mentioned that the sum of £43,500, given in the steam scheme for fixed charges, included £3,100 on the 6,000-k.w. plant, representing standby coal, which is entirely saved on the battery scheme.

## DISCUSSION.

Mr. Jenkin. Mr. B. M. JENKIN: The author has put before us some very interesting points in connection with batteries. One of the most interesting is his suggestion to split the booster up into three parts instead of making it with only one generating armature. This makes it possible to reduce the size of the booster very much. This is clearly shown by the author in Figs. 6 to 11, in which he compares the usual method, where the booster is made with one generating armature which deals with the whole current, with his own method, in which the triple booster has three armatures which are worked in series or in parallel as required. For comparison it should be noted that in the latter case there are 280 cells in the battery as compared to 240 cells in the former case. This, as he points out, is one of the reasons why the booster is reduced in its kilowatt output. I would suggest that his method of working should be carried still further. The chief value of a battery is on the discharge, when it should give the maximum possible output. Therefore, I would suggest that it is a mistake to make the battery do anything more at that time than deliver current to the busbars, all of which can be used for the load. As long as a booster is used to help to discharge the battery, some of that most valuable current on the emergency is being used to drive the booster. If the number of cells be increased until the emergency discharge can be got without the use of a booster, the whole of the current that comes out of the battery is available for the feeders. Power to charge the battery can be afforded very much more easily than to discharge it, because during charge ample plant is available, and a great deal more power can be put into the booster economically and advantageously during that period than during the discharge. That occurs to me as the result of what the author has pointed out. The next point is the question of how these boosters should be switched. The author leaves this rather vague, and suggests the switch shown in Figs. 16 and 17 for changing the boosters from working in series to working in parallel. I have been unable to follow the reason for that complicated proposal, and do not think it is really necessary. He has suggested in Fig. 14 that these separate commutators of the booster generator, or at least two of them, might be connected to the same armature in a single field. That, I think, is unsatisfactory because the boosters cannot then be handled independently of each other. Each generating armature should be in its own field so that its voltage can be regulated independently. If this is done, to change the three armatures in series to three in parallel, one simply reduces the volts on one of the armatures until it reaches zero, closes a short-circuiting switch, and cuts out that booster armature. The same thing is done with the next, which leaves one armature in series with the battery. This condition must be reached before it is possible to put them in parallel. Up to this point the discharge of the battery is limited to the current capacity of one booster armature. With the author's arrangement there must be this transition stage. An examination of Fig. 15 makes this clear. As the current increases, a second armature is put in parallel. To do this it is run up to the same volts as the booster already in circuit, and is then switched in in parallel. It is not necessary to have any complicated switch with resistance to do this, but the armatures must be in separate fields, so that each one can have its voltage regulated independently of the other. Mr. Jenkin.

I would suggest that the absence of the booster during discharge is a thing that should be aimed at, especially if the battery is to be regarded as a standby in emergency, when the discharge current may rise to its full value at once, giving no time to switch over the boosters. I do not think any switchboard hand would care to do such a tricky thing as taking three armatures in series and changing them to three

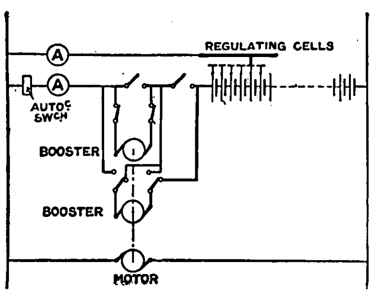


FIG. A.

in parallel on an emergency when he wants to use his battery as a standby; I think he would certainly find that extremely difficult. Even in the case of Fig. 15 of a normal 1-hour discharge the author shows that he works all boosters in series during the first quarter of an hour of discharge, during the next half-hour he runs them in parallel, and then for the last quarter of an hour he puts them in series again. That involves a great deal of switching when the maintenance of the load depends entirely on the continuity of the battery discharge. The author further suggests in that arrangement that there should be regulating cells. But previously he has told us that regulating cells are disadvantageous, as it is extremely difficult to charge the cells connected to the regulating contacts. In spite of that, he shows in his arrangement in Figs. 9, 10, and 11, regulating cells in series with his booster connection. I would suggest that the better plan is to use regulating cells and at the same time put in a battery with a sufficient number of cells to take the emergency discharge. Then one is entirely independent of the boosters in emergency. But in order

