DISCUSSION ON "THE CHOICE OF FREQUENCY FOR SINGLE-PHASE, ALTERNATING-CURRENT RAILWAY MOTORS", AND "TWENTY-FIVE *versus* FIFTEEN CYCLES FOR HEAVY RAILWAYS", AT NIAGARA FALLS, N. Y., JUNE 27, 1907

H. G. Reist: With engine-driven generators the problem is a comparatively simple one, since not much difficulty is experienced in building machines for 15 cycles. The cost of the generators will be increased somewhat, perhaps 30 per cent. With turbine-driven generators the increased difficulty is very much more serious. As has been pointed out by one of the speakers, in smaller size generators, about 2000 kw. capacity, the increase of steam consumption on account of the limit in speed becomes serious, and undoubtedly there will be many places where generators of that size, or smaller, will be needed for long distance railway work. On larger sizes, the speed is more favorable for the turbine, but the generators have to be built with two poles only, which makes it a difficult designing problem. The machine becomes massive, the magnetic circuits become exceedingly long, and the weight of the machine must be greatly increased over that of the 25-cycle machine. Roughly, probably the weight and the cost would be increased fifty per cent. over a similar 25-cycle machine. The efficiency would also be a little less, although that is probably not a very serious matter; it might be one per cent. less at full load than with the higher frequencies.

C. W. Stone: If the design of turbine-driven generators is to be complicated by a combination of lower frequencies and single-phase operation, the generator becomes almost prohibitive unless 450 revolutions instead of 900 are used on the large capacity machines. On machines of 8,000 or 10,000 kw. capacity, 450 revolutions is very bad from the steam end. All the recent 25-cycle machines of large capacity have been run at approximately 750 revolutions. To increase the speed from 750 to 900 rev. per min. and make the generator both single-phase and 15 cycle is not to be considered.

E. J. Berg: While I do not believe that it will be necessary to resort to a frequency lower than 25 cycles, I think that some of the objections raised against the lower frequency are not well taken. A so-called half-frequency generator was invented several years ago, a generator with a given number of poles giving half the frequency of the regular generator operated at the same rotative speed. In construction, this generator was similar to the induction motor; in its action, to the well-known frequency-changer. Instead of exciting the field by direct current, alternating current of a given frequency was used, and the magnetic field made to rotate in the same direction as the armature but at half its speed. By this scheme, the frequency corresponding to one-half the speed could be obtained, not only from the stationary, but from the revolving member. Obviously, the excit-

ing current had to be delivered at the lower frequency, but this was not objectionable, as the actual power supplied was slight and therefore the inefficiency of the low-speed turbine of little consequence.

L. B. Stillwell: I am much pleased to find a question of such transcendent importance as this, of the best frequency for railway work, receiving the serious consideration of the engineers of our manufacturing companies.

The electric railway fraternity now for the first time is undertaking the electrification of railways operating heavy traffic and employing steam locomotives. This work presents a problem more important commercially than any we have hitherto attacked. We are dealing with people who are not of the type that we had to deal with in the early days of electric lighting. The railways of the United States are managed by men whose education in most instances is largely an engineering education. They have their own excellently prepared and thoroughly experienced engineering staffs who will pass upon these questions. Therefore, it is of especial importance in considering such questions as this, that we should take a broad view, saving money for our clients by fighting out differences of opinion on paper and on the floors of these conventions, and, if possible, agreeing among ourselves upon all necessary fundamental standards.

