Selection of the optimum electrode - pair of a co - ordinating gap for protection of electrical power systems

---

Assoc. Prof. A. RUMELİ * and U. ÜNVER **

ABSTRACT

In this paper, using co - ordinating gaps protection of electrical plants against atmospheric or internal overvoltages has been taken into account giving particular attention to the effect of spark - gap geometry so far as the protection provided by co - ordinating gap is concerned.

Among various spark - gap electrodes, the optimum pair from protection point of view for a given system conditions has been tried to be determined by experimental tests. In these experiments, various electrode pairs with different dimensions and shapes have been subjected to impulse voltages at increasing gap - spacings. Thus, flashover characteristic of each electrode - pair has been obtained and the optimum electrode - pair has been determined making use of these characteristics.

ÖZET

Bu çalışmada elektrik güç sistemlerinin iç ve atmosferik aşırı gerilimlere karşı koruyucu eklatörler kullanılarak korunmaları incelenmiş ve özellikle bu eklatörlerin geometrisinin korumaya etkisi araştırılmıştır.

Koruma açısından, çeşitli elektrod sistemleri arasında en uygun korumayı sağlayan elektrod sisteminin deneysel bulunuşu yapılmıştır. Deneylerde farklı boyut ve yapılarda çeşitli elektrod sistemlerine değişik elektrod açıklıklarında darbe gerilimi tatbik edilmiştir. Böylece bulunan atlama karakteristikleri yardımıyla en uygun koruma sağlıyan elektrod çiftinin bulunmasına çalışılmıştır.

---

*) Middle East Technical University Ph. D. - Ankara.

**) Middle East Technical University M. Sc. - Ankara.

1. INTRODUCTION

Electrical plants are often subject to internal or external overvoltages. As a result of these, serious damages of flashovers might take place on the electrical equipments under service conditions. In order to prevent such damages and to protect the equipment against overvoltages, surge diverters, expulsion tubes (protector tubes), and co-ordinating gaps are mostly used as protective devices. Among them, the cheapest one is the co-ordinating gap. So, it is quite economical to use a co-ordinating gap instead of a surge diverter wherever possible.

In practice, the co-ordinating gap electrodes used are usually rods of different shapes. In this paper, howver, various electrode-pairs with different geometric shapes have been taken into account from protection point of view and the optimum one has been determined for a given system conditions. For this purpose, experimental impulse flashover characteristics of each electrode-pair have been obtained and used.

2. CO-ORDINATING GAP AS A PROTECTIVE DEVICE

2.1. Basic requirements of insulation co-ordination

Transient overvoltages which appear on a system are usually limited to a protective level by a protective device. As a principal of insulation co-ordination, the protective level of the protective device to be used must be below the impulse insulation level of the equipment to be protected by a protective (safe) margin as illustrated in Figures 1 and 2.

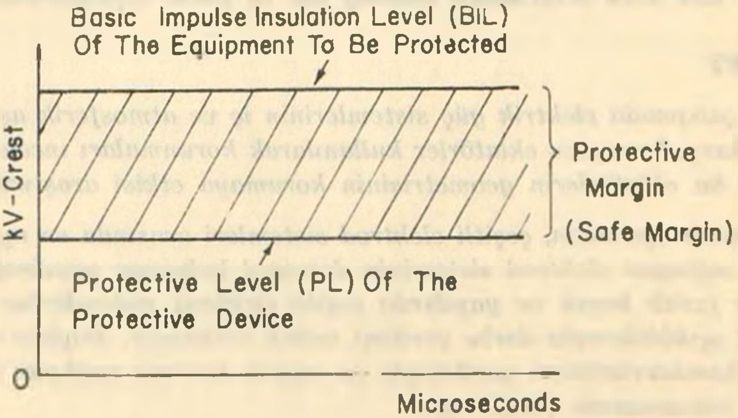
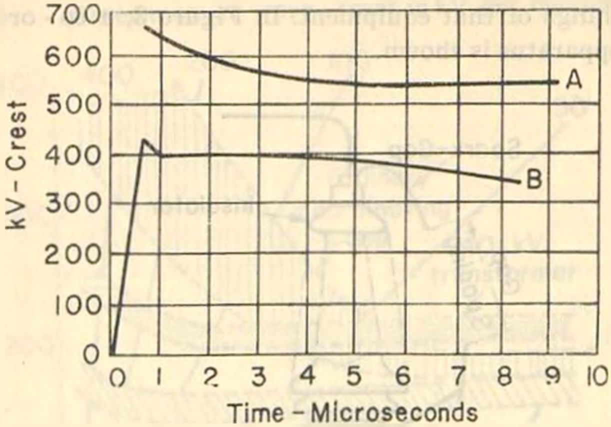


