DISCUSSION ON "SINGLE-PHASE *versus* THREE-PHASE GENERATION FOR SINGLE-PHASE RAILWAYS", AT NIAGARA FALLS, N. Y., JUNE 27, 1907

P. M. Lincoln: I agree with the author of this paper, that it is highly desirable to keep power service and street railway service separate if it is at all possible. However, at times commercial considerations may make it essential to supply both polyphase power service and single-phase railway service from the same generating station. When that is necessary, the author of this paper has pointed out several methods by which it may be accomplished. There is one modification, however, which he has not mentioned, but which I believe has considerable advantage over any of the methods mentioned by the author.

The ordinary three-phase system may be represented by an equilateral triangle, in which the three sides of the triangle will

FIG. 1

be the voltages of each of the three phases, as in (a), Fig. 1. When we put a single-phase load on one of the legs, this triangle becomes distorted, affecting both the relative lengths and phase relations of the three phases. It assumes a form something like (b), Fig. 1, so that the three-phase triangle is considerably distorted from its original shape. When it is necessary to supply both single-phase and three-phase from the same generating system, we can give the three-phase voltage an initial distortion so that a true three-phase relation shall lie somewhere between the initial distortion selected and final distortion which may be expected due to the single-phase load. By this means the maximum unbalancing that can take place in the three-phase circuit is approximately one-half what it would be if we started with a balanced three-phase. Fig. 1, (c) shows roughly in diagram the condition that might be expected. At best the effect on the three-phase circuit is anything but good.

Therefore, I do not feel like recommending any method or any system where a single-phase railway and a general power distribution are drawn from the same generating system; but, as I

have already said, commercial considerations sometimes make it necessary to consider such a system.

Henry G. Stott: One other method, not mentioned in the author's paper, might be brought up for discussion; that is, the method of using the grounded neutral on the three-phase system. Where power is required for general purposes, as well as for single-phase railroad work, this method might be applicable, as, by the use of partly loaded induction motors in different parts of the line, the balance of the phases and also of the voltages would be restored. This makes an extremely simple combination where general three-phase power, as well as single-phase operation, is required.

V. Karapetoff: It seems to me that where difficulties should arise, on account of unbalancing, in cases where single-phase and three-phase lines are fed from the same generators, we would have to regulate the three-phase system by means of induction regulators. It is not necessary to regulate the three legs; only one phase needs to be regulated. The triangle of voltages is originally an equilateral triangle; then it becomes a distorted triangle. It is plain that this latter triangle can be made again an equilateral triangle by moving in a certain direction *one* of the phases, by having in the three-phase system a suitable induction regulator in one leg, so arranged that a vector of any desired direction or magnitude can be added to the line voltage. Therefore, the problem of regulation is not as difficult as it might seem at the first glance.

John B. Taylor: I fail to see how a single-phase induction regulator can be practically applied to a three-phase system in such a way as to compensate for the unbalancing effects of a single-phase load. More important than the drop in voltage due to line resistance, etc., is the distortion due to the reaction in the generator under single-phase load conditions.

All things considered, there will be many cases where the expense of the motor-generator set will be justified. This enables the transmission system to work on balanced three-phase load, at unity power-factor, and also removes the grounds from the transmission system. Where the single-phase load is taken as a part of a large system, unless transformers or motor-generators are introduced, a ground on the single-phase system involves, of course, a ground on the entire system and this in many cases would be decidedly objectionable.

William McClellan: The paper has reference to large systems giving opportunity for sectionalized distribution. So far, single-phase electrification has been over short distances with not more than two sections to be fed. Such a system presents little difficulty where a company is generating its own power. While from a technical standpoint the unbalancing may be inconvenient, it does not affect the coal-pile seriously. When, however, power is bought from a power company and taken from three-phase transmission lines, the effect is more serious. Under

modern contracts for power, unbalancing over a certain maximum amount, must be paid for. Under such conditions it is possible to connect the transformers in V which, however, would never give a balanced three-phase load. A better method is to connect the transformers in T and use the 90° phases on the two sections of the trolley. When these two sections are equally loaded, the three-phase load will be balanced and the average balancing of the load will be considerably better. Such a system requires, however, that the three legs at the high-tension side of the transformers be opened nearly simultaneously.