The paper which Mr. Putnam and I had the honor to present before the Institute in January last, raised this question of frequency in railway service. Our feeling was that a mistake in all probability was being made. The figures which we worked out were intentionally broad, probably broader in application than any we shall see in our time, but it seemed advisable to look at the entire railway field and attempt to realize the magnitude of this problem. We therefore followed out our analysis of the comparative costs of operation, by figures showing the total cost of electrifying the railways of the United States. Some of the technical journals, whose specialty is steam railway practice, have ridiculed the idea of considering even the possibility of the electrification of all the steam railways in the United States. Probably no one here expects that this will be done in the near future, if ever; but it is significant to find that if we consider the average railway in the United States upon which there are but seven trains in each direction per day and apply to its operation single-phase alternating current, using a transmission voltage equal to that which is to-day in use transmitting power from Niagara Falls to Rochester and Syracuse, it would be possible to save approximately 18% of the present operating costs. This conclusion has not been assailed in respect to anything that is material. Even if we admit every exception to our total figures which was noted in the discussion, we still have a saving of at least 15%. This is a very important and a surprising fact. It indicates not that all of the railways

in the United States will be electrified in the next ten years, but it does indicate strong probability of a more rapid extension of the application of electricity to the operation of trunk-line systems than has been generally realized, even by electrical engineers.

In calculating the reduction in operating costs, it is hardly necessary to say that we recognize also what several of our critics have kindly pointed out; namely, that the principal object in view, when the management of a railway decides to electrify its lines, is not reduction of operating expenses but increase of earning power. This fact is well known and has been referred to in many previous papers and discussions. The two reasons undoubtedly constitute an argument operating powerfully to induce railway electrification. The point which I wish to emphasize is that this electrification is in all probability coming at a rate which greatly emphasizes the importance of early standardization of everything essential to interchange of traffic.

A recent bulletin of the Census Bureau of the United States, prepared by Mr. Martin, shows that from 1900 to 1905 the products of companies manufacturing electric apparatus were more than doubled. In the year 1900 few would have dared to predict such an increase.

When we take the broad view and realize the probability of a more rapid extension of the use of electric equipment in trunk-line railway service, the suggestion that it is of utmost importance to adopt a standard frequency especially adapted to this work appears less radical than it does to the factory engineer who is interested primarily in the problem of designing a complete line of turbo-generators.

The total cost of electrifying a railway, is in general not less than \$200 per kilowatt of generating capacity installed, and in considering the effect of 25 versus 15 cycles the difference in the cost of the average turbo-generator might easily be \$5 one way or the other without materially affecting our conclusion. Moreover, in dealing with the problem of trunk-line electrification we may as well throw aside all of the smaller generators, as this service will rarely, if ever, call for a generating unit of less than 3000 kw. A single freight train, such as is hauled over some of our trunk lines, would require one 3000-kw. generator.

There is another field the limits of which, while not clearly defined, are sufficiently understood; that is, the interurban. Much argument has been presented at various meetings of the Institute this year bearing upon the question of the possible use of a 1200-volt direct-current system as a substitute for the high potential alternating-current system. This system, perhaps, has its field in the interurban service. I think it can have no proper application in the broad service of trunk-line railways of which I am speaking. A potential of 1200 volts on the trolley or third-rail will never be satisfactory for the operation of freight trains. We must go radically higher. Anything less than 6000

volts in single-phase service is out of the question, and the question for us to decide is: "What frequency shall be adopted for alternating-current railway operation"?

The paper which Mr. Storer has read is one of the exceptionally valuable papers of the year. It contains precisely the kind of information which is needed in dealing with the very important question of frequency; and a half dozen pages of facts, such as he has given us, are worth any number of pages of general speculative opinion. In the discussion of my paper in January, the engineers of both the great manufacturing companies engaged in single-phase work, who had to do with the design of the motors and their application to trucks within the limits of space available, testified unanimously to the effect that at given cost 15 cycles secures one-third more draw-bar pull than does a frequency of 25 cycles. The people who will buy electrical apparatus to equip trunk-line railways will buy draw-bar pull. Recognizing this, it seems to me that we must recognize also the fact that, in view of the evidence set forth in the Institute papers and discussions this year, 15 cycles should be adopted in general for heavy railway work. I do not mean to say that a resolution to this effect should be passed, but I do say that unless evidence in favor of 25 cycles not hitherto presented can be brought forward, 15 cycles should be chosen by consensus of sound engineering opinion and should be introduced into practice as promptly as possible.

