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327. — TECHNICAL SURVEY OF MODERN LIGHTNING AND OVERVOLTAGE PROBLEMS

(REPORT OF THE INTERNATIONAL STUDY COMMITTEE ON LIGHTNING AND SURGES)

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REPORT

The following report of the committee contains firstly a summary of the present state of knowledge of lightning research and of surge arrester technique. To this is added a short discussion of the questions which require further working out. This type of presentation of report seems suitable at the present time, because the exchange of ideas and information between each other about the work and researches going on in different countries was made considerably more difficult during the war. The committee held a meeting in February 1947 in Switzerland, at which the most important questions arising to-day in this branch were discussed.

I. — STATE OF KNOWLEDGE.

a. **Lightning research.** — In this field reports are available of work carried out during the war in the U. S. A., England, Sweden and Switzerland.

In the *U. S. A.* fundamental experiments were continued at the Empire State Building in New York [1]. During these measurements, an attempt was made to measure the value of the lightning current at some point of the lightning track by the blackening caused on a photographic film [2]. Measurement on the behaviour of lightning currents were also continued at the Cathedral of Learning at Pittsburg, in which connection the use of fulchronographs as measuring instruments merits special notice.

The method of measuring the peak value of the current by the residual magnetism of magnetic materials in the form of wire or powder (magnetic links), which was developed in 1920 by the German Study Society for Super Tension Networks, was widely used especially in the U. S. A. for measuring the maximum value fo lightning current in high tension transmission systems. Special attention was given to measurement of the peak values of lightning current components in steel towers, ground wires, counterpoises, grounding systems and arresters. Additionally more complicated measuring equipment was employed to give some data on the shape of the current in function of time, such as fulchronographs and oscillographs [3]. Through further development of the magnetic link method, peak values of surges, also their steepness, were measured (wave slope indicator). For this purpose the maximum value of the current flowing into a constant high tension resistance or into a high tension capacitor, is measured by a magnetic link. In this way, the klydonographs which were formerly much used, have been successfully replaced by a more accurate method, after it had been discovered that klydonographs could lead to entirely erroneous conclusions being drawn. Under [4] are listed american papers on lightning in general, whereas papers on research and measurements on high voltage systems are listed under [13].

In *England*, lightning current peak values were measured on the steel cables of barrage balloons using magnetic links [5]. In addition experiments on the growth of long sparks were continued [6], and the question of lightning tests on small models discussed [7]. Some general english conclusions on the formation and localisation of lightning are indicated under [8]. The lightning tests carried out in England between 1933-1940 by the E. R. A. have been published in a comprehensive book "Surge Phenomena" [9]. A new report on the effects of lightning discharge has been recently published by the South Africa scientist B. F. J. Schonland [10].

In *Sweden*, further experiments have been carried out in the High Tension Research Institute of the University of Uppsala using the technique developed by Prof. H. Notrinder. The voltage magnetically induced by the lightning current is measured in a frame-aerial located at a distance from two to ten km. From this voltage, ligthning current can be calculated if certain assumptions on field propagation are made [11].

In *Switzerland*, oscillographic measurements of lightning currents were started on a 70 m high lightning tower on the Monte San Salvatore near Lugano, on which a report was given in the last C. I. G. R. E. [12].

b. **Surge protection of high tension systems.** — Reports on measurements of surges on high tension systems during the war period are only available from U. S. A. [13]. With the exception of statistical summaries of overvoltage faults on lines, measurements were taken chiefly at substations, and usually only the *peak value* of the overvoltages was measured. The klydoonograph was still the most widely used apparatus for measuring, though magnetic links as under *a* were also used to a certain amount. The measurement of the peak value of the voltage is replaced in the latter case by the measurement of the peak value of current, which is limited by a metallic resistance, and which is isolated from the system by an arrester so long as no overvoltage occurs [14].

