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REPORT OF THE TRANSMISSION COMMITTEE

I—DATA FROM OPERATING PLANTS ON THE EFFECT OF ALTITUDE ON THE OPERATING TEMPERATURE RISE OF ELECTRICAL APPARATUS

BY PERCY H. THOMAS, CHAIRMAN

RECOGNIZING the absence of conclusive data on the altitude correction to be applied to the temperature rise of electrical apparatus, and further the lack of uniformity of the general practise as well as the frequent entire omission of the correction, the Transmission Committee undertook the collection of data as to the opinion and practise of operating engineers and sent a list of questions to 150 companies and individuals.

The information received is herein summarized and discussed. It should be noted that no effort has been made by the Committee to make laboratory tests or scientific investigations—nor does the Transmission Committee offer any definite rule of correction, for this is the function of the Standards Committee. The data collected is presented as information for the use of any committee or individuals who may find it helpful.

Thirty-one replies were received. Of these 15 were from plants operating apparatus at 5000 ft. (1524 m.) altitude or higher, which are here called high-altitude plants. Of these 15 high altitude plants six make no correction for altitude and six have noticed no effect of altitude. Comments of more or less interest have been received from some of the above and are here summarized.

*From W. N. Clark, Arkansas Valley Ry. Lt. and Pr. Co.,
Canon City, Colorado.*

Altitude 9000 to 10,000 ft. (2743 to 3048 m.)

Take account of altitude both in purchasing and loading transformers. Have no definite rule for correction but have by experience determined which design of transformers operate satisfactorily. The transformers in question are step-down transformers in the Cripple Creek district, ranging in capacity from 100 to 900 kw.

We have noted that on some of the more modern closely rated equipment that the temperature remains high. This does not apply to some of the older more liberally rated apparatus such as generators and transformers.

Six 200 kv-a., oil-insulated, self-cooled transformers required water cooling coils to prevent constant excess temperature at rated capacity, however, part of the cause was poor circulation of air in and out of building.

The correction factor is not large. I think it should be made. I think the capacity should be rated lower for the higher altitudes something similar to the method of rating air compressors.

Lightning discharges take place over longer setting of horn-gap arresters.
From W. O. Vickery, The Trinidad Electric Transmission.

Railway and Gas Co., Trinidad, Colo.

Altitude 6000 to 7000 ft. (1828 to 2133 m.)

No account taken of altitude up till spring of 1915.

No rules adopted, but it is thought best in future to specify temperature and altitude in purchasing electrical apparatus.

From general observations it is noted that oil-insulated, self cooled transformers run approximately 10 per cent higher than manufacturer's guarantee. This is also noted on induction motors, except that induction motors run only about 7 per cent higher than guarantees. Generators seem to operate about 5 to 6 per cent higher than guaranteed rating of temperature.

Nothing definite. However, the loss of the coils in a 2000 kw. turbo-armature we believe could be partly attributed to higher temperature resulting from high altitude.

Generally speaking, increased temperature at high altitudes was called to our attention in the spring of 1915. Since that time, observations have been made, which lead us to believe that there is considerable increase in temperatures of electrical apparatus when operating at altitudes of 7000 to 10,000 ft. (2133 to 3048 m.) above sea level, and it is believed rules should be formulated covering such apparatus when making purchases.

From R. W. Toel, Chf. Engr., Denver Tramway Co., Denver, Colo.

Altitude 5280 ft. (1609 m.)

Take account of altitude in loading transformers.

Air transformers have been noticed to operate from 10 to 12 deg. cent. higher than manufacturers specifications under given load conditions.

Air transformers have failed due to high temperatures operating under normal conditions.

Should think that a correction factor should be made of at least 10 deg. cent. higher than temperature rating for apparatus used at sea level under same operating conditions.

From J. H. Rider, 8 Queen Anne's Gate, Westminster, S. W. London.

Altitude 6000 ft. (1828 m.), neighborhood of Johannesburg, So. Africa.

Takes account of altitude in generators, motors and transformers both in purchasing and loading apparatus.

To secure a maximum temperature rise of 35 deg. cent. in motors with an ambient air temperature of 35 deg. cent., motors must not exceed a temperature rise of 30 deg. cent. with an ambient air temperature of 25 deg. cent.

The neighborhood of Johannesburg is at an altitude of 6000 feet above sea level, and from experience where I have had to adopt the following basis for the temperature of the motors, namely, a maximum temperature rise of 35 deg. cent. with the surrounding air at a temperature of 35 deg. cent.

As the plant has to be tested at the maker's works at sea level, the prescribed limits for such a test are a temperature rise of 30 deg. cent. with the surrounding air at a temperature of 25 deg. cent. as experience has shown that these figures correspond very closely indeed with the limits for the higher altitudes.

I have had considerable difficulty with some manufacturers in getting them to design their plant for what appears to them to be abnormally low temperature rises at sea level, but by persistence have succeeded now in getting those figures without difficulty.

Yes; correction should be made for altitude.

From K. C. Randall, 133 Dewey Avenue, Edgewood Park, Pa.

Have never allowed nor encountered requests for allowance in rating of apparatus because of expected operation at high elevations.

Have never heard of instances where loading is in any way controlled by elevation.

I believe that in general the extra complications from introducing corrections for elevation will be largely a paper burden and in general of no material significance, particularly as standard apparatus should be employed as far as possible and that any acknowledgment of the effect of elevation will only add to the expense of both consumer and manufacturer without any return to either. This is particularly true, as the wide range of conditions of installation, ventilation and operation will have in general much more bearing on operating conditions than variation in elevation.

From Charles S. Ruffner, Genl. Mgr., The Electric Company of Missouri, Webster Grove, Mo.

Confining the questions strictly to the effect of air pressure on thermal conditions might omit considering other factors in the cooling of apparatus at high altitudes. The prevailing lower temperatures at high altitudes, with particular reference to the invariably cool nights, might, in practise entirely offset any difficulty with the volumetric thermal capacity of the air.

Personally I have not noted any cooling difficulties in any apparatus operated at high altitudes arising from the rare atmospheres, and I cannot think of any important practical question in that connection excepting only in the design of forced ventilating systems. In that case, the

apparatus being cooled by air blast might require a larger volume of free air. Such a case has not, however, come under my observation.

A few simple experiments on the rate of transfer of heat from any substance to atmosphere of different pressure might determine the quantity of air at different pressures required for equivalent cooling effects.

From P. M. Downing, Chf. Engr., Hydroelectric Dept., Pacific Gas and Elec. Co., San Francisco, Cal.

In this connection I might say that the effect of altitude on the temperature reading of electrical apparatus, is something that we have never considered of great importance. The writer has had personal experience in the operation of such apparatus at altitudes ranging from sea level to 8500 ft. (2590 m.), and although I have never made any careful tests, have never been able by casual observation to notice any change in the heating of the apparatus.