At the meeting in May when Mr. Sprague's paper was read some interesting facts were brought out in the discussion, especially the statement that one of the great manufacturing companies since January had produced a new single-phase motor of remarkable characteristics which operated substantially as well at 25 cycles as at 15 cycles. This is a very interesting statement, and it suggests information which I hope will be promptly and conclusively disclosed because some of us in the consulting field are now confronted by the problem of frequency for railways which at the present time are considering only the equipment of a terminal or a short division, but which by reason of the saving effected in operation and of increased earning power are morally certain to extend that electrification over much greater parts of their existing systems.

W. N. Smith: I cannot escape the conclusion that the question of electrification of steam railroads is so extremely broad that, as has been indicated by both Mr. Storer and Mr. Stillwell, we should not deliberately tie ourselves down to any existing commercial frequency which was developed primarily for lighting and stationary power.

If the steam railroads want draw-bar pull, which is unquestionably what they need to get the maximum amount of tonnage over a given track in a given time, they will not wish to be handicapped by the facilities offered by some local power company, no matter how large it may be, which may have 25 cycles

to offer, if 15 cycles is going to be the best thing for them to use. Great as is the power development here at Niagara Falls, I doubt if there would be enough 25-cycle power generated to supply the commercial demands of this region, now developing so rapidly, and at the same time supply the railway power required by such wholesale electrification as it is conceivable that large railway systems might eventually undertake. I do not believe that there is sufficient power capacity at present installed in any one plant anywhere in the country which would justify the undertaking of the wholesale electrification of a large steam railroad in its own vicinity, in addition to its own commercial load. It appears to me that the problem will without doubt result in the railway companies either having their own power stations, and getting developed for themselves the kind of machinery that they need the most, or calling into existence commercial power companies which will do it for them, developing coal mine power or large water power in such units and by such methods of distribution as the railway companies, their biggest customers, may demand.

William McClellan: If we examine these papers carefully, we shall find a decided agreement between the two authors as to facts, though the opinions and conclusions given are somewhat different. Apparently there is no uncertainty as to the weight-efficiency. Variable adhesion is eliminated as having no practical bearing. As far as the difficulty of generating 15-cycle power by turbines is concerned, Mr. Berg has anticipated me. We had a paper a year or two ago on a type of generator excited with alternating current. It was suggested that such a machine could be built self-exciting, in our case for 15 cycles, and run at double speed, thus making it possible to drive it efficiently by a turbine.

Apparently, the chief argument against 15 cycles is the difficulty of changing present commercial standards; this is certainly entitled to most serious consideration. Nevertheless, it should not be forgotten that great advances have been made in the past by discarding what seemed at the time as fixed practice. This was one of the arguments against the adoption of the metric system. Notwithstanding this, it was announced a few days ago that the Baldwin Locomotive Works had built a locomotive with its regular workmen and had used the metric system throughout. The engineers and workmen were well pleased with the system, and the arguments against its adoption were apparently refuted.

It has also been stated that a low frequency would not be suitable for other purposes than motive power. In this connection it should not be forgotten that it is probable that large lighting and power loads will not be worked from the same bus-bars as traction loads. It is also worth noting that the present tendency of economic progress is to limit transportation companies strictly to the transportation business, and it is not likely

that they will go into the business of selling power. Lighting and power for their own shops, stations etc., is relatively unimportant.

The important point noted in the Stillwell-Putnam paper was that the cost of the motive power equipment is by far the greater part of the expense of electrification. This brings us directly to the motor and its efficiency.

A short time ago there seemed to be a decided unanimity of opinion that the compensated-field single-phase motor was the type which the manufacturers had found to be most advantageous. It was expected that it would be greatly improved but the type would remain standard. With this motor, much would be gained by using 15 cycles. The engineer with the facts before him, and if not limited by local considerations, would necessarily hesitate a long time before refusing to adopt this motor.

Recently, however, we have had public notice that another type of motor is developing rapidly and is said to be nearly as good as the direct-current motor without commutating poles. From the standpoint of both weight and efficiency, this motor will perhaps not offer increased advantages when adjusted to a circuit of lower frequency than 15 cycles. If so, the whole matter is uncertain, and it would be exceedingly unwise to make any decision whatever until we have more definite information in regard to this motor.