A report has also been made on the first measurements of the *steepness* of the overvoltage surges [15]. These measurements differed from earlier such measurements of lightning currents in Switzerland [16] in that the greatest instantaneous value of the steepness of the gradient was not measured but instead an average steepness, which is comparable with that of the C. E. I. definition. In this definition, as is well known, the wave front is represented by an imaginary line which passes through the points 10 % and 90 % of the surge voltage [17]. A part of the literature on overvoltage measurements is also to be found under [4].

c. **Experiments on lightning arresters on systems.** — The experiments were principally conducted in the U. S. A. [18]. In addition to the peak values of the current in arresters, some measurements were made on the steepness of the current with magnetic links, also some measurements on the form of the lightning current with oscillographs and fulchronographs. In Switzerland a measuring discharge counter was developed to give an approximate value of the charge (Coulomb), flowing through the arrester and installed to observe the operation of arresters on systems : however, there are no publications available on the results obtained [19].

Satistics on the number of arrester defects were presented to the C. I. G. R. E. 1946 from Finland, from which relatively high number of defects are to be seen in some cases [20].

An important cause of lightning arrester failure seems to lay in the appearance of condensed water vapor and the corrosion of the spark gaps inside the arresters, if these are not absolutely sealed.

Cases have been experienced in which high-voltage surge arresters have broken down in service even when no overvoltages have been present, and even when the arresters are efficiently sealed against the ingress of moisture. Such failures occur in humid weather conditions, and are due to the wet deposit on the outer surfaces of the porcelaine causing the voltage distribution to become so irregular that internal power-frequency spark discharges take place in some of the "units". Ultimately, the complete arrester breaks down internally and is destroyed by the sustained power-frequency current. It is believed that this phenomenon has been responsible for some of the arrester failures which have been attributed to surges.

II. — PRESENT TECHNIQUE OF OVERVOLTAGE PROTECTION.

In the technique of overvoltage protection, great progress has been made in some countries during the war. For example in the U. S. A. and Switzerland values were standardized for the average or maximum permissible breakdown and residual voltages [22]. While the American rules permit a tolerance of $\pm$ 20 % alternatively 15 % for substation arresters, and 25 % alternatively 20 % for distribution type arresters on these voltages, the Swiss and Italian rules lay down maximum values, so that tolerances are only permissible in a downward direction, but not upward. In this way the grading of this voltage with respect to the permissible maximum surge voltage level for the insulation to be protected (basic level) is better assured [22].

Arresters to-day are more frequently used in the U. S. A. than in Europe. The chief cause of this is the general use of solid neutral grounding in the U. S. A. which makes the use of arresters considerably easier. The larger frequency of lightning storms in certain districts of the U. S. A. is only a smaller factor in the greater use of arresters there.

There are to-day two fundamentally different conceptions of the type and method of arrester installation. The basis behind the first is that it is desired specially to protect the most expensive apparatus, that is to say the transformers, by the arresters. For this purpose the arresters are connected as near as possible to the transformers and in the limit each transformer has its arrester which is in many cases directly incorporated. The second conception attempts to use arresters to keep away overvoltages from all substation insulations. This idea requires that the arresters be connected to the incoming and outgoing lines. In the limit an arrester group would be connected to every line.

In the U. S. A., stations up to the highest operating voltages are provided with arresters. In Europe arresters are only used in stations of the low and medium ranges of high tension up to about 60 kV rated voltage. For higher voltages, it is usually preferred to build surgeproof transformers, that is to say transformers capable of standing up to flashovers at the terminals or the protecting gap without suffering internal damage and without use of arresters.

The protection of generators with arresters is also more general in the U. S. A. than in Europe. The difficulties in Europe are again due to the fact that the neutral point is either isolated or only grounded through a high impedance. Additionally, generator insulation which is not favoured by the high surge factor of an oil insulation, is often not liberal enough to ensure a safe grading with the arrester, that is to say that an effective protection is not provided.