Figure 1 : The relation between the impulse insulation level of an equipment to be protected and the protective level of a protective device to be used.



Fugire 2 : Protection of an insulation with characteristic of 'A' by a protective device with characteristic of 'B'.

In practice, protective margin is expressed in percentage and is given by

$$PM = ((BILL/PL) - 1) \cdot 100$$

where, BIL : Basic impulse insulation level of the equipment to be protected

PL : Protective level of the protective device to be used

The ratio, BIL PL may be called as protective ratio' and for impulse co - ordination, its minimum recommended value is 1.2 and for switching surge co - ordination, it is 1.15 provided that earths of all the protective devices and of equipment are directly connected together (1,2). These values provide the protective margins of 20 % and 15 %, respectively.

2.2. Basic points to be considered in the application of co - ordinating gaps

So as to provide satisfactory protection, co - ordinating gaps are usually used in the areas where lightning strokes do not occur frequently and in the systems in which switching surges do not reach very high values (3).

They are placed at a distance from the equipment to be protected or on the bushings of that equipment. In Figure 3, a co - ordinating gap placed on an apparatus is shown.

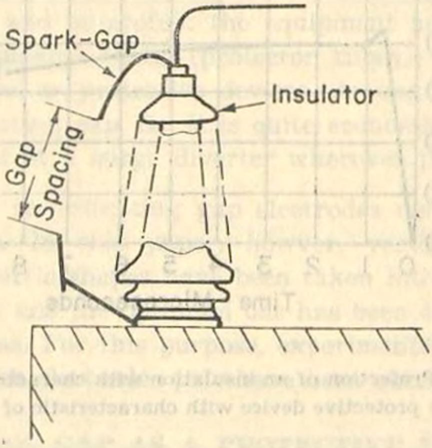


Figure 3 : Application of a co - ordinating gap.

Impulse flashover characteristic of a co - ordinating gap in time domain is such that the gap may be unable to protect the equipment insulation against the surges of steep wave - front. Because, the steeper the wave - front of the surge, the higher the flashover voltage in the gap may appear. By connecting adequate lengths of cables betweeen overhead lines and terminal equipments, some measure of protection may be provided so that the cables can cause the wave - front duration of the surges to be increased. Thus, co - ordinating gaps become more effective.

Co - ordinating gaps are generally used in systems in which interruption of the power supply can be tolerated or compensated for by high - speed automatic reclosing of the circuit breakers. Because, a gap does not interrupt power voltage after it has once been flashed over by a surge, therefore does not limit and interrupt follow current (i.e. the power frequency current which flows in the path created by the flashover). Thus, the circuit must be de - energized by system circuit breakers to clear up the gap breakdowns each time the gap operates.