From C. D. Gray, Asst. Elec. Engr., J. G. White Engineering Corporation, 43 Exchange Place, New York.

Our personal opinion is that if the altitude is over 6000 or 8000 ft. (1828 or 2438 m.) some attention should be given to this matter and we would probably specify about 5 deg. lower temperature than for a machine used at lower altitudes.

From J. F. Dostal, Genl. Mgr., The Colorado Springs Light, Heat and Power Co.

Altitude 6000 and 7000 ft. (1828 and 2133 m.)

Take no account of altitude either in purchasing or loading apparatus.

Feel that some allowance should be made. Have noticed that fans run hot.

From E. R. Davis, Genl. Mgr., Pacific Light and Power Corporation, Los Angeles, Cal.

Altitude 5000 ft. (1524 m.)

To yours of July 26th covering data sheet for references to effect of altitude in temperature of electrical apparatus, the replies to all the questions except the first may be summed up in the statement that this company is not taking any account of the effect of altitude on operating apparatus and has no observations or tests on record which would have any bearing on the matter.

The above data indicate clearly that most engineers operating at altitudes over 5000 ft. (1524 m.) have ignored the question of the effect of altitude on the operating temperature of electrical apparatus. This appears rather to be because of lack of tests on their own apparatus and lack of convincing engineering data in any form. As at most, the effect of altitude involves a limitation of only a few per cent and as apparatus is seldom loaded to exactly 100 per cent of capacity, the point of view is natural. However, at the higher altitudes where engineers have made an

effort to look into the subject they usually conclude that a correction should be made.

While in most cases the altitude correction is not important, there are some where it is of great importance, for example to such a company as the Chile Exploration Company which expects to have 100,000 kw. of transformers and motors at 9000 ft. (2743 m.) altitude, much of which will be carefully rated, or as the Cerro de Pasco Mining Co. with apparatus at the extreme altitude of 14,000 ft. (4267 m.)

Obviously the data collected by the committee form no basis for the drawing of a definite altitude correction, and the collection of data was not undertaken with that in view. It serves however to show the attitude of engineers in general on this question and thus it is of considerable interest.

Two of the replies above quoted are to the effect that their authors considered that the altitude correction is not of magnitude enough or sufficiently precise to warrant a formal rule.

Two of the replies included certain matters not strictly pertinent to the subject of the inquiry but still cognate and of some interest, they are appended below.

From J. H. Rider, 8 Queen Anne's Gate, Westminster, S. W., London.

One of the things which no manufacturer ever pays attention to is that the temperature rises of generators and motors tend to increase as time goes on, even with the same load. This is because the first temperature tests are made with the machine in a new and clean condition, with all ventilating passages in good order. During working, however, it is impossible to keep dirt from collecting in the air passages, and so the ventilating facilities get worse and worse as time goes on.

It is quite impracticable to clean out the ventilating spaces without dismantling and then rebuilding the whole machine, which, in practise, is impossible, as a user is entitled to expect his machine to run satisfactorily for very many years, if he gives proper attention to the bearings, brushes, etc.

The above point, perhaps, does not concern only motors which are intended to work at high altitudes, but it shows that the test temperature of such machines at sea level must be quite as low as those which I fixed upon if satisfactory after running is to be obtained.

If your committee, therefore, could both fix upon a standard for temperature tests at sea level to give reasonable working temperatures at high altitudes, and also make such sea level figures low enough to provide for the gradual clogging of the air passages, you will have done a very great work.

From R. S. Masson, 705 Security Building, Los Angeles, Cal.

I was much interested in your letter about the effect of altitude on the temperature rate of electrical apparatus. I have been determining for

a number of years in my own mind that humidity was the real nigger in this altitude woodpile. In other words, I am of the opinion that altitude as such does not effect the cooling capacity of the air to any material extent but that humidity, which may be directly related to altitude in some instances, causes the trouble.

When the writer undertook to operate certain motor-generator sets in Phoenix, Arizona, about three weeks ago, it was found that the machines ran very much above their testing temperature and, after accusing power factor and other common enemies, it was found that there must be another cause. Phoenix was then a close neighbor to great areas of desert and the average humidity was so low that the air was practically dry. We then tackled this problem of constructing a humidifier which, in effect, was not much different from any of the attempts which have been made by power house operators; ours having the form of water screens rising out of a water bath like the old overshot water wheel and the air flowing through these screens. This air was conducted through canvas housings to the ends of the motor generator sets and allowed to flow out through the stators, without changing the machines themselves at all. The effect was very marked and increased the capacity of the normal rated 600-kw. machines about 125 to 150 kw. at the same temperature rise.

Referring then to the problem as presented in your letter. Here was a machine located at an elevation of about 800 ft. (243 m.) which was having all of the troubles that had previously been experienced at altitudes of 8000 and 10,000 ft. (2438 to 3048 m.) It would be interesting to have some of the operators of plants in high altitudes test out this method of cooling the air to see if they cannot put their machines on the same basis as the sea level machines.

This test which we made, however, was not quite true, as the effect of blowing the air through these water screens was to actually cool the air by evaporating the water and, of course, the machine was practically running in a lower temperature. In order to make a true test of the effect of humidity alone it would be necessary to re-heat the air, after it has accumulated moisture, to the temperature of ordinary air. This test I will be glad to make, if it would be of any interest, as it can be done in the said Phoenix motor-generator apparatus without inconvenience or unnecessary delay.

The above extracts are self explanatory.

II—EXPERIENCE WITH GROUNDED NEUTRAL ON HIGH-TENSION TRANSMISSION LINES

To secure a comparison of the experiences of various companies operating high tension systems with grounded neutrals, the Transmission Committee sent an information blank to a large number of power companies and the present report covers the information secured.

It is believed that the various replies can be best offered by printing verbatim or in rearranged form the more important reports; comments will then be made.

*From the Pennsylvania Water and Power Company,
Mr. A. Bang, Testing Engineer.*

The Pennsylvania Water and Power Company operates a hydroelectric plant located at Holtwood, Pa. The generating capacity of this plant is at present about 83,500 kw.; the current is three-phase current, 25 cycles, and generated at 11,000 volts. This voltage is stepped up to 70,000 volts by means of three-phase transformers which are delta connected on the low-tension side and star connected on the high-tension side.

ONE LINE WIRING DIAGRAM OF GENERATING STATION—TRANSMISSION AND SUBSTATION

The bulk of this power is transmitted to Baltimore, Maryland, through three 70,000-volt 40-mile (64-km.) long transmission circuits. At the terminal station in Baltimore the voltage is stepped down from 60,000 volts to 13,200 volts by means of three-phase transformers, delta connected on the high-tension side and star connected on the low-tension side. This power is then distributed through a 13,000-volt underground cable system to a number of substations located in Baltimore.