Chas. P. Steinmetz: The problem of taking care of single-phase loads on three-phase systems is rather complicated. I do not believe any induction regulator can take care of it to the extent of balancing the load. The cause of the unbalancing on single-phase load is to be found in the flow of power which with single-phase load is not constant, as it is with the balanced three-phase system, but pulsating. This pulsating flow of power gives a pulsating armature reaction; superimposed upon the fundamental sine wave of the generator it produces the effect of a double frequency pulsation or magnetism due to the pulsation of the flow of power. This results in the production of a strong third harmonic. In some conditions, in extreme cases where the single-phase load is short-circuited, this triple harmonic may reach disastrous values, 250 per cent. of the normal voltage, or even more. This is merely the extreme case of unbalancing.

To restore the equilateral triangle by giving it an initial distortion is open to the objection that the distortion of the triangle is not always the same but depends on the nature and the power-factor of the load. If the power-factor of the load is approximately constant, within a moderate range, as with single-phase railroading, this can be done. But, after all, with any generator of reasonably good regulation, the matter usually is not serious because an induction motor can take care of a very great distortion of the equilateral triangle and still work with no appreciable change in efficiency, no appreciable change of heating. In most cases then we can let the triangle become as distorted as it chooses, and the induction motors and other apparatus will show no difference, except perhaps synchronous converters. Synchronous converters in such systems would necessarily be installed, as they usually are in railway work, with heavy reactances, reactances of ten per cent. or more in the leads. This reactance, by phase displacement of lead or lag, can take care, not only of line drop and control of voltage, but also of distortion of the triangle, and thus supply at the converter the equilateral triangle with a greatly distorted generator triangle, by merely a small change in the angle of lag of the three different phases, one of the three currents lagging perhaps while the other is leading to a small extent. So the converter can also take care of itself.

The main difficulty is where lighting is done from several phases. But even there, if we look at the distortion of the tri-

angle with single-phase load, we find that naturally the loaded phase drops with the ordinary single-phase load. Of the other two phases, one drops more than the loaded phase and the other remains practically constant; that is, of the two unloaded phases the distortion is such as to keep one of the phases almost constant and in that phase through a potential regulator which has relatively little work to do, constant potential may be supplied. That is probably the simplest way of taking care of unbalanced loads. My old scheme, the monocyclic system, was to build the generator three-phase; use one phase for lighting and maintain it at constant voltage, and carry the three-phase load by the auxiliary phases. After all, that was another form of Mr. Lincoln's proposition to start with a distorted three-phase system and use the distortion to distribute the load between the different circuits in the desired manner.

A. H. Armstrong: I am inclined to look at this matter a little more broadly than some of the previous speakers. For instance, the method proposed by Mr. Lincoln can be used successfully in cases where the railway company generates its own power, although in such cases the company would have the privilege of generating and distributing single-phase power, and the simplicity of single-phase distribution would recommend it above all others. We are confronted, however, with the problem of power purchased from foreign concerns, and the tendency of the times seems to be toward establishing large centers of power distribution. The generation and distribution of power is carried on as a separate business by itself. It may be associated with lighting, railway, and power industries, but in any case it is generated and distributed three phase. It is a very difficult problem to connect single-phase railway systems to a three-phase power distribution system without interfering in some degree with other uses of a common power supply. In fact, managers of power distribution systems are very loathe to make contracts which involve the use of single-phase power for railway purposes. In such cases the introduction of a motor-generator set seems almost necessary, aside from the question of frequency supply, if the distribution circuit of the power producers is to be properly safeguarded.

Unfortunately, in a large number of single-phase projects suggested, the margin of profit between installing alternating-current apparatus and direct-current apparatus is rather small. Owing to the inferiority of the alternating-current railway motor, there is no advantage in adopting alternating-current car equipments unless there is a considerable reduction either in first cost or operating expense, or both. The added expense of motor-generator sets oftentimes acts as a serious handicap when considering the installation of alternating current railway equipments fed from a foreign three-phase source of supply. In such cases it will be necessary to use some of the methods proposed for balancing the load on the three phases rather than consider the expense of a motor-generator set.