In Fig. 4, the protection provided by a co - ordinating gap and by a non - linear resistor type surge diverter (DELIE PZ 8) to protect a 40 kV transformer is described. As seen in the figure, the surge diverter is able to protect the transformer whatever the wave - front steepness of

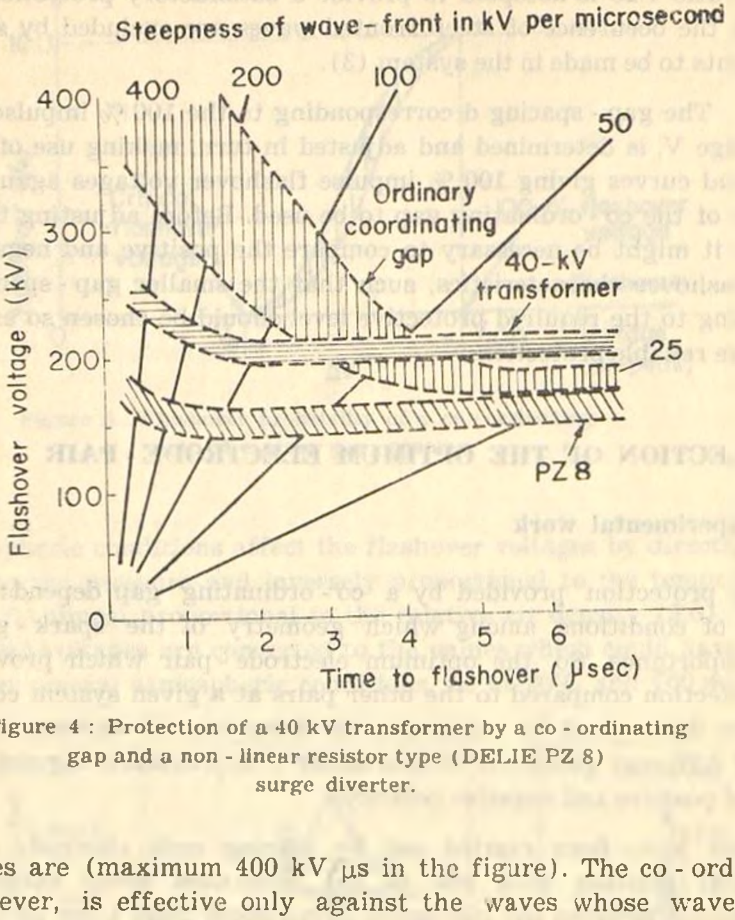


Figure 4 : Protection of a 40 kV transformer by a co - ordinating gap and a non - linear resistor type (DELIE PZ 8) surge diverter.

the surges are (maximum 400 kV μs in the figure). The co - ordinating gap, however, is effective only against the waves whose wave - front steepnesses are below 50 kV μs.

2.2.1. Adjustment of the gap - spacing

The gap - spacing of a co - ordinating gap is adjusted to a particular distance so that the gap could provide a reauired protective level. For this purpose, the following steps are to be considered in sequence.

i) Basic impulse insulation level (BIL) of the equipment to be protected is first determined.

ii) A minimum protective ratio of 1.25 is chosen between the BIL of the eqipment and the 100 % impulse flashover voltage V_i of the gap, i.e $BIL/V_i \geq 1.25$ is to be satisfied. Then, V_i can be determined. In general, the ratio 1.25 is accepted to provide a satisfactory protection provided that the occurence of steep fronted waves are excluded by some arrangements to be made in the system (3).

iii) The gap-spacing d corresponding to the 100 % impulse flashover voltage V_i is determined and adjusted in turn, making use of the experimental curves giving 100 % impulse flashover voltages against gap-spacings of the co-ordinating gap to be used. Before adjusting the gap-spacing, it might be necessary to compare the positive and negative polarity flashover characteristics, such that the smaller gap-spacing corresponding to the required protective level should be chosen so as to provide more reliable protection.

3. SELECTION OF THE OPTIMUM ELECTRODE-PAIR

3.1. Experimental work

The protection provided by a co-ordinating gap depends upon a number of conditions among which geometry of the spark-gap is of great importance. So, the optimum electrode-pair which provides the best protection compared to the other pairs at a given system conditions has been determined by examining the behaviour of various electrode-pairs of different geometric shapes under 1 50 standard impulse voltage waves of positive and negative polarity.