A minor part of the power generated at Holtwood is transmitted at 70,000 volts to Lancaster, Pa., where the voltage is stepped down to 2200 volts through single phase transformers connected in open delta.

The accompanying one line wiring diagram and tabulations of the resistances and reactances of the various apparatus used in the generation and transmission of power will give an idea of the size and characteristics of the plant and transmission system.*

The transmission of power to Baltimore was started in the autumn of 1910 and to Lancaster in the autumn of 1913.

Both of these systems are run with the neutral grounded at the power house only. The Lancaster system has always been run grounded; the Baltimore system has been grounded all the time except for a short interval during the summer of 1911 when the grounds were temporarily disconnected to try out such method of operation.

Ungrounded connections did not seem to give any relief from lightning disturbances experienced during that summer and it was felt that when run ungrounded the possibility of the line being kept in service for any length of time, with one phase accidentally grounded and without the location and the character of the ground being known, there would be incurred danger to life and property along the transmission line and especially would nearby telephone service be exposed to damage. As in the case of *short circuits* on the transmission line, a very brief interval of arcing may suffice to cause great damage to conductors and insulators on account of the large generating capacity back of the trouble, and as the majority of the transmission line trouble has been short circuits and not single grounds, it has been thought better not to make any difference between these two cases, but to try to cut out the circuit immediately upon its becoming faulty and carry the voltage on a duplicate circuit, independent of whether the cause of the trouble was a short circuit or a single phase ground. It has been endeavored to arrange the relay apparatus so as to cut down as far as possible the number of seconds that a faulty line may be exposed to short circuits.

The Baltimore system, where there are three transmission lines, is normally operated so that certain groups of transformers are connected to each line in such a way that the high-voltage sides of the lines are entirely independent, while the low-tension sides of the transformers are all connected to the same bus; though to some extent separated by reactance coils.

For this system two transformers per circuit are grounded during the lightning season, whenever possible. The object of this arrangement is to obtain a heavier rush of current on that transmission line on which the spill-over occurs so as to operate special series relays used in connection with the Nicholson arc extinguisher which is installed on these lines. Tests indicate that there is no harmful interchange of current when the neutrals of two transformers in parallel are grounded, even when these transformers are of different capacity or made by different manufacturers.

*For further descriptive details of this plant and particularly the transmission lines see: (1) Engineering Data Relating to High Tension Transmission Systems, Sub-committee Report. A. I. E. E. PROCEEDINGS, October 1914. (2) Foundations for Transmission Line Towers and Erection of Towers, by J. A. Walls, A. I. E. E. PROCEEDINGS, June 1915. (3) Four Year's Operating Experience on a High Tension Transmission Line by A. Bang, A. I. E. E. PROCEEDINGS, July 1915.

Outside of the lightning season only one transformer per circuit is grounded as a matter of switching convenience.

On the Lancaster system only one transformer is normally used and consequently only one grounded.

At present the transformers are grounded through metallic resistances. The system was originally run dead grounded from the neutral point of one transformer per circuit. It was thought that the ground short-circuit currents produced thereby were too heavy, and that some of the early transformer breakdowns might have been due to this cause, so a resistance was inserted between transformer and neutral ground. From tests and calculations made later it would appear that even with the present reactance coils the current that one single dead grounded transformer can receive may be dangerous but that this would not be the case if several transformers of the same bank were grounded at the same time and that with all the transformers grounded at the same time, it would be quite possible to run safely without ground resistance. However, this latter arrangement has not yet been tried out as a practical operating condition on the high-tension transmission lines.

On the 13,000-volt cable system in Baltimore the arrangement of having all the transformers dead grounded has been adopted and been in service for the last year and a half apparently without causing any inconvenience. The reason why this system was adopted here instead of the former system where only one transformer was grounded through a resistance was to make certain of a sufficient current on a ground to trip the relays which on account of the desire to get selective action of the relays between various substations, are set for rather high tripping current. The condition of running entirely ungrounded on the cable system has never been tried but would hardly be of any great benefit, as most of the cable troubles apparently start between conductors and not as grounds.

The first resistance tried for the transformers at the power house were concrete blocks, which proved unreliable on account of lack of constancy in resistance and because they gave rise to arcing when voltage was built up on them.

Cast iron grid resistances were then substituted and have been satisfactory on the whole. The difficulties experienced with them are their limited heat capacity in the case of some ground hanging on unexpectedly long, and also on account of the occasional failure of the insulation between grids.

The ground connections used at the Holtwood power house are of different types. In the main they consist of:

- (a) Several copper plates buried in the mud in the forebay.
- (b) Twenty-four $1\frac{1}{2}$ -in. (38-mm.) galvanized iron pipes driven 9 ft. (2.7 m.) in the wet earth in the neighborhood of the first tower of the transmission line.
- (c) Several heavy castings lowered in the tail race (the connections to some of these latter were accidentally torn loose and have not been restored.
- (d) Besides the above artificial grounds an effort has been made to tie in all metal parts in the power house with the ground system and to tie in specially with such metal parts as are in direct connection with the river water, as for example, head gates and racks. The power house

grounds are furthermore tied in with the overhead ground wires on the transmission lines. All these connections are made solid and, therefore, do not easily lend themselves to regular tests; such tests are consequently not made, but occasionally inspections are made of the cables connecting with the ground plates, etc., to see that such connections have not been torn loose.

From time to time other tests have been made on the individual "ground" and some of the results are as follows:

1. Forebay ground consisting of four interconnected copper plates, 2 ft. 6 in. (82.2 cm.) by $3/32$ in. (2.38 mm.), buried in the mud, 0.04 ohms.

2. Large castings in the tail race (three in multiple) 4.4 ohms.

- (3) Individual tower grounds on the transmission line, stubs set in concrete but grounded by means of a paragon cone and measurements taken with the ground wire removed, 150 to 350 ohms.

- (4) Recent measurements taken between all the power house grounds connected in multiple, and a similar system of grounds at the substation 40 miles (64.3 km.) away, showed a combined resistance of about 2 ohms, though it is not possible to say how much of this is located at the power house and how much at the substation.

The current in the neutral is used to secure selective relay operation in the following way:

One or two of the transformers of each group supplying a transmission circuit have their neutrals grounded at the power house. The ground current from any transmission circuit will, therefore, pass through the neutral ground resistance of that circuit, and this ground current acts through a current transformer on a relay, which latter opens the low-tension switches of the transformers connected at the power house to that particular transmission circuit. This system, from the very start of the plant, has given satisfaction in respect to selective action on grounds and is considered as one of the main advantages of running the system with a grounded neutral. It is to be noted that the above relay action is quite distinct from the action obtained with the Nicholson arc extinguisher, the latter requiring a heavy ground current to energize its series relay, while the former does not require heavy current for the operation of its relay.

