DISCUSSION OF "THE GROUNDED WIRE AS A PROTECTION AGAINST LIGHTNING."

PRESIDENT SCOTT:—This is certainly a very important and very interesting topic, one on which it is very difficult to secure complete and definite information. The conditions surrounding the problem are indefinite and hard to determine, as in fact are all experiments in connection with lightning work. We should be very pleased to hear from those who have had experience with this subject. I think Dr. Perrine has had something to say on this in the past.

DR. F. A. C. PERRINE:—From my own experience, I would say, that there seems to be no question but that a grounded wire on a pole line properly grounded does benefit in lightning protection. In relation to the question as to whether barbs are used or not, I agree with Mr. Mershon that they can have comparatively little effect in discharging the atmosphere, for the reason that the atmosphere that we wish to discharge is a moving atmosphere and not a stationary one. If the atmosphere were a stationary one the barbs on the wire would undoubtedly aid in the discharge. On the other hand, after a cloud has discharged in the neighborhood of the line, and the line and its accompanying guard wire has reached a stationary condition, just before the bomb charge is about to disappear from the line through the ground circuit, I believe that the points on the grounded line will tend to aid the release of the bomb charge from the power line; and while there is not much in favor of the barbs, it would be my opinion that if it is possible to obtain a wire with a point on that is not thereby mechanically weakened, it would be advantageous to obtain such points. But such a wire is not on the market. I agree that it is not wise to fool with barbed wire, because you can get much greater permanence with simple twisted strand wire or single wire.

There is one point that has not been brought out, and that is the question of possible loss of energy due to inductance to the grounded wire. On one line that I am familiar with they claimed that there was a very serious loss of energy due to electromagnetic induction to the grounded wire, the grounded wire making short circuits parallel to the line. I made some tests on this and could not find anything that seemed to be really appreciable. I would also like to call attention in reference to the communication that Mr. Mershon read, to the fact that the power line at Lachine, where they have found no trouble, although only protected by lightning arresters, is a line of long iron poles, where the earth-tension is undoubtedly brought nearer the line than would be the case with wooden poles. We have no practical experience except with one or two lines such as the Lachine line.

MR. MAILLOUX:—In one line in Arizona 25 miles long, which connects at a station at one end, a receiving station at the other end, and a second power station about eight miles from the

receiving end, no provision was made for lightning protection except by spark-gap lightning arresters at the stations. In other words, the line, a 3-conductor line, about 25 miles long, with transmission voltage of 22,000 volts, has only three points at which it is protected by lightning arresters. I was curious to know what had been the experience, and wrote to the operating engineer, Mr. D. W. Beldon, one of our members. He replied that the line had never been without current since it was started, last fall; that notwithstanding the fact that there had been many lightning storms, including one which occurred while the load was at its peak, there has never been any trouble at all from lightning. There is a discharge over the lightning arresters, but it has never been such as to interfere in the slightest manner with the operation of the line.

MR. A. J. WURTS:--I am pleased to note that Mr. Mershon does not recommend altogether abandoning the spark-gap lightning arrester.

I do not agree with him where he states that "this discharge will pass to earth by gradual leakage over the insulation of the system if the approach of the cloud is slow enough to give time for such leakage." I do not believe that the velocity of the cloud has any immediate influence on the static charges in overhead wires as to whether they leak to earth or become disruptive. I consider the cloud or upper storm strata and the earth to form the two terminals of a huge static machine and I think you will agree with me that a lightning discharge does not start from a single point but that the main discharge as we see it is made up of a large number of smaller tributary discharges which in turn are made up from still smaller sources, very much as our water sheds are ultimately concentrated into one large stream or river. I believe the same to be true in the earth terminal, that there also are tributary discharges from all sources of electrostatic capacity and from all directions toward the main stroke. I believe that all electric wires, grounded or otherwise, car rails, gas pipes, water pipes, all form a part of the earth terminal of this huge static machine and that a grounded wire in the neighborhood of an insulated electric line will not materially protect that line but that all will discharge alike and that the discharge will tend to be disruptive with every discharge of the static machine—with every stroke of lightning. If there is any virtue in the theory of the leakage of the static charge, surely this ought to manifest itself in our trolley wires, all of which are thoroughly well grounded as far as leakage is concerned, although for disruptive discharges it is admitted that the ground connection is of no avail, owing to the large inductive resistance intervening between the overhead wire and the ground connection.

