LONG DISTANCE TRANSMISSION AT 10,000 VOLTS.

(THE POMONA PLANT.)

BY GEORGE HERBERT WINSLOW.

The Pomona plant was installed in the summer and fall of 1892 for the San Antonio Light and Power Company, of Pomona, Cal. It was increased in the following spring, and early last year the capacity of the plant was doubled by duplicating the entire equipment. At the present time, when the plant has been in regular operation for more than two years, and its complete success has established confidence in the successful outcome of many similar projects of greater magnitude, it seems fitting to present a careful description of the entire installation. The electric plant was installed under the personal direction of the writer, as electrical engineer, who presents many of his personal observations on its construction and operation.

The plant is used to transmit energy from a waterfall to substations at Pomona, $13\frac{3}{4}$ miles distant, and San Bernardino, $28\frac{3}{4}$ miles distant, from which points it is distributed for incandescent and arc lighting. It consists of a Pelton water power plant and a Westinghouse alternating current transmission plant in which generators supply currents to sets of raising and lowering transformers operating at 10,000 volts, and delivering current to the local circuits at 1,000 volts.

The water power for this plant is derived from the San Antonio creek, which is chiefly supplied by the melting snows and the rains on San Antonio Mountain. Side canyons, however, also furnish some water. The creek flows for several miles through a narrow valley at the upper end of the San Antonio canyon in a bed which it has washed for itself in the layer of

boulders and gravel formed by the action of an immensely larger stream in past ages.

At the lower end of the valley, a sharp ridge extends eastward from the side of a neighboring mountain, from which it originally split off, and blocks up the valley except at a narrow place at which bed-rock is exposed, and through which the stream plunges suddenly downward at least 90 feet between precipitous walls of rock, forming the San Antonio Falls.

To utilize this fall, part of the water is diverted by a dam about 200 feet above the falls into a canal which conducts the water to a tunnel passing through the ridge. At the other end of this tunnel, the water enters a large pipe leading to the power-house, which is located 412 feet below the level of the outlet of the tunnel.

PIPE-LINE.

A vertical projection of the pipe-line, giving the sizes of the pipe, is shown in Fig. 1.

FIG. 1.—Pipe Line, Pomona Plant. Effective Head 390 feet.

The pipe is of sheet steel, double-riveted throughout, and was delivered on the ground in sections having a length of 11 feet 6 inches. These sections consist of four sheets, each three feet long.

The diameter of the pipe up to within 450 feet of the power-house is 30", with the exception of the length which connects it to the sand-box at the top of the pipe, which length is considerably expanded, so as to allow the water to flow slower on entering, and thus to reduce the entrainment of air. Near the power-house a "reducer" is inserted in the pipe to reduce the diameter to 24", and this size is maintained from this point to the power-house. The pipe was designed to carry 2000 miner's inches of water (measured under a head of 6 inches), without unnecessary loss by friction. The capacity is equivalent to 50 cubic feet per second, or 1882 H.P. at 390 feet effective head, assuming

a wheel-efficiency of 85 per cent. This is nearly three times the power for which the present station was built, but the extra capacity of 1000 horse-power obtained by increasing the capacity of the pipe costs so little when compared with the cost of building an entire new pipe-line, that it is much more profitable to lay the larger pipe in the first place, if sufficient water can ultimately be developed to utilize the added capacity.

The thickness of the pipe is increased as it nears the power-house, to provide for the increase in pressure in the lower parts. At the first bend it is made greater than that of the sections above it on either side, because the pressure on it there is greater. After passing the second air-valve, first No. 10 and then No. 8 steel is used, the latter size being continued to within a short distance of the power-house. The last few lengths are of No. 6 steel.

The horizontal distance between the mouth of the tunnel and the power-house is 1940 feet, and the difference in level between the tunnel and the floor of the power-house is 412 feet. The total length of the pipe is 2370 feet.

The sections of pipe as received from the makers were coated with asphalt both inside and out, and parts of this coat were of course scraped off through rough handling. After the pipe was laid and jointed, a man went through it and painted the joints with hot asphalt to prevent rusting.

In order to protect the pipe from the great changes in temperature which occur in the mountains between midday and midnight, earth and loose rock were placed around and on top of the pipe without any tamping, and where enough earth could not be conveniently obtained, brush was cut and piled on the pipe and covered with a light layer of earth and rock.

The lower end of the pipe is closed by means of a 24 in. Ludlow gate-valve, which is bolted to a cast-iron flange riveted to the end of the pipe.

The stem of the valve is geared to a small hand-wheel, partly on account of its weight, but chiefly in order that the gate may not be shut too quickly, as otherwise the pipe would be subjected to severe strains, resulting from suddenly checking the velocity of the column of water. For use under heavy pressures the gearing is also necessary in order to be able to move the valve at all. The head of water on this plant is so great that it is impossible to open the valve while the pipe is full, and the receiver empty. It is therefore necessary to equalize the pressure by filling the receiver through a by-pass, or to partially empty the

pipe by means of a relief-valve attached to the pipe close to the gate. The relief-valve is primarily designed to protect the pipe from shock by allowing the escape of a considerable quantity of water in case of an increase of pressure in the pipe; such, for example, as would occur should any obstruction partially close the opening of the gate. It has a circular valve so proportioned that a slight movement of it will afford a large opening for discharge. The valve is held in place by a weighted lever, and is set so that a very slight increase above normal pressure will cause it to open.

The gate is connected by a tapering pipe of steel to a horizontal, cylindrical steel receiver 20 feet long and 42" inside diameter, from which the water is distributed to the wheels. The object of such a large receiver is to avoid the loss in head which would be occasioned by the eddies formed when drawing the water from the side of a smaller pipe. It also serves to keep air from being drawn into the discharge pipes in case it accumulates in the receiver. (Last year the receiver was lengthened to 48 feet.) An air-valve is placed at the top of the receiver. Two tapering cast-iron pipes (a large and small one) are bolted to the lower side of the receiver at an angle of 30 degrees.

