CHAPTER - 4

VOLTAGE DISTRIBUTION ACROSS THE TEST OBJECT AND SUPPORTING CAPACITANCE:EFFECT OF DAMPING RESISTOR

4.1 General

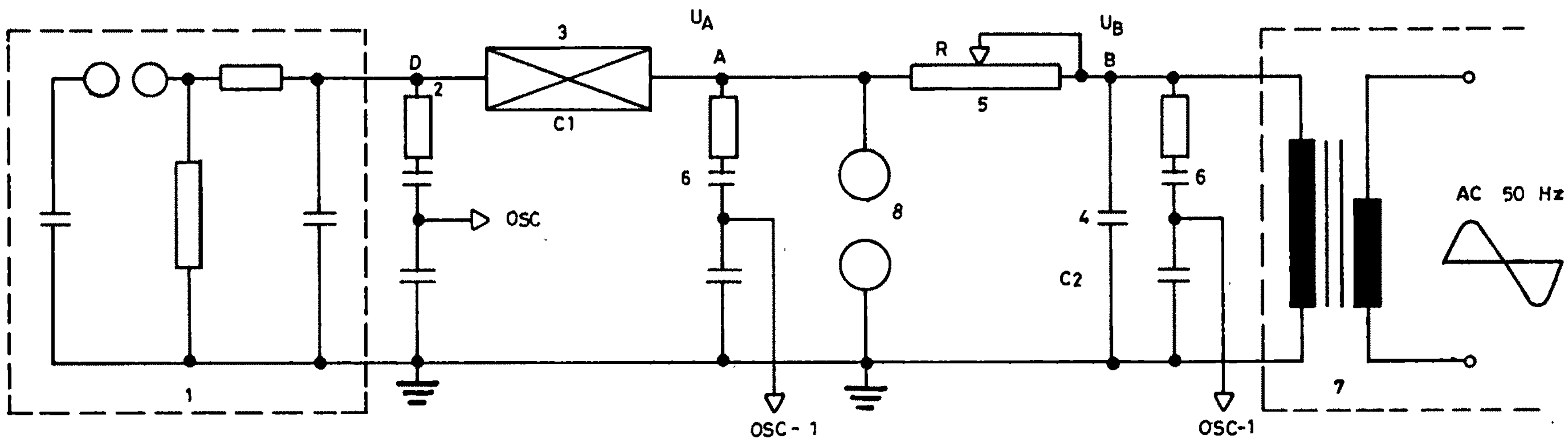
It has been discussed in detail in Chapter-3 regarding the protection of the high voltage testing transformer in the event of a flashover across the open gap i.e. the longitudinal insulation. To reduce the severity of the chopped wave on the testing transformer, it is advisable to connect a high voltage damping resistor between the test object terminal and the supporting capacitance. From the protection point of view of the High Voltage Testing Transformer, this is the best location of the damping resistor. Higher the value of the damping resistor, the severity of the chopped wave on the high voltage transformer winding insulation reduces drastically.

Some of the international laboratories adopted different circuits for conducting bias voltage test. The main difference was in the connection of the HV damping resistor. IEC publications-56 and -129 have specified some requirements to be satisfied while conducting bias voltage test. The interpretation of the bias test requirement specified by these standards is studied theoretically based on the legal aspects and from the systems requirement point of view and the same is discussed in this Chapter. The bias test circuit layout and some of the results reported in the literature are discussed in brief.

Experiments were carried out to study the effect of location of the damping resistor on the voltage distribution across the test object and the series combination of the damping resistor R and the supporting capacitor C_2(refer Figure 4.1) when impulse voltage is applied to the opposite electrode (point D of Figure 4.1). The transferred impulse voltage on AC terminal at point A and B i.e voltage U_A and U_B were measured for various combinations of the supporting capacitance and damping resistance for capacitive controlled rod-rod gap and rod-rod gap electrodes configurations for lightning and switching impulse voltages. The various results obtained were analysed and discussed in detail in the following sections. The transferred impulse voltage for some cases was measured using damped capacitive voltage divider and resistive voltage divider. Some of the problems faced while conducting experiments are also highlighted.

4.2 Requirement of standards and their interpretation

The IEC publications-56 and 129, give very little information regarding the bias voltage test on capacitive controlled rod-rod gap and disconnector type open gaps. No bias voltage test circuit layout is given in either of these two standards. These publications have made some reference regarding the test arrangement. However, one can interpret the same in different ways, as convenient, from time to



1. Impulse Voltage Generator
2. Damped capacitive voltage divider, 2200 KV, 713 pF
3. Test object, (either Rod - Rod gap, or capacitive controlled gap, see figure 4.9)
4. Supporting capacitor C2
5. Variable high voltage damping resistor 0 to 8.56 KΩ (variable in steps)
6. Damped capacitive voltage divider, 60 KV, 99.98 pF
7. Power frequency transformer, 750 KV, 750 KVA
8. Sphere gap for protection

Note: -When voltage U_A is measured the divider (6) is connected at point A
-When voltage U_B is measured the divider (6) is connected at point B

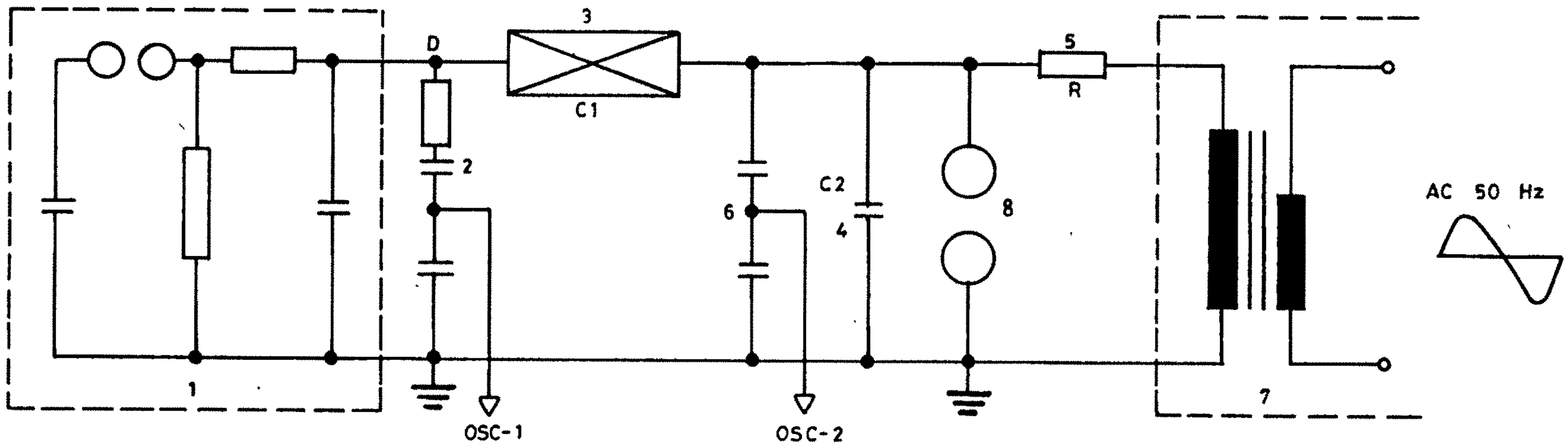
Figure.4.1 Circuit layout for the measurement of transferred impulse voltage at terminals "A" and "B" time. IEC publications 129 states that 'the opposite terminal energized at the power frequency voltage $0.7U/\sqrt{3}$ kV (r.m.s. value) in case of lightning impulse bias test and $U/\sqrt{3}$ kV in case of switching impulse bias test' where U is the rated system voltage. Consequently, even with a damping resistor connected between the supporting capacitance and the test object terminal as shown in Figure 4.1, can also meet the obligations of both the standards if the requirement of the voltage distortion on AC wave is fulfilled. IEC publication-129 also states that 'the voltage drop can be greatly reduced by using a capacitor of convenient value connected in parallel to the terminal of the power frequency side'. This statement is for guidance and although it implies that it would be better to have the supporting capacitor, C_2, connected directly to the terminal of the test object. However, the test does not specifically state that it is obligatory. Therefore, one may test the test object by connecting the damping resistor between the supporting capacitor and the test object terminal, and may comply with the requirement of the standards, which however may not be correct in true sense.

Sometimes the voltage grading across the interrupters is achieved by resistors or resistor/capacitor combinations. Consequently, if a high ohmic damping resistor is connected between the supporting capacitor C_2 and the terminal of the circuit breaker, the impulse voltage distribution across the interrupters would be different than would be the case when the supporting capacitor is directly connected to the test object terminal.

4.3 Interpretation of standards as per the system requirements

Discussions in the above section pertains to the strictly legal aspects of the standards. However, it is felt that, if the object is tested by connecting the damping resistor between the supporting capacitor and the test object terminal, the longitudinal insulation is not stressed to the required test voltages and hence the performance of the equipment in the system cannot be guaranteed.

Whenever such a strict interpretation of a relevant standard of the equipment under test is difficult to obtain, a comparison between the test arrangement and the service conditions will frequently help to clarify the correct situation. For example, in service condition when an open switch is energized on one side, the power supply will be either a transmission line or a large power transformer. In either case the source impedance will be very low. Therefore, the laboratory set-up should try, as far as possible to simulate this condition. This condition is usually achieved in the laboratory by connecting a large capacitor directly to the terminal of the open switch. Thus it is felt that the insertion of a damping resistor between the supporting capacitor and the terminal of the test object would not be a faithful reproduction of the service conditions and it would be better to avoid such an arrangement. Hence, it is advisable to adopt the bias test circuit shown in Figure 4.2.



1. Impulse voltage generator; 2200 KV, 66 KJ, "HAEFELY" make.
2. Capacitive voltage divider for impulse voltage measurement; 2000 KV, 713 pF; "HAEFELY" make.
3. Test object (for details, see figure 4.9)
4. Supporting capacitor C2
5. Damping resistors 0 to 8·56 KΩ (Variable in steps)
6. Capacitive voltage divider for power frequency voltage measurement; 650 KV, 866·66 pF.
7. Power frequency voltage transformer, 750 KV, 750 KVA; "KEC" make.
8. Sphere gap for protection.

OSC-1 Impulse Oscilloscope; "HAEFELY" make.
OSC-2 General purpose oscilloscope; "HEWLETT PACKARD" make.

Figure. 4.2 Test circuit for conducting bias voltage test.

4.4 Test circuit adopted by various laboratories

Udo/75/ conducted bias test on a vertical rod-rod gap configuration using switching impulse voltage and a power frequency voltage. The switching impulse voltage was applied to the upper electrode of a vertical rod-rod gap, synchronizing to the crest of the 50 Hz voltage which was supplied to the lower rod continuously. The peak value of the power frequency voltage was kept constant. The test circuit used by Udo is given in Figure 4.3. A damping resistor of 4 Kilo Ohms was connected between the lower rod terminal and the supporting capacitance. The results obtained by him are given in Figure 4.4.

Boyd et al/81/ conducted bias test on a horizontal rod-rod gap. The test circuit is described in Figure 4.5. Two impulses of different polarities were applied to the two buses, as shown in Figure 4.6. Impulse generator was set to give 350/3000 microseconds wave and the negative polarity impulse was obtained with the use of High Voltage Transformmer by discharging a 390 microfarad capacitance through the primary winding. The time-to-crest was approximately 2000 microseconds. The damping resistor of 10Kilo Ohms and rod-plane gaps (G) were used for the protection of the High Voltage Testing transformer.