The current obtained when an accidental ground takes place on the line will naturally vary greatly, depending upon

- (a) The character of the ground, *i. e.*, whether it in itself contains appreciable ohmic resistance or not; but even if we consider that we are dealing only with "dead grounds" the amount of current will vary with the total amount of impedance in the circuit and will, therefore, depend on

- (b) The amount of resistance contained in the grid iron rheostat used in the neutral of the transformer;

- (c) The number of transformers grounded;

- (d) The generator capacity behind the ground;

- (e) The location of the ground, *i. e.*, whether near the substation or power house;

- (f) Furthermore the ground current will vary with time, being greater during the first few cycles and then gradually dying out, due to the de-

magnetizing of the generators and the heating of resistance grids, in the neutral.

In the following tabulation some results are given of calculations of the ground current as based on a number of oscillograms taken on the P. W. & P. Co's. system to determine the exact value of ground currents for different locations and conditions.

INITIAL RUSH OF CURRENT WHICH TAKES PLACE ON THE P. W. & P.
CO'S. SYSTEM WHEN A LINE IS GROUNDED.

BALTIMORE—HOLTWOOD CIRCUIT

Number of generators used	Number of transformers grounded	Location of ground	Initial ground current	Ohmic res. in neutral rheo. per transformer
3	2	At power house	656 amp.	58.4 ohms
		At sub-station	430 "	58.4 "
3	1	At power-house	380 "	58.4 "
		At sub-station	290 "	58.4 "
HOLTWOOD—LANCASTER LINE				
1	1	At power house	280 amp.	116 ohms

The accompanying sample oscillogram illustrates the characteristics of such a ground current.

"B" PHASE GROUND IN PINEY ISLAND—GEN 1 AND 2—TRANS. 1 AND 2
—GROUND STACKS 1 AND 2—VOLTAGE 10,500 VOLTS BEFORE TEST

The operating record for 1915 of the P. W. & P. Co's. system is given below, as far as single grounds are concerned without accompanying short circuits. It should be noted that in *all* cases the grounds were cleared without serious interference with the operation of the system and that none of them lasted more than four seconds. (Only in one case was a small part of the load lost and then only for a few minutes.)

NUMBER OF SINGLE WIRE GROUNDS ON THE HOLTWOOD-BALTIMORE
CIRCUITS, 1915, THEIR CAUSES AND THE METHODS BY WHICH
THEY WERE CLEARED.

	Cleared of itself with- out relay action	Cleared by arc extin- guisher	Cleared by inter- locking relay	Cleared by hand	Total
Lightning.....	1	4	1	0	6
Sleet.....	0	0	0	0	0
Birds.....	..	..	6	..	6
Insulator failure.....	0	0	0	0	0
Total.....	1	4	7	0	12

Grounded operation is preferred as enabling a faulty line to be cut out of service promptly so as to minimize damage to equipment or damage to property or life of outsiders, specially since a short period of operation ungrounded did not prove of benefit in reducing disturbances from lightnings pillovers. An advantage claimed for an ungrounded system is that it permits service to be continued in the event of failure of insulator on one conductor, but it is rare to have a sufficient number of suspension units on one insulator on a steel tower line damaged simultaneously to an extent to cause a permanent ground at that insulator, so that, as far as the circuits of the Pennsylvania Water and Power Company go, the advantage above claimed is of slight importance. The grounding of the neutrals should under certain conditions, result in subjecting the insulation of the high-tension circuit to a stress lower than that obtaining when running ungrounded. However, since the effort has been made on this company's lines to insulate rather against lightning than against generator voltage (insulation for 110,000 volts working pressure being in use on a circuit having a working voltage of but 70,000 volts) such lower stressing of the insulators has not been considered a factor of importance.

In short, grounded neutral operation facilitates certain protective relay operation, while the benefits to be derived from ungrounded operation in the sense of obtaining freedom from trouble from momentary flashovers on a transmission line, or being able to operate for a length of time with one conductor grounded, have not appeared worth while in practise.

The grounding of the neutral at the power house only, does not seem to influence telephone operation at all during normal operation. Whenever a ground occurs on the transmission line and the current therefore is flowing back through the soil to the station, very serious interference with telephone conversations will be observed, but this condition will as mentioned ordinarily not last for more than a few seconds.

Outside the lightning season, both high-tension grounds and short-circuits are cleared by overload relays and ground relays at the power house, and reverse current relays at the substation. During the lightning season the Nicholson arc extinguisher equipment is put in service and given the first chance to extinguish flashovers on the line. In case this apparatus and the relay arrangement described both fail to clear the trouble, the field is destroyed automatically on all the generators at the power house and brought back again after 1.5 seconds.

As to the chief causes of interruptions an idea will be had from the tabulation below, which gives a record for the year 1915 of all the disturbances on the Pennsylvania Water and Power Company's system as far as they had their origin on one of the three Baltimore circuits. This record includes both grounds and short circuits. The disturbances are divided into three groups, depending on the momentary loss of load resulting from them, *i. e.*, total interruption (T. I.), partial interruption (P. I.), and mere voltage or frequency disturbances (V. D.).

Operating record for the Holtwood-Baltimore transmission line:

Cause	T. I.	P. I.	V. D.	Total
Lightning.....	3	13	8	24
Defective insulators.....	..	1	..	1
Sleet on cables.....	..	..	2	2
Birds on line.....	..	..	8	8
Wires blown together.....	..	1	..	1
Defective cable clamp.....	1	..	..	1
Lineman's mistake.....	..	1	..	1

Only a current less than one ampere flows normally in the neutral connection. The frequency of this current is not known.

AVERAGE REACTANCE AND RESISTANCE OF BUS REACTANCE COILS
AND UNDERGROUND CABLES USED IN SHORT CIRCUIT CALCULATIONS

HOLTWOOD BUS REACTANCE COILS

	70,000 volt values		13,200 volt values	
	Reactance	Resistance	Reactance	Resistance
1 bus reactance coil...	21.5 ohm	.352 ohm	1.037 ohm	.017 ohm

HIGHLANDTOWN BUS REACTANCE COILS.