I am sure you all know that wire fences, gas pipes, and even gilt mouldings around a room will give off discharges during a thunder storm, and these discharges, as I take it, are due to the

release of the electric stress by the lightning discharge breaking through the dielectric. The charge then which had previously existed in all bodies having electrostatic capacity, seeks to establish a path to the main lightning discharge; so that every piece of metal, every conductor, whether "grounded" or otherwise adds to the capacity of the earth terminal. I have even noticed discharges between parts of large steel buildings.

Admitting now that discharges do occur from all kinds of conductors, it would appear that the overhead grounded wire could hardly be considered a reliable source of protection because if it really did protect, I do not believe that we would obtain sparks from the inside metallic parts of buildings, protected (?) as they are by well grounded water pipes, forming the best possible overhead grounded wire.

MR. THOMAS:—I do not know of results where all the conditions have been carefully investigated and where it is definitely known that there has been trouble without a grounded wire, that it has been stopped by the addition of a grounded wire, and (to make the proof of the efficiency of a grounded wire complete) we should have also the other case, where the removal of the grounded wire shows the beginning of trouble again. Such a case would be very unlikely and in its absence we must wait for a very large number of ordinary tests.

In regard to Mr. Mershen's assumption as to the nature of the effect of lightning upon the line, he concludes that it is practically all electrostatic induction, but I believe he is hardly justified in neglecting the electromagnetic entirely.

In discharges which come to the ground in the immediate neighborhood of the line, we certainly cannot neglect the electromagnetic effects. The difficulty of protecting oil tanks and powder magazines even with a considerable amount of grounded conductor in the neighborhood is also well known.

Dr. Perrine has spoken of the losses on grounded wires close to transmission lines. I am surprised to find that it does not amount to anything. I should think it probably would be considerable, and if the grounded wire is made of considerable conducting power, *i.e.* low ohmic resistance, I imagine there will be found quite a little loss; and more than that, if these grounded wires are placed close to the transmission line, as must be done to get effectiveness, it must considerably increase the electrostatic capacity of the system. This might be a serious item in a large plant. The problem is very complex and I think we should go very slow in staking too much on grounded wires.

Another point on which I think Mr. Hayward can give us some information—it is generally supposed that the striking of the lightning to the ground is the most harmful feature. I am inclined to believe that the discharge within the cloud in a more or less horizontal direction will produce a much more destructive effect upon a transmission line which happens to lie somewhere near parallel to the line of this discharge than a vertical discharge will.

DR. PERRINE:—I would like to speak a word, Mr. President, in explanation. I see Mr. Thomas has distorted my statement that I could not find a loss, to the statement that I found no loss. There is a good deal of difference between the two. The matter is difficult to measure. I tried to measure it, and couldn't find it. I didn't say it wasn't there.

Then there is another point that I want to call attention to now that I think this discussion is getting a little mixed on, and that is, that there are two things to protect against. One is the gradual charge and discharge of the line due to conditions of the atmosphere, and it may be that a line is at a high potential at one part of the country and at a low potential at another, or that the line is gradually acquiring a charge from the wind blowing over the line when there is no lightning in the neighborhood, and in perfectly clear weather you can have that. It is against this form of trouble that I believe that the guard wire is of most advantage. I do not believe that the guard wire is of any very great advantage when you have lightning discharges of severe character. There you do get, as both Mr. Wurts and Mr. Thomas have stated, an electromagnetic effect as well as electrostatic but the gradual charge and discharge of a line that would come in perfectly clear weather is a very nasty thing, and, as I said, one line that I saw myself, 46 miles long, which Mr. Mason was handling with me, was the only line, as Mr. Mason remarked, that he ever succeeded in taking hold of when there was no dynamo connected with it, in dry weather, without getting a shock. He attributed that almost entirely to the protection of the neighboring grounded wire.