WATER-WHEELS.

The above pipes conduct the water from the receiver to the under sides of two independent Pelton water-wheels, which drive an alternating current generator and its exciter.

To the end of each pipe is attached a Ludlow gate-valve, the stem of which passes horizontally into the dynamo room through a bushing in the concrete wall. The larger of the two stems is geared to a hand-wheel; the other is fastened directly to a smaller hand-wheel. The flow from each pipe can thus be completely controlled from the dynamo room. The pipe running to the generator wheel is provided below its valve with two nozzles cast in one piece, and attached to the valve by means of a limited ball-and-socket joint, which permits them to be moved vertically to deflect the water. (See Fig. 2.)

The pipe supplying the exciter wheel has below its gate a throttle-valve, the stem of which passes through the wall into the dynamo room, where it can be connected to a governor. The wheels are located directly below the receiver, and above a race-way which conducts away the water after it drops from the wheels.

The speed of a Pelton wheel is dependent for a given load and head of water upon the amount of water striking the wheel,

and therefore, to maintain a constant speed this amount must be changed every time the load changes, and in proportion to the latter. In the case of the generator-wheel this change is produced by deflecting the water. Constant-speed regulation may also be obtained by throttling the water, as is done in the case of the exciter-wheel. When the water is throttled there is loss in efficiency due partly to the scattering of the water as it flows from an aperture which it no longer completely fills (which causes much water to miss the buckets), and partly to the loss of head caused by friction in passing through the valve. With the deflecting nozzle there is no loss of efficiency due to this cause. There

FIG. 2.—Pelton Water-wheel with Deflecting Nozzle.

is, however, a great waste of water at light loads, since under a constant head the same quantity of water must be disposed of at all loads, and for light loads the greater part of it is wasted. To avoid this loss the use of a reservoir naturally suggests itself. It is an unfortunate fact, however, that high heads are confined to mountainous countries and that there a reservoir usually necessitates a high and consequently costly dam. The necessity of building a dam to withstand freshets so increases its cost as to make

the use of a reservoir commercially impossible with high heads. Therefore, the water must continue to be wasted, and the chief apparent objection to deflecting nozzles is seen to be of no importance.

A set of tips of different diameters is supplied with each nozzle, so that the size of the jet used may correspond to the maximum load, and thus unnecessary waste of water be avoided. The tips for the generator-wheel range from $1\frac{1}{2}$ to $2\frac{1}{2}$ inches in diameter, while those for the exciter are from $\frac{7}{16}$ to $\frac{3}{4}$ inch. When tips are used of the proper size for the full load there is no need of throttling at the full load, and, therefore, no loss from this cause; and with the deflecting nozzle there is no waste of water at full load, so that for full load the two arrangements are equally good. This is not, however, the normal condition of operation of a lighting plant, for in such a plant each dynamo is driven by a separate wheel, and the load is constantly changing, so that here the deflecting nozzle has the advantage. The deflecting nozzle is also to be preferred under high heads, to avoid the risk of straining the pipe by suddenly checking the flow of water, as would be necessary with a throttle valve if the entire load were suddenly thrown off.

Regulation by throttling is, therefore, only advisable in cases where the head is not excessive, and where the quantity of water obtainable is limited, as is the case where it has to be stored in, and supplied from reservoirs, or when the supply is liable to sudden stoppage. The writer recalls instances of its value in cases which occurred while he was at Bodie, Cal., in the fall of 1893. There the water was conducted 4,700 feet in an open ditch to the pipe, and was delivered by the pipe under 350 feet head to drive an electric generator for a 12-mile synchronous power transmission. In cold weather anchor-ice would form and suddenly block up the ditch at some curve, and the water-pressure would begin to fall slowly, owing to the gradual emptying of the pipe, which could no longer be kept full by the diminished flow from the lower end of the ditch, which now acted as a reservoir. Having throttle valves in the nozzles, however, very little water was wasted, and the plant was thus kept running until the ditch was cleared, whereas with a deflecting nozzle the pipe would have been quickly emptied, even if the gate-valves had been used as throttling valves (which is feasible if the load only varies slightly). Sometimes the head became so low that it

was necessary to throw off part of the load and to run at reduced speed, to keep the motor in synchronism.

GOVERNOR.

As already stated, the speed of the generator-wheel is maintained constant for different loads by deflecting the stream. This is done by raising or lowering the deflecting nozzles from the the dynamo-room by means of a lever fixed to a shaft which passes through the wall. The position of the nozzles is controlled automatically by means of the Pelton differential governor. The ability of this governor to keep the generator at a practically constant speed depends on the governor being driven at a constant

FIG. 3.—Water-Wheel Governor.

speed. I say *practically* constant, for there must be *some* change in speed before the governor can act, and then an appreciable time is required for this action to produce its effect. The constant driving-speed in the present case is furnished by the exciter-wheel shaft. The arrangement for governing is briefly as follows: The generator is geared to stop itself by turning the water off the wheel, and the source of constant speed is geared to speed up the generator by a contrary action. These two actions neutralize each other when the generator-speed is the same as the fixed speed, but when either preponderates the difference acts. Thus an increase in generator speed will act to stop the generator, while a decrease, by making the fixed speed predominant, acts