One of the international laboratories conducted bias test on capacitive controlled gap(UHV range circuit breaker), where a damping resistor of 7.5 Kilo Ohms was connected between the supporting capacitor C_2 and the circuit breaker terminal. The test object capacitance was 325pF, i.e. the circuit shown in Figure 4.1 was adopted for bias volt-

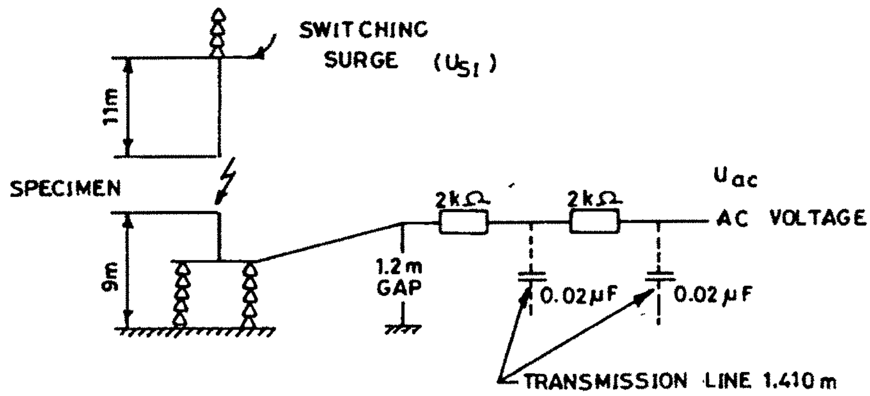
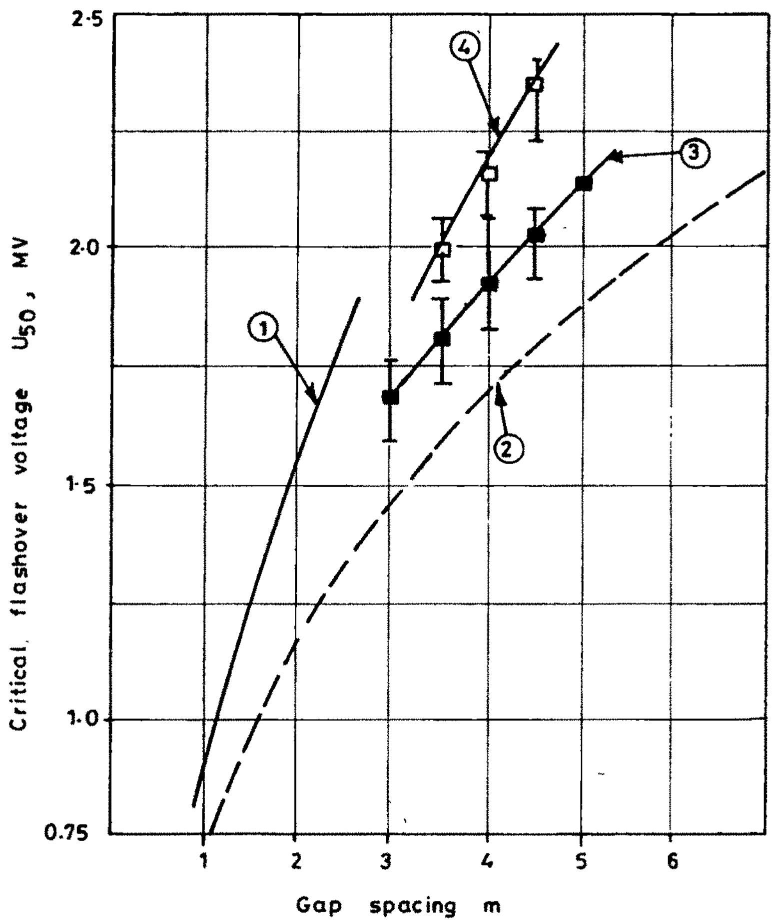
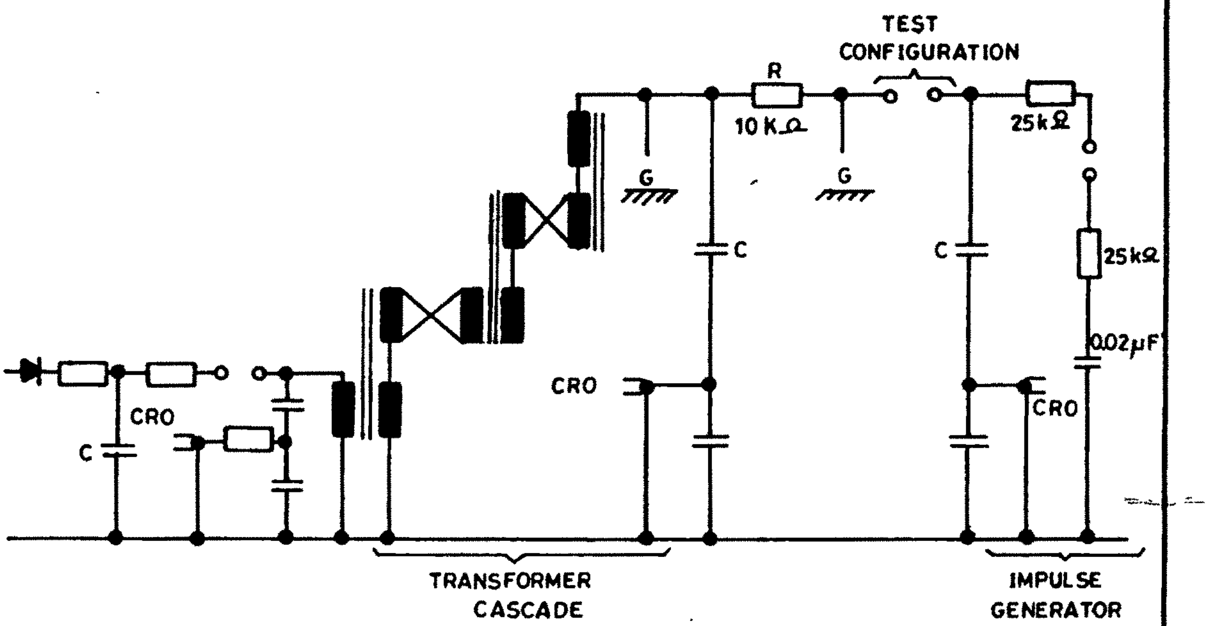


Figure. 4.3 Test circuit for conducting bias test on rod - rod gap (ref. 75).



Curve - 1, U_{ac} = 0·0, U_{SI} → negative
Curve - 2, U_{ac} = 0·0, U_{SI} → positive
Curve - 3, U_{ac} = -0·525 x $\sqrt{2}$ / $\sqrt{3}$ MV, U_{SI} → positive
Curve - 4, U_{ac} = +0.525 x $\sqrt{2}$ / $\sqrt{3}$ MV, U_{SI} → negative

Figure. 4.4 50 % flashover voltage as a function of gap spacing of rod - rod gap electrodes configuration (ref. 75).



R= damping resistance, G= protective gap. C = Capacitance

Figure. 4.5 Test circuit for bias test (ref. 81).

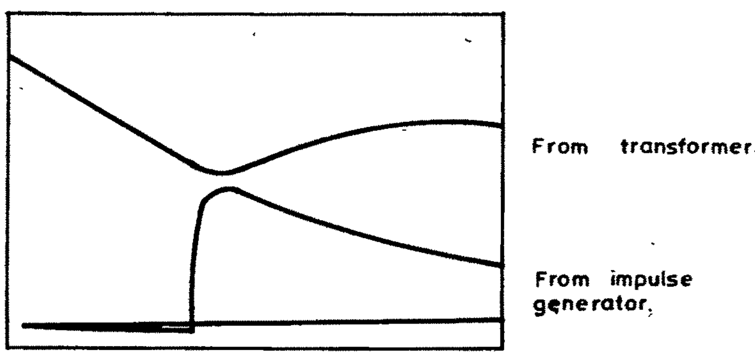


Figure. 4.6 Wave shapes of test voltage-to-ground during phase-to-phase test (ref. 81).

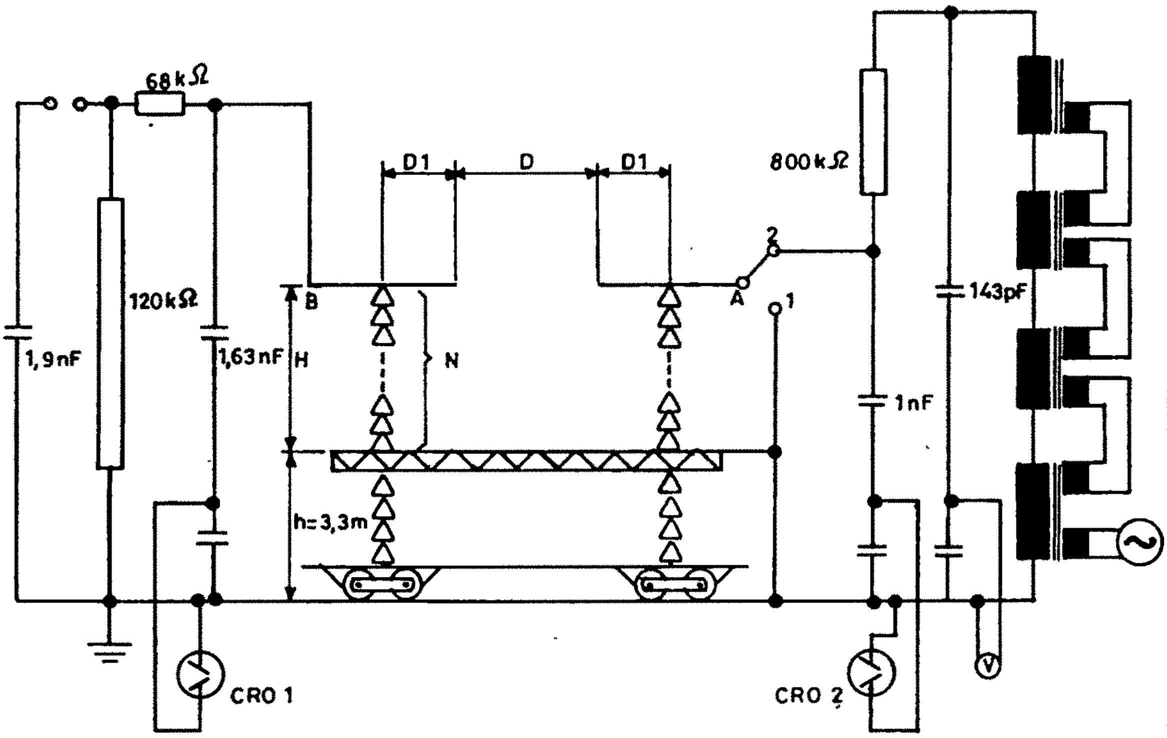
age testing.

Boehne and Carrara/122/ also conducted bias voltage tests on EHV disconnector type open gaps. Figure 4.7 gives the circuit arrangement adopted for conducting bias voltage test. They have not described in their article about the use of various equipments. The 800 Kilo Ohms resistor may be used for the protection of the high voltage testing transformer insulation in case flashover occurs across the gap. They have shown two dividers, the output of one divider was connected to CRO-2 and the output of other divider was connected to a voltmeter. It is not clear which divider was used for the measurement of AC power frequency voltage. CRO-2 may have been used to check the syncnronisation of the two peaks.

Bachofen/121/ conducted lightning impulse and switching bias test on disconnectors. The bias test circuit adopted by him is shown in Figure 4.8a. Lightning arrester was used for the protection of the High Voltage testing transformer. Damping resistor was not used. The typical oscillograms of AC wave and impulse wave are shown in Figure 4.8b. The results obtained by him are discussed in Chapter 2, Section 2.4.

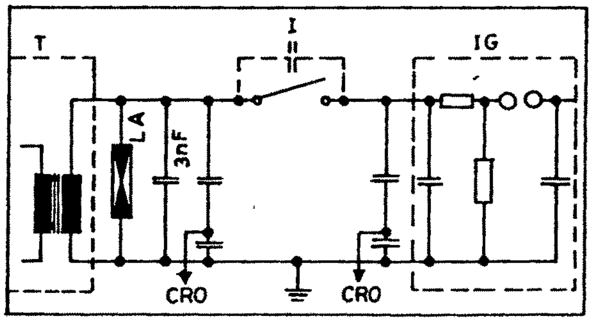
4.5 Measurement of transferred impulse voltage at different points of the bias test circuit

When impulse voltage is applied to the terminal D of Figure 4.1, part of the voltage appears across the power frequency terminal to earth. This voltage distribution is affected by the insertion of a damping resistor between the terminals of the test object and the supporting capacitance. To study the



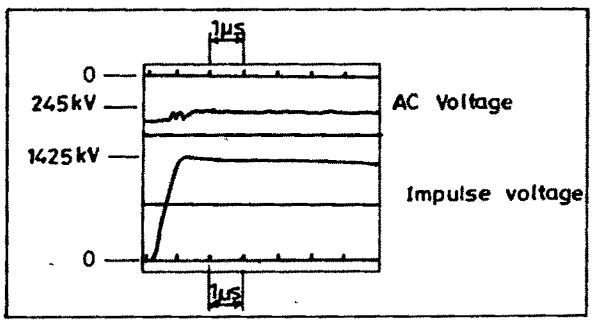
N = Stack height
D = Open gap spacing
D1 = Length of the rod projecting inside the assembly.

Figure. 4.7 Circuit arrangement for the tests with bias voltage (ref. 122).



T = Power frequency test transfomer. IG = Impulse generator.
LA= Lightning arrester. I = Test object.

a) Schematic of bias test set-up.



b) Typical oscillogram of bias test Test object 420 kV oil circuit breaker HPF 516 / 8C.

Figure. 4.8 Impulse bias test circuit used by Hochspannugsfabrik, oberentfelden (ref. 121).

voltage distribution across the test object for various combinations of damping resistor R and the supporting capacitor C_2, the circuit connections of Figure 4.1 were used. The damping resistance was variable in steps of 1.71, 3.46, 5.05, 6.84 and 8.56 K Ohms. Different values of supporting capacitor were used to study the effect of various combinations of supporting capacitance C_2 and the damping resistor R.