DR. A. E. KENNELLY:—This is a very interesting and important subject and one that must always be of great practical consequence, because it is one of the standing difficulties in our transmission line work. We can protect against the regular difficulties, but lightning is one of the difficulties that cannot be reckoned with. Experience in this matter extends to a much earlier date than is generally supposed, because in a certain sense we have experience on this question for at least 50 years, in the protection of telegraph and telephone wires. It is true that the effects of lightning in telegraphy are of much less consequence than in a power transmission system, because the amount of property that may be damaged in telegraphy by a lightning stroke is comparatively small. Nevertheless, the experience which can be accumulated on the long wires in telegraphy bears upon the experience which we seek to accumulate in the protection of transmission lines. It has been a popular impression derived from many years' experience in telegraphy that the presence of neighboring overhead wires does protect against indirect lightning effects. Of course, we know that when we speak of the direct flash nothing can afford protection, but in regard to these surges due to lightning discharges in the vicinity, there is a strong popular belief among telegraphists, that neigh-

boring wires do protect. If we know anything at all about lightning—and we do not know very much—it is that when we put a conductor wire under ground, or in an electrical conducting shell, that the buried wire is freed from electrostatic disturbances, and also, to a certain extent, freed from electromagnetic disturbances. We all believe that a buried wire, disconnected from all apparatus, is in no danger of a lightning stroke, induced or otherwise. When grounded wires are carried over and above, or in the neighborhood of, a working wire, the earth is virtually raised over that wire, or in the vicinity of that wire, and we partially produce that effect which a completely buried wire more thoroughly attains. I think, therefore, it stands to reason, that if only there are grounded wires enough over and above and around a working wire, immunity from indirect lightning surges is brought to that wire. But whether it is worth while incurring the expense and trouble of stringing the grounded wires around the working wire is another and a different question. Some years ago I had occasion to collect some information of this character from the representatives of local stations, and I found the evidence was somewhat in favor of protection by means of guard wires suspended in the neighborhood of the working wires.

The question of electrostatic capacity and its increases due to grounded wires on the working wires, is one of the minor considerations to be taken into account, but after there are three wires up in a three-phase overhead system, the extra capacity that can be given by adding other wires is comparatively trivial. It is the first extra wire that counts, and when you have several wires up together side-by-side it would not seem that the electrostatic difficulty is going to be a serious one. The amount of energy which may be wasted, in transformer fashion, from the main line to the loops of the grounded lines as secondary circuits, is also a matter to be considered, and I do not think that it has been worked out. It would seem, therefore, that there is an advantage, theoretically at least, in having grounded wires around working wires, but the disadvantage of having to string extra wires around a transmission system is very serious.

MR. LINCOLN:—Mention has been made of the electromagnetic as well as the electrostatic effect. I wish to call attention to the fact that these grounded wires are to a certain extent a protection against electromagnetic as well as electrostatic effect of a lightning discharge in the neighborhood of the transmission line. The grounded wires constitute a short-circuited secondary and the induced effects from the lightning discharge in the neighborhood will be largely absorbed by that short-circuited secondary. In a solid metallic conductor you can get no electromagnetic effect; so the ground wires may approach that condition.

One other point which has been brought out before, is in regard to the discharge by the grounded wires of the atmosphere which blows across the line. Mr. Mershon does not treat of that in his contribution, but I think it is an important point. In this

climate we do not get that effect so much as in the West, because the atmosphere here contains much more moisture.

MR. F. S. WOODWARD:—I would like to speak of just one practical point in regard to barbed wires on a line that I am familiar with. For about two years after erection they remained in good condition, then began a series of breaks due to rusting. Nearly every break of a barb wire was followed by a short circuit in line wires. As a result of this experience the barb wires were replaced with No. 4 B. & S. iron wires. The extra cost of larger size iron wires was more than offset by lesser cost of erecting.

This line had ground wires every six poles. The ground wires were brought about half-way up the pole and then divided, passing up at extreme end of cross-arms. This to some extent protected linemen when at work, as otherwise they were in contact with the ground return.