Tests have been carried out by placing each electrode-pair in a vertical position with one of the electrodes being earthed. The gap-spacing between the electrodes is increased from 1 cm up to 10-12 cm and at each gap-spacing, impulse flashover voltages are measured. So, impulse flashover characteristics are obtained as a function of gap-spacings.

For each electrode-pair, at each gap-spacing, critical and 100 % impulse flashover voltages have been measured. These voltage levels are indicated in the flashover probability curve in Fig. 5. The critical impulse flashover voltage, here, is the withstanld voltage of the gap which has the highest peak value, i.e flashover probability of the gap just below this value is zero. 100 % impulse flashover voltage, howver, is the lowest peak value of the impulse voltage at which flashover takes place at each application of five successive impulses (4). For different electrode-pairs, different critical and 100 % flashover voltage values are measured for a given gap-spacing.

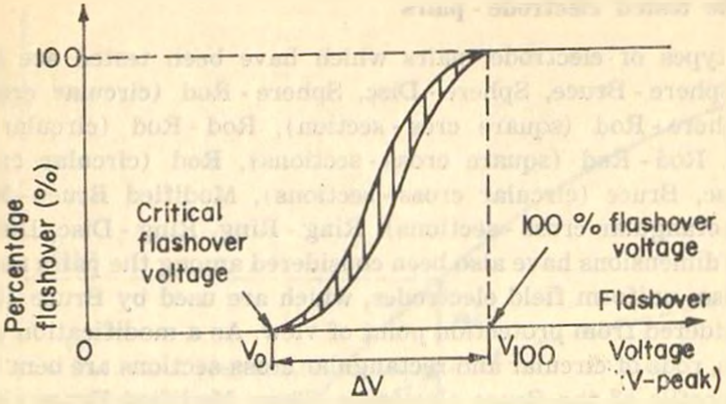


Figure 5 : Flashover probability of a co - ordinating gap at a given gap - spacing.

Atmospheric conditions affect the flashover voltages by directly proportional to the pressure and inversely proportional to the temperature of the air, i.e almost proportional to the relative air density (5,6). Thus, the measured voltages are converted to the values which could have been measured at normal atmospheric conditions, i.e at 20°C and 760 mm Hg.

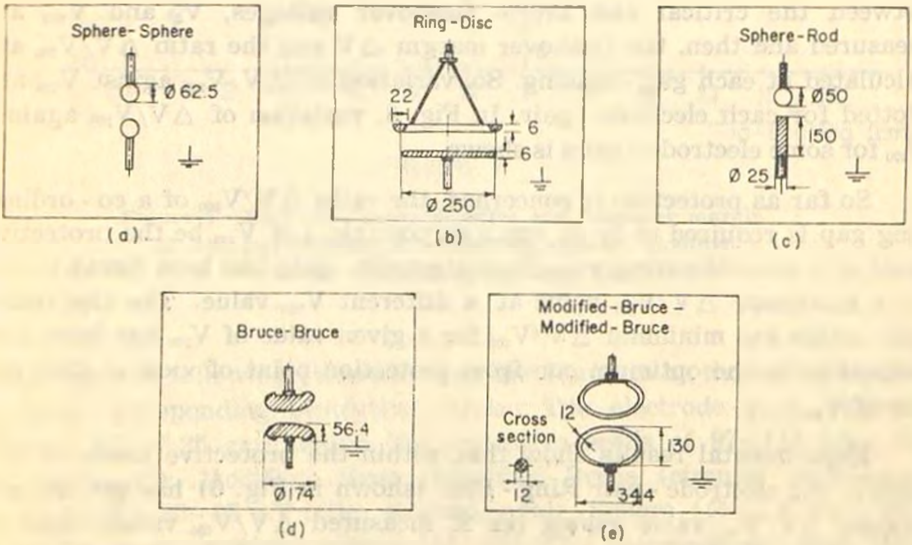


FIGURE 6

Figure 6 : Some of the electrode - pairs tested under impulse voltages. (dimensions are in mm.)