4.5.1 Measurement problems

One of the requirements of the high voltage dividers is the requirement of a very good step response, so that it can reproduce the waveshape faithfully on the low voltage arm of the divider. The various bias voltage test circuits used by various laboratories are given in Figures 4.3, 4.5, 4.7 and 4.8. It has not been mentioned in any of these circuits whether the divider which was used to measure the power frequency voltage and voltage drop on AC terminal was an ordinary capacitive voltage divider or a damped capacitive voltage divider.

Some of the points related to this subject have been discussed in detail in Chapter-3. Based on that experience it was observed that to measure the transferred impulse voltages U_A and U_B, it is a must to use a damped capacitive voltage divider for accurate measurements.

Further, in order to reduce the loading effect because of the high voltage arm capacitance of the damped capacitive voltage divider on the measurement of the transferred impulse voltages on AC terminal, an air dielectric capacitor having high voltage arm capacitance of 100pF was used for this study. A variable external damping resistance was connected in series with the 100pF air dielectric capacitor, it was observed that for the exact reproduction of the wave on the low voltage arm of the divider, the value of external series resistance was found to be approximately 1500 Ohms.

4.5.2 Capacitive controlled rod-rod gap

Figure 4.9a gives the layout of the two series connected capacitive controlled rod-rod gaps. The capacitance between two terminals (C_1) was 600pF. The capacitor C_1 was made of polypropylene film and high density kraft paper. The capacitor C_2 was made using only kraft paper. Both types of capacitors were impregnated using transformer oil at high vacuum (0.001 torr).

The circuit layout shown in Figure 4.1 was used for the measurement of voltage U_A and U_B when an impulse voltage is applied to the impulse terminal 'D' of Figure 4.1. The voltage U_B could be measured easily by using damped capacitive voltage divider. However, some problems were faced for the measurement of voltage U_A at point A using either capacitive voltage divider or resistive voltage divider, and the same are discussed latter in this chapter.

4.5.2.1 Lightning impulse voltage distribution

Lightning Impulse Voltage of 1.36/52.0 microseconds waveshape having a peak magnitude of 325.0kV was applied to the impulse terminal D of Figure 4.1 of the capacitive

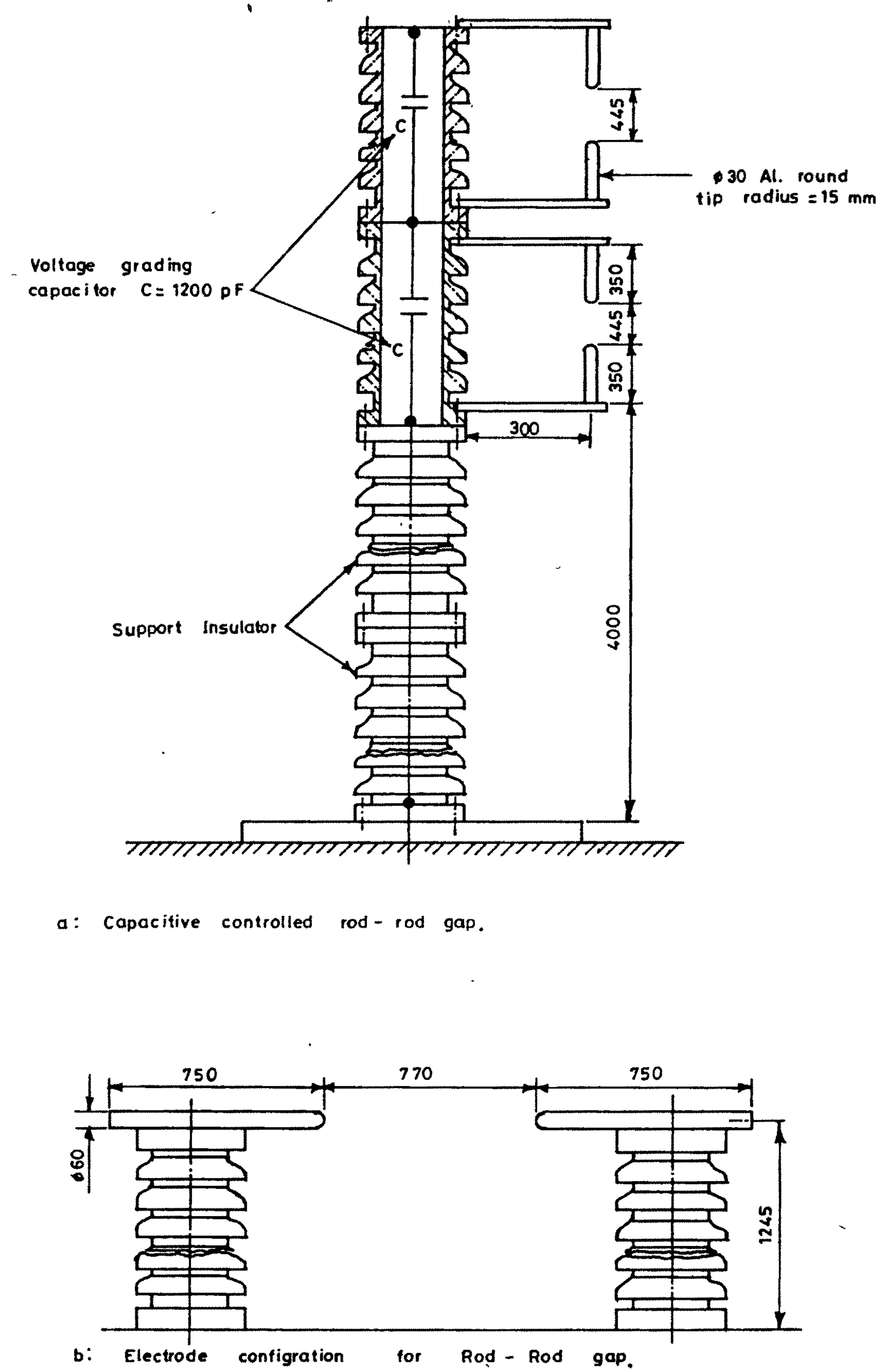


Figure. 4.9 Different electrode configurations used for the measurement of voltage drop and U_{50} voltage.

controlled rod-rod gap. The transferred impulse voltage at point B was measured using a small damped capacitive voltage divider having a ratio of 477.0. Figure 4.10 shows the transferred impulse voltage U_B as a function of supporting capacitance, for different values of damping resistor R. The voltage U_B for damping resistance of zero Ohms gives the correct value of the transferred impulse voltage at point B, which should be compensated at the power frequency terminal while conducting bias voltage test at full BIL. As the value of supporting capacitance increases, it is seen that the voltage U_B decreases. The calculated values of voltage U_B for resistance R equal to zero Ohms compare very well with the measured values. As seen from these results when a supporting capacitance of 6600pF is connected across the power frequency terminals, the measured value of voltage U_B is 8.24% of the applied lightning impulse voltage (damping resistance R is equal to zero Ohms). When a damping resistance of 8.56 K Ohms is connected in the circuit the measured voltage U_B is 6.3%. Thus the error introduced in the measurement of voltage U_B because of the insertion of a damping resistance is 1.94%.

Figure 4.11 shows the transferred impulse voltage U_B as a function of damping resistance for various values of the supporting capacitor C_2. As seen from this figure, the voltage U_B decreases with the increase in damping resistance. The slope of the curves decreases as the value of the supporting capacitor C_2 increases. Thus, higher

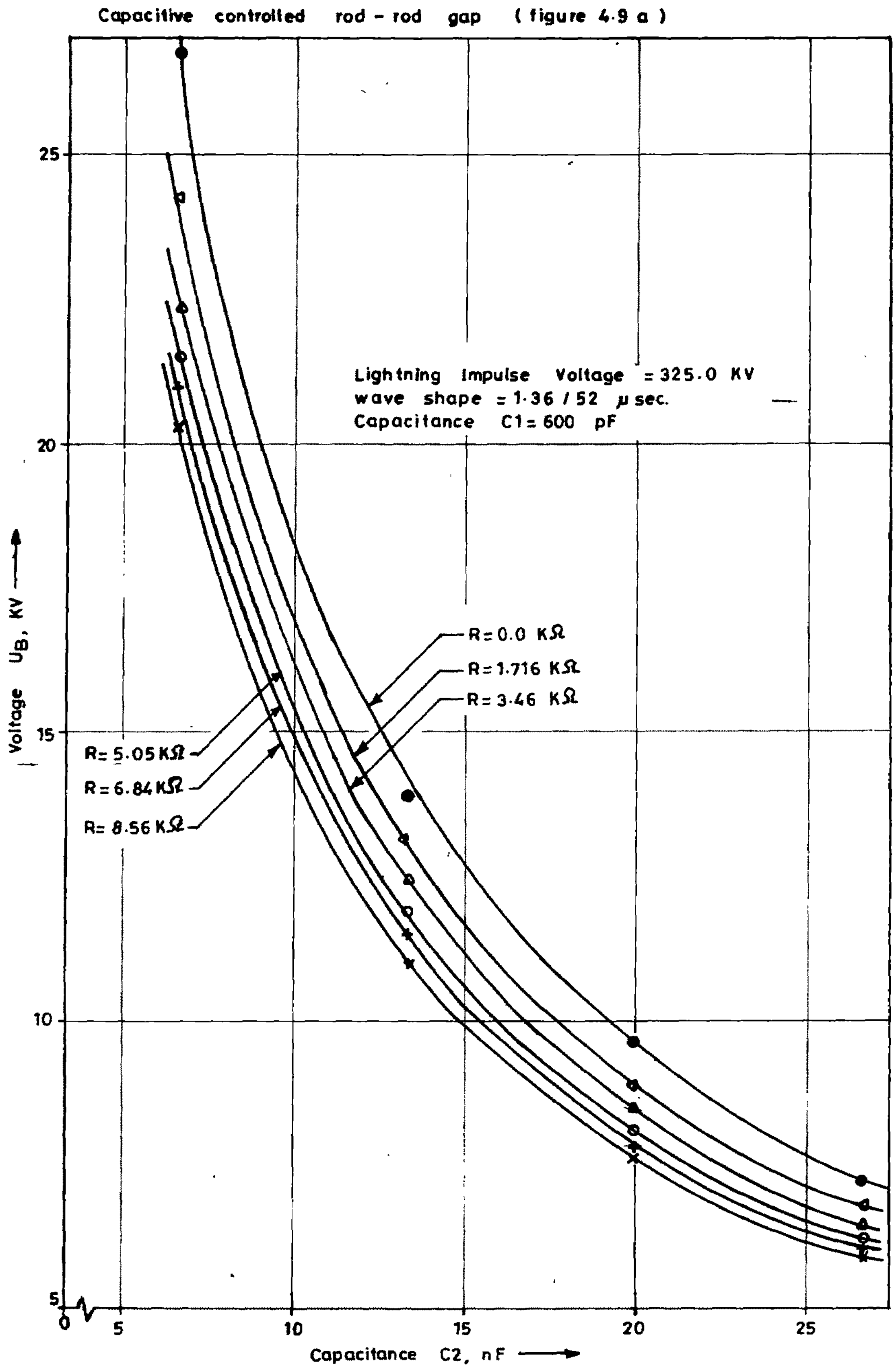


Figure. 4.10 Variation of transferred impulse voltage U_B (LI) as a function of supporting capacitance C_2

