avenue trains need only to proceed onto track circuit *4T* whence the proper signal, *No. 4Lb*, will clear for this route.

Westbound Lexington avenue train movements are, of course, affected by eastbound Myrtle avenue train movements. Precedence of route between these two trains is determined by priority of time in the operation of push button *M* and shunting of track circuit *A2T* in practically the same manner as precedence is established between the two conflicting westbound movements previously described. This arrangement is satisfactory since the running time through the interlocking is nearly the same from either Washington avenue or Lexington avenue station.

Auxiliary Buttons and Releases for Unusual Moves

Auxiliary push buttons *L, M* are placed at home signal *4R* to permit a train, stopped at the signal, to select either route; in fact, all possible train movements, except those against traffic, take place in logical order. All parallel moves can be made simultaneously and conflicting trains awaiting their turn are locked out until the track is clear and the proper route set up. Approach locking becomes effective as soon as a signal is cleared for any route. Route locking release is obtained when trains enter the final track circuit in the route, or in case of trouble, by means of a manual release accessible only to the maintainer. The position of switches *3* and *5* is checked by means of d. c. polarized switch repeating relays through the contacts of which are controlled all signal and route selecting circuits. Air compressors, switchboards and all except five of the relays are located in the lower floor of the tower. Concentration of all relays at one point simplifies the wiring and tends to minimize delays by facilitating quick determination of the cause of a failure.

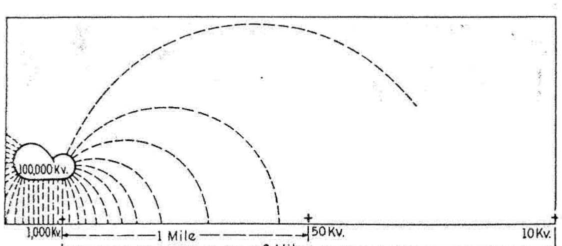
For several months after the automatic feature was placed in service at Grand and Myrtle Junction, there were occasional delays due to failures, for which the cause could not at first be determined. The trouble was finally traced to insufficient time element in the operation of certain relays. However, during the four months following December, 1924, there was but one failure causing delays to trains or interruptions in the automatic operation of the plant. Practically no increase in maintenance force or maintenance costs is necessary because of the change in method of operation at this plant and the economic saving to the company is very high, since the cost of installing the automatic feature was but little greater than $5,200, the approximate yearly saving in towermen's salaries.

A Study of the Causes of Lightning*

By J. W. Peek, Jr.

Consulting Engineer, General Electric Company, Pittsfield Works, Pittsfield, Mass.

A LIGHTNING stroke is generally thought of as a local but severe high voltage discharge from some cloud. As a matter of fact, the electric energy that manifests itself in the flash is, the moment previous to the flash, stored in the surrounding air for a considerable distance. A certain small part of this energy is stored in the air immediately around the observer, and a small induced current may flow in the body of even a distant observer when a flash occurs. The thundercloud acts as one plate of a huge condenser, the earth as the other, while the intervening air is the insulation. When the voltage between earth and cloud becomes high enough, this insulation breaks down and the energy is dissipated in the short circuit or lightning flash.



Showing How an Induced Current May Pass Through the Body of an Observer Even at Some Distance

The electrical energy is changed into heat, light, sound and chemical energy. The light is seen in the flash, while the sound is heard as thunder. Thunder is caused by air waves set up by the explosive nature of the discharge.

The chemical effects of the lightning stroke are often detected by our senses in the odor of ozone that is frequently noticeable after a storm. The chemical changes occur in the path of the discharge. The two main gases in the air are nitrogen and oxygen. Each molecule of oxygen is normally made up of two atoms. The electric field tears these apart. Some of these single atoms recombine in groups of three. Oxygen with a molecule made up in this way is called ozone. It is very active chemically because the extra atom is easily detached. The nitrogen of the air is also made to combine with the oxygen, producing nitrous oxide and, in the presence of vapor, nitric acid.

Along the discharge path are untold numbers of electrons and ions—chunks of electricity moving at enormous velocities. It is possible that the ionic bombardment of the nitrogen and oxygen atoms along this path transmutes some of these atoms to helium or hydrogen. However, this is quite uncertain and speculative.

The voltage between cloud and ground previous to the discharge causes voltage between different parts of the atmosphere. Right under the cloud the voltage difference per foot of air measured in a vertical direction may be very high. In fact, a certain percentage of the lightning voltage exists between earth and any point above.

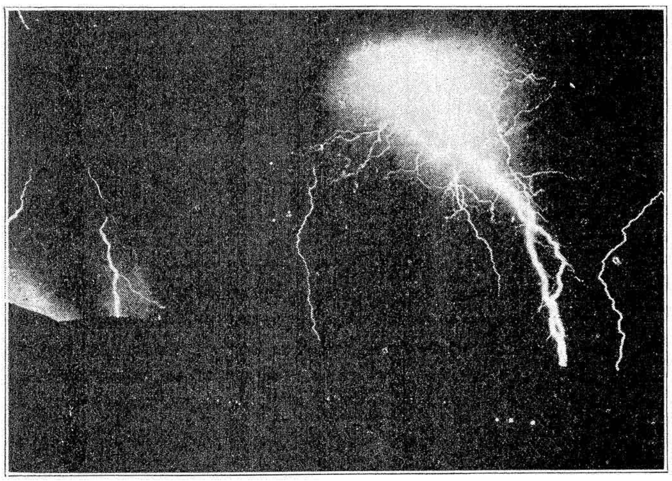
Lightning is an unorderly, predatory form of electricity, dangerous not because of its enormous energy, but because of its enormous power and "flighty" habits. The distinction between energy and power is that energy is measured in kilowatt seconds or kilowatt hours, while power is measured in kilowatts. A concrete example is always of interest. If all of the energy of a severe lightning stroke could be put into a storage battery, it would carry an electric automobile about five miles or operate an electric iron for a day. However, since this energy is dissipated in a few millionths of a second in a limited space, the effect is a terrific explosion, and the power is millions of kilowatts though the kilowatt seconds or hours are small.