3.1.1. The tested electrode - pairs

The types of electrode - pairs which have been tested are Sphere - Sphere, Sphere - Bruce, Sphere - Disc, Sphere - Rod (circular cross - section), Sphere - Rod (square cros - section), Rod - Rod (circular cross - sections), Rod - Rod (square cross - sections), Rod (circular cros - section) - Disc, Bruce (circular cross - sections), Modified Bruce - Modified Bruce (rectangular cross - sections), Ring - Ring, Ring - Disc, Disc - Disc. Different dimensions have also been considered among the pairs mentioned above. Also, uniform field electrodes, which are used by Bruce (6), have been considered from protection point of view. As a modification of Bruce electrodes, rods of circular and rectangular cross-sections are bent to simulate the profile of the Bruce electrodes. Thus, Modified Bruce electrodes with small and large dimensions are obtained. Some of these electrode - pairs are shown in Fig. 6.

3.2. Comparison of the electrode - pairs from protection toint of view

In order to determine the optimum electrode - pair from protection point of view, impulse flashover characteristics, which are obtained as mentioned in sub - secetion 3.1, are used. Fig. 7 shows such a flashover characteristic of an electrode - pair which is obtained by the impulse voltage tests. For each gap - spacing, a flashover margin ΔV exists between the critical and 100 % flashover voltages, V_0 and V_{100} are measured and then, the flashover margin ΔV and the ratio $\Delta V/V_{100}$ are calculated at each gap - spacing. So, variation of $\Delta V / V_{100}$ aginst V_{100} are plotted for each electrode - pair. In Fig. 8, variation of $\Delta V / V_{100}$ against V_{100} for some electrode - pairs is shown.

So far as protection is concerned, the ratio $\Delta V/V_{100}$ of a co - ordinating gap is required to be as small as possible. Let V_{100} be the protective level of a co - ordinating gap. Each electrode - pair has been found to have a minimum $\Delta V / V_{100}$ value at a different V_{100} value. The electrode - pair which has minimum $\Delta V / V_{100}$ for a given value of V_{100} has been considered to be the optimum one from protection point of view at that value of V_{100}.

Experimental results show that within the protective levels of 35 - 82 kV, the electrode - pair Ring - Disc (shown in Fig. 6) has got the minimum $\Delta V / V_{100}$ value among the 22 measured $\Delta V / V_{100}$ values, each of which corresponds to one electrode - pair. This may be seen from Fig. 8 to some extent. So, it is considered to be the optimum electrode - pair providing the best protection within the protection levels of 35 - 82 kV.