MR. RUSHMORE:—There is one point which I have not heard mentioned. If a transmission line runs through a mountainous country where a considerable difference in latitude exists between different parts of the line, there will be an electrical effect, due apparently to the difference in altitude which causes a much greater difference of potential between wires and ground in the low than in the high altitudes. In some instances it is known that a considerable difference of potential exists between the base and summit of mountains. A grounded wire strung along the line should be of assistance in the prevention of trouble from this cause.

MR. R. S. KELSCH:—The Lachine Rapids Hydraulic and Land Co., Ltd., of Montreal, Can., operating a general overhead distributing system for light and power work, at 2200 volts three-phase, has experienced considerable trouble and suffered damage to transformers principally, from lightning.

When this company began operating, there were five telegraph, telephone and electric light companies operating in the city of Montreal—which compelled the Lachine Rapids Company to construct 95 per cent. of their lines below the lines of other companies. A careful record kept of the eighteen circuits indicated that the greatest amount of trouble, such as transformer burn-outs, etc., caused by lightning, occurred on the circuits that were built under the lines of other companies. When this record was started, it was supposed that the circuits running into the open districts where there were no wires above them, would show the greatest number of transformer burn-outs, etc., but the result was just the reverse.

MR. JOHN F. KELLY:—I believe that the main protective effect of the grounded wire is not against lightning discharges, but principally against the ordinary atmospheric electricity. We all know that with a difference of a few yards in elevation we may find a difference of several thousand volts, and a wire suspended at any distance above the earth will in time gain the same potential as the air or bring the air to its potential. The charge so

accumulated on a wire will discharge to earth when the conditions are favorable, the most favorable place being usually determined by the weaknesses in transformers and dynamos. As to the accumulation of that charge, the rate at which it accumulates, I remember in the old telegraph days, before the dynamo service was much developed, in western New Jersey, in the hill country there ran a telegraph line through a tunnel, and was protected by lightning arresters. Well, they couldn't put in lightning arresters fast enough 20 years ago to keep that line in service. There was trouble in calm weather, when there was no sign of disturbance in the neighborhood at all. Then, when the alternating current service was first introduced, I remember watching a line in the hills of Connecticut. The sparking on the lightning arresters was constant on account of the atmospheric charge even in fine weather, although the line was only a few miles long. The circuit-breaker, in connection with the lightning arrester, was high chattering all the time. Now, I think it is against electricity of that nature that the grounded wire is of service, if it is of any service at all.

The most important point in Mr. Mershon's paper, to my mind, is that, if his theory is correct, the grounded wire may be placed below and yet be equally as protective as if placed above. No one heretofore has attributed any protective effect to the grounded wires when below the working conductors. The great danger in even laying it heretofore has been, that being above, in breaking, it would fall on the transmission wires.

But as to how much protective effect it really has, I think there is considerable doubt. Mr. Mershon has referred to one line on which it appears to protect perfectly. I think I recognize the line, and on that line there are a lot of water crossings, the aerial line at each crossing being replaced by a sub-aqueous cable, and at each of these crossings both sides are protected by lightning arresters. So that is one thing. The other thing is difference in elevation between the two ends of the line. The effect of hilly country, to which Mr. Rushmore alluded, is not very pronounced there. And the third thing is that they never have run without the grounded wire. On the other hand, I know of a plant in the south where they have put in grounded wires and then grounded them as often as they could. It is, however, a pretty bad country to obtain good grounds in as the clay soil takes hold deep down in the dry season. A number of the grounds have been made in water courses and some have been kept artificially wet, but I think they have not been able to find any improvement whatever. My own feeling is that while there is some protective effect from the grounded wire, that it doesn't pay for the complications.

It has been said that the electrostatic effect on the working conductors is of no importance, but I think when you get lines 150 or 200 miles long with a very high voltage and ordinary frequencies, it becomes highly important, especially if one uses

a single grounded wire not set in neutral position. I have never seen a grounded wire so placed. If it is set out of the neutral position it will affect not only the amount of electrostatic line charge but it will affect its distribution, so that the flow will be different on the three legs of the line. The disturbing effects of a balanced electrostatic charge are bad enough.