	70,000 volt values		13,200 volt values	
	Reactance	Resistance	Reactance	Resistance
1 bus reactance coil...	30.8 ohm	.381 ohm	1.49 ohm	.0184 ohm

HOLTWOOD-BALTIMORE—TRANSMISSION LINES

	70,000 volt values		13,200 volt values	
	Reactance	Resistance	Reactance	Resistance
1 transmission line...	13.1 ohm	12.1 ohm	6330 ohm	.5850 ohm

INDIVIDUAL REACTANCE AND RESISTANCE OF TRANSFORMERS
HOLTWOOD TRANSFORMERS

Operating No.	Office number	Serial number	Kw. rating	Per cent impedance	Per cent reactance	Per cent resistance (at 50°C)	Reactance in ohms phase H. T. (at 25 cycl.)	Resistance in ohms phase H. T. (at 50° C.)
1	102.	598555.	7,500	4.03	3.82	1.25	25.0	8.20
2	103.	598554.	7,500	5.14	5.00	1.20	32.7	7.83
3	108.	298572.	10,000	4.98	4.90	.99	24.0	4.85
4	109.	301699.	10,000	4.98	4.90	.99	24.0	4.85
5	107.	278098.	10,000	4.98	4.90	.99	24.0	4.85
6	105.	750832.	10,000	4.90	4.84	.84	23.7	4.12
7	106.	750833.	10,000	3.57	3.52	.72	17.3	3.52
8	110.	343227.	10,000	4.98	4.90	.95	24.0	4.85
9	111.	1198081	12,500	5.02	5.03	.77	19.6	3.02
10								
HIGHLANDTOWN SUBSTATION TRANSFORMERS.								
2	207.	360644.	12,500	5.32	5.23	.95	15.1	2.74
3	201.	237663.	10,000	4.94	4.79	1.21	17.2	4.33
4	202.	237664.	10,000	4.94	4.79	1.21	17.2	4.33
5	203.	237662.	10,000	4.94	4.79.	1.21	17.2	4.33
6	204.	237661.	10,000	4.94	4.79	1.21	17.2	4.33
7	205.	278093.	10,000	5.05	4.90	1.22	17.6	4.41
8	206.	324822.	10,000	5.05	4.90	1.22	17.6	4.41

REACTANCE AND RESISTANCE OF GENERATORS AND REACTANCE COILS AT HOLTWOOD

HOLTWOOD GENERATORS

Number	Kw.-rating	Reactance (at 25 cycles)				Resistance		Field current amps.	Averages		
		Starting value		Final value		at (50°C.)			H. T. reactance		H.T. resistance
		L. T.	H. T.	L. T.	H. T.	L. T.	H. T.		Start	Final	
1	10,000	1.32 Ω	53.4 Ω	5.67 Ω	229 Ω	.0651 Ω	2.63 Ω	275			
2	10,000	1.32 "	53.4 "	5.67 "	229 "	.0651 "	2.63 "	275			
3	7,500	1.21 "	48.9 "	5.67 "	229 "	.1075 "	4.35 "	275			
4	10,000	.84 "	33.9 "	4.53 "	183 "	.0646 "	2.62 "	275			
5	10,000	.84 "	33.9 "	4.53 "	183 "	.0649 "	2.62 "	275			
6	12,000	1.48 "	59.8 "	4.78 "	193 "	.0651 "	2.63 "	300			
7	12,000	1.48 "	59.8 "	4.78 "	193 "	.0585 "	2.36 "	300			
8	12,000	1.29 "	52.3 "	5.60 "	227 "	.0675 "	2.72 "	450	49.4	208	2.82

HOLTWOOD REACTANCE COILS

1	.670 Ω	27.1 Ω	.01479 Ω	.598 Ω		
2	.520 "	21.0 "	.01082 "	.437 "		
3	.520 "	21.0 "	.01082 "	.437 "		
4	.520 "	21.0 "	.01082 "	.437 "		
5	.525 "	21.2 "	.01432 "	.579 "		
6	.580 "	23.5 "	.01582 "	.640 "		
7	.833 "	33.7 "	.01495 "	.604 "		
8	.580 "	23.5 "	.01495 "	.604 "		
9	.465 "	18.8 "	.01405 "	.570 "	2.34	.545

*From Public Service Electric Company,
Mr. N. A. Carle, Chief Engineer.*

We distribute current at 13,200 volts, three-phase, 60 cycles, with the neutral not grounded. Several years ago, we contemplated grounding the neutral but decided at that time to install an arcing ground suppressor on the system. Since the arcing ground suppressor has been installed we have found that whenever a ground occurred, the surge suppressor would immediately make a dead ground on the phase that was in trouble and this would give the operator time to parallel another line or cable to take the bad one out of service.

The surge suppressor has never failed to operate in case the system became grounded on any one phase, and has, in several instances, in addition to protecting the system, saved employees from becoming electrocuted when they came in contact with the 13,200-volt wires.

We have found in many instances, that a line insulator may arc over, causing an instantaneous ground which is instantly stopped by the arcing ground suppressor cutting in. After taking out the suppressor and testing the line, we found in these cases that the ground had disappeared.

If a ground occurs on a 13,200-volt line paralleling a neighboring telephone wire, it causes a very slight disturbance, the extent of which depends upon the length of the paralleling circuits; the amount of current flowing, etc. In case a short-circuit and ground occurs at the same time, the ground suppressor going in would cause very serious telephone disturbances, depending upon the length of the paralleling circuits. In order to remedy any trouble that might arise from this source, we installed in the operating station in which the ground suppressor is installed, instantaneous circuit opening relays on each generator, so that in case a short circuit occurs on any feeder, the arcing ground suppressor cannot operate.

In my opinion it does not pay to ground the neutral of a transmission system unless the voltage is moderately high, say for aerial systems above 60,000 volts, and for cable systems, above 22,000-volts. It is not so very difficult to insulate cables for 22,000 volts, and it is not particularly hard to get line insulation that will stand up satisfactorily under 60,000 volts. The highest voltage under which we are operating at the present time is 13,200 volts.

We have had no experience in grounding the neutral but it would seem to me that the proper place to ground it is in the generating station, and that resistances should be used so as to limit the current to an amount great enough to insure the operation of the relays in case of trouble.

Our 13,200-volt transmission system in this state is shown herewith.

The surge suppressor is installed in our Marion Station, which is our largest generating station. We also have surge suppressors installed in our Perth Amboy and Burlington stations.

The charging current for the feeders connected to our Marion station, which takes in what is known as the Northern Division, is approximately 75 amperes.

We have five per cent 13,200-volt feeder reactors installed on all 60-cycle feeders from Marion and Essex stations, with the exception that the tie feeders between our City Dock and Marion stations, and between

TRANSMISSION SYSTEM OF PUBLIC SERVICE ELECTRIC COMPANY WITH PEAK LOADS FOR WINTER OF 1914-1915.

our Essex and Marion stations, have 2.5 per cent feeder reactances at each end, making a total of 5 per cent between the generating stations.

Between our City Dock and Marion stations, we have seven three-conductor 13,200-volt tie feeders. At each end of these feeders we have a seven-section selective relay which cuts out the bad cables in case any trouble occurs between these two stations. On all other feeders we use standard makes of circuit-closing inverse time limit relays.