to speed up the generator. The governor consists, in part, of two similar miter-wheels which are mounted upon pulleys and placed face to face, loosely, upon a horizontal shaft, and are driven at equal speeds in opposite directions, one by the generator shaft, and the other by the exciter shaft. The speed of the pulleys is 200 R. P. M. In Fig. 3 it will be seen that between these wheels, and at right angles to the supporting shaft, there is fixed to the latter a cross-bar carrying two miter-wheels, one at each end, which mesh with the two oppositely-revolving miter-wheels first mentioned. The result is that as long as the two outside wheels are revolving at the same speed, the two central wheels will merely revolve upon their axes without tending to move in either direction the bar upon which they rotate. Now, if the generator-speed increases, the corresponding side of each central wheel will have to travel faster forward than the other side travels backward, and the difference between these two movements will result in a movement of the central wheels in the direction of the faster wheel, and the cross-bar will consequently move the same way. The shaft to which the cross-bar is attached will, of course, turn with it, and as this shaft carries a pinion meshing in a toothed quadrant connected to the lever which controls the nozzles, the stream will be pulled away from the wheel until the generator speed falls to its normal value. This point is quickly reached with a full load, owing to the drag of the load, but for a light load the inertia of the armature and wheel prevents them from responding so readily, and the governor does not act quite so quickly. Consequently the generator is not only brought to its proper speed but is carried slightly above it, which causes the governor to reverse, and thus sets up a slight and regular *see-sawing* in the speed. This see-sawing will be increased if there is any lost motion in the governor and its connections. It will also be increased because for a full head and light load the jets only impinge slightly on the buckets, and, since the jets are round, and their upper edges alone strike the buckets (which are themselves curved in the opposite direction) a slight movement of the governor produces a much greater change in the speed of the wheel under light loads than when the whole of each jet is in use. This effect of the jets is more marked when the governor is working to cut down the speed than when it is increasing the speed, because *withdrawing* the jets a given distance causes a greater change in the quantity of water striking the buckets than would be caused

by *advancing* them an equal distance. The see-sawing will be further increased if the nozzles are not fully counter-balanced, as they would then tend to fall away from the wheel.

In order to avoid see-sawing it is the practice in this plant to reduce the head every morning during the light load. This was at first done by opening the extra 4" relief-valve and allowing water to escape until the pressure had gone down to that corresponding to the desired head. The valve was then set tentatively until the pressure became nearly constant, when the final adjustment was made by partly closing the valve on the generator-wheel pipe. It was afterward found that the working pressure of the water at the nozzle could be sufficiently reduced by the last mentioned valve without also reducing the quantity of water in the pipe, and therefore the relief valves are no longer used for this purpose. In either case the governor throws more and more of the stream onto the wheel to compensate for the decrease in head, and the see-sawing stops. Where a double deflecting nozzle is used, it would seem advisable to have in the upper branch a throttle valve so connected to the deflecting levers that when running under light load the valve would be entirely closed and the regulation be attained by deflecting the open nozzle. When the whole stream of this nozzle had come into use and more water was required, the valve would be opened. In this way the water would be used during light load under more favorable conditions than obtain with a simple deflecting nozzle, see-sawing would be avoided, and in case the supply of water became less, either suddenly, as by a sharp freeze, or gradually, because of diminished rainfall, the water would be used most economically and efficiently during the time of maximum load, which is the critical time. The effect of such an arrangement of the nozzles and valves would be to increase the capacity of the plant for a given minimum water supply, the period of minimum supply being precisely that in which all possible economies are of value. It may be objected that tips of such a size should be used as would bring both streams into full use during maximum load, and that then no valves would be required, but against this is the fact that the maximum load (particularly in a lighting plant) does not reach the same value every night and that it is, therefore, always necessary to use tips large enough to meet the possible demand of any night.

In order to avoid breaking the teeth of the quadrant in case the governor should continue to act after it has moved the nozzles

to either their highest or their lowest point, the pinion on the governor shaft is mounted loosely between two laterally movable toothed ratchets which normally hold it in a fixed position. When the quadrant reaches either of its extreme positions, one of these ratchets will be disengaged by an adjustable lug on the corresponding side and end of the quadrant, and will thus allow the pinion to stop, though the shaft continues to turn. Both ratchets may be instantly disengaged by hand, and the position of the nozzles be regulated by a hand-lever when starting up, or in case of accident to belts or of decrease in head of water.

To start the plant, the governor ratchets are first disengaged, and the exciter is brought to a moderate speed; the generator is then started and its field is charged; it is then brought to about three-fourths of its full speed, and the speed of the exciter is then slowly increased until the cross-bar on the governor ceases to move. At this moment the ratchets are thrown in, and the governor takes charge of the generator-speed. The speed of the exciter is now slowly increased to its full value, which of course brings the generator to full speed.

The speed of the exciter-wheel is regulated by a small throttle-valve, the changes in the position of which do not have any noticeable effect on the pressure in the pipe, owing to the small size of the jet controlled. This valve is so made as to have an equal pressure on each side of its axis when partly open, and hence can be moved from one position to another with little effort, which makes it of special value for use with automatic governors. When tightly closed, however, the areas subjected to pressure are no longer equal, and the valve sticks tightly.

An effort was made to automatically govern the exciter by means of a ball governor driven by a belt from the exciter-wheel shaft, and actuating the valve by means of two leather friction-cones acting alternately on a beveled disk geared to the valve, but this proved unsatisfactory and was finally discarded, chiefly on account of the difficulty of maintaining the proper adjustment, by reason of the wearing away of the cones and of their swelling from dampness. The exciter was therefore controlled directly by hand for a long time. At present the valve is worked from a distance by a simple electrical arrangement devised by Mr. Imlay, in which advantage is taken of the fact that when the exciter is at full speed the movements of the valve necessary to regulate the speed are small.

The device consists essentially of two fixed solenoids in series, energized by current from the exciter, and normally acting with equal force on two iron cores supported respectively at the opposite ends of a walking-beam connected by levers to the valve, their normal function being to keep the valve stationary. Either of the coils may be short-circuited at will, by means of a relay controlled by two keys and likewise actuated by current from the exciter. When either coil is short-circuited, it ceases to hold its core, and the core on the other end of the walking-beam is pulled down by its own coil, thereby turning the valve in a corresponding direction. In order that this movement may not be too rapid the coils and cores are immersed in oil, which causes the coils to act as dash-pots to the cores; by this means the movement of the valve may be made as slight as is desired.