In the seventh edition of Culley's Handbook of Practical Telegraphy, p. 126, the use of individual ground wires on the poles, not connected by an overhead conductor, is described. Several able telegraph engineers have told me that this type of line construction has given them the same protection in nature and amount that the overhead grounded conductor is said to afford. Obviously, Mr. Mershon's condenser theory cannot apply here, and in consequence, these observations tend to throw doubt on the completeness of the theory.

MR. HAYWARD:—I wish to suggest to the Committee on High-Tension Transmission, that they send out word to every operating engineer, to everybody who has any stations of high-tension lines under his charge, and ask that every one of their engineers operating under them be made an observer; to have everybody working under them make careful observations, not only when the storm is on but when the storm is coming, as to what happens—time it as nearly as possible, record it in a log book. In the case of a breakdown from lightning, let him go right to the spot as if it were a fire, and let him collect the evidence right then and there, and at the end of a year or two we shall all know far much more about this lightning question than we know to-day.

I think that the location, other than the elevation,—the nature of the ground—has a great deal to do with lightning discharges. I think where you have a broad valley and your lines are lying in the valley near the base of a mountain, that you will get discharges which on the average are quite different.

Our system embraces 20,000 volts and some 400 or 500 miles of high-tension circuit spreading over a country that is about 150 miles long. Starting in the old days when the insulation was low, with 2000 volts, when all the wires were in the trees, we never knew any lightning trouble in any shape. As we improved our installation our lightning troubles came on us more and more, and now, carrying 20,000 volts, with lines thoroughly insulated, we know what lightning means. I do think that overhead grounded wires, such as telephone and telegraph wires, are a protection, for this reason, that I have never lost a transformer in our business section which is the most thickly covered with other wires. But they are not complete protection by any means, even at 2000 volts, for although our lines at Salt Lake City are almost all on the same poles as the telephone wires, yet the telephone wires do not entirely protect them. At the same time, we cannot help feeling that if you absolutely surround your wires with a grounded network, that they must be protected, except against perhaps some great stroke of light-

ning, so to speak. However, that is absolutely impracticable from our point of view. We have had many and many an instance where there has been a sudden discharge of lightning, and almost instantaneously, or immediately following, there has been a jump from the lead outside the transformer to the case of the transformer, rather than going through the transformer coil. We have had a lightning discharge smash up the insulators on the line, cut into the station, jump from the lead coming from a transformer from 16,000 volts, cut off the transformer and the puncture papers in the lightning arresters never show any discharge. Now, all those occurrences which we have all show the same sort of effect. Our troubles come at the moment when the lightning discharges. Troubles due to the raising of the potential of the line when there is a dust storm, or wind storm or a thunder cloud, are taken care of on the lightning arrester. I have never heard or known of any trouble from that. Every single occurrence that has ever given us any trouble has been at the moment of the lightning discharge.

MR. JOHN F. KELLY:—Mr. Hayward, I think, is probably right as to his having no trouble on very high-tension lines from atmospheric electricity, but the conditions are very different on lines of moderate-tension or low-tension, like telegraph wires. On a high-tension line the voltage with which one is sealing on the line is itself of a magnitude comparable with the atmospheric difference of potential discharge, and consequently when the dielectric strength is made sufficient to resist the puncturing of the insulating material, puncture by the charge accumulated by the wires is also presumably guarded against. But on low-tension circuits, where the normal voltage is much below the difference of potential that may arise from atmospheric charge there is no such guard against atmospheric effects.

PRESIDENT SCOTT:—Mr. Hayward has the difficulties which come to engineers through coöperation. He is trying to coöperate some three or four different plants in different places and in different directions from Salt Lake City, and which have been laid out with different voltages and under different conditions, as separate independent plants entirely,—the old Pioneer plant at Ogden, the Utah Power Company, the big Cottonwood, and now, I believe, he is linked in with the Telluride Power Transmission Company. Is there any further discussion?

MR. W. L. WATERS:—I did not quite follow Mr. Mershon's theoretical calculation, but I would like to suggest an alternative calculation, which has the advantage, from my point of view, that gives results which agree more with my own practical experience.