When a ground or short circuit occurs on a cable or aerial line, a test is made for location as soon as possible. If the ground or short circuit is of such high resistance that a good test cannot be made, the resistance of the fault is decreased either by further breakdown from testing transformer, or by reduction with 600-volt direct current. The location is then made by means of a slide-wire bridge using the loop method. The chief causes are mechanical injury to the cable, defective joints, water in the cable (probably caused by a previous breakdown somewhere near this same location) and high-voltage disturbances, cause unknown.

From Pacific Light and Power Corporation,

Mr. H. A. Barre, Elec. and Mech. Engineer.

The arrangement of the high-tension distribution has been such that it has been possible to operate alternately with the grounded neutral system and the ungrounded delta system. The experience with the ungrounded delta system has been so disagreeable that we have made up our minds that under our conditions a grounded neutral system is essential.

The determining conditions seem to be the number of miles of line and the capacity of apparatus connected to the system.

The business of this company consists of supplying power to the company's commercial distribution, which covers all classes of load and includes some 15,000-volt underground cable; and of furnishing service to two large railroad companies, each of which has a maximum demand of about 25,000 kw. The total system peak load for the past years has been 76,000 kw. at the generating stations.

The 150,000-volt, 240-mile (386-km.) line from Big Creek is served through delta-star connected transformers at the generator end, with the neutral of the high-tension side grounded, and delivers power through delta-delta connected transformers at the receiving station. One-half of these latter lowering transformers have a secondary voltage of 15,000 volts. The remainder have a secondary voltage of 60,000 volts. The reason for this arrangement is that the base of the company's distributing system is a very extensive 15,000-volt network. The close-in parts of this net work receive power from the substation directly at 15,000 volts. The remote parts are fed with 60,000-volt feeders.

The 15,000-volt network, including the lines of the two railroad companies, embrace about 1600 miles (2574 km.) of line. The 60,000-volt system at the present time has about 85 miles (136 km.) of line.

Connected to the 60,000 volt system through compensators are about 300 miles (482 km.) of 50,000-volt line. Fed from this line are about 45 miles (72 km.) of 10,000-volt lines, and 45 miles (72 km.) of 15,000-volt lines, which are not otherwise connected to the net work. These 10,000-volt and 15,000-volt lines were not connected during the time of trouble with the ungrounded delta system which is described later.

On account of the fact that it was desirable to make the lowering transformers of the Big Creek system of the same design for both voltages so that they could be connected in series for 60,000 volts or in parallel for 15,000 volts, the 60-kv. and 15-kv. systems are in phase, hence they require delta-delta transformations at the remote points where the 60,000-

TRANSMISSION LINES OF PACIFIC LIGHT AND POWER CORPORATION

volt feeders deliver to the 15,000-volt network. This precluded the possibility of a grounded star connection at the latter points of transformation.

Previous to the advent of Big Creek, the 15,000-volt system had been fed from a 40,000-kw. steam turbine plant of which the neutral was

grounded. After Big Creek commenced service, this steam plant was needed only in emergencies and the opportunity for establishing the ground through it was lost except during such hours as it might be operated. This left the 15,000-volt network without an established neutral, and it was found that whenever any trouble occurred which involved the accidental grounding of a 15,000-volt wire, the flow of charging current was sufficient to set up very serious surges in the system. These invariably caused breakdowns at more than one point on the system, sometimes three or four points, and the damage to the service and apparatus became a matter of most serious concern. These breakdowns were usually flash-overs or punctures of transformers and switch bushings or line insulators.

It happened that while this condition existed, a new station was being built at Vernon, in which were being installed, amongst other things, a bank of three 5000-kw. transformers with a voltage ratio from 60,000 to 15,000. As an experiment, the 15,000-volt side of this bank of transformers was connected in star with the neutral point grounded, and the bank connected to the 15,000-volt bus bars. The 60,000-volt side was delta connected, and being, therefore, out of phase with the 60,000-volt bus bar, was left idle; in other words, an idle bank of transformers having closed delta secondary was used to establish the grounded neutral on the 15,000-volt system. This bank had a very large capacity, full load being something like 600 amperes.

It was found that this effectively eliminated the surges and that after its installation whenever line trouble occurred the effects were localized in the section affected, and in practically every case the system of operation employed to sectionalize the net work, both automatically and manually, has served to protect the service. Some troubles have occurred on the 60,000-volt system, but since there is a ground established to it by connections to another plant, they do not at the present time appear serious.

My personal opinion is that this is largely due to the fact that the 60-kv. system is of comparatively small extent and when it grows, a system of connections to establish a grounded neutral of large current carrying capacity will be an absolute necessity.

My general opinion is that power stations and other sources of supply should always be operated on a grounded neutral connection having the generator side delta connected. The delta-delta system is preferable for receiving stations and distributing substations.

We have not found the installation of resistance in the neutral of any advantage. My opinion is that the difficulty of making a good ground answers the resistance question.

On the 150,000-volt Big Creek lines, accidental grounds are handled as follows:

When the operator at the power house sees the recording ground ammeter showing a ground, he reduces the generator field by cutting in a special rheostat installed for this purpose. As soon as the ground ammeter drops back to zero he cuts out the resistance and the voltage comes back to normal, and the automatic voltage regulator takes control. This resistance is not cut out all at once, but the time which elapses from the time the arc breaks until normal voltage is restored, is from five to ten seconds.

At the receiving station at Eagle Rock the operator kills the field of condensers at once by opening the circuit of the automatic voltage regulator. As soon as he sees that the power house has overcome the trouble and the voltage is coming up again, he closes the regulator circuit.

Governors at the power house must take care of the speed when the load is dropped. They always do this.

For the remainder of the system on those lines which are controlled by automatic circuit breakers, the switches are closed after opening of trouble, and if the short circuit or ground is still on the line, the switch is left open and men sent out to find the trouble. Where the switches are not automatic, the above operations are performed manually.

On the 150,000-volt system from Big Creek, the troubles are entirely of two kinds:

First, the personal element, of which three cases have occurred:

(a) Where a man digging a well put in too heavy a charge of powder and blew some debris into the line.

(b) A tree was left standing too close to the line and in felling it, caused a ground.

(c) A farmer drove a hay stacker with derrick erected at a height of some 36 ft. (10.9 m.) above the ground into contact with the line.

Second, the other and more frequent cause of trouble, of which some twelve or fifteen cases occur each year, is the spilling over of insulators in the middle half of the line. We have not been able to determine the cause of these spillovers or locate any operating or climatic coincidents which would indicate their origin. They seem to occur at all hours of the day and night and under all weather conditions, but are absent from the end quarters of the line.

Outside of the 150,000-volt system, the greater number of troubles occur from personal interference, either accidental or malicious, of both employees and outsiders.

On a system containing so many miles of lines and nearly 100 substations, the opportunities for misunderstandings and mistakes are many. This is intensified by the fact that the operation of the lines and substations are under the control of three entirely independent corporations.