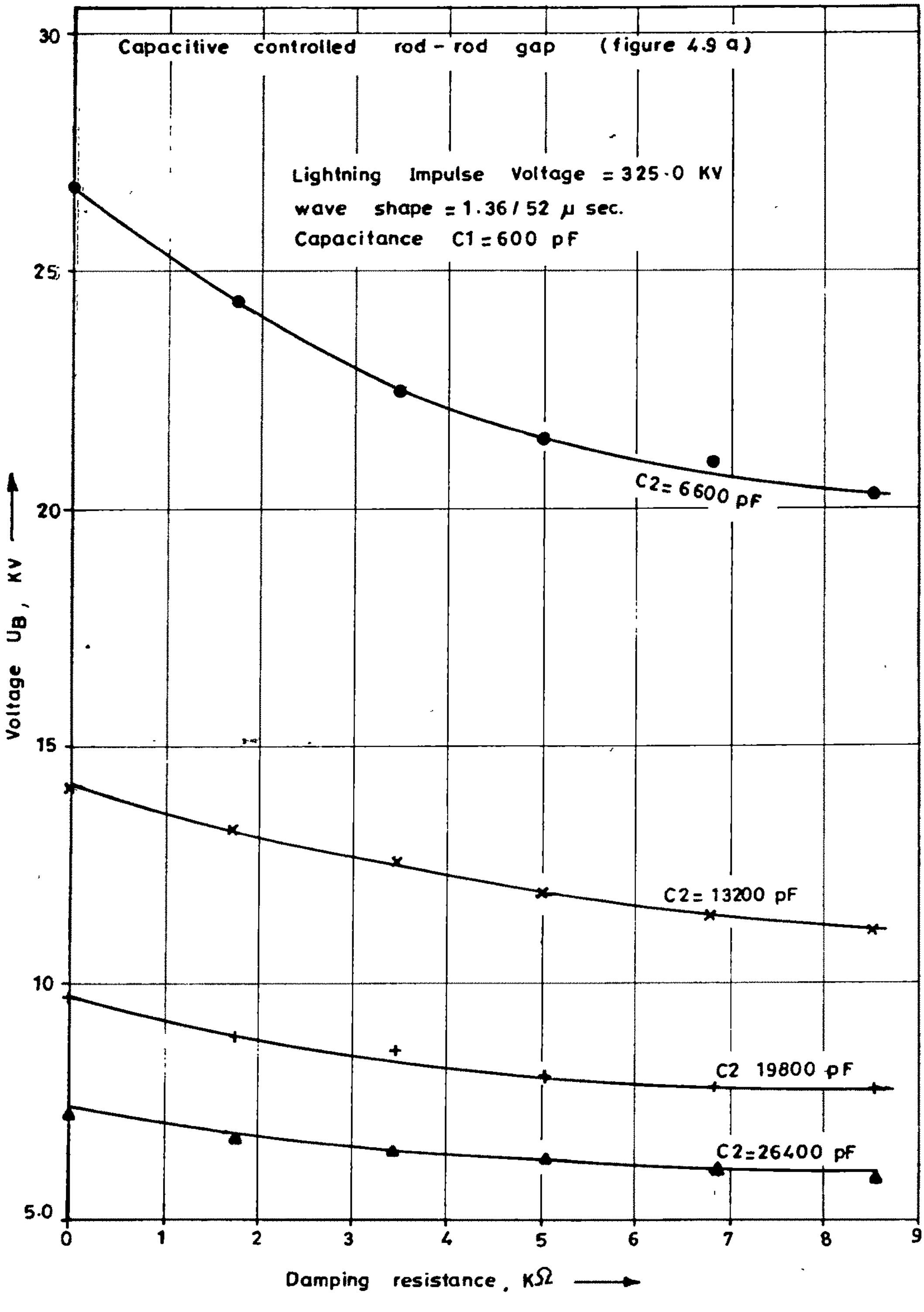


Figure. 4.11 Variation of transferred impulse voltage U_B (LI) as a function of damping resistance, $C_1 = 600$ pF.

the value of the supporting capacitor C_2, lesser is the error introduced in the measurement of voltage U_B for a given range of damping resistor R. For example, when damping resistor of 8.56 K Ohms is connected between the terminals of the test object and the supporting capacitor, the magnitude of voltage U_B reduces by 2% and 0.4% with respect to the applied impulse voltage for supporting capacitance equal to 6600pF and 26400pF respectively.

It was very difficult to measure the lightning impulse transferred voltage U_A at point A. When a capacitive voltage divider is connected at point A, the circuit layout and the response of the circuit changes, which is a function of the waveshape of the applied impulse wave. An attempt was made to measure the voltage U_A using a damped capacitive voltage divider having a primary capacitance of 713pF. It was observed that the voltage U_A was always equal to the share of voltage between test object capacitance (C_1=600pF) and the divider capacitance i.e. voltage U_A was equal to 45.69% of the lightning impulse voltage which is applied to the opposite terminal. This divider had an uniformly distributed internally connected damping resistor at certain intervals between various capacitive elements.

However, when a small damped capacitive voltage divider having a lumped connected external damping resistor of 1500 Ohms was used (as shown in Figure 4.1 item no. 6, the primary capacitance of this divider was 100pF, air dielectric), the voltage U_A was not equal to its share between capacitance C_1 and the divider capacitance. The voltage U_A was also measured using a non-inductive resistive divider. It was observed that the voltage U_A measured using resistive voltage divider and 100pF air dielectric damped capacitive voltage divider was more or less same. The voltage U_A measured using 100pF air dielectric damped capacitive voltage divider as a function of damping resistance is given in Figure 5.14. It was observed that for any value of the supporting capacitance, the magnitude of voltage U_A is not affected. When a lightning impulse voltage is applied to the impulse terminal D of Figure 4.1, it induces at point A, a voltage which is increasing with the increase in damping resistance values, but is not at all affected by the supporting capacitance. This is because of the high value of the damping resistance coming into picture.

In other words, this phenomena is attributed to the different circuit time constants. The time constant of the damped capacitive voltage divider which was used for the measurement of voltage U_A was 0.15 microseconds, while the time constant of a series combination of damping resistance R and the supporting capacitance C_2 is different. For example, when damping resistance R is equal to 8.56K Ohms and supporting capacitance C_2 is equal to 26400pF, the time constant would be 225.98 microseconds, which is approximately fifteen hundred times more compared to the time constant of the measuring devices. This may be one of the reasons, why the measured value of voltage U_A is much higher compared to voltage U_B. This effect was even noticed when damping resistance was 117 ohms. When damping resistance R is equal to 117 Ohms, the voltage U_A was equal to four times U_B and when damping resistance R is equal to 15 Ohms the voltage U_A was approximately 1.2 times the voltage U_B. For damping resistance R equal to zero Ohms, the calculated and measured value of voltage U_A(Or U_B) were same. Hence, it may be concluded that the measurement error is because of the different circuit time constants. Table 4.1 gives the magnitude of voltage U_A for damping resistance R equal to 117, 15 and 0.0 Ohms.

It is worthwhile mentioning here, that when voltage U_A was measured using damped capacitive voltage divider (item No.6, Figure 4.1) no oscillations on voltage U_A were observed. The response of this divider was compared with the damped capacitive voltage divider (2) whose response is according to IEC publication 60. However, when the voltage U_A was measured using resistive voltage divider, some oscillations were observed on the front. This may be because of the improper step response of the resistive divider or perhaps when capacitive voltage divider is used, the capacitance of the divider absorbs the high frequency oscillations and hence are not seen on the wave.

Since it was difficult to measure voltage U_A, and also it was not known whether the measured value is correct, other approach (discussed in Chapter 5) was used to find out the effect of damping resistor, when connected between the

TABLE : 4.1

Voltage U_A for different values of damping resistance R.
Lightning impulse voltage = 325 kV, divider time constant = 0.15 microseconds

Sr. No.	Damping resistance R Ohms	C_2 nF	Voltage U_A, kV: Resistive divider	Voltage U_A, kV: Damped capacitive divider	Remarks
1	117	6.6	41.0	38.15	No oscillations were observed when voltage U_A was measured using damped capacitive voltage divider. However, some oscillations were observed when voltage U_A was measured using resistive divider.
2	117	13.2	36.9	34.7	
3	117	19.8	31.7	30.0	
4	117	26.4	31.4	29.3	
5	15	6.6	27.2	26.8	
6	15	13.2	16.2	16.7	
7	15	19.8	10.8	10.35	
8	15	26.4	10.0	9.76	
9	0.0	6.6	25.5	26.8	
10	0.0	13.2	13.68	13.83	
11	0.0	19.8	10.0	9.64	
12	0.0	26.4	7.5	7.2	

test object terminal and the supporting capacitance. The results are discussed in Chapter-5.

4.5.2.2 Switching impulse voltage distribution

Switching impulse voltage of 258/2650 microseconds waveshape having a peak magnitude equal to 312kV was applied to the impulse terminal D of figure 4.1 of the capacitive controlled rod-rod gap. The voltage U_B was measured using damped capacitive voltage divider. Figure 4.12 shows voltage U_B as a function of supporting capacitance C_2 for various values of damping resistance R. It is seen that the difference in voltage U_B with and without damping resistor upto 17.0K Ohms is very small. Thus, as far as the transferred impulse voltage U_B which is to be added to the power frequency voltage for the compensation of the voltage drop on AC wave is concerned the damping resistor in the case of switching impulse wave introduces a negligible error. Figure 4.13 gives voltage U_B as a function of damping resistance for various values of the supporting capacitance C_2. The calculated and measured value of voltage U_B is same when damping resistance R is equal to zero ohms.

Figure 4.14 shows voltage U_A as a function of supporting capacitance for various values of damping resistance R. For a given value of damping resistance, as the value of supporting capacitance increases, the voltage U_A decreases. As the value of damping resistance increases the slope of the curves decreases, i.e. the percentage variations in voltage U_B decreases with the increase in damping resistance for a given range of supporting capacitance.

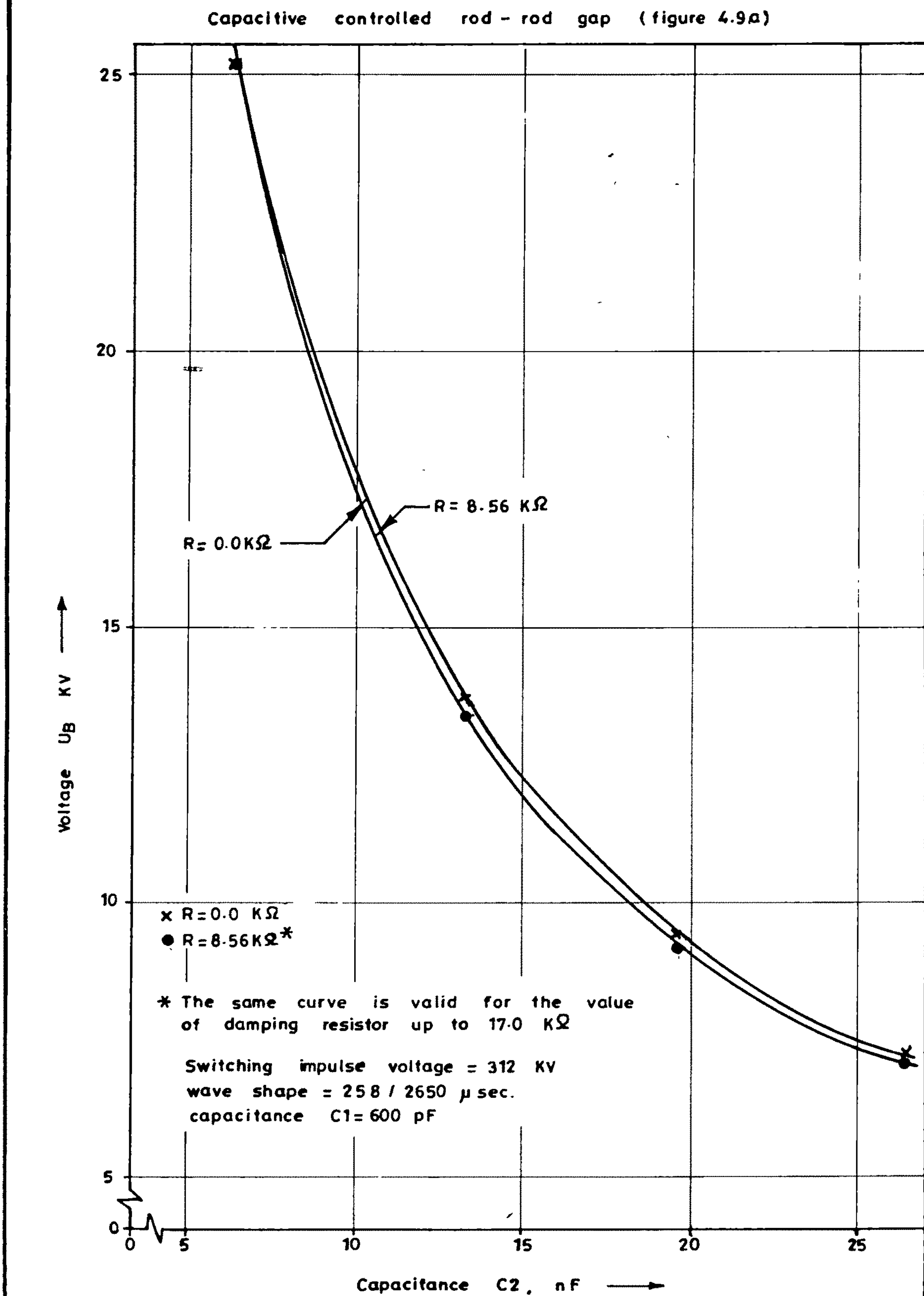


Figure. 4.12 Variation of transferred impulse voltage U_B (SI) as a function of supporting capacitance, $C_1 = 600$ pF.