Let us assume that a cloud has just discharged, and that we are left with an induced charge on the transmission wire which raises this wire to a high potential above the earth, and we wish to find out to what extent the presence of a grounded wire will lower this potential. The system which we have to consider

consists of the transmission wire B , carrying a charge Q_1 , the grounded wire A , carrying an induced charge Q_2 , and the earth G , also carrying an induced charge. For the purpose of calculation, the earth can be considered as an infinite conducting plane, and by Lord Kelvin's theory of electric images the distribution of electricity induced on the surface of the earth can be replaced by charges $-Q_1$ at C , which is the image of B , and $-Q_2$ at D , which is the image of A . Then we have for the potential of wire A

$$(1) \quad V_2 = p_{ab} Q_1 + p_{aa} Q_2 - p_{ac} Q_1 - p_{ad} Q_2$$

where p_{ba} , p_{ac} , etc., are Maxwell's coefficients of potential. And assuming that the diameter of the wires is infinitely small compared to the distance between them, these are given by the expression,

$$p = -2 \log r$$

where r is the distance from the center of one wire to the center of the other.

But as the wire A is grounded its potential V_2 is zero. Thus putting $V_2 = 0$ in equation (1) and solving for Q_2 we get

$$Q_2 = Q_1 \frac{\log \frac{H_2 - H_1}{H_2 + H_1}}{\log \frac{4H_2}{d}}$$

where d is the diameter of the wires.

Similarly, we have for V_1 the potential of the transmission wire B .

$$V_1 = p_{bb} Q_1 + p_{ab} Q_2 - p_{bc} Q_1 - p_{bd} Q_2$$

substituting for Q_2 in terms of Q_1 , and evaluating we get

$$V_1 = 2 Q_1 \left\{ \log \frac{4 H_1}{d} - \frac{\left(\log \frac{H_2 - H_1}{H_2 + H_1} \right)^2}{\log \frac{4 H_2}{d}} \right\}$$

Assuming the ground wire not present this becomes:

$$\overline{V}_1 = 2 Q_1 \log \frac{4 H_1}{d}$$

so we get as the value for the shielding effect:

$$\frac{\overline{V}_1 - V_1}{\overline{V}_1} = \frac{\left(\log \frac{H_2 - H_1}{H_2 + H_1} \right)^2}{\log \frac{4 H_2}{d} \cdot \log \frac{4 H_1}{d}}$$

Taking the numerical value used by Mr. Mershon, *i.e.*, No. 00 wires 12 inches apart, and taking the height above the ground as 30 feet, we get the shielding to be 25 per cent. Taking what perhaps is a more practical case, No. 4 wires 24 inches apart, we get the shielding to be 14 per cent., which is rather different from Mr. Mershon's result.

But I think that a theoretical discussion of this subject is not very much to the point, because we really know very little about the conditions in the phenomena which we are discussing. It is also extremely difficult to get any reliable practical information as regards the effect of the ground wire because unless we do as Mr. Thomas has suggested, *i.e.*, try a number of transmission lines both with and without a ground wire, we cannot really get any definite information. The fact that one transmission line is satisfactory without a ground wire and a second one is also satisfactory with a ground wire gives us no really definite information.

My own experience has been confined to European conditions, *i.e.*, short mountain lines worked at 5,000 to 10,000 volts. The conditions under which they work are violent lightning storms, and heavy sleet and snow storms during certain seasons of the year. The sleet and snow storms very often bring down the ground wire, producing a short circuit, and the screening effect of the ground wire does not seem to be very appreciable in a lightning storm. So that the general opinion of operating engineers is that the ground wire is far more trouble than it is worth.

MR. CURTIS:—In this discussion I notice that several gentlemen have referred to the failure of telephone lines located above power leads to protect the latter from lightning or electrostatic induction. When we take into consideration the fact that modern telephone lines are composed of metallic circuits almost exclusively and are not grounded, their failure in this respect

hardly seems strange, and further if they actually *do* afford the slightest shielding action it must be accounted for by some other theory than that pertaining to grounded wires. I believe the same statement is practically true of telegraph circuits, which are rounded normally only at their extremities, which would render them ineffective owing to conductor resistance, except for exceedingly short distances from their terminals. I have known long metallic telephone circuits, with clear weather prevailing their entire length and breadth, to give off electrostatic discharges sufficiently severe to destroy the coils connected to them, the current of course seeking the shortest path to ground.