Another cause of trouble is the usual one of washing out of lines during floods and similar accidents, depending on the weather.

A considerable number of interruptions have occurred by reason of the continued failure of a certain class of pin-type insulators on the 50,000-volt lines, which have been in operation about ten years. There seems to be a continuous depreciation or weakening of these insulators, which becomes noticeable, in those parts of the line where the weather conditions are most severe.

The suspension insulators used on some of the distributing lines have caused a number of failures, although careful inspection of the Big Creek line has so far been successful in eliminating the defective insulators in time to prevent trouble.

The only other serious cause of interruption is the combination of summer fog and dust, causing surface leakage over the insulator, which carries sufficient current to set the pole on fire. In the last few years, interruptions from this cause have been practically eliminated by the expedient of electrically connecting the insulator pins, which are of iron.

No complete detailed analysis of these various kinds of trouble has been made, so that I am not able to give you more than the above generalization.

*From Mt. Whitney Power and Electric Company,
Mr. Fred G. Hamilton, Supt. W. Div.*

This company is operating practically 200 miles of 33,000-volt transmission lines. The lines are arranged in the form of a figure eight and are fed by four hydroelectric and two steam plants.

TRANSMISSION LINES OF MT. WHITNEY POWER AND ELECTRIC CO.

The neutral is grounded on each hydroelectric plant, but there is no ground at the steam plants or any of the substations.

The elevation of the hydroelectric plants is practically 1150 ft. (350 m.) while the substations are located at an elevation of 350 ft. (106 m.)

It has always been our method of operation and we have no data upon non-grounded operation. We have experienced no particular difficulties particularly chargeable to the grounded system. We have had grounds

and short circuits on the transmission line which we cleared up by cutting out the faulty section, by trial, between the substations. The switching is controlled by a load dispatcher at the Visalia steam plant.

This system gives us very efficient service and the worst cases of interruptions are only of short duration. Since our voltage is comparatively low and we have had no experience on non-grounded operation, we are not in a position to give comparative data, which would be of much assistance. For our voltage we feel that non-grounded lines would probably give us as good service as our grounded system.

*From The Toronto Power Company,
Mr. F. G. Clark, Chief Engineer.*

The question of grounded or ungrounded neutral can be considered from different points of view.

Where drainage of accumulated electrostatic charges is required to avoid excessive d-c. potential, grounding is very effective as it will drain off all such charges to earth, while on ungrounded systems this will have to be taken care of by the lightning arresters. This phenomena is very unusual in the northern part of this continent, and is usually safely taken care of by the lightning arresters.

Continuity of service can be preserved by either one of the two systems depending entirely on local conditions.

Grounding should be applied:

Where a reliable selective relay protection is available cutting out a faulty line without causing a service interruption.

Where the lines have to be operated in parallel on the high-tension side and where the line insulation is unreliable.

In this case grounding will prevent the spreading of a breakdown on one phase of one line to other phases of another line thus avoiding a long total interruption.

Where this high insulation exists so that other phases can stand momentary over-voltage due to one phase flashing to ground or where the lines can be operated sectionalized from the high-tension side, the spreading of a fault from one line to another due to the momentary voltage rise on the sound phases as occurs on an insulated system, is not to be feared. Accordingly nothing can be gained from grounding in this case. On the contrary, grounding may cause unnecessary disturbances and interruptions, whenever one phase only is affected which would be particularly detrimental to continuity of service where no reliable selective relay protection available.

The decision on the question of solid or resistance grounds should be guided by the line insulation and by the ability of the apparatus to withstand short circuit strains. Where low and unreliable insulation on the line is the prime object of grounding and where the equipment is built to resist effectively any short circuit strains, solid grounds should be used.

Where, however, the insulation is high and reliable and where the equipment may be somewhat mechanically weak, a ground resistance will be desirable to reduce the mechanical strain of single phase short circuits.

I would further advise that our transmission system from Niagara Falls to Toronto is composed of four circuits operating ungrounded at 60,000 volts. The transformers on either end are delta connected.

*From Puget Sound Traction, Light and Power Company,
Mr. G. E. Quiman, Engineer, Seattle Division.*

The four hundred odd miles of high-tension transmission lines of this company are delta connected and operated without grounds.

It is our opinion that probably the chief advantage of grounding the neutral of a high-tension transmission system, is that it eliminates most of the trouble experienced on an isolated system from arcing grounds. The principal disadvantage of grounding is that line trouble more frequently results in interruptions to service. It is our experience that the insulating qualities of wood poles and cross arms make it possible to retain a line in service until the defective point is located and frequently until arrangements can be made to take the line out for repairs.

Even insulator failures resulting from arcing grounds seldom cause serious service interruptions where the lines are carried on wood poles.

We are inclined to believe that where all important business is served from duplicate transmission lines, the grounded system is preferable, but where single lines have to be depended upon the isolated system makes possible greater continuity of service.

*From The Colorado Power Company,
Mr. Norman Read, Asst. General Manager.*

The Colorado Power Company is at present operating both its 100 kv. transmission and 13 kv. distribution systems connected in delta and with no artificial neutral.

*From The Montana Power Company,
Mr. H. H. Cochran.*

This company operates ungrounded, and believes this method preferable. Telephone operation is very satisfactory.

The typical protection for two transmission lines in parallel consists of three pole overload relays at the generating station end of the line, operated by three current transformers in each line, and three-pole reverse current relays operated by three current transformers and potential transformers in each line. The system has sufficient line charging current to trip relays when one wire of the system is grounded.

*From Utah Power and Light Company,
Mr. Markham Cheever, Chief Engineer.*

From our principal generating stations power is transmitted at 130,000 volts to a central substation near Salt Lake City. At this substation the voltage is reduced to 44,000, and numerous feeders make connection with an extensive and complicated network of 44,000-volt lines. Everything is now operated with neutral ungrounded and we see no reason for changing the 130,000-volt system, since up to the present time there have been during two year's operation, practically no operating difficulties.

Upon the 44,000-volt system we are considering the installation of a suitable grounding compensator located at the main central substation for the purpose of facilitating automatic sectionalizing of disabled lines and for the reduction of high-voltage strains.

Our earlier experience in this territory with 44,000-volt systems of moderate sizes indicated the advisability of operating with neutral un-

grounded, since there were many cases of grounds which would clear themselves without disturbing service and some cases of dead grounds which permitted the continuance of operation until repair could be made. During the winter of 1912 and 1913 a number of systems were paralleled and since that time many extensions have been made. With the enlarged system we are finding that practically all cases of grounds develop into serious trouble and it is often difficult to localize the disturbance.

From the Chicago and Interurban Traction Company,

Mr. Robert J. Bell, E. E.