It is worth repeating that the whole argument centers around the motor, or motor capacity, if you will, and no decision should be made to standardize frequency until the type of motor is standardized first.

Chas. P. Steinmetz: Probably the railways will generate their own power. At the same time it is a serious matter to depend on one power house only, or even two power houses, and if in an emergency power can be derived from some other station it is a great advantage.

The amount of power which would be required by the steam railways after electrification is frequently vastly overestimated. I understand some investigation on this subject has been made by Mr. Ferguson of Chicago, which I hope will be communicated later.

I believe the conclusion was that if all the railways entering Chicago received their power from Mr. Ferguson's steam-turbine station, the railway load would by no means be the largest load on the system, but probably within the overload capacity of the station.

The question before us is: first, whether the adoption of the lower frequency is necessary; secondly, whether this lower frequency should be 15 cycles or any other frequency. At present we have two standard frequencies, 25 cycles and 60 cycles, but the spectres of sundry other abandoned frequencies still haunt the electrical engineer—125 cycles, 133 cycles, 50, 40 and 30 cycles. It appears to me, and probably to everybody who re-

members and still sees the difficulties due to the existence of these odd frequencies, that it would be disastrous to introduce another frequency and then after a year or so find it was not necessary and have to abandon it. Therefore, we should be extremely careful to see whether a lower frequency is necessary. If it is necessary, which frequency should be chosen?

I do not believe 15 cycles is a suitable lower frequency. If we have to use a lower frequency it would be because the alternating-current railway motor is practically inoperative, at least in larger units, at 25 cycles. If that is the case, then 15 cycles probably is not yet the most suitable frequency; but the most suitable frequency is far lower than 15 cycles, and 15 cycles would perhaps be a compromise frequency. The experience of compromise frequencies and compromise designs has been disastrous, and would better not be repeated. If it seems wise to adopt lower frequencies, we should probably have to adopt not 15 but 12.5 or even 10 cycles.

In considering lower frequencies we must realize that, with the single exception of the series alternating-current motor, every part of the system, from the steam turbine generator to the incandescent lamp lighting the cars, the lower frequency is a handicap. This brings us to the need of a lower frequency. We must consider that every type of electrical apparatus has a frequency at which its design is most economical, most satisfactory, and most reliable. For small apparatus usually a somewhat higher frequency and for large apparatus a somewhat lower frequency is best suited. For instance, economically the most efficient frequency for the induction motor is 40 cycles; as a result, induction motors are built for 60 cycles or 25 cycles, both frequencies being sufficiently near the economical frequency for practical purposes. The 60-cycle frequency is mainly used with smaller motors, and 25 cycle with larger motors; and the maximum economy for smaller sizes shifts upward, and for larger sizes downward in frequency.

In the transformer we find the maximum economy is beyond the commercial frequencies. The 125-cycle transformer is better and more economical than the 60- or the 25-cycle transformer. Where the maximum economy lies we do not know; there must be some definite frequency, because we know that the alternating-current transformer is not well suited for 10,000 cycles; it is difficult to design; not economical; that is, 10,000 cycles is too high a frequency, but within the range of available frequencies, the higher the frequency the better for the transformer.

The maximum economy of the synchronous converter is at 25 cycles. A converter designed for a frequency higher than 25 cycles, or lower than 25 cycles, is, as a rule, inferior to the 25-cycle converter.

In the alternating-current series motor the maximum economy is at the lowest possible frequency; the lower the frequency the

better the motor. The best series alternating-current motor would be the motor designed for zero frequency; that is continuous current. In that, I agree with Mr. Sprague. In any other apparatus, the larger the size the more urgent the need of lower frequency, and, while good results have been obtained with 25 cycles on moderately small motors in interurban service, for large units, as heavy locomotives, 25 cycles seem almost impracticable for the series alternating-current motor.