PROFESSOR D. C. JACKSON:—The problem which exists with respect to protecting a line from sparking to ground or surrounding parts, no matter what the cause, is to keep the line as nearly as possible at the same electrostatic potential as the ground. Now undoubtedly the grounded guard wire does something in that direction, and Mr. Mershon is right in making his computation and saying that there is some effect from the guard wire; but on the other hand, he has not taken data of such a form and of such numerical values as to give results that may be considered to be always applicable, or adaptable to commercial conditions in a long and important transmission line. For instance, the guard wire in Mr. Mershon's example is taken too close to the line wire, and since the protective effect is dependent upon the logarithm, as the guard wire gets further away from the line the falling off of the protection is enormously rapid. I therefore think Mr. Mershon is misleading us by taking his one foot distance; he is exaggerating the effect.

There is another element that Mr. Mershon has omitted, which has a great deal of influence. You must bear in mind that if one has an induced discharge upon a transmission line and guard wire due to a cloud overhead, and that cloud discharges into a cloud at some distance, or discharges to earth, there is an almost *instantaneous* change of the potential of the earth under the line at certain points and also of the atmosphere surrounding the guard wire. The resistance of the guard wire, its inductance and capacity enter to modify the instantaneous change of the charge in the guard wire itself and consequently the guard wire during this period (because of resistance, self-inductance and capacity), is unable to exert its full influence to protect the line wire; and Mr. Mershon has omitted to introduce the effects of the self inductance and capacity and resistance of the guard wire and its ground connections into his formula. I think that he has omitted them because they cannot yet be put in, for the reason that we do not have a reasonable knowledge of their values under the conditions and therefore have no way of representing them in the formulas. So I say Mr. Mershon is right in presenting the matter as he has, but he is without question exaggerating the effect of the guard wires, and very largely exaggerating it, when he says that it may be expected to afford a protection of some-

thing like 70 per cent. I think if this was taken at 7 per cent. or $\frac{7}{10}$ of 1 per cent., it perhaps would come nearer the truth.

MR. MERSHON:—I think that in general I agree with Professor Jackson—but I would like to take up one or two points in connection with what he has said.

As regards the theory of the matter, I agree pretty thoroughly with Professor Jackson. I will not commit myself too far, however, in that regard. As regards what Mr. Waters has said, I made an assumption in treating this matter, on purpose to keep the problem simple. I assumed that the space potential at each of the two wires was the same. I think if the wires are in the same horizontal plane it is a pretty fair assumption, and this is the relative position which most frequently has place in practice.

As regards the size and distance between wires, I am not so very far wrong. If I remember rightly, the distance I have taken as between the wires is exactly that which existed on a line on which it was claimed the ground would give very good protection. The size, also, was approximately that which I have taken; for barbed wire was used whose effective size, because of the twisted strands, is considerably greater than a single wire of an equivalent section. For most cases in practice I think the figures I have given furnish a fair sort of criterion. I have purposely avoided the questions of oscillatory effect, of self-induction and all those complicated questions which require elaborate assumptions of questionable accuracy.

It seems to me that the question of electromagnetic action is one of amperes and frequency, and not of volts, as Mr. Thomas has stated, and it is hardly conceivable to me that the currents at the distances that flashes often occur would be great enough to affect the line seriously from electromagnetic action.

Now, as regards the position of the cloud, that changes the problem to some extent, but I do not think it changes it altogether. The shielding action, even if the cloud is affecting only part of the line, would have place to a considerable extent.

As regards the discharge of the atmosphere itself—suppose the particles of air or moisture around the wire are charged, isn't it likely that the effect of the inductive action due to the great mass of particles beyond the wire will be considerably greater than that of simple leakage from those particles to the wire, if there is such a leakage effect? The flash between clouds, it seems to me, does not alter the problem so very materially. You have the effect there of a redistribution of charge, and you still have to a considerable extent the shielding action of the grounded wire.