The relay is not really necessary, but was used to break the circuit in experiments made before the plan of short-circuiting one coil was devised, and has been retained because very convenient. A momentary closing of either key suffices to correct any change of speed, such changes being indicated by the compensating voltmeter. The current in the coils is reduced by a resistance in series with them about equal to that of one coil, and the current for the relay is shunted from the resistance at about two volts. The current normally passing through the coils and resistance, is about two amperes at 100 volts (about $\frac{1}{4}$ H. P.) and when one coil is short-circuited, the current in the other increases to three amperes, so that the maximum power used is $\frac{2}{3}$ H. P.

POWER-HOUSE.

The power-house is 66 ft. long by 30 ft. wide, and has walls $12\frac{1}{2}$ ft. high. The walls, which are of concrete, were all built by tamping concrete in a space between temporary wooden walls forming a mould, a few feet of wall being built at a time and the planks then loosened and raised to the height of the next section, the walls being thus made at the least expense for timber. The best English Portland cement was used. The walls were consolidated and cement saved, by the use of well-washed fragments of rock imbedded in the concrete. In order to obtain the greatest available fall, the power-house was placed as far as possible below the level of the fall. This necessitated blasting into the side of the hill so far that the entire wall next the hill was below the level of the adjoining rock.

The station was built to accommodate four 120 k.w. 7,200 alternation, 12-pole, single-phase Westinghouse alternators, with their full complements of raising-transformers and switchboard apparatus, and two exciters. The first installation consisted of one generator with one 90-ampere 125-volt "I" exciter, capable of exciting the four alternators, and of 240 k.w. capacity of oil transformers in 40 units of 6 k.w., 21 of these being located at the power-house.

TRANSFORMERS.

Several different methods of connecting the raising and lowering transformers were given careful consideration, the test of actual use favoring a series connection for both primary and secondary coils of both sets of transformers, a plan which had proved to be thoroughly reliable in its practical operation at the Westinghouse plant at Portland, Oregon. It was however decided, in order to be able to change the initial pressure on the line in case of accident to any of the transformers, to connect the primary coils of the raising transformers in multiple to the dynamo, put the line coils all in series with the line, and with a similar set of coils in the lowering transformers, and connect the other coils of the latter in multiple to the distributing circuits.

The next question was what size of transformers should be used. Many small transformers meant less cost per unit for repairs, greater facility of handling, and greater flexibility in case it were desired to change the voltage on the line. Their use, however, also meant greater first cost, more complication, and somewhat lower efficiency, but these points were outweighed by the former, and a transformer unit of 6 k. w. was chosen. Each transformer is contained in a cast-iron box provided with vertical outside ribs, which serve to stiffen it, and also to cool the oil with which the box is filled, and which entirely covers the transformer. The box is covered by a cast-iron lid, which has conducting and radiating ribs both outside and in, the inner ones dipping into the oil at its hottest part and helping to cool it. The oil when heated rises through open spaces around the coils and spreads out in all directions, guided by the ribs on the lids, and sinks slowly down between the core and the sides of the box, thus having ample opportunity to become cooled. Each box is provided with a pet-cock at the bottom, by which to draw off the bottom layer of oil, should it become too thick by evaporation. It

also has an oil-gauge to show whether the tops of the coils are completely covered without having to raise the lid. The boxes are supported upon a substantial timber frame, upon the top of which two iron bands serve incidentally to protect the wood, but chiefly to metallically connect the boxes to each other and to the earth, in order to dissipate the static charge received by the boxes, which is very unpleasant. The core of the transformer is connected to the box by a copper strip fastened around a block of wood upon which the core rests in the box. To provide against the danger which would result from accidental connection between the primary and secondary coils, an insulated sheet of copper is placed between the latter and close to the dynamo-coil, and is connected to the core by a tongue which is stuck between the plates.

The line-coil, of No. 7 B. & S. gauge wire, is inside the dynamo-coil, and is kept everywhere at a distance of one-half inch from the latter, the ground plate, and the core, by walnut blocks boiled in paraffin, between which ample openings are left for circulation of the oil. The ratio of transformation is 1000 to 450, so that in a bank of twenty transformers the dynamo-pressure required for 10,000 volts on open circuit is 1110 volts, and on full load about 3 per cent. more than this, or 1140 volts. The space between the 1000-volt coil and the core is one-eighth of an inch. The terminals of the line-coils are brought up through the oil in mica-fibre tubes passing through heavy glass bushings held in paraffined wooden blocks which are attached to the sides of the boxes. The 1,000-volt terminals are similarly supported, but without glass bushings. The transformers are all connected in multiple to the dynamo-circuit, which is supported directly above them on a light pine framework which also supports the fuse-blocks. The latter are single-pole, and the fuse passes through a hole in a marble block, the object of so confining the arc being to blow it out by its own force. Only one fuse is used on each transformer. The secondary or line coils are all connected in series by U-shaped insulated wire connections which may be readily detached when making periodical tests for insulation of terminals, and which are entirely independent of the frame-work supporting the dynamo circuit. Accidental contact with the exposed connectors is prevented by the framework above mentioned, and there is an inflexible rule that the high tension side of the transformers shall not be touched under any circumstances whatever while the dynamo is running.

Clark's insulation is used on all wires connected to the transformers and to the dynamo, and the terminal wires of the full bank, which must often be disconnected for testing, are further insulated by heavy glass tubes at points where they might come in contact with other wires. All other transformer-wires are supported upon double-petticoat glass insulators, and all dynamo-wires upon porcelain knobs.

SWITCHBOARD.

The switchboard is of narrow redwood boards, tongued, grooved and beaded, nailed on a framework of yellow pine, the latter supported on porcelain insulators to keep it dry. The switchboard outfit for one generator and one exciter consists of two 120 amp. fuse blocks, an A. C. field rheostat with a 25 amp. D. P. field switch with fuses, an exciter rheostat, one 150 amp. ammeter and a 200 amp. D. P. jaw-switch. From this switch the current passes to two 4-dynamo, marble switch-panels which are connected in multiple to the dynamo, and are each provided with two pairs of contact plugs. By means of these panels and of two 200 amp. dynamo-changing switches below them, any feeder can be operated from any dynamo which is connected to the switch-panels. Between each panel and its switch is a pair of 65-ampere Wurts shunt-wire fuse-blocks, each provided with an extra fuse and shunt which can be connected by inserting a plug, should it be desired to double the fuses during the run on account of overload or of weakness in the fuse. The remaining instruments on each feeder are a voltmeter, a No. 1 switchboard-converter and a 150 amp. type "E" compensator. When both feeders were run from one alternator, one voltmeter was connected to the generator and the other to the feeder, and in this way the amount of compensation could be watched.