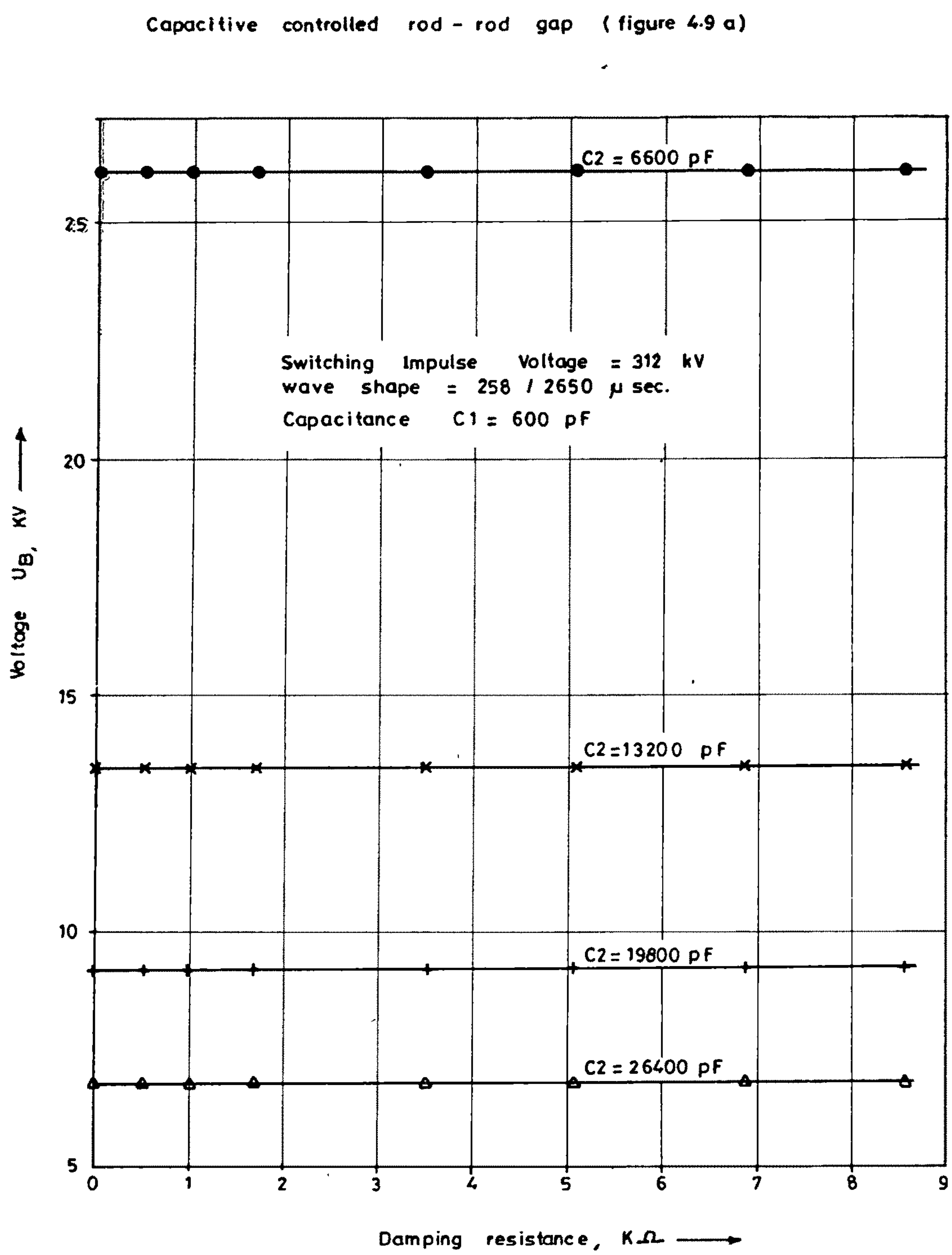


Figure. 4.13 Variation of transferred impulse voltage U_B (SI) as a function of damping resistance, C_1 =600 pF.

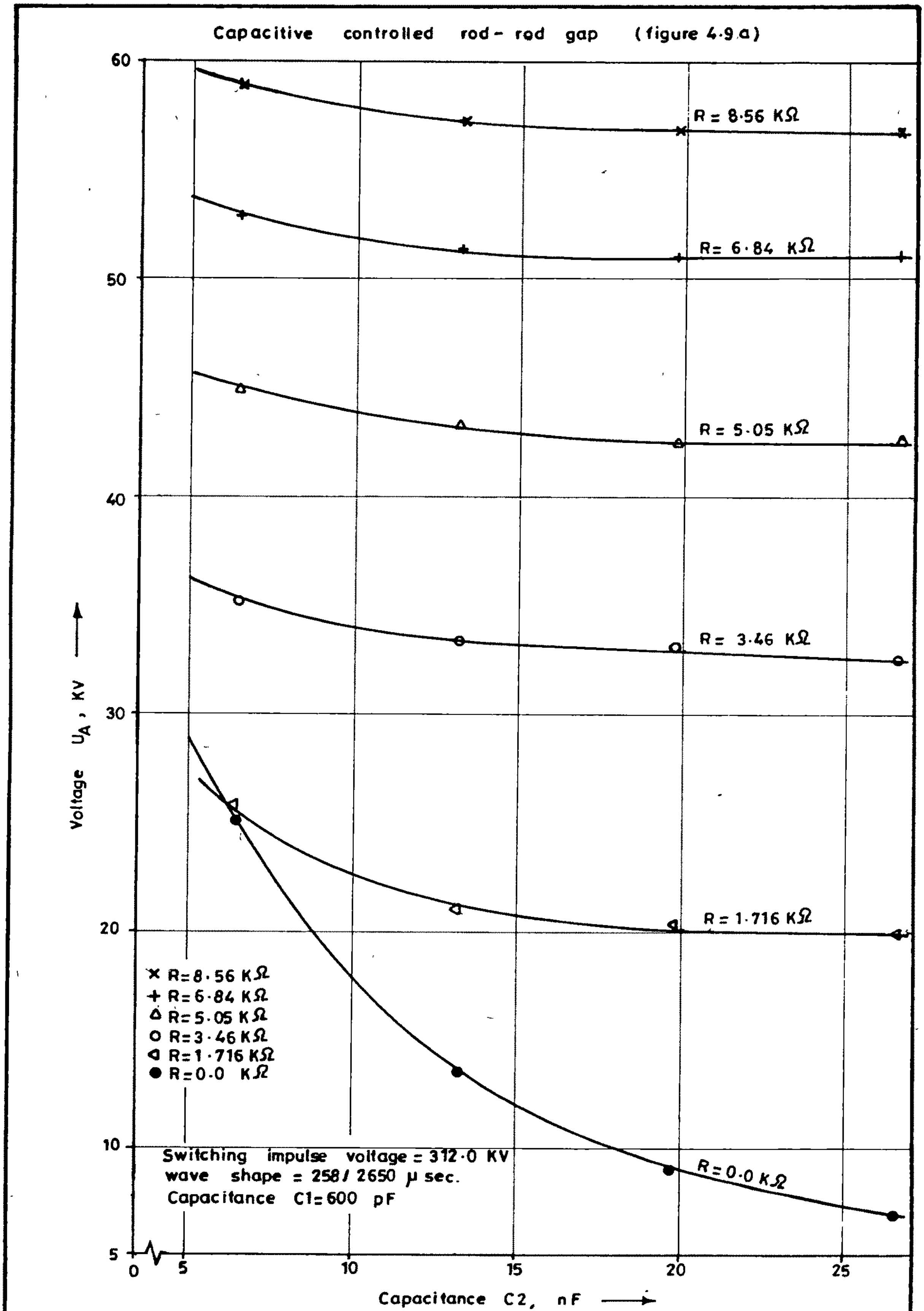


Figure. 4.14 Variation of transferred impulse voltage U_A (SI) as a function of supporting capacitance, $C_1 = 600$ pF.

Figure 4.15 gives voltage U_A as a function of damping resistance R. As the value of damping resistance increases the voltage U_A increases. For example, when damping resistance of 8.56 K Ohms is connected between the terminals of the test object and the supporting capacitance the percentage increase in voltage U_A with respect to the applied impulse voltage is approximately 14% when supporting capacitance of 13200pF is connected as shown in Figure 4.1. This is much lower compared to the percentage increase of lightning impulse transferred voltage U_A (approximately 75%, Figure 5.14) for capacitive controlled rod-rod gap.

4.5.3 Rod-rod gap

Figure 4.9b gives the details of the horizontal rod-rod gap electrode configuration used to simulate the open gap of the disconnector. The 60mm diameter aluminium rod having a tip radius of 30mm was used for this simulation. The two rods were mounted on a support insulator, the height from the ground level was 1245mm. One rod was connected to the impulse voltage generator and the other rod was connected to the power frequency terminal.

The circuit layout shown in Figure 4.1 was used for the measurement of transferred impulse voltage U_A and U_B when an impulse voltage is applied to the impulse terminal D of Figure 4.1. The voltages U_A and U_B were measured using damped capacitive voltage divider.

4.5.3.1 Lightning impulse voltage distribution

Lightning impulse voltage of 1.02/48 microseconds wave-

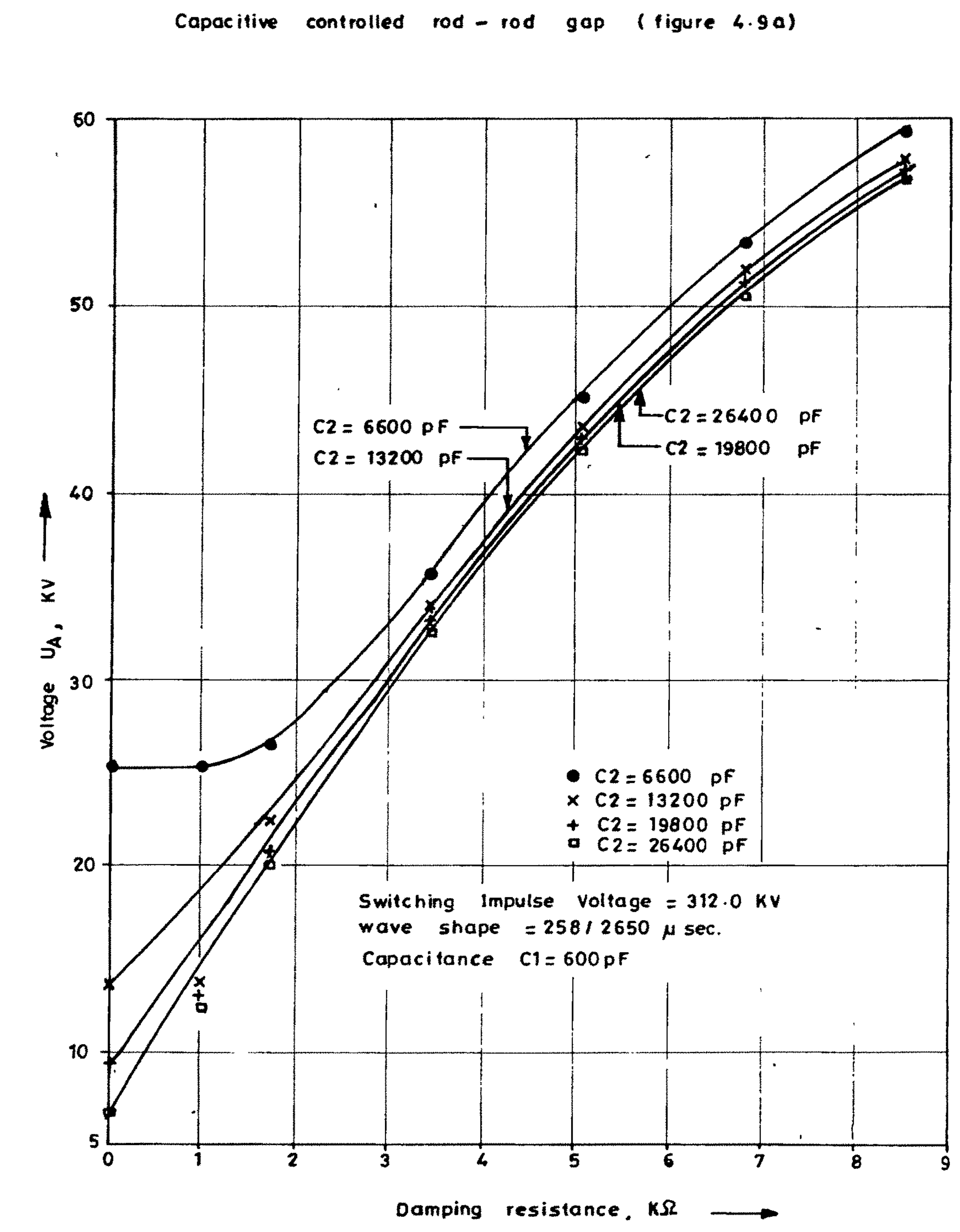


Figure. 4.15 Variation of transferred impulse voltage U_A (SI) as a function of damping resistance, C_1 = 600 pF.

shape having a peak magnitude of 350kV was applied to the impulse terminal D of Figure 4.1 of the rod-rod gap. The open gap spacing was 770mm. Figure 4.16 shows the voltage U_B as a function of supporting capacitance for various values of damping resistance. The various points marked on the curves give the average value of voltage U_B of five readings taken at the same capacitance value. The magnitude of the measured voltage U_B was not constant for the same circuit conditions and impulse voltage level. The variations were of the order of ± 0.3kV. This was not the case with the capacitive controlled rod-rod gap. In this case the variations observed may be because of the open gap electrodes configuration, where the capacitance between two electrodes might have been changing because of the change in atmospheric conditions. As seen from this figure when a supporting capacitance of 866.66pF is connected across the power frequency terminals, the measured value of voltage U_B is 1.34% of the applied lightning impulse voltage (R=0.0 Ohms). When a damping resistance of 8.56 kilo Ohms is connected in the circuit, the measured value of voltage U_B is 1.13%. Thus the error introduced in the measurement of voltage U_B because of the insertion of a damping resistance is very small (0.21%) compared to the capacitive controlled rod-rod gap. This error decreases with the increase in supporting capacitance.