It is evident then that the frequency must be lowered so as to approach that of maximum economy, or the type of the motor must be changed. There is no reason to assume that the series motor is the final development of electric railroading. I have really never felt satisfied that the series commutator motor is the solution of the problem and have repeatedly said so. There are other kinds of motors in which the maximum economy is not at the minimum frequency, but is, as near as we can judge at the present time, not far from 25 cycles. If then we adopt the lower frequency, we might find that we have handicapped ourselves in designing alternating-current commutator motors of different types.

Mr. Ernst Alexanderson has succeeded in devising a type of motor in which it appears that the maximum economy of the alternating-current commutator motor is not at zero frequency but probably is in the neighborhood of 25 cycles, and for this motor that would be the best frequency. In this respect, I disagree with Mr. Armstrong in the data on the relative comparison of 25-cycle and 15-cycle motors. I believe that his statements rather represent a period which is past, but still influenced by the experience with the series motor. As far as our present experience goes, the two frequencies, 25 and 15 cycles, in railway-motor design at the present time seem to be equal in economy, and for all I know 25 cycles may be the better frequency. That necessarily means that 15 cycles has no right to exist.

The great and only difficulty with the alternating-current motor is the commutation; all other troubles are secondary, and merely results of the limitations imposed upon the design by the attempt to make the sparking at the commutator least destructive. During the operation of the motor electromotive forces are induced in the short circuited coil under the brush, which lead to more or less disastrous sparking and heating of the commutator, destruction of the brushes, energy losses by parasitic currents, etc. To reduce this effect we can either reduce the electromotive forces induced in the short-circuited coil, by reducing the frequency—and that is after all the gist of the desire to lower the frequency: to get lower electromotive forces induced in the short-circuited coil at commutation—or we can attempt to reduce the currents produced by these electromotive forces by inserting high resistance commutator leads. This is beneficial to some extent, although it introduces the great difficulty to protect these high resistance leads against self-

destruction by excessive local heating. But the benefit is limited, because while we reduce the current the insertion of resistance raises the voltage. The solution of the difficulty is to modify the type of the motor so that no electromotive forces are induced in these short-circuited coils, and that is what Mr. Alexanderson has done and concerning which I believe he will give us a paper in a very short time.

Peter Junkersfeld: Considering passenger trains only, and assuming for the sake of argument that it would be physically possible to electrify all the steam railroads centering in the city for a distance of 25 miles from the respective passenger stations, within the next year, we have estimated that the total power demanded by these various railroads would probably not exceed 20 per cent. of all the power generated in Chicago by all the various companies. This figure of 20% would even then be true only for the next year. After that, the proportion of power demanded by the steam railroads would decrease, due to the fact that the amount of power required for all other purposes increases in a much faster ratio. The large amount of industrial power and the very large amount of interior lighting not yet supplied electrically and that still to be developed in Chicago would justify the opinion that at the end of five years the total steam railway demand would not exceed, possibly would be less than ten per cent. of the total electric power generated in the city. This applies to Chicago and to the railroads for a distance of 25 miles radiating outward from their passenger terminals, so that, as Dr. Steinmetz has said, the proportion of power which will be demanded by the electrification of the steam railroads is not nearly so much as we might imagine.

Gano S. Dunn: How would it work out if freight were included?

Peter Junkersfeld: We made no calculations on that, and it is a hard thing to estimate.

The most optimistic speakers on this subject of railway electrification have said that they hardly expected to see all of the railways electrified within their lifetime; in other words, it is largely a problem of the next generation. We all agree that we should look out for the next generation, but in doing so we should not neglect the present. The electrification of steam railways at and near their terminals, however, is particularly important, in fact that problem is a live and pressing one now.

In the electrification of such terminals the question of direct current or alternating current has by no means yet been settled. There is still a great deal of controversy on this point, and the probabilities are, in my mind, that ultimately the direct current will perhaps be largely used in electrifying terminals. This does not apply to the electrification of long steam railroad lines, trunk lines, etc., but it does apply to the electrification of terminals, not only because of the present state of the railway motor art, but also because of agitation against overhead high tension wires and things of that sort particularly in large cities.