A study of lightning is of considerable practical im-

*Paper presented in the G. E. Monogram.

portance in providing protection against it. It is necessary to make such a study in two ways—by observation of natural lightning and its effects on buildings and transmission lines, and by observation of artificial lightning in the laboratory. By means of artificial lightning, knowledge can be gained in a few months that would require years to gain in the field. This follows because laboratory discharges can be repeated at will, while it may be necessary to wait years for a natural discharge to occur at any given place. Before artificial lightning could be produced, it was necessary to determine the nature of natural lightning. Several years were spent in measuring the voltage, the current, the frequency, the wave front, and the duration of lightning disturbances on transmission lines.

When a thundercloud passes near or over a pole line, the air between the cloud and line is under an electric stress. The greater the distance above ground, the greater the voltage or stress. The line is said to be charged. It is a "bound charge," however, and held fast by the cloud. Nothing much happens until the voltage becomes high enough to cause a breakdown, or lightning



A Lightning Stroke Over the Island of Ceylon

bolt to some other cloud or to ground. The "bound charge" is set free and waves of voltage and current pass over the line at the velocity of light, or 186,000 miles per second. This is called an induced voltage, and lightning has not struck the line in producing it. As the wave passes along, the line voltage is applied to insulators and finally to transformers or arrester gaps at an extremely rapid rate. Fortunately, leakage or corona losses help reduce the voltage as the wave travels along, but on reaching an open ended line, the voltage almost doubles as does a water wave when it strikes a sea wall. Most lightning disturbances on pole lines occur by induction with the actual flash hundreds or thousands of feet away. The line may occasionally be struck. When a direct stroke does occur, the disturbance is very severe.

The induced voltage that occurs on a line depends upon the potential of the electrified air in which the line is located at the instant before the flash. It is a certain percentage of the lightning flash, the actual percentage depending upon the position of the cloud in relation to the line. During any storm there are many disturbances at low voltage, a lesser number at higher voltage, and finally very few in a year at very high voltage. Voltages of 500,000 to 1,500,000 and higher have been observed on lines.

The field study of lightning has been supplemented by a laboratory study with artificial lightning. The artificial lightning is produced by a lightning generator. This generator, which was first built for lower voltages some years ago, has been extended to produce voltages of 2,000,000 above ground or higher than most voltages induced in transmission lines. The discharge is explosive and the power is of the order of millions of kilowatts for a few millionths of a second. Currents as high as 10,000 amperes have been obtained. The voltage increases at the rate of millions of volts per second. In common with natural lightning, artificial lightning has the following characteristics: Large wooden posts can be split and blown apart; metal can be "punctured." When a sandy spot is struck, a tube of sand fused into "glass," with tree-like branches, is produced. Such tubes are called fulgurites. Because of the explosive nature of lightning some quite unexpected phenomena frequently happen.

The lightning generator consists of high capacity condensers just as in the case of the clouds, only the insulation is glass and it is relatively more compact. As in the case of the cloud-lightning, the electricity is stored at a relatively slow rate and discharged at an enormously rapid rate in a few millionths of a second.

The lightning generator has been of considerable help in gaining a knowledge of natural lightning. In fact, it has afforded a means of estimating the voltage of a real lightning stroke. The method was very simple. The voltage of a real lightning stroke cannot be directly measured by placing a meter between cloud and earth. However, for any given flash, the voltage induced on a transmission line can be measured. The length of the flash and cloud arrangement with reference to the line can be closely estimated. A model cloud and line were constructed to scale for a case where the measured voltage on the real line was 1,000,000 volts. Discharges were produced on the model from the lightning generator. The voltage on the model cloud could be measured as well as the induced voltage on the model line. It was found that, under these conditions, 1 per cent of the lightning was induced on the line. If the 1,000,000 induced on the real line was 1 per cent of the lightning voltage, the voltage of the flash must have been 100 times 1,000,000 or 100,000,000 volts. Of course, lightning voltages vary, but this gives a good idea of the order of a severe lightning stroke. It is estimated that the current was about 80,000 amperes, and the energy 13,000 kilowatt seconds or 3.6 kilowatt hours.

The lightning generator offers a means of finding the best insulations to withstand lightning as well as the best way to design transformers, insulators, and lightning arresters.

A wire parallel to the line and connected to earth at each tower is sometimes used on transmission lines. The value of this "ground" wire has been determined by measuring the voltage induced from a model cloud on a model line with and without ground wires. It was found that a favorably installed ground wire reduces the lightning voltage on transmission lines from one-half to one-fourth of the value without ground wires. The investigation of the ground wire is a good example of the value of combining field work and laboratory work. Reports on operating experience with the ground wire after many years are conflicting. About half of the reports are favorable, while the other half express doubt as to its value. Tests on models show that the ground wire gives good protection when favorably installed, but little protection if unfavorably installed. This seems to explain the conflicting experience in practice. The line insulator ring shield and the transformer shield have a similar action and prevent high local voltages. It is possible to design line insulators and bushings with very high lightning breakdown voltages, and arrester gaps with low lightning breakdown voltages.