Figure 4.17 gives the curves for voltage U_B as a function of damping resistance for various values of the supporting capacitor. The slope of the characteristics curve is almost same for different values of capacitance C_2, thus

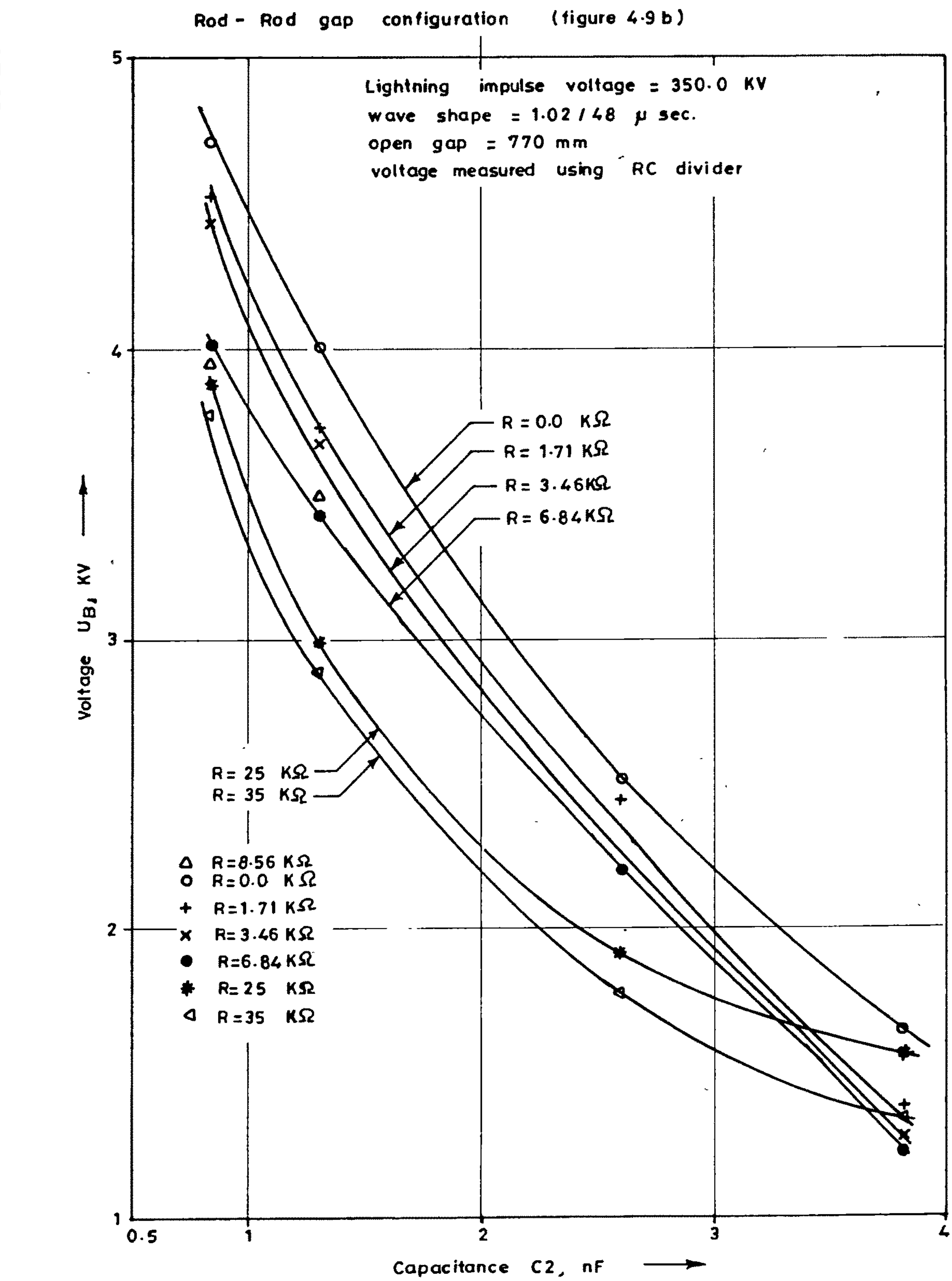


Figure. 4·16 Variation of transferred impulse voltage U_B (LI) as a function of supporting capacitance, rod - rod gap.

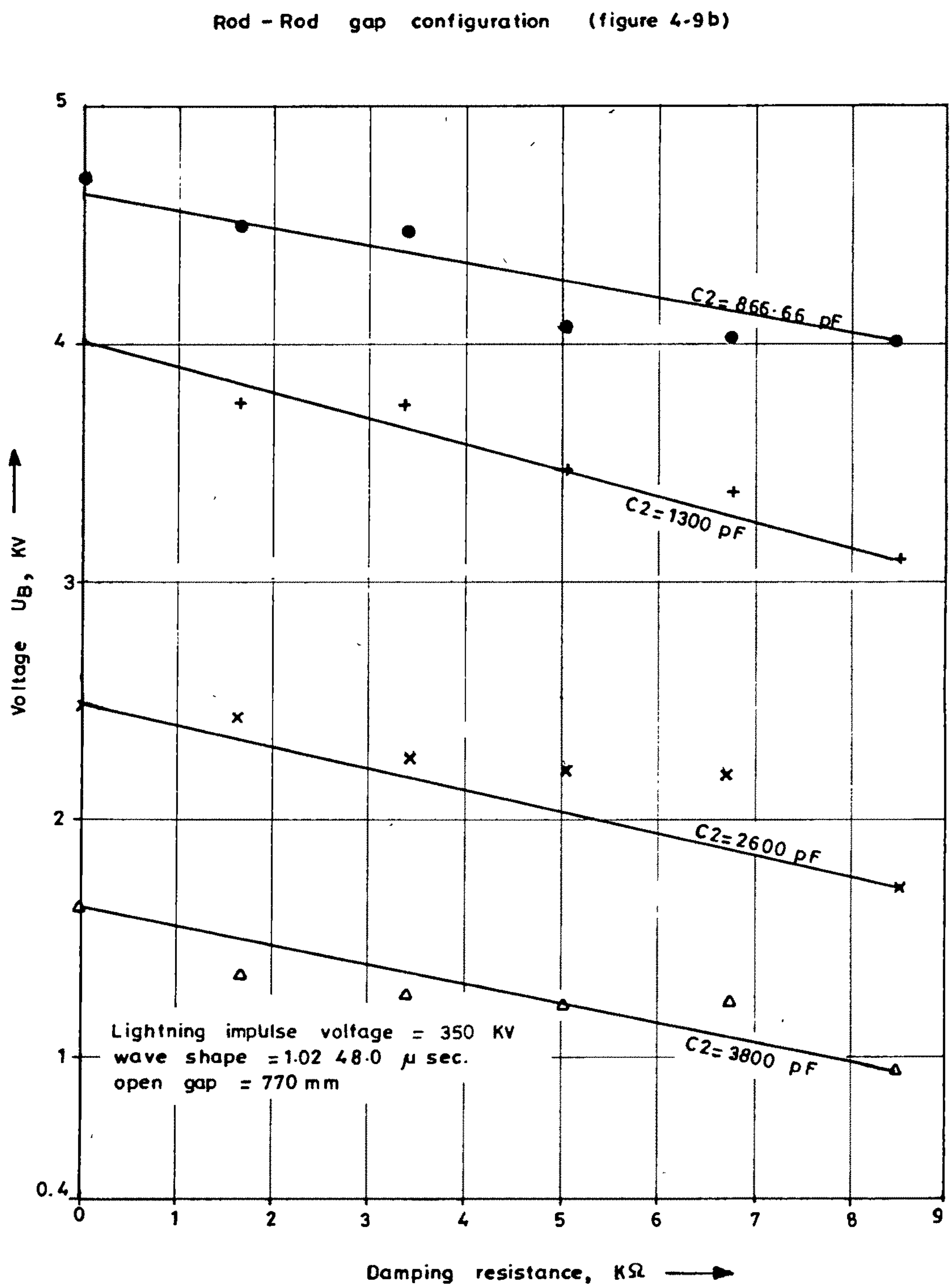


Figure. 4-17 Variation of transferred impulse voltage U_B (LI) as a function of damping resistance, rod - rod gap.

the error in the measurement of voltage U_B is more or less same for any value of supporting capacitance for a given range of damping resistance. Also, the variation of voltage U_B is linear with respect to the damping resistance, this was not the case with the capacitive controlled rod-rod gap.

Further, it may be noted that in the case of rod-rod gap even when supporting capacitance of 866.66pF is connected in the circuit, the voltage U_B is only 1.34% of the applied lightning impulse voltage (for damping resistance equal to zero ohms). This is very much within the permissible limits of voltage distortion on AC wave specified by IEC publications 56 and 129 (the permissible voltage distortion limits on AC wave is mentioned in Chapter-3, section 3.6). Thus, one may still use lesser value of supporting capacitance for conducting bias voltage test on rod-rod gap. However, in the case of capacitive controlled rod-rod gap (C_1 = 600pF) even when supporting capacitance of 6600 pF is connected across the power frequency terminal to earth, the voltage U_B is 8.24% (for damping resistance equal to zero ohms) of the applied lightning impulse voltage. This is higher than the permissible limits specified by the standards. Hence, to control the voltage distortion on AC wave it is still necessary to use higher value of the supporting capacitance C_2.

Figure 4.18 gives the curves of voltage U_A as a function of supporting capacitance for various values of damping resistance. The observed variations in voltage U_A for the

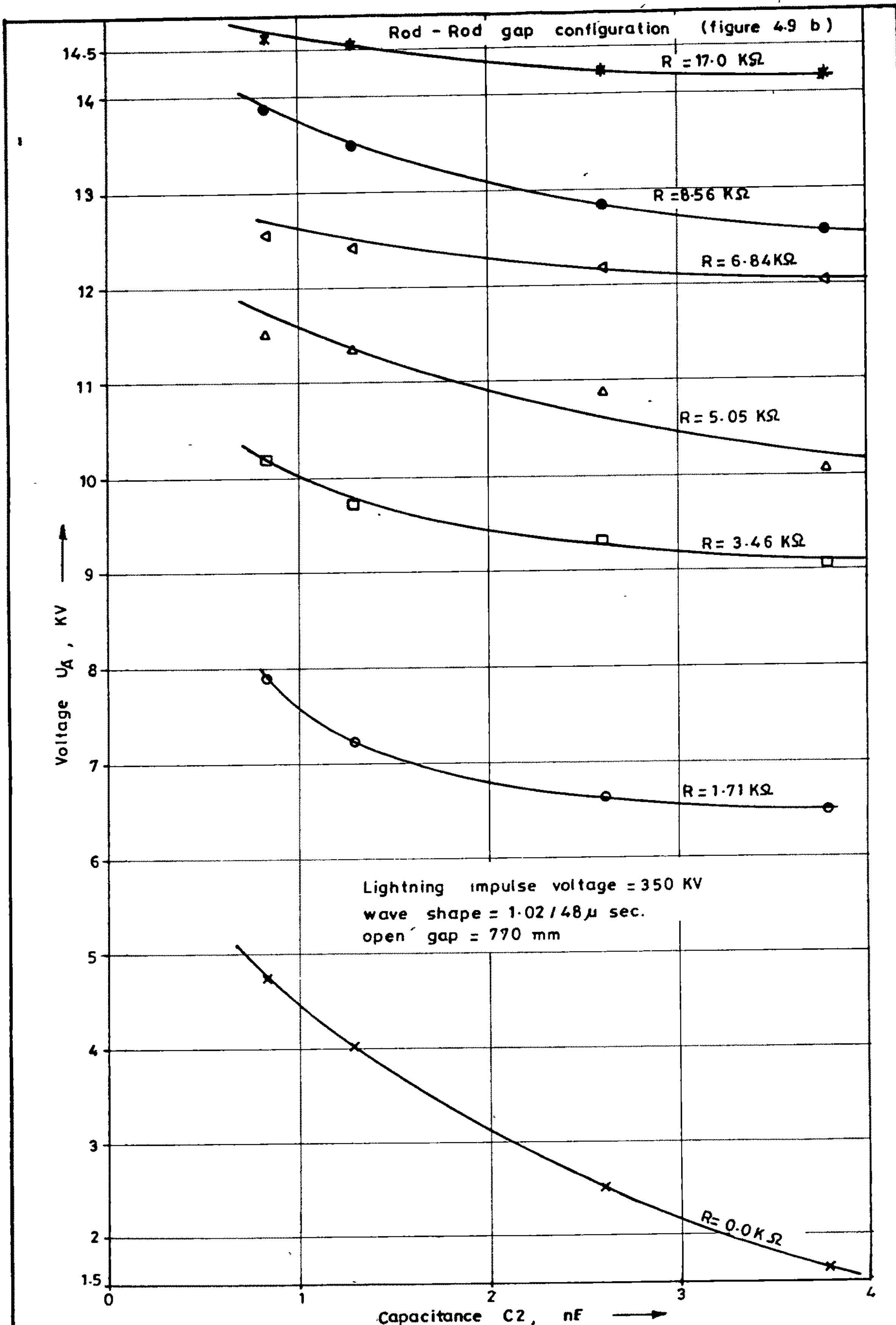


Figure. 4.18 Variation of transferred impulse voltage U_A (LI) as a function of supporting capacitance, rod rod gap.

same circuit conditions and the same impulse voltage level was approximately ± 1.1kV. Hence, each reading was taken five times and average value of voltage U_A is plotted in this figure. The voltage U_A for damping resistance of 17K Ohms is approximately 3 times (C_2=866.66pF) the voltage U_A measured when damping resistor is not connected. However, the percentage difference with respect to the input impulse voltage applied to the opposite electrode is approximately 3%. Figure 4.19 gives the voltage U_A as a function of damping resistance for various values of the supporting capacitance. The voltage U_A increases with the increase in damping resistance and decreases with the increase in supporting capacitance. However, the percentage of error in the measurement of voltage U_A increases with the increase in supporting capacitance for a given range of damping resistance.