We seem in this country to be passing into an era in which public regulation will perhaps have quite a great deal more effect on electrical development than in the past, and we are confirmed in that impression if we observe the experiences in other countries. In many of these, the electrical development has not been so great as in this country, not because they are less ingenious, but because they have had certain handicaps. These handicaps may appear here, there is already some evidence that they will appear, and may work somewhat against the operation of terminals with high tension overhead trolleys, but may not work against future similar single-phase operation of the long railway lines.

Coming now to the question of power supply for terminals, and even admitting for the moment that possibly single-phase motors could be used for that purpose, we should be extremely careful before recommending an odd frequency, because on the crowded tracks of the terminals the question of reliability and continuity in moving the trains is of primary importance; of much greater importance than the moving of the trains between the large cities. In order to secure the best results it should not only be possible for the railway companies to buy power, when this can be done more economically, but at least to be in a position to readily interchange power with other power supplying companies. Otherwise, the railroad companies will have to make large investments in reserve power equipment to protect their business. The greatest factor in economical electric power generation is a diversified demand, which means a very large number of peaks, and as a result non-coincident peaks. One of the greatest factors in electrical development in a community is low cost of electric power. That can only be secured in the ultimate by having an arrangement so that the interchange of power can be made readily and quickly between the different power consuming systems whether owned or operated by one or by several companies.

The selection of the frequency for any given service should be based on the predominating demand. In a number of the larger cities in this country the predominating demand has been in favor of 25 cycles. That condition still exists to-day, and Dr. Steinmetz has told us that for synchronous converter work, which is 75 per cent. at least of the total demand in three or four of the larger cities, that 25 cycles is the best frequency. For that additional reason, we should be careful before recommending any odd frequency if we want to conserve the best interests of the various companies or clients we represent.

Henry G. Stott: I think that the question of supplying power for railroads has been looked at from a slightly different standpoint than it is by those who are accustomed to the conditions obtaining in most of the large companies that are developing their own power. I wonder which power plant in the United States could give an emergency supply equal to 25% of its rated

capacity. Railroad plants and lighting plants have to be designed for a peak load. In a lighting plant the peak load will last not to exceed 400 hours per annum. That means an enormous investment for a short time. The railroad plants have practically a peak load of from 800 to 1000 hours per annum. How can we expect either our lighting plants or railroad plants to carry a reserve of 25% above their peaks for the purpose of guaranteeing a supply to anyone else, and if they do it, at what price can they do it?

The question seems to me to be one which will be solved by the location of a number of plants along our railroad lines. These plants will be able to give a much more reliable service, which, after all, will ultimately be the criterion applied by everyone to the question, rather than the cost. Imagine, for example, a transmission line from Niagara Falls to New York, and our railroads depending upon it, and subject to every thunder storm that comes up. I have no data at hand to show what the average interruptions of such power would be, but I know this—it would be greatly in excess of the interruptions which would obtain in a number of smaller plants distributed along the line. In other words, we can get better insurance by carrying our power in the shape of coal on freight cars than we can by carrying the power on high-tension wires. The insurance given by a number of distributed plants is going to be infinitely greater than we can obtain in any other way.

A. H. Armstrong: From the discussion it would appear that certain advantages in motor design can be taken advantage of at 15 cycles which are not possible with higher frequencies. The problem now becomes one of weighing possible advantages of motor construction against the handicap of using 15 cycles for the generating and distributing system, and seeing if these advantages are sufficiently great to warrant the introduction of an odd frequency with all its engineering and commercial complications. The history of alternating-current distribution has been a constant tendency toward the adoption of lower frequencies as the demands of new apparatus became pressing. Up till now the question of low frequency has been governed by the performance of converters. A frequency of 25 cycles has been sufficiently low to satisfy all the needs of the situation. With the advent of the alternating-current single-phase motor, we have a type of apparatus calling for low frequency, but the greater advantages of 15 cycles must be great indeed to warrant a departure from the standard 25 cycles now in universal use, especially as the single-phase motor is not in any sense inoperative at the higher frequency. It is not a question of the adoption of 15 cycles in order to make alternating-current motor installations possible, as the recent inventions of Mr. Alexanderson and others have given us a motor which is thoroughly commercial at 25 cycles.