The much discussed question of whether it is possible to save insulation by using arresters, has two aspects : In the U. S. A. the solution has proved itself ou some systems to insulate transformers provided with arresters for a lower level than that corresponding to the present day basic level of the rated voltage [23]. It is being at present discussed whether in this case (solid neutral point grounding and arrester at the transformer) the insulation could be chosen in all cases one class lower than according to the present day basic levels. In Europe the neutral point is also grounded on most systems of 100 kV or more system voltage (English grid 132 kV, most networks 150 kV, French and Italian systems 220 kV, etc. In the contrary, the neutral point is almost never solidly grounded on systems of medium and low high tension voltage ranges, in which a need for an effective overvoltage protection exists mostly. As the arrester in this case must be built to suit the line-to-line voltage and also because European medium voltage systems are often considerably weaker insulated than are the American, it is often not possible to save insulation by using arresters. In elderly European systems, it is possible for the paradoxical case to occur that the incorporation of arresters requires an improved insulation, if a good service reliability is to be expected from the arresters. The reducing and exact keeping to of agreed break-down and residual voltages of arresters is therefore of great importance as also a tolerance which is as small as possible, on these values.

III. — PRESENT PROBLEMS OF LIGHTNING RESEARCH AND OVERVOLTAGE PROTECTION.

a. **Lightning research.** — As it is now possible to obtain exact data on the form of the lightning current in every detail by measurements on high objects specially endangered by lightning (Empire State Building, Cathedral of Learning, Mte San Salvatore, etc.) the question remains to be answered if and how the lightning current in a low object on the level differs from a lightning stroke to high objects. For the Empire State Building, it was found that the lightning is nearly always negative, that is, originates from a negatively charged cloud, so that the lightning rod forms the positive point. The leader stroke proceeds in this case practically always from the lightning rod towards the cloud. According to the photographs of Schonland, this is reversed on the level, thus the lightning proceeds downwards from the cloud to earth [1]. The same can also be concluded from the downwardly directed branches of many ordinary lightning photographs.

In the measurements made up to now on Monte San Salvatore approximately one half of the lightning strokes were found to be negative and the other positive [12].

The question still unsolved at present is that of lightning strokes on small objects on a flat plain such as transmission towers, houses, etc., which due to their smallness and position are only infrequently struck by lightning. Research on these ligthning strokes only seems possible at present through the installation of numerous simple means of measurement for definite single characteristics of the lightning current, as for example peak value, steepness and charge.

The principal interest exists to-day for the measurement of the average steepness of the single strokes, for their duration and the interval between them, also for the total charge of the individual strokes and for the whole multiple stroke.

A great importance exists in lightning research for all methods which allow the lightning current to be reliably measured from at distance. In the method of measuring the induced voltage in a frame aerial, the chief difficulty is, without doubt, in the evaluation of the results, that is to say the calculation of the lightning current from the measured induced voltage.

A question still completely unanswered to-day is that of whether special characteristics of the terrain or the air produce an especially high lightning stroke frequency, that is to say whether it is possible to find out in advance the places where lighthning will strike. This question is more to the front at present than formerly, since no positive proof or even safe confirmation of the hypothesis of Dauzère on the endangering effect of excessively ionized areas of the air could be successfully obtained [24].

b. **System overvoltages.** — Practical interest is in the first place concentrated on the *steepness* of lightning overvoltages on overhead lines. A wider range of data is desired to put the question of the stressing of transformer windings on a better basis. Especially the question is, if the greatest steepness is produced by a flashover on the transformer or protection gap.

A second point of discussion in committee, was concerned with the transference of overvoltages through transformers. *Generator defects* on the low voltage side of transformers have occurred during lightning storms which could not be fully cleared up. The question then arises whether the defect was really the result of overvoltages. In these generator defects, star/delta transformer connection with solid neutral grounding on the high tension side was apparently frequently involved. In these cases, an overvoltage on the high tension side between phase and ground is transformed into an overvoltage between two phase terminals on the low voltage side connected to the generator. The normal arrester protection to ground at the generator terminals usually does not help in this case as it does not operate. The theoretically possible solution would be to connect arresters between the phase terminals, but has found no practical application up to the present. Additionally no data are available on the operation or otherwise of arresters installed, chiefly in the U. S. A., to protect generators.