4.5.3.2 Switching impulse voltage distribution

Switching impulse voltage of 248/2600 microseconds waveshape having a peak magnitude equal to 350kV was applied to the impulse terminal D of Figure 4.1 of the rod-rod gap. The voltage U_B was measured using damped capacitive voltage divider. Figure 4.20 shows the voltage U_B as a function of supporting capacitance for various values of damping resistance. Figure 4.21 shows the voltage U_B as a function of damping resistance. The characteristic of these curves is similar to the curves shown in Figure 4.13 for capacitive controlled rod-rod gap, i.e. for rod-rod gap also the switching impulse voltage U_B does not change with the increase in damping resistance. Thus,

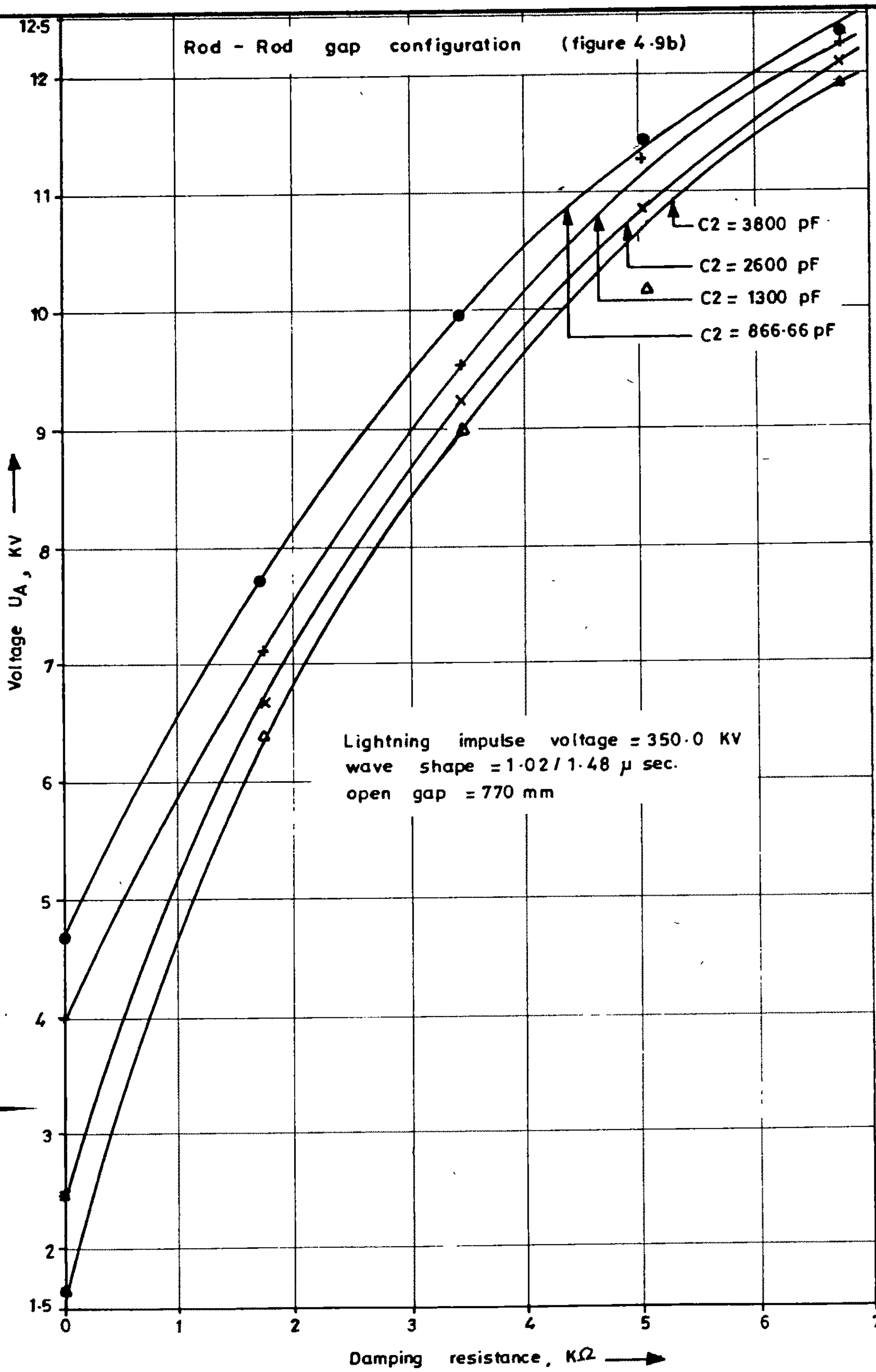


Figure. 4·19 Variation of transferred impulse voltage U_A (LI) as a function of damping resistance, rod - rod gap.

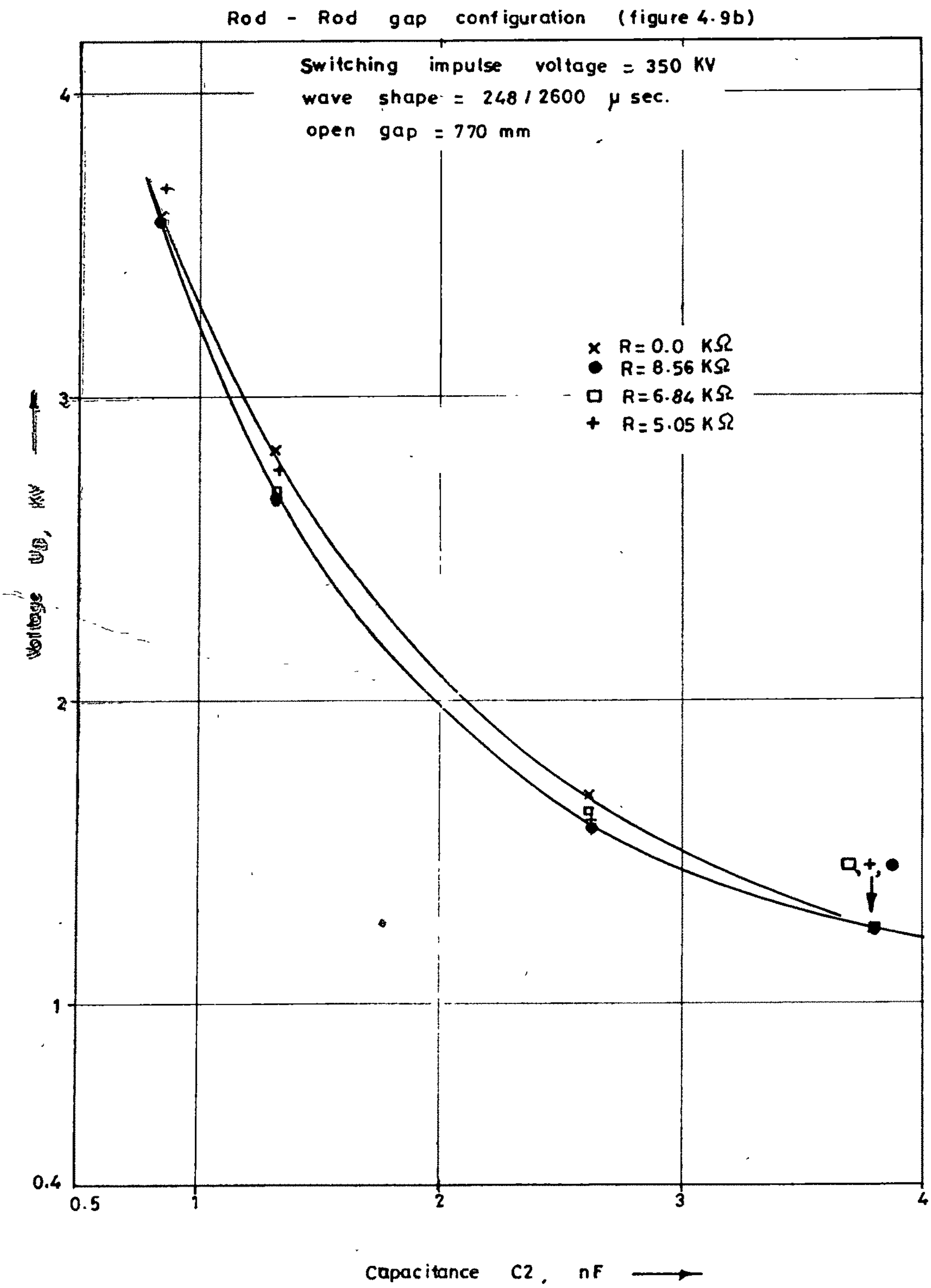


Figure. 4.20 Variation of transferred impulse voltage U_B (SI) as a function of supporting capacitance, rod - rod gap.

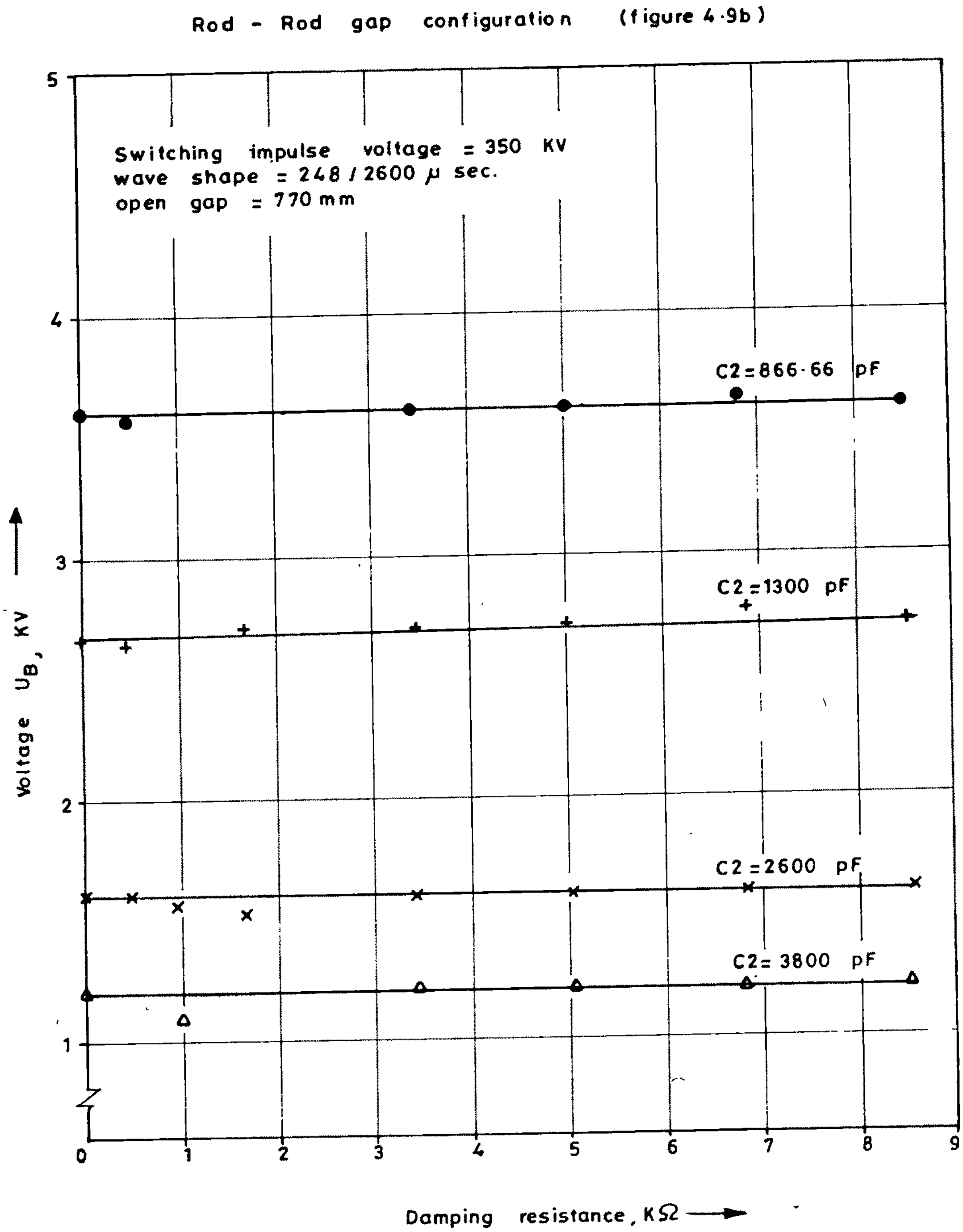


Figure. 4·21 Variation of transferred impulse voltage U_B (SI) as a function of damping resistance, rod-rod gap.

the error in the measurement of voltage U_B is negligible when damping resistance is connected in the circuit. The voltage U_B decreases with the increase in supporting capacitance.