I agree thoroughly with Mr. Junkersfeld that the electrification

of steam railroads is not to be considered entirely from an alternating-current standpoint, and, instead of steam road terminals presenting a problem calling for a change in the frequency of supply in order better to accommodate the limitations of alternating-current motor design, I would suggest that this class of railroad electrification presents a problem of alternating versus direct current with a decided preference for direct current.

While recent improvements have made the alternating-current motor a thoroughly commercial piece of apparatus with a frequency supply of 25 cycles, due weight must be given to the further consideration that any continued development of this type of apparatus must show further improvements which will make 25 cycles still more desirable; in other words, having a successful 25-cycle alternating-current motor to-day, we can look to the future with the confident hope that any continued development will still further minimize any possible advantage which 15 cycles may enjoy over 25 cycles. At such a short period as two months ago, it appeared that a frequency of 15 cycles was necessary in order to make possible the construction of large alternating-current single-phase motors giving good commutation. The improvements made in two months, however, have made the adoption of 15 cycles less attractive, and it is fair to assume that we have not heard the last from alternating-current motor designers and that the future holds bright promise of still further developments. If we can get a motor just as good at 25 cycles, or even nearly as good, there is no reason to adopt low frequency. In fact, there is every reason to adhere to a frequency so universally in use as 25 cycles.

N. W. Storer: I have only a few words to say in conclusion. Mr. Steinmetz raised the point in regard to suitability of 15 cycles for railway work. He insists that the lower the frequency the better the motor will be. On this point, I cannot agree with him. There is much more to be considered in building a single-phase motor than simply to reduce the short-circuit current to a minimum and thus obtain good commutation. If the frequency is reduced much below 15 cycles, the pulsations of torque will cause considerable trouble. Everything considered, I regard 15 cycles as the best frequency for railway purposes. It is a simple matter to obtain very satisfactory commutation in a 15-cycle single-phase motor. Within the last few days we have been testing the locomotive of which I speak and I have seen the motor carry 100 per cent. overload in current for several minutes at a time when hauling a train with the brakes set, and there was practically no sparking at the commutator, the commutation being much better than almost any of the standard direct-current series motors could do under similar circumstances.

So far as commutation is concerned, we have not regarded that as the main reason for recommending a lower frequency than 25 cycles for railway work. Our desire has been simply to increase the capacity of the motors. If this Alexanderson motor

which has been mentioned by so many speakers is able to give the same capacity at 25 cycles that the compensated series-wound motor gives at 15 cycles, I should say by all means stick to 25 cycles, unless there are some other defects in the motor of which we are not aware. No one wishes to add another to the standard frequencies any less than I do. We should cling to the standards as far as possible. I believe that, if in future development it is found that the installation of 15-cycle current for the electrification of a large system can be done more cheaply and operated more cheaply than the same work can be done with 25 cycles, the 15 cycles will certainly be used. As I have said before, it is solely a matter of dollars and cents.

Now, in regard to power distribution, I am much gratified to learn that the power required by the steam railroads entering Chicago is such an insignificant amount compared with that required for other purposes. For this very reason, there should be practically no interference in that case with the systems now in operation. The steam railroads certainly will require enough power when they electrify their terminals in and about Chicago, or any other large terminal, to build their own power houses and furnish their own power throughout. I do not believe it would be at all feasible for the company to draw, even to a very limited extent, from the lighting companies for power to operate their railways.

I agree with Mr. Stott that it is impossible for the various industrial plants to carry sufficient reserve capacity to take care of 25 per cent. or 20 per cent. of their normal load to provide for railway emergencies, particularly as the biggest railroad loads will come just as they do in street car service, at the hours of the day where the lighting load is heaviest and all the people want to travel at the same time. Steam railways must work out their own salvation. In electrifying their lines they must provide sufficient reserve capacity to take care of the entire system.