DISCUSSION ON "SHUNT-COMPOUND-WOUND SYNCHRONOUS CONVERTERS FOR RAILWAY WORK," AT MILWAUKEE, MAY 30, 1906.

J. B. Taylor: Mr Waters' statement of the tendency to leave off the series field windings of synchronous converters for railway work is either in the nature of a prophecy, or else he has not compared the number of plants operating with compound windings with those operating without them.

For large city systems where there are a great many cars, and the load changes gradually (depending on the hour of the day), shunt-wound converters are used in some cases, as they have the advantage of simpler connections and there is not much to be gained from the compound winding. On the smaller systems, and also on the largest system, where there are sudden changes in the load, there are a number of decided advantages to be gained by placing the series field on the converter. This has been the practice for a number of years past, is still the practice, and I am satisfied will still continue to be the practice until something quite different comes up.

The principal advantage of the compound winding is the more or less automatic compensation for line-drop, so as to maintain approximately constant direct-current voltage at the sub-station. There are some incidental advantages, such as the ability to secure desired division of load between machines, and saving of time in starting and placing machines in service. Machines having different characteristics, if they are shunt-wound machines, will sometimes give considerable difficulty in obtaining the desired division of load, whereas, with compound-wound machines an adjustment of shunt on series field will permit the operator to divide the load in the desired manner. The converters may be started at four o'clock in the morning, and run until two o'clock the next morning without touching the field rheostat. When starting a converter from the alternating-current side, a small field excitation will make the converter lock in step with synchronous speed with correct polarity. This separate excitation is given by the series field on closing the equalizer switch, provided another machine in the station is carrying a load.

There should be no marked increase in cost due to the series field winding; there is no more copper on the field, and what copper there is used is to better advantage, as it is obvious that a large copper strip with a small amount of insulation can be placed more effectively than a small winding insulated for 500 or 600 volts.

As far as the efficiency of the converter itself goes, there is no reason why the series field should involve increased losses. It is true, the use of a reactive-coil involves certain small losses, but these are more than compensated by the advantages. If the reactive-coil has a kilovolt-ampere rating that is 15 per cent. of the converter rating, and even if the losses in this coil are as large as 5 per cent. of its rating at full load on the converter, this

loss would be only 0.75 per cent. of the converter rating. At light load the reactive-coil loss is practically nothing.

The series field is of especial benefit on the small system where the fluctuations in the load are felt at the generator. The tendency of the increased leading component on the converter, due to the series field, reacts on the generator and tends to keep the voltage up. As a result we find that the small systems operate with very little attention to the voltage. They are started up, and as the load comes on, the generator voltage, instead of falling seriously, tends to remain constant. The result of this is that we get fairly constant voltage at the sub-stations; and while in railway work only fairly constant voltage is required, it is better to have the voltage stay between 590 and 610 volts, than to drop from 600 down to 550 or 525.

Besides maintaining the schedule, the maintenance of voltage reduces consumption of energy, as anyone knows who has figured the watt-hour consumption of a car. In order to make a low watt-hour consumption the voltage must be kept up.

On most systems the substations are so far apart that it is impracticable to count on one relieving another to any great extent. It could be done at the expense of a great amount of copper or by having the converter voltage fall off very rapidly with increasing load.

There is a special case, in one of the French cities, where the character of the load is somewhat the same as we have in New York on the elevated system, where many trains and heavy loads are on all the time, and where the sub-stations are quite close together. In this case it is desirable to have the load shared by the sub-stations because the feeder-drop between them is comparatively small. In that case they have the series field winding, but reverse it so that the converter will purposely have a very drooping characteristic and one sub-station is relieved by those adjacent to it. Cases like this are quite special. As I said at the outset, the compound winding is in general use and there appears to be no present tendency to dispense with it.

P. M. Lincoln: I agree with Mr. Taylor in taking exception to the conclusions reached by Mr. Waters. The shunt-wound synchronous converter and the shunt-wound generator have much the same characteristics. They both have the drooping voltage characteristic, they differ in degree only, the shunt-wound converter will not drop its voltage so much with increasing load as will the shunt-wound direct-current generator, but the drop is there. Where a rising voltage characteristic is desired on account of operating conditions, it is necessary, of course, to have the compound-winding. The compound-winding does not add materially to the complication or to the cost of the system. The additional cost is practically all in the switch-board apparatus, principally in the necessity of using equalizer switches, etc., but that, as will be recognized, is a small portion of the total cost.

By properly designing the transformers which connect to the converters; that is, by introducing the proper amount of inductance, the necessity for reactance-coils can be entirely avoided. As a matter of fact it is avoided in the standard construction of some of the manufacturing companies. As to load distribution between converters, Mr. Waters says that this is not good with compound-wound converters. I believe the equal load distribution between converters is not so much a function of the compound winding as it is of other elements. If a number of converters are operated from the same low-tension bus-bars, the brush tension, brush friction, and other small irregularities will cause a considerable difference in the distribution of the load. If, however, between the high-tension bus-bars, the point of equal potential on the system and the converters, there is placed a sufficient amount of inductance, as is the case when each converter is fed by its own group of transformers or its own secondary windings in a group of transformers, then the difficulties in load distribution disappear. That is the logical way of operating. Where the rising voltage characteristic is wanted, it is perfectly easy to supply it; where it is not wanted it is easy to leave it off. There is no particular difficulty in doing it. One instance which I might state which will show the contrary of Mr. Waters' statements as to modern tendency, is the case of the Manhattan Elevated Railway in New York. Originally they put in their converter stations and operated them for a number of years as straight shunt-wound converters. However, within the last few months, or possibly a year, the practice in this group of stations has been changed and the converters are now operated compound wound.

W. L. Waters: Mr. Taylor says that there is no difference in cost between a shunt and compound-wound converter. Speaking as a designer, I can say a compound-wound converter costs about 6 or 7 per cent. more than a shunt-wound converter. In order to get automatic compounding, a compound-wound converter has to be designed so that it can introduce a large leading current into the line; that is, it must be capable of being highly overexcited. A shunt-wound converter, on the other hand, is designed to run on unit power-factor and to have a normal excitation. A compound-wound converter is designed so that it can be run with from 30 to 50 more ampere-turns in the field than a shunt-wound converter. This means that there must be from 30 to 50 per cent. more copper on the fields, and space must be allowed for this extra copper. This makes the frame bigger and the whole machine heavier. Mr. Taylor may possibly have confused factory cost and selling price. I was speaking entirely of factory cost. The price at which a machine is sold is entirely a commercial question and has nothing whatever to do with the factory cost.

Referring to the question of efficiency; as I have stated above, a compound-wound converter usually has from 30 to 50 more

ampere-turns on the field. This means that the loss in the field-coils is from 30 to 50 per cent. greater than in a shunt-wound converter. This is one place where efficiency is lost; the other is in the reactance-coils.

Referring to Mr. Lincoln's statement that the use of reactance coils can be avoided by designing the transformers with sufficiently high self-induction; this can certainly be done. It will mean, however, that the transformers are no longer standard, and that all the adjustment of the compounding has to be done on the series winding, which will mean again that the series winding has to have a bigger margin allowed so as to get this adjustment.

Both Mr. Lincoln and Mr. Taylor misunderstand me if they think I contend that general practice is toward the use of shunt-wound converters. I meant to say that when the points of extra complication increased cost, reduced efficiency, and less reliability are considered by the operating engineer, he will usually come to the conclusion that the shunt-wound converter is preferable.