Figure 4.22 shows the voltage U_A as a function of supporting capacitance for various values of damping resistance. Variation of voltage U_A is not linear with the increase in the supporting capacitance C_2. Figure 4.23 shows voltage U_A as a function of damping resistance. The percentage increase in voltage U_A with respect to the applied switching impulse voltage for various values of supporting capacitance C_2 for the range of damping resistance from R=0.0 to R=8.56 kilo ohms is approximately maximum 0.285 per cent. This is much lower compared to the capacitive controlled rod-rod gap.

4.6 Conclusion

The study of voltage distribution across the test object and the series combination of damping resistor R and supporting capacitor C_2 was carried out carefully for various combinations of damping resistor R and capacitance C_2.

The transferred impulse voltage U_B could be measured without any problem either by using damped capacitive voltage divider or resistive voltage divider. However, some problems were faced while measuring the transferred impulse voltage U_A.

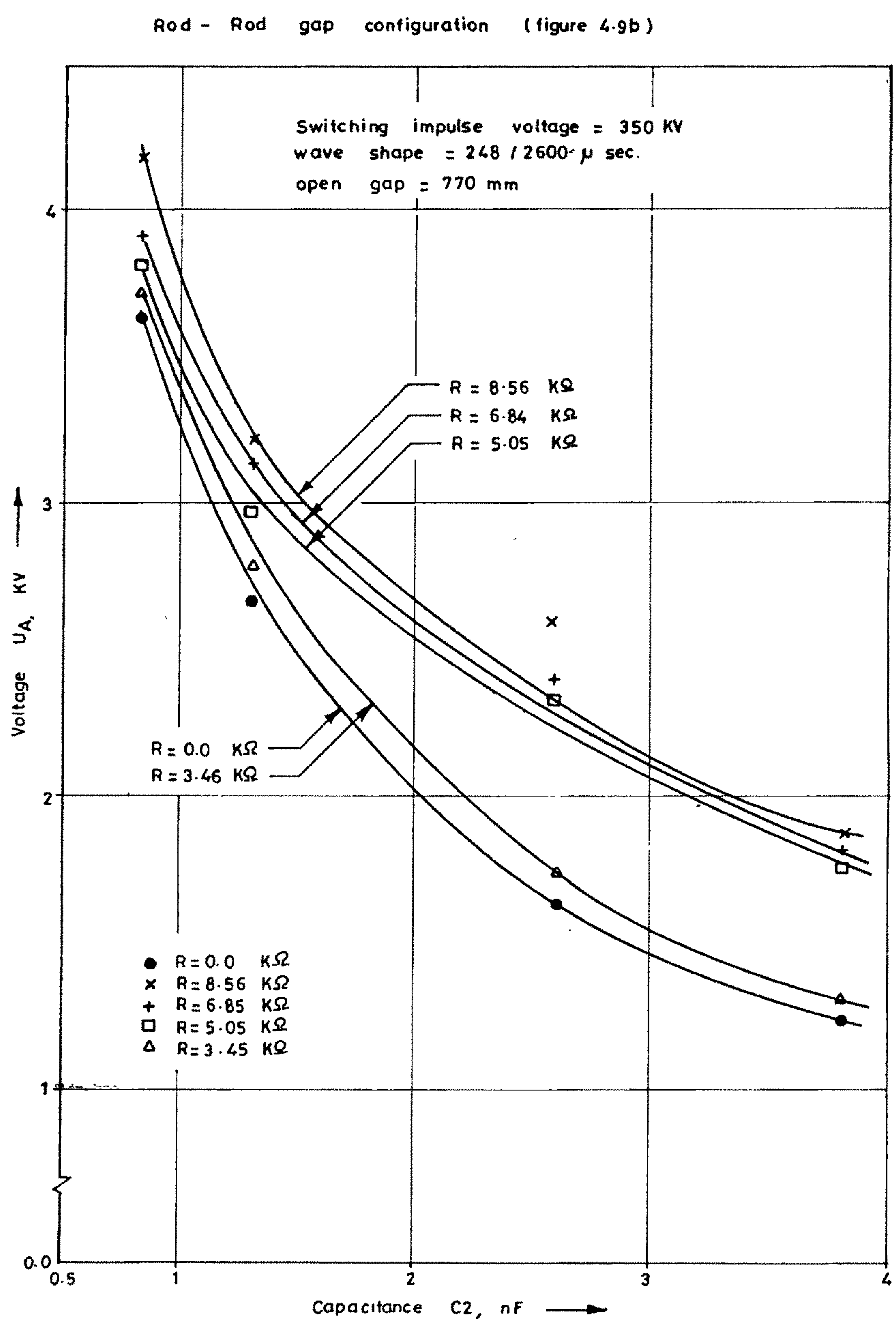


Figure. 4·22 Variation of transferred impulse voltage U_A (SI) as a function of supporting capacitance, rod – rod gap.

Rod - Rod gap configuration (figure 4.9 b)

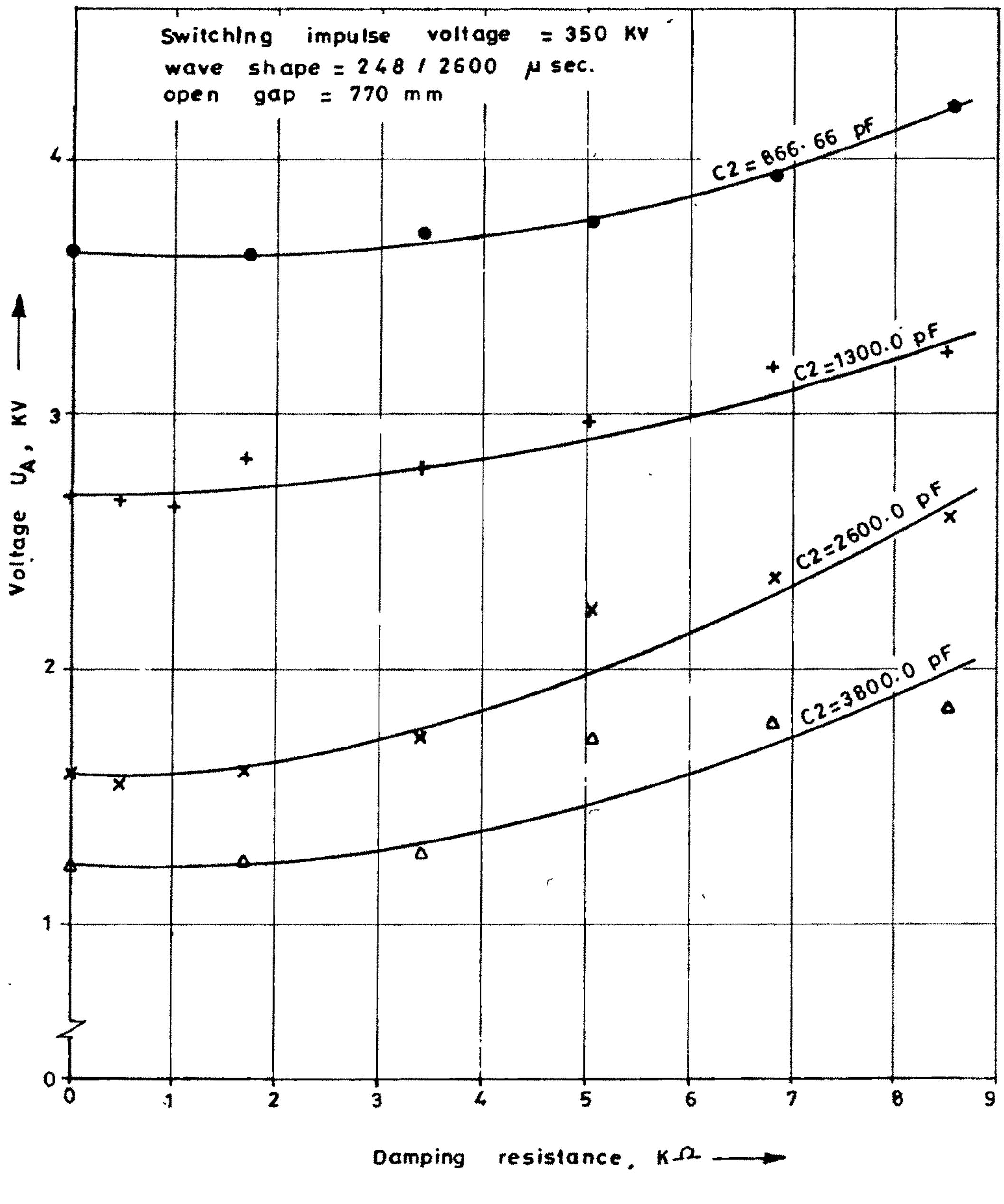


Figure. 4.23 Variation of transferred impulse voltage U_A (SI) as a function of damping resistance, rod - rod gap.

Some of the general conclusions **drawn** from this study are as follows:

1. As far as legal aspects of the standards are concerned the damping resistor can be connected between the test object terminal and the supporting capacitance, this reduces the severity of the chopped wave on the transformer insulation. However, from the systems requirement point of view this location of damping resistor is not correct.
2. It is observed that for the measurement of transferred impulse voltage on AC terminal also requires a damped capacitive voltage divider. Any other type of divider which does not have a good step response gives incorrect value of the transferred impulse voltage.
3. For capacitive controlled rod-rod gap, the lightning impulse transferred voltage U_B decreases with the increase in the value of damping resistance. The difference in the voltage U_B (ΔU_B) for damping resistance R equal to 0.0 and 8.56 Kilo Ohms decreases with the increase in supporting capacitor C_2.
4. For capacitive controlled rod-rod gap it is very difficult to measure the lightning impulse transferred voltage U_A. When damped capacitive voltage divider having an internally connected damping resistance is used for the measurement of voltage U_A, the magnitude of voltage U_A is found to be equal to the share of the voltage between test object capacitance and

the divider capacitance. The supporting capacitance C_2 does not play any role for sharing of the lightning impulse voltage. This phenomena may be attributed to the different time constants of the circuit elements.

5. The switching impulse transferred voltage U_B for capacitive controlled rod-rod gap remains constant with the increase in the value of damping resistor R. However, it decreases with the increase in supporting capacitor C_2.

6. The switching impulse transferred voltage U_A for capacitive controlled rod-rod gap could be measured without any problem. Voltage U_A decreases with the increase in supporting capacitance. However, for a given range of damping resistance the percentage variations in voltage U_A is much less compared to the lightning impulse transferred voltage U_A. Also the magnitude of voltage U_A increases with the increase in damping resistance.

7. The supporting capacitance required while conducting bias voltage test on rod-rod gap would be in the range of few hundreds of picofarads. However, for capacitive controlled rod-rod gap the required value of the supporting capacitance would be of the order of few nanofarads.

8. The percentage variations in lightning impulse transferred voltage U_B for rod-rod gap is very

small when damping resistance is connected between the supporting capacitance C_2 and the terminal of the rod-rod gap.

9. For a given range of supporting capacitance C_2, the percentage variations is lightning impulse transferred voltage U_A for rod-rod gap decreases with the increase in damping resistance.

10. The switching impulse transferred voltage U_B for rod-rod gap is independent of the value of the damping resistor when connected between the test object terminal and the supporting capacitor C_2. The voltage U_B decreases with the increase in the supporting capacitance C_2.

11. The switching impulse transferred voltage U_A for rod-rod gap decreases with the increase in supporting capacitance. The percentage increase in voltage U_A for various values of supporting capacitance C_2 for the range of damping resistance from $R = 0.0$ to $R = 8.56$ Kilo Ohms is approximately maximum 0.285 percent. This is much lower as compared to the capacitive controlled rod-rod gap.