As regards the difference in altitude, I have gotten the altitude effects in a great many cases and it never seemed to me necessary to explain them by leakage from the atmosphere. Simply because you cannot see a cloud, is no proof that it does not exist. The cloud need not necessarily be a mass of moisture; it may be air under some condition differing from that of the surrounding air; so that in considering a charged cloud, we should

consider any mass, whether it be moisture or whether it be air of a different density from the air around it, and which might accumulate a charge on the surface of separation between it and the surrounding air.

As regards protection from electromagnetic effects, if there are any, the resistance of the ordinary grounded wire would be too high, and the self-induction too high, to furnish much protection, especially as you cannot conveniently ground the wire any oftener than at each pole.

As regards the gathering of data, the grounded wire is taken up in the lists which the Transmission Committee are sending out, many of which are coming back filled in. We should be only too glad to get the minute attention to the subject of lightning protection, as well as other points taken up by these lists, that Mr. Hayward advocates, and we shall certainly expect to get a fine lot of data from Mr. Hayward's plants.

MR. W. J. HAMMER:—Last fall I had the pleasure of spending some days investigating the Valtellina 20,000 volt, 3-phase Railroad in Italy constructed by Messrs. Ganz & Co., of Budapest, Hungary.

I remember that one of the methods of protection used was a drain pipe filled with water, which acted as a water resistance, and which was connected to the wires and to the ground, the intention being that while there would be ordinarily no leakage, when lightning passed over the circuit these would act as a protective device. The main reliance, however, was placed on a form of lightning arrester which by its simplicity commended itself strongly to me. I understand that since these have been put in place no lightning has ever entered the power-house, and it is claimed that there is no necessity for lightning arresters inside of the power-house.

The device, which was placed just outside the power-house, consisted of three funnels, one attached to each of the 3-phase circuits, being supported by porcelain insulators. Underneath each funnel is a little spray of water which is thrown up so that it is a short distance from the funnel, but not making contact therewith. Should any abnormal voltage appear on the line due to lightning it is carried off by the jets of water.

MR. W. A. BLANCK:—I will state that in most of the Italian and German high-tension lines lightning arresters are used only in power stations and substations and seldom on the line itself. The use of iron such as barbed wire along the line for protection of the same from lightning has been abandoned.

The lightning arresters mentioned by Mr. Hammer are used on the Valtellina Railroad in northern Italy and consist of a small reservoir which furnishes constantly dripping water to the various wires of the high tension system. The small drops of water upon reaching the wires are charged and upon leaving them carry off this charge and in this way very satisfactory results are obtained.

MR. MERSHON:—I would like to hear from Dr. Perrine and some of the other members who have spoken of the losses due to a grounded wire as to how that loss could occur and as to the nature of it. Do they mean atmospheric loss. It seems to me that with grounded wires, especially if the neutral of your system is grounded and you have between the grounded wires and the line wires anything like the distance there is between line wires themselves, you will not get much loss. For you are then concerned with a voltage a great deal lower than that between the line wires and you presumably keep the atmospheric loss between them pretty well down.

MR. MAILLOUX:—I want to caution Mr. Mershon, in his statement about the loss due to electromagnetic effect caused in the parasitic circuits, constituted by the grounded sections. He says that the resistance of these segments would be a protection against loss. I think that there is a certain resistance at which that loss will be the maximum. If we have an infinitely great resistance, of course we would have an e.m.f. there, but no current. With an infinitely small resistance we would have a reactance loop in which you would have a full counter e.m.f. effect and very little loss excepting the small $I^2 R$ loss necessary to keep the large current flowing; but there is between those extremes a critical resistance which corresponds to the maximum loss. Evidently, we only have a differential e.m.f. due to the difference between the electromagnetic effects of the three wires. If the conducting wire could be placed in the center of the triangle perhaps the resultant effect would be negligible anyway.

PRESIDENT SCOTT:—The paper we will take up now is: "On the Testing of Electrical Apparatus for Dielectric Strength." by P. H. Thomas.