The oil-transformers were tested before shipment with 20,000 volts between the line-coil and the core, and were then taken out of the oil and boxed. In order to expel any moisture which might have been absorbed by the insulation of the coils or have condensed on the cores during their long journey, the transformers were connected in two banks of ten each, the line-coils of each set being connected in series to the generator, which was run at a reduced speed, and the secondary coils each short-circuited on itself. The coils were thus gradually heated to a point somewhat above the boiling point of water, which at that elevation was

about 201 deg. F. They were kept at this temperature for a short time and then paraffin oil of a special grade ("Diamond") was poured slowly into the boxes at the edges so that the coils would begin to absorb oil at their lower ends, and thus drive upward the air and volatile gases occluded by the insulation. The transformers were then again brought to their former temperature, which caused expansion and partial expulsion of the air remaining in the insulation. Some of the air would however collect under the insulation at the top of the coils, and had to be freed by mechanical agitation, produced by stirring the folds of insulation or by pounding on the boxes. The heat caused volatilization of some of the lighter elements of the oil, these coming to the surface as bubbles, just as the air did at first, and the agitation was kept up at intervals until bubbles from this cause also were entirely eliminated.

The 20 transformers were then connected as they would be when in regular use, and the two terminals of the line-coils, which were to give 10,000 volts, were connected in series with one hundred 100-volt lamps, which were then brought to full candle power, showing that the transformers were all in good condition. A similar test was then made at Pomona at the end of the 14-mile transmission line running to that place, after which the transformers there were prepared for work in the same way as at the power-house, except that the grouping and initial voltage were changed.

LINES.

There are two transmission lines, one $13\frac{3}{4}$ miles long, which supplies Pomona, and another $28\frac{3}{4}$ miles long, which supplies San Bernardino. (See Fig. 4.) Each line consists of two No. 7 B. & S. gauge, hard-drawn copper wires. The joints in the wire are made with McIntire connectors. To further improve the joint, the ends of the wires were bent back side by side and soldered together. After the Pomona line was completed and the first ten miles of the San Bernardino line was put up, the supply of connectors ran out, and the regular telegraph joint was substituted. The conductivity was assured by soldering as before.

The wires are supported upon large double-petticoat flint-glass insulators designed for this plant. These insulators are of perfectly clear flint-glass, which gives a better surface-insulation than is attainable with any other kind of glass.

It was at first proposed to use oil insulators. The reason they were not used was because the glass companies which had undertaken to furnish them, found on trial that they could not make them without considerable experimenting, which would have delayed the installation of the plant. This was no doubt fortunate, as the country through which the line passes is subjected to hot, dry winds which not only blow dust onto the insulators, but also inside them, and during the day the sun beats on the insulators until they become so hot that they nearly blister one's hands. If oil were used under these conditions it would soon evaporate and thicken, and become filled with dust. It would therefore seem undesirable to have used oil insulators in this case, or to

FIG. 4.—Route of Lines.

use them in any other until an increased voltage makes them necessary, and the transmission of greater amounts of energy over the circuits justifies the additional expense necessary to keep the insulators in good condition.

The two circuits are carried on the same pole line for $7\frac{1}{2}$ miles. (See Fig. 4.) The inside pair of pins was used for the circuit to Pomona, and the outside pair for that to San Bernardino, until after the acceptance of the plant, but in anticipation of the installation of another generator, the Pomona circuit was changed to the right-hand pair of pins, and the San Bernardino circuit to the left-hand pair, to avoid the fluctuation in lights which would result from inductive interference between two independent circuits.

Commercial lighting in Pomona was begun November 28th, 1892, and a telegraphic order was at once sent for another set of reducing transformers, to be used at San Bernardino, where the local circuits were already nearly completed. It was a condition of the franchise for the latter place that lighting should be begun before January 1st, and work was pushed rapidly on the transmission line, over 28 miles long, until it was finished. The order for transformers had, however, been given too late for them to be delivered in time, and it was decided to reduce the pressure at Pomona to 5,000 volts and to take to San Bernardino the half of the Pomona bank thus made available. In order to avoid the re-heating which would have been required had the transformers been dismounted for shipment, the latter were hauled to San Bernardino on wagons without springs, after the lids had been packed so that the oil could not splash out. The transformers reached their destination after midnight, and the next day, December 31st, they were connected to the transmission line for a few moments to see that the latter was all right, after which all the lights on the circuit were thrown on for the night.

When the new transformers arrived they were set up and heated in the same way as the others. The heating was continued night and day until complete, without interrupting the regular lighting service. The change of both circuits to 10,000 volts was made February 16th, 1893.

SUB-STATIONS.

The sub-stations at Pomona and San Bernardino are small brick buildings, one story high, with flat tin roofs and numerous windows. The Pomona building contains two rooms connected by a door near the switchboard. The front room is used as the office of the company, and the other as a transformer room. The 10,000-volt circuit enters over the door, and is connected directly to the bank of lowering transformers, no switches or other appliances being used on the high tension lines either there or at San Bernardino. The switchboard appliances are a Stillwell regulator, two 100-amp. marble fuse-blocks with double plugs and fuses; a 100-amp. jaw-switch, 150-amp. ammeter, compensating voltmeter, compensator and converter.

The San Bernardino sub-station is longer than that at Pomona, and is not divided by a wall. The transformers are placed in a

row along a side wall, and along part of the end wall next the switchboard. The transformers near the switchboard heat the most. This is probably due to the slight drop in wiring between them and the more distant converters. During the first year of operation a little new oil was put into the converters about every four months to make up for that evaporated, but none of the old oil was drawn off. The switchboard apparatus is like that at Pomona.