We have a 33,000-volt three-phase 25-cycle transmission line, extending from the Public Service Co. power plant at Blue Island, to Bradley

BRADLEY SUB-STATIONS TRANSFORMERS 1950-430 VOLTS. POWER HOUSE TRANSFORMERS 9000-33000 VOLTS

Ill., a distance of about 45 miles (13.7 km.) This line consists of three No. 4 hard drawn copper wires placed on 35-ft. (10.6-m.) cedar poles spaced 110 ft. (33.5 m.) apart.

We have three substations on this line with one 500-kw. synchronous converter in each of these stations. The Bradley substation has, in addition to the converter, a 500-kw. frequency changer, 25-cycles to 60 cycles.

Our transformers are Y-connected on the primary in all the substations. At the power plant they are Y-connected on the secondary side.

We have a telephone line on the same poles, but do not experience any serious trouble. There is some noise but not enough to interfere with service. This line is transposed at every fifth pole. The neutral connection at the transformers is grounded, and we have not experienced any trouble therefrom. We have experienced one great advantage by grounding the neutral, that is, in case of line trouble, where one of the phase wires becomes grounded, we are able to test out and find what phase it is, then have the disconnecting switches pulled out on this phase at each end. We are then able to operate on the remaining two wires by the use of the grounded neutral.

This system has saved us a great number of hours of shut-downs and we have had no trouble caused by this system of operation.

As to the advisability of grounding the neutral, while it may not work successfully on all systems, I think it worth while to try it out, especially if the transformers are not loaded too heavy.

We operate grounded at the substations and at the power plant.

We lost some insulators during electrical storms (which having the neutral grounded may encourage). All our trouble has been from direct lightning strokes.

It makes our telephone line a little noisier when we are working on two line wires than otherwise.

A general layout of the line with the transformer connections is shown herewith. We have an overload relay on our oil switch which is set to trip out on normal overload, and we make use of the current to ground when we are using two line wires.

These grounds are cleared by linemen sent over the circuit. The causes are various, but very frequently can be traced to a broken insulator. I think no current flows to ground through the ground connection but have never made any test to that effect.

From Alabama Power Company,

Mr. W. E. Mitchell, Operating Manager.

Our experience here in Alabama has caused us to become firm advocates of the grounded neutral on our high-tension system, and grounded solidly without any resistance whatever. This is based on about nine months of operation with it ungrounded and a year's operation with it grounded. This matter is discussed somewhat briefly by Mr. Dewey and myself in a paper which we read before the S. E. Section of the N.E.L. A. in September of this year. We found that our insulator troubles in the way of breakdowns and flash-overs were much worse and much harder to locate and control when ungrounded than when grounded. Grounded neutrals also made it possible to use the selective relays for cutting out immediately any section of line which might be in trouble. The grounding of the neutral turns any arcing ground immediately into a phase-to-neutral short circuit, which is much simpler to handle and to relay for than an arcing ground on an ungrounded system.

From The J. G. White Engineering Corporation,

Mr. C. D. Gray, Asst. Electrical Engineer.

My personal opinion is that systems up to about 38,000 volts should be operated with isolated delta connections, although this depends upon the local conditions under which the system under discussion might be connected. For systems above 38,000 volts I believe the star connection with grounded neutral to be the best, although in this case also the local conditions would influence a decision as to whether it should be star or delta. The locality in which the line is to be operated I believe has a great deal to do with it, and also the chances of interference with telephone telegraph and other systems of this kind.

Our experience has been that the delta system has less influence on telephone and signal circuits than the grounded neutral connected system. A great disadvantage of the star-connected grounded neutral system is the fact that the circuit breakers are thrown out on trouble on any one of the three wires of the system, and that it is practically impossible to operate with one wire down, or with one transformer out of service in a bank of three, unless the conditions of grounding are very favorable, where as with the delta system the open delta connections of transformers can be used temporarily at least without causing a great deal of trouble.

Another point in favor of the star-connected grounded neutral system is the fact that trouble on the line can be located better by means of the Nicholson or other similar testing method. The line insulation has been

so improved in the last few years that it is now possible to operate delta connected whereas previously it was not possible on account of the insulators, it being necessary to reduce the potential to ground in order to favor the insulators.

With regard to the operation of three-phase systems, I agree very well with the paper of Messrs. Jollyman, Downing and Baum, given before the Institute on May 29, 1914. This would be especially true with any system operated with pin-type insulators similar to that of the Pacific Gas and Electric Co.'s. system.

In conclusion I would say that I am not greatly in favor of one system over the other, but that the local conditions would largely influence a decision in the matter, and it seems to me that it is more a matter of experience from operation in any particular section of the country rather than the result of theoretical decision.

*From Mr. Charles E. Waddell,
Consulting Electrical Engineer.*

The two high-tension systems with which I am most familiar do not ground the high-tension neutrals: these systems are the North Carolina Electric Power Company, which serves Western North Carolina and which operates at 66,000 volts and 6600 volts, and the Florida Power Company which serves the west coast of Florida in the mining district and which operates at 60,000 volts.

My inclination, which is tending toward a fixed opinion, is that it is possibly wise to ground the secondary system of small substations supplying consumers regardless of the secondary voltage, be it even as high as 2000, the object being the protection of life and property. On the other hand I am forced to conclude,—certainly for this vicinity,—the grounding of the neutral of high-tension transformers at the tie-in substations would be a menace rather than a protection. As you are fully aware, the recent general practise is to ground the secondaries of the instrument transformers used in connection with the switchboards. While this has proved a great protection as far as life is concerned, I have found that the practise has increased the number of burnouts and really interferes with continuous service.

A considerable number of additional replies were received which contained no information of special interest.

An examination of the above replies emphasizes what is perhaps the proper point of view on this subject, namely, the effect of grounding the neutral of a high tension system will be different in different sorts of systems, it may be an advantage in some and a disadvantage in others. Furthermore the effect of grounding through a resistance is different from the effects of grounding directly. Each case must be considered on its merits and most of the probable cases are illustrated by the above replies.

The neutral may be grounded in different plants for various reasons:

(a) To prevent throwing full line potential on other line wires by a ground on one line.

(b) To enable relays to operate quickly and surely or selectively.

(c) To prevent arcing grounds.

(d) To locate breakdowns.

(e) To take the place of one line wire on a three phase system when this wire may be interrupted. This requires the disconnection of the grounded wire.

(f) To enable grounds to be extinguished by the Nicholson automatic system of grounding through a fuse.

When the ground connection is specifically omitted it is usually to enable operation with one line grounded and thus minimize interruptions.

Actual practise shows that grounding is more often resorted to on high voltage, and in large and complicated systems. Wooden pole-wooden crossarm lines below 60,000 volts offer the best chance of operating successfully with one line grounded.

In conclusion attention is called to the very full and illuminating reports of several of the companies sending replies. The thanks of the Committee is due to these and the others who have cooperated with the Committee in collecting the data reported.