The committee has also discussed the question of surge testing of power *transformers*. All members agree that a surge test in itself is desirable. To a certain extent opposition still exists to the use of this type of test, because the methods used for the discovery of any winding short-circuit which may possibly occur do not always appear to be reliable [25]. In the U.S.A. this surge test is recommended and is already carried out widely by several manufacturers. The method of finding any defect which may occur is left to the concern making the test. Generally the measurement on the neutral point current of the winding under test is regarded as the safest indicator of the occurrence of breakdowns. In a few cases, this test has already proved itself a useful means for showing up construction and design faults. A further clearing up of this question of the surge testing of transformers seems to be very important and the committee recommends all efforts to this purpose.

The committee furthermore expresses the desirability of short notes presented by the members of the C. I. G. R. É. to the meeting or to the Committee nº 8, and concerning severe damage in high voltage networks caused by lightning or surges. It is suggested to report especially observations made in cases where generators, transformers or apparatus were damaged, possibly with some information on the precautions taken to avoid further damage.

c. **Lightning arresters. Surge arresters.** — All present day arresters are designed and built with the purpose of rendering harmless overvoltages due to lightning. Now experience in all countries using arresters, shows that arresters also operate from time to time on other overvoltages, specially those caused by swichting and earth faults on ungrounded systems. It would be very valuable to collect further experiences on this subject. For either account must be taken in the design of the arrester of these overvoltages arising from other causes, or the lightning arrester must be so constructed that it is prevented from operating for other types of overvoltages. According to the few facts which have been published in the literature up to now on this matter [26], it appears that these overvoltages not caused by lightning are a greater source of danger to the arresters in Europe than in the U. S. A. The cause of this observation is probably again due to the different systems of neutral point grounding. The solid neutral point grounding is favourable first to the purpose of elimination of earth fault overvoltages and second also in the matter of the lower arrester stressing (phase to neutral voltage instead of line — to — line voltage at the arrester) than high impedance grounding. It would be valuable to possess a recording instrument with which the height of the overvoltages, which may occur, could be recorded in high tension stations in a simple and cheap way but more accuratly than with a klydonograph, in which also it might be possible to distinguish between overvoltages caused by lightning and other reasons, and also to supervise the behaviour of the arresters.

An important question which has already been referred to, has to do with the dispersion of the breakdown and residual voltages of arresters. A reduction of the tolerances of this values is of great economic interest. The breakdown voltage varies especially for arresters for very high voltages with the field in the neighbourhood of the arrester, which can be strongly distorted by nearby objects. This type of dispersion can be reduced by a suitable design of the form of arrester electrodes, stress rings etc. The variations between the single units of a particular design and that which can take place in one arrester over a long period are both important. One can speak of "design dispersion" and "service dispersion". This last is partly defined by circumstances of environment, especially due to damp or moisture which may penetrate. Some other part of dispersion has not received any satisfactory explanation up to the present. It would be desirable to obtain some data on this dispersion in function of the years in service.

The working out of this question would seem to be possible by measuring periodically the breakdown voltages of arresters with surge voltages for a large number of arresters, for example, twice per year. Additionally service statistics should be kept of the number of arrester faults occuring.

In this connection it would also be valuable to collect further data on the quantity of the electric charge flowing away when arresters operate. For valve type arresters, the charge is a good measure of the value of the energy stressing of the arrester, in any case a better measure than the peak value of the current. This question should be investigated on a broad basis, before the present requirements for arresters are made more strict as was proposed at the last C. I. G. R. É. meeting [27].

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