The Stillwell regulator has long been recognized as a valuable adjunct to the central station operating a number of feeders of different lengths from a single dynamo. Its utility is still greater in a system of long-distance transmission in which the transmission circuits are supplied from one dynamo, as was the case in this plant during its first year of operation, since it is not practicable to install such a system so as to operate with small line-loss, and therefore means must be provided to compensate for the large differences in the pressure at the ends of the lines. The use of regulators at the power-house was impossible when but one bank of raising transformers was used for the two circuits. Even when it became possible by the use of separate banks of transformers, it was still undesirable because the attendant at the power-house would often have had to work both the regulators at once to properly compensate for changes in load, and his attention would have been required by the regulators at exactly the time he should have been free to attend to the generators. A regulator was therefore placed at each sub-station, as already stated. These are each of 2000 lights capacity and have a range of 10 per cent. up, and 10 per cent. down. This variation of 10 per cent. (100 volts) is divided into 14 equal parts, so that each step corresponds to 7.1 volts. The diagram (Fig. 5) was taken one Sunday, while using only 5000 volts, and shows the number of changes required during the evening at each station. The line marked "off" is the base line, and the divisions above and below correspond to the steps on the dial and show to what an extent the regulators were used to increase and decrease the pressure. This diagram shows how impossible it would be to furnish lights without using regulators, even on Sunday when the load is much smaller than on other days. It also shows that on that day the pressure at Pomona was being mostly reduced while that at San Bernardino at times (as at the point marked "very bad light") could not be sufficiently increased. This indicates that the pressure of the lowering trans-

formers at one of the sub-stations should be changed so as to make the pressures at both more nearly equal, and thus increase the effective range of the regulators. In the present plant this is done by changing the number of transformers.

The distribution from both sub-stations is effected in the usual manner at 1000 volts for incandescent lighting, the only point of interest being, that a considerable number of Helios arc lamps are successfully used on the incandescent circuits.

OBSERVATIONS.

While in use, the transformers in the sub-stations give forth a continuous hum which depends for its tone on the number of alternations. This is an excellent indicator for the attendant, whose attention is instantly called to any change in the running conditions of the plant by the resulting change of tone. Its indications not only mark changes which are taking place and which can be detected on the voltmeter, but also give notice of coming changes before there is any other indication of them. It is thus possible to foretell a coming drop in voltage in time to use the regulator and thus keep the voltmeter needle perfectly still, though the voltmeter is a very sensitive instrument, and the regulator is often moved four or five notches. The hum often changes, however, without any corresponding movement of the voltmeter, but the sound is then somewhat different. At rare intervals the switchboard lights will suddenly change slightly in candle-power before any change is noticeable on the voltmeter.

It is noticeable that the needle will often stand for a time perfectly still on the center, and, on a slight rise in the hum, will start gently rising, never more than three-quarters of an inch, and then as the tone gradually becomes lower, slowly fall back to the center and stop without passing it. At other times the variation in hum is more sudden and the needle will rise and oscillate above the center. Again, the needle will oscillate equally about the center during a regular rise and fall of hum, its movement being apparently due to one impulse and not seeming to be modified by subsequent variations. There is no apparent change in candle-power of the lamps during the voltmeter changes noted. These notes were made while the plant was running at only 5,000 volts, but they were later confirmed when using 10,000 volts. During dry weather there is considerable intermittent oscillation of the voltmeter-needle without there

FIG. 5.—Diagrams Showing Use of Stillwell Regulators at Pomona and San Bernardino, with Notes of Simultaneous Conditions at Cañon.

being any change in load or any other apparent cause, while in wet weather, the needle remains perfectly still for many minutes at a time, often for as much as half an hour. A possible explanation of this oscillation may be found in the presence of static charges on the line, due to atmospheric electricity. That the line is often heavily charged from the air, is shown by a number of observations. One afternoon a painful shock was obtained on touching the line at the canyon end, drifting clouds and a strong wind being noticed in the valley. Again, while using the telephone a report was heard in it so sharp as to cause momentary deafness. Later, after a moderate wind had been blowing for some time, loud reports were noticed on the telephone at long intervals. As the wind became higher the reports came oftener, and the intervals between the reports became shorter. It was evident that there was a discharge from the lines through the telephone (which was on a metallic circuit) and that it depended on the rate at which the wind blew. In order to get the strongest effect the two wires were connected in the usual way to the raising and lowering transformers, and one side of the telephone connected to one wire. On connecting the other side of the telephone to ground a sharp report was heard, and on maintaining the connection there was a sound as of steam escaping at a distance, with intermittent and very faint crackling. If the ground contact was made slowly, there was a bright spark before the metals touched, and a loud report. If the fingers were interposed a smart shock was received. By making and breaking the ground connection rapidly, the line was prevented from accumulating a heavy charge, and no spark was visible, though a faint crack was heard. If a slight space was left between the telephone wire and the ground, a spark occurred at fairly regular intervals, and when the space was lessened the sparks became smaller and more frequent. When the wind lessened, the sparks and reports became almost imperceptible, but on the wind becoming strong and blustery a large spark was again obtained. When one line wire was disconnected from the transformers at Pomona the effect obtained from grounding that wire was less, owing to the reduction in capacity.

These observations, which were made on the Pomona circuit during hot, dry and cloudless weather, show conclusively that the lines were heavily charged by the action of the wind. The wind no doubt blows electrified air and dust against the wires,

the latter thereby accumulating a static charge with a rapidity which we have seen depended on the speed of the wind.

Some curious conditions met with in the operation of the plant are shown in the ampere curves in Fig. 6, which were taken during very wet weather. Taking the maximum load measurements at 7 P. M. for March 14th and 8th, we note that the total apparent energy delivered by the sub-stations is 73 per cent. and 75 per cent., respectively, of that delivered by the generator, while for a smaller load at 9 P. M. the respective percentages decrease to 47.6 per cent. and 48.6 per cent. in spite of the fact that the apparent energy delivered by the generator is in the latter case only half as great as in the former. These results are due to changes in the angle of lag caused by changing the load.

