(4) Resistance of a conductor to the transmission of electric current (symbol, R.; unit, the ohm) corresponds to the friction of water in a pipe. This resistance is directly proportional to the length of the conductor, and inversely proportional to its area of cross-section.

(5) The electric current is equal to the electromotive force divided by the resistance. This is also analogous to the flow of water, which increases with the pressure, and decreases as the resistance or friction increases, although the law is not exactly the same.

Formula (Ohm's law), $C = \frac{E}{R}$.

(6) Energy wasted in a conductor by being converted into heat (symbol, H.; unit, the watt, as before) corresponds to the waste of power, also converted into heat, by the friction of water in a pipe, and is equal to the square of the current multiplied by the resistance.

Formula, $H = C^2 R$.

CONCLUSIONS.

(A) From (4) and (6) it is evident that increasing the distance, and consequently the length of wire (other things remaining the same), will proportionately increase the resistance and the loss of power; but if the cross-section of the wire is increased in same proportion as its length, the resistance and loss will remain the same. This, however, increases the weight of the wire as the square of the distance. Hence the law: For a given power and electromotive force (which fixes the current) the cost of copper, for a specified percentage of line-loss, varies as the square of the distance.

(B) From (3) it appears that the same power is obtained from high electromotive force or voltage and small current as from low voltage and proportionately large current—another analogy to water power. But (6) shows that the loss of power varies as the square of the current, and hence inversely as the square of the voltage. If the loss ($C^2 R$) is to remain the same, R can be increased as much as C^2 is decreased, or as much as E^2 is increased, which means that the cross-section and weight of the wire will be inversely proportional to E^2. Hence the law:

For a given power and distance the cost of copper, for a specified percentage of line-loss, varies inversely as the square of the voltage.

(C) Combining (A) and (B) the following law is established:—

If the voltage is increased in proportion to the distance, the cost of wire for transmitting a given power with a specified line-loss remains constant.

The annexed table shows the cost of copper, at 14 cents per lb., per kilowatt transmitted by the 2-wire system for various distances at different voltages, with 10 per cent. waste of energy in line.

Considering the fact that the total cost of steam or water power, electric generators, switch-board and motors seldom exceeds $150 per kilowatt, it is evident that when a distance is reached that makes the cost of wire (and transformers, if used) exceed that amount, or the entire cost of the remainder of the plant, that distance may be considered to be near, if not beyond, the economical limit, unless the conditions are peculiarly favorable for electric power.

With 500 volts this condition is reached inside of three miles; with 1000 volts, inside of six miles; with 3000 volts, at about seventeen miles, and with 10,000 volts, at about fifty miles (allowing for transformers).

It is evident from the foregoing principles and figures that the key to long distance transmission is high voltage.

Volts.	Miles. 1.	2.	3.	4.	5.	10.	15.	20.	30.	40.	50.
500.........	$20.00	$80.00	$180.00	$320.00	$500.00	$2,000.00	$4,500.00	$8,000.00	$18,000.00	$32,000.00	$50,000.00
1,000.........	5.00	20.00	45.00	80.00	125.00	500.00	11,25.00	2,000.00	4,500.00	8,000.00	12,500.00
2,000.........	1.25	5.00	11.25	20.00	31.25	125.00	281.25	500.00	1,125.00	2,000.00	3,125.00
3,000.........	.56	2.22	5.00	8.89	13.89	55.56	125.00	222.22	500.00	888.89	1,388.89
4,000.........	.31	1.25	2.81	5.00	7.88	31.25	70.31	125.00	281.00	500.00	781.25
5,000.........	.20	.80	1.80	3.20	5.00	20.00	45.00	80.00	180.00	320.00	500.00
10,000.........	.05	.20	.45	.80	1.25	5.00	11.25	20.00	45.00	80.00	125.00
15,000.........	.02	.09	.20	.35	.56	2.22	5.00	8.89	20.00	35.56	55.56
20,000.........	.01	.05	.11	.20	.31	1.25	2.81	5.00	11.25	20.00	31.25
30,000.........	......	.02	.05	.09	.16	.56	1.25	2.22	5.00	8.89	13.89
40,000.........	......	.01	03.	.05	.08	.31	.70	1.25	2.81	5.00	7.81
50,000.........	......	......	.02	.03	.05	.20	.45	.80	1.80	3.20	5.00

SYSTEMS.

Direct Current.—Direct-current generators, suitable for power purposes, cannot be made to operate successfully at a much higher electromotive force than 1000 volts, on account of the arcing and short circuiting of the commutator and its connections required to rectify the current.

The direct current cannot be transformed to a higher voltage, except in a machine similar in construction to a generator and open to the same objections.