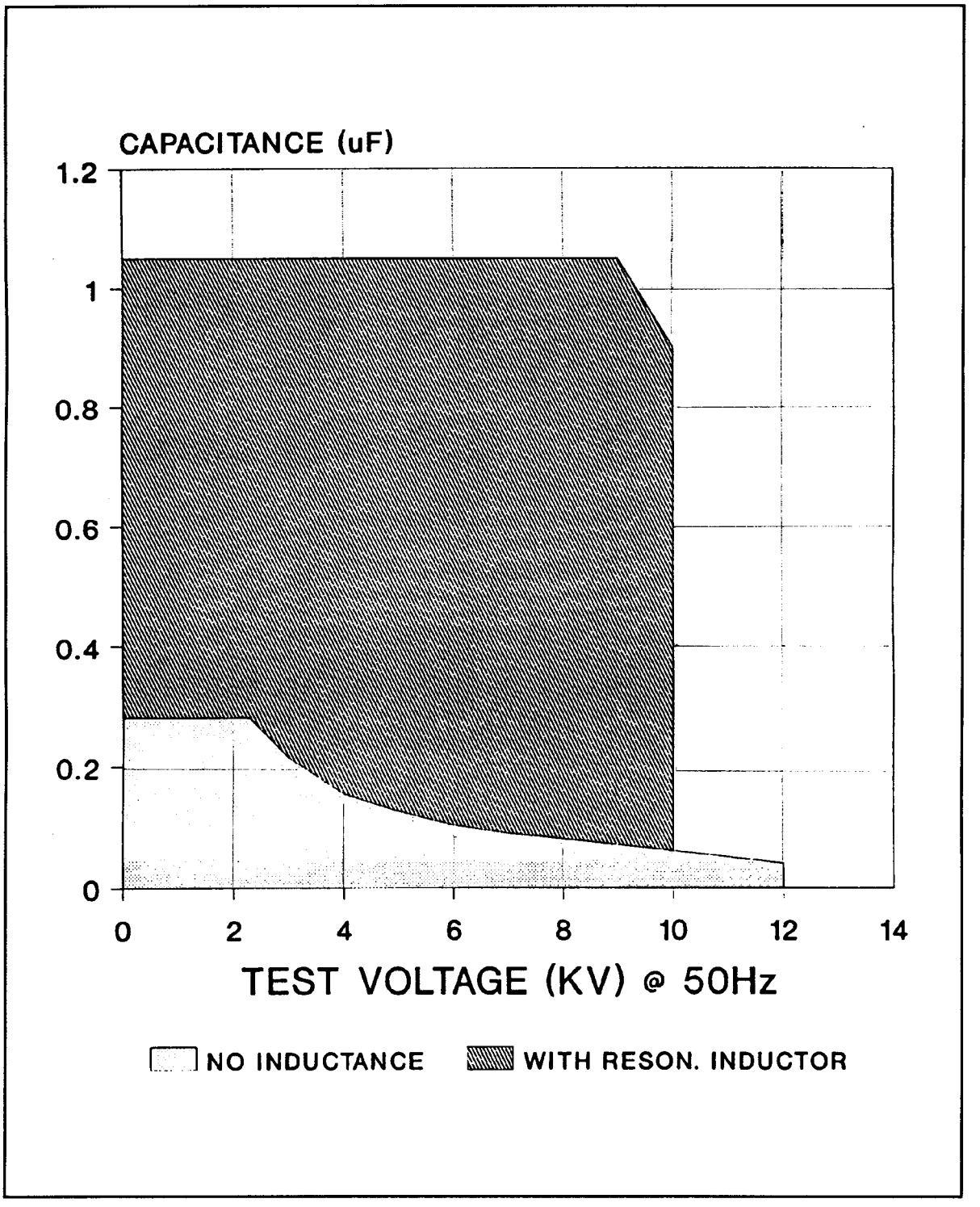

FIGURE 6B. USING THE RESONATING INDUCTOR @ 50 Hz

8. INTERPRETATION OR RESULTS.

There are three determinations that will help asses the condition of the machine insulation. These are:

1. Power factor at low voltage.

2. Power factor TIP-UP.

3. Comparison between phases.

To help in the interpretation of the test results, it is convenient to prepare plots of the power factor of the insulation against the test voltage for the different portions of the insulation. It is most convenient to have data available from factory tests or from previous measurements in order to make a proper judgement.

1. POWER FACTOR AT LOW VOLTAGE.

The power factor of the insulation at low voltage is an indiction of the condition of the insulating material. Thus if the power factor at low voltage has increased, it indicates the possibility of moisture or other contamination of the insulation.

The moisture content of insulation can typically be confirmed by a DC insulation test. Moist insulation will show unacceptably low insulation resistance.

The power factor of older insulating materials is very susceptible to absorption and penetration by moisture. Modern insulating materials are typically impervious to moisture and do not exhibit the same effect.

It should be remembered that it is the trend of the increasing power factor of the machine insulation that should initiate corrective action rather then the absolute value of the power factor.

2. POWER FACTOR TIP-UP.

Power factor tip up is a measure of the insulation at higher voltage. Power factor tip up indicates non linearities in the insulation. Tip-up is caused by partial discharge activity within the insulation and is undesirable as it cause further degradation of the insulation.

The acceptable amount of tip-up depends on the type of insulation used. Older types of insulation systems, such as "asphalt-mica", are quite tolerant of partial discharge and will perform adequately for a long period of time even if they exhibit substantial tip-up. They exhibit substantial tip-up even when new. Excessive tip-up on older

machines may indicate a need for rewinding the stator.

New types of insulation, using polyester and epoxy type resins, do not tolerate partial discharge as well. Because the insulation is typically very hard it suffers from damage due to vibration and stresses caused by the differential expansion and contraction of component as the machine heats up and cools down due to the loading cycles.

Excessive tip-up on machines with modern insulation may indicate a need to re-wedge the windings, reapplication of semiconductor voltage stress grading areas, or other problems.

With age and deterioration, the tip-up will increase or the same tip-up will be exhibited at a lower voltage.

3. COMPARISON BETWEEN PHASES.

It should be remembered that each machine will have at least six similar components of insulation. These components will show a gradual increase in power factor and tip-up with age if they are deteriorating similarly.

The similarity between the readings on a machine can be used to draw certain conclusions even if prior history of the machine insulation is not available. Thus, if any one of the components shows a marked difference from the others, this should trigger and investigation and perhaps additional test.

The capacitance and the power factor of the phase to ground insulation should provide the same, if not identical readings. The same applies to the three phase to phase readings.

Even though the phase to ground insulation will exhibit a much different capacitance then the phase to phase insulation, their power factor should be basically the same.

GOOD LUCK

AND

GOOD MEASUREMENTS!