In the Cañon curve of March 8th, the load at 9.30 p. m. is seen to have increased considerably, although the sub-station loads were decreasing. This increase was due to the fact that the rain which had previously ceased to fall at Pomona, began again.

TESTS.

The electrical resistance of the Pomona circuit is 74.9 ohms and that of San Bernardino 156.4 ohms at about 90 degrees F.

The insulation resistance of the circuits varies from far beyond the limits of an 11-megohm bridge in dry, hot summer weather, to as low as 0.65 megohm during light rain. The latter value is that obtained with the two San Bernardino wires in series, and represents an insulation-resistance per mile of over 37 megohms. On a clear, sunny day the insulation-resistances of one Pomona wire and of one San Bernardino wire were respectively 11 megohms and $5\frac{1}{2}$ megohms, which are in the exact relation which would be expected.

The lines cannot be tested for grounds or for continuity with a magneto bell, as their capacity is such that the bell will ring loudly when the wire is perfectly insulated and the circuit open. This capacity also prevents the use of the ordinary converter test for line leakage, as the lamp on the secondary will burn as though there were a ground even when the line is perfectly clear. By adding lamps, however, the light may be cut down until the last lamp added extinguishes them all. This would not occur if the light of the first lamp was due to a difference of potential on the primary caused by a ground, as then the added lamps would be-

come as bright as the first. The primary current is thus seen to be limited, and to be due to the capacity of the line. If the proper number of lamps has been added, to just secure darkness when the line is known to be free from grounds, the converter

FIG. 6.—Ampere Curves. Showing Excess of Cañon Load over the sum of Pomona and San Bernardino Loads, and also Decrease in Difference between Cañon Load and this Sum as the Cañon Load Increases.

Notes on March 8th. Raining in afternoon and nearly all night at Pomona. Snowing throughout canyon and a mile or so outside of mouth of canyon. 8 inches of snow at power-house, covering insulators and cross-arms completely. 1 inch of snow on wires. Snow damp and clinging. No wind. 20 converters at Cañon, 19 at Pomona and at San Bernardino.

may be used to show grounds on that line, since the presence of a ground will cause all the lamps to brighten. The line test should only be made after ascertaining with one lamp that the generator is not grounded, as otherwise the leakage cur-

rent for the greater number of lamps might burn the insulation of the generator. A very good example of Prof. Fleming's "condenser effect" was met with in the summer of 1893, while the engineer was trying this converter test for measuring line leakage. The primary of a 1000—100-volt converter was connected between the ground and one terminal of the generator, the other terminal of the latter being connected to one wire of the Pomona circuit. The resulting secondary pressure

FIG. 7.

was 30 volts, which made one lamp burn dimly. When ten lamps were turned on, the pressure dropped to 14 volts. When all lamps were turned off the pressure became ten times as great, or 140 volts. One generator brush was then raised, and the second wire of the circuit was connected to the first. On completing the circuit again there was a sudden flash on the armature, followed by a crackling noise and a brush discharge which lasted until the circuit was broken. The Pomona wires were then disconnected from the dynamo terminal, which was left free. With this arrangement faint sparks and a glow were noticed, as

though the armature winding were grounded on the core, but a Wheatstone bridge test showed an insulation resistance of over 10 megohms. Since then the machine has been used regularly and has not broken down, so it is evident the spark must have resulted from a sudden increase of the potential of the armature winding above that of its core, which latter was permanently connected to earth.

This sudden increase may be explained as follows. On closing the circuit the condenser formed by the line and the earth began to discharge through the metallic circuit afforded by the armature and converter windings, but the self-induction of this circuit checked the discharge so quickly as to produce an excessive pressure which could only be relieved by the discharge taking place through the insulation of the armature-winding to the grounded core, which is what happened.

A similar test was made on the San Bernardino wires in the previous January during dry weather, the only change being that the single lamp was not turned off. With only one wire connected, one 16 c. p. lamp came nearly to candle-power. On connecting the second wire to the first (at San B.) the lamp burned at full candle-power. Ten lamps (the full load) were then put on the converter and burned dimly. As they were turned off one by one, the others brightened until the last lamp lighted up as before. This test did not cause any discharge on the armature, in spite of the fact that the circuit was twice as long and the capacity thus twice as great. The probable explanation of this is that the inductive resistance of the converter was not so great as in the other case, on account of the single lamp being left burning. It is also possible that the breakdown in the other test was assisted by the presence of copper dust on the winding.

A comparison between the ammeters used at Pomona and San Bernardino showed that for readings above $67\frac{1}{2}$ amperes the San Bernardino instrument read higher than the other. As there was no reason for considering one instrument more accurate than the other, and no way of telling which was right, the San Bernardino readings taken during the test were reduced to the average of simultaneous readings on the two instruments.

A short test of the Pomona circuit was made on April 11th, the results of which are given in Table I.

A preliminary efficiency test on the San Bernardino circuit was made April 13th, 1893, with the results shown in curve in Fig.

7. In this, as in all the other tests, a variable load was obtained by the use of a water resistance.

An efficiency test of the San Bernardino circuit lasting five hours, during which the generator was kept at full load or overload, was made April 14th, 1893. The voltage at San Bernardino during the tests was measured with a Weston portable voltmeter. Readings were taken every fifteen minutes, and the efficiencies and the corresponding voltages for different loads are

TABLE I.
EFFICIENCY TESTS. POMONA CIRCUIT.
April 11th, 1893.

Cañon (20 Converters).			Pomona (18 Converters).			
Amperes.	Volts.	K. W.	Amperes.	Volts.	K. W.	Efficiency per cent.
120	1100	132	105.85	919	97.28	73.7
118.5	1100	130.35	105.85	945	100.01	76.73
119.5	1100	131.45	107.4	929	99.78	75.9

TABLE II.
42½ MILE TRANSMISSION TEST. CIRCUIT TO SAN BERNARDINO, BY WAY OF
POMONA, 85 MILES.
May 2nd, 1893.