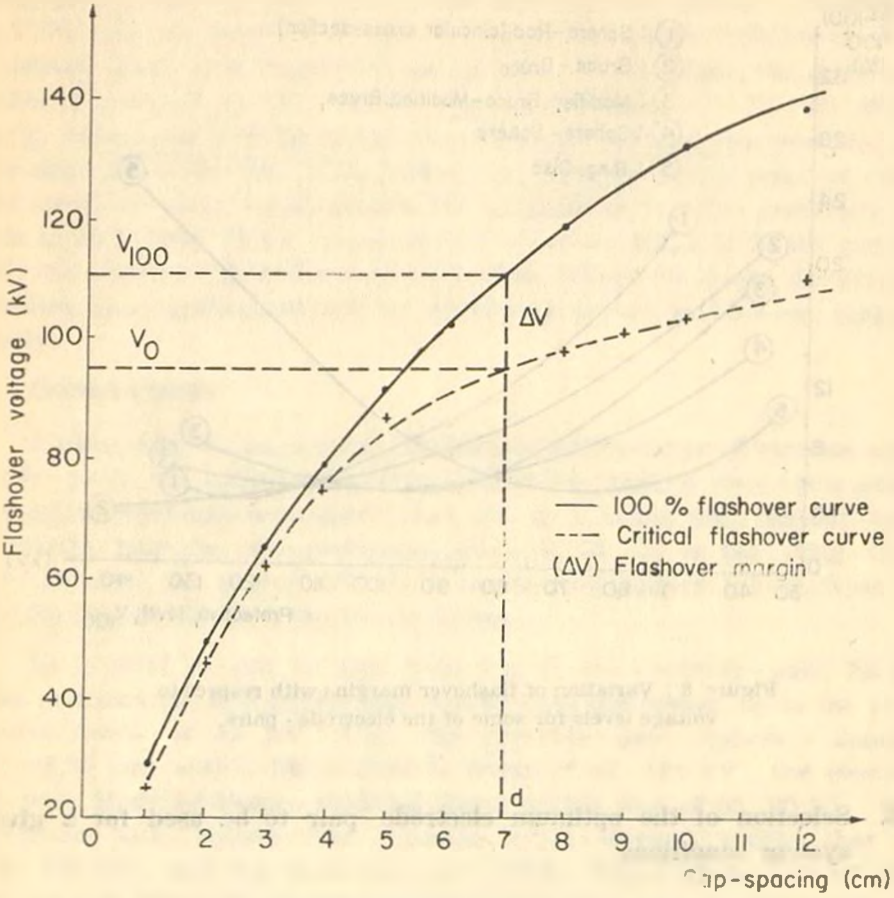


FIGURE. 7

Figure 7 : Flashover characteristics and flashover margin ΔV at a gap - spacing d_t. (Electrode system : Modified Bruce - Modified Bruce - Fig. 6)

Similarly, the following electrode - pair are found to be the optimum ones at the corresponding protective levels : The electrode - pair, Sphere - Sphere (∅ =6.25 cm) within the protective levels of 97 - 114 kV ; the electrode - pair, Modified Bruce - Modified Bruce (circular cross - section) within 85 - 95 kV ; the electrode - pair, Sphere (∅ =5.0 cm) - Rod (circular cross - section) within 115 - 123 kV ; the electrode - pair, Bruce - Bruce within 123 - 145 kV. These electrode - pairs may be seen in Fig. 6.

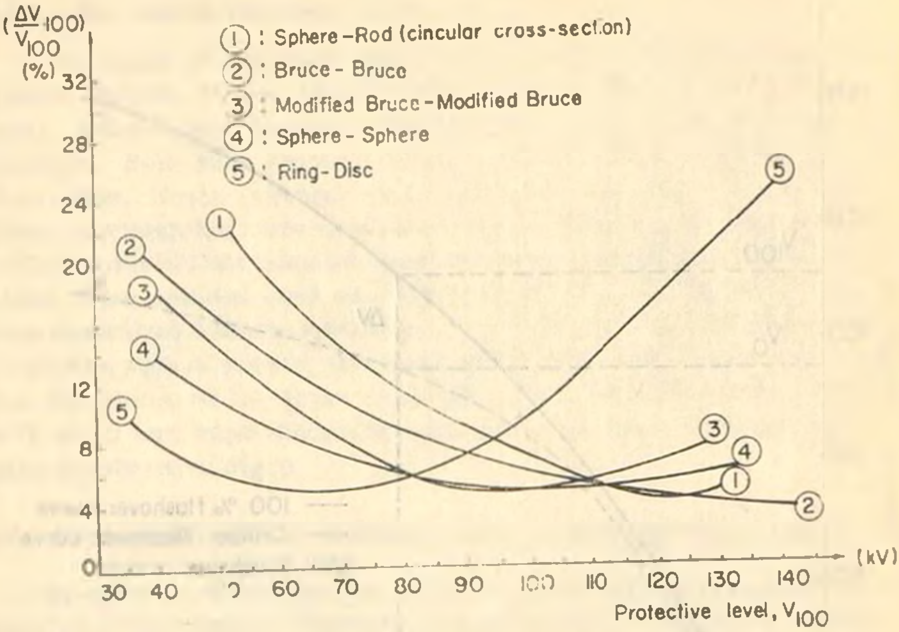


Figure 8 : Variation of flashover margins with respect to voltage levels for some of the electrode - pairs.