Cañon (20 Converters).			San Bernardino (18 Converters).			
Amperes.	Volts.	K. W.	Amperes.	Volts.	K. W.	Efficiency per cent.
95	1120	106.4	80.75	847	68.4	64.28
96	1130	108.5	78.8	865	68.16	62.82
100	1200	120.0	81.7	893	72.96	60.8

plotted in Fig. 7. The most prominent feature of this efficiency curve is its irregularity. This is, however, satisfactorily explained by referring to the curve of generator voltage, on which it is seen that the high efficiencies correspond to high voltages, and *vice-versa*.

It will be noted that the apparent efficiencies shown by the preliminary test at San Bernardino agree very closely with the results of the long efficiency test there. On calculating the apparent efficiencies for different loads from data obtained by lab-

oratory tests, and comparing them with the measured apparent efficiencies, it is found that they agree within three or four per cent. This very close agreement is exceedingly gratifying, particularly when we consider that the tests of the plant were made with ordinary commercial instruments, and that the laboratory tests were made about a year before the commercial tests.

An interesting and unique test was made May 2d, 1893, by connecting the Pomona line wires in series with the San Bernardino circuit, and transmitting about 100 h. p. to San Bernardino by way of Pomona. The length of the circuit was 85 miles, and the distance of transmission $42\frac{1}{2}$ miles. This is the greatest distance yet covered by any transmission since the Frankfort experiments. The measurements are given in Table II. The apparent efficiencies are much lower than those indicated by calculations, as in the latter no account was taken of the capacity and inductance of the circuit. The voltage of the generator as measured is about 5 per cent. above that calculated, and the amperes measured, notably exceed the amperes calculated. These results are attributable to the introduction of the Pomona loop, which added both capacity and inductance.

In order to reduce the cost of operation, the San Antonio Company first dispensed with the sub-station attendant at Pomona after 11 p.m. This they did sometime before the acceptance of the plant, after assuming the responsibility for any damage which might result. No trouble occurred and, after the acceptance (May 6th, 1893,) the same plan was put in operation at San Bernardino. After working in this way for several months, the Pomona station was started in the afternoon and then locked up until the next morning. This arrangement was made possible by running the generator so that the pressure would be right at Pomona, the pressure at San Bernardino being kept right by the attendant with the Stillwell regulator.

In January, 1894, another 120 k.w. generator was installed with an equal capacity of oil transformers, and the Pomona and San Bernardino circuits are now each operated from separate generators with separate banks of transformers at 10,000 volts. Since this change the San Bernardino attendant has also been dispensed with, and the book-keeper starts up in the afternoon and then locks up the station for the night, as at Pomona. The voltage of the lamps on each circuit is regulated by the engineer at the power-house, the generator pressure necessary at different

loads to keep the lamps at the proper brilliancy being automatically indicated by the compensating voltmeter on each circuit. Thus after the plant is started the engineer has sole charge.

The following associate members were elected at the meeting of Council held at Niagara Falls, June 27th, 1895.

DANIELSON, ERNST,	Consulting Electrician, 16 Scheele Gatan, Stockholm, Sweden.	Elihu Thomson. E. W. Rice, Jr. H. M. Hobart.
GHERARDI, BANCROFT, JR.,	Assistant in the Engineering Dep't Metropolitan Tel. & Tel. Co.; resi- dence, 6 East 34th St., N. Y. City.	W. L. Bliss. Sam'l Sheldon. A. L. Riker.
HESSENBRUCH, GEO. S.,	Assistant Electrical Engineer Ac- cumulatoren Fabrik, Hague, Ger- many; 3 Head Place, Boston, Mass.	B. C. Paddock, Jr. F. Wm. Erickson. R. W. Pope.
HORNSBY, HARRY H.,	Electrical Inspector, City Hall; resi- dence, 1801 Barry Ave., Chicago, Ill.	C. C. Haskins. B. J. Arnold. L. K. Comstock.
HUGUET, CHAS. K.,	Instructor in Electrical Engineering, Tulane University; residence, 1216 Carondelet St., New Orleans, La.	Brown Ayres. A. L. McRae. A. F. McKissick.
JEHL, FRANCIS,	Representative, F. Hardtmuth & Co., 60 Liberty St., N. Y. City.	Wm. J. Hammer. R. W. Pope. Francis R. Upton.
MERRILL, EDWARD B.,	Principal and Instructor in Elec- tricity, etc., at the Toronto Techni- cal School; residence, 38 Cecil St., Toronto, Ont.	T. R. Rosebrugh. John Langton. W. M. Ruther- ford.
ORMSBEE, ALEX. F.,	Electrical Engineer; residence, 183 Joralemon St., Brooklyn, N. Y.	F. B. Crocker. Max Osterberg. W. H. Freedman.
PEIRCE, ARTHUR W. K.,	Instructor in Electrical Engineering, The Colliery Engineer Co., Scranton, Pa.	J. Hally Craig. Geo. Cutter. Wm. H. Donner.
PRICE, EDGAR F.,	Electrician, Newark & South Orange Railway Co.; residence, 16 Rector St., Newark, N. J.	Philip A. Lange. L. A. Osborne. H. M. Wharton.
SAWYER, FRED. W.,	Student, Worcester Polytechnic Insti- tute; residence, 42 Harvard St., Worcester, Mass.	A. S. Kimball. R. W. Pope. Edw. Caldwell.
TORCHIO, PHILIPPO,	Engineering Dep't, The Edison Elec. Illuminating Co., 53 Duane St., N. Y. City.	Wm. J. Hammer. E. A. Leslie. J. W. Lieb, Jr.
YOUNG, CHARLES I.,	Electrical Engineer, Westinghouse Elec. & Mfg. Co., Pittsburg, Pa.	A. J. Wurts. Chas. F. Scott. L. B. Stillwell.
Total, 13.		