3.3. Selection of the optimum electrode - pair to be used for a given system conditions

In this part, selection of an optimum electrode - pair will be considered for the protection of the equipment working under the nominal system voltages of 11 kV and 15 kV, respectively. The highest system voltages corresponding to these voltages are 12 kV and 17.5 kV, respectively (7). The corresponding protective levels may be found from the relation, BIL/$V_{100} \geqq 1.25$, where, V_{100} is the protective level of the co - ordinating gap to be used and BIL is the Basic Impulse Insulation level of the equipment to be protected. The BIL values corresponding to the highest system voltages of 12 kV and 17.5 kV are given as 75 kV and 95 kV, respectively (7). So, the corresponding protective levels may be found to be equal to or greater than 60 kV and 76 kV, respectively (from $V_{100} \geqq$ BIL/1.25). In order to determine the optimum electrode - pairs for the given conditions above, the minimum values among $\Delta V/60$ values and $\Delta V/76$ values, each of which corresponds to one electrode - pair, should be chosen, respectively. The flashover margins, ΔV's corresponding to $V_{100}=60$ kV and $V_{130}=76$ kV and also the ratios, $\Delta V/60$ and $\Delta V/76$ may be found from the corresponding characteristics of each electrode - pair. It is found that among the $\Delta V/60$ values, the minimum value is provided by the electrode - pair, Ring - Disc (Ø=25 cm). Similarly, among the $\Delta V/76$ values, the minimum value is also provided by the same electrode - pair. This shows that from protection point of view, the electrode - pair, Ring - Disc is the optimum pair at the protective levels of 60 kV and 76 kV, respectively (i.e for the BIL's of 75 kV and 95 kV, respectively). In order to provide these protective levels, the corresponding gap - spacings should be adjusted to 2.6 cm and 3.8 cm, respectively.

4. CONCLUSION

Making use of the impulse flashover characteristics of various electrode - pairs, the optimum one from protection point of view for a given protective level has been determined. So, it is found that the optimum electrode - pair for the protective level of 70 kV is the Ring - Disc (Ø=25 cm) ; for that of 100 kV is the Sphere - Sphere (Ø=6.25 cm) ; and for that of 130 kV is the Bruce - Bruce.

In general, as can be seen from Fig. 8, the electrode - pair, Ring - Disc provides the best protection, compared to the others, up to the protective levels of 82 kV. Also, the electrode - pair, Sphere - Sphere (Ø=6.25 cm) within the protective levels of 97 - 114 kV ; the electrode - pair, Modified Bruce - Modified Bruce within that of 85 - 95 kV ; the electrode - pair, Sphere - Rod (circular cross - section) within that of 115 - 123 kV ; and the electrode - pair, Bruce - Bruce above that of 123 kV, provide the best protections. Therefore, they may be considered to be the optimum electrode - pairs within these corresponding protective levels.

5. REFERENCES

1 — 'Application guide for non - linear resistor - type lightning arresters for alternating current systems', IS : 4004, Oct. 1967.

2 — 'Guide for application of valve - type lightning arresters for alternating current systems', USAS C.62.2, Mar. 1969.

3 — 'Recommendations for insulation co - ordination. application guide', IEC 71A, 1962.

4 — Bowdler, G. W. : 'Measurements in high voltage test circuits', Pergamon Press, 1973.

5 — Hawley, W. G. : 'Impulse voltage testing', London : Chapman and Hall, 1959.

6 — Kuffel and Abdullah : 'High voltage engineering', Pergamon Press, 1970.

7 — 'Recommendations for insulation co - ordination', IEC 71, 1960.

8 — 'Electrical transmission and distribution reference book', Westinghouse Elec. Corp., Indiana, 1964.