Mr. Jenkin. to work those regulating cells to the same extent as the main battery, I think the booster should be put in parallel with the regulating cells as shown below in Fig. A. The booster is placed in parallel with the regulating switch circuit. During charge, the whole of the cells are equally charged through the booster. The regulating switch is adjusted to suit the busbar volts, and the booster voltage is adjusted to give the required charge and at the same time keep the current through the regulating switch circuit at zero. During normal discharge the same method is followed, so that all the cells are equally discharged. During the beginning of the discharge the booster is run inverted and the motor delivers current to the busbars. At the end of the discharge the switch is on the end cell and the booster shut down. In emergency the heavy discharge is taken through the regulating switch circuit, and the booster is automatically cut out as the switch is moved to the end cell. The regulating switch circuit is available for emergency discharges at all times, and is not affected by the booster connections which might be set with armatures in series or in parallel, charging or discharging. I think, therefore, that might be a better way of dealing with the problem than any the author has described. I do not think it is mentioned in the paper, and I do not know that it is used. I have not tried it myself, but I hope to do so on the next occasion when I have to put in a big battery.

Mr. Shawfield. Mr. C. E. C. SHAWFIELD: The title of the author's paper is: "Battery Economics and Battery Discharge Arrangements," but I am afraid that part of his paper which relates to the economical use of batteries, particularly as affecting the coal bill, is very much overshadowed by that part which deals with the discharge arrangements. I had rather hoped, when he told me he was writing the paper, that he would have gone very fully into the possible savings which can be effected in the boiler house by the judicious use of batteries for peak loads. There is another section of his paper, too, with which I can hardly agree, and that is his advocacy of the use of batteries for standby purposes, particularly where he suggests putting in discharge arrangements, boosters, etc., capable of enabling a battery to be discharged at a 5-minute rate. I can hardly imagine, in this country at all events, conditions are likely to arise in a central station where a 5-minute discharge of a battery—that is to say, a discharge of a battery at its 5-minute rate—is likely to be required, or if such circumstances did arise, I think they would last a considerably longer time than 5 minutes and that the inevitable shut-down would only be postponed for a very short time. I should be inclined to say that practically the 1-hour rate is the shortest rate of discharge at which it really pays to use a battery, and that if that can be exceeded a good deal of capital will have been spent in providing for conditions which are unlikely to arise. With regard to the question of regulating cells *versus* boosters, I was certainly under the impression, until a short time ago, that the booster was the best and most economical method of charging and discharging a battery—particularly discharging. But I was very much surprised to

Mr. Shawfield.

find, when I had the opportunity of going through the Berlin Electricity Works, that quite the contrary opinion appears to be held on the Continent generally. In very large battery installations in Berlin boosters are quite unknown except for the purpose of charging, and they are not used to a very large extent for that purpose as the batteries are frequently charged through a rotary converter or motor-generator run at what one may term an over-voltage. These regulating switches are really wonderful in their simplicity and certainty of operation. I happened to see one in service moving over several contacts when carrying a current of 4,000 amperes. The contacts looked quite on the small side, but there was not the slightest trace of sparking, and although this particular switch had been in service for seven or eight years, the contacts appeared to be absolutely new, and I was assured that no repairs had been done to the switch since it had been installed. With regard to the cost of regulating cells, it does not appear as if it was actually any higher than the cost of boosters. In the case of a battery giving 1,000 k.w. for three hours, that is, roughly, 4,000 amperes at 250 volts for a period of three hours, I was informed that the cost of a regulating switch and connections (which were quite short, as it was placed alongside the battery-room, and the connecting bars only had to come through the wall), delivered and erected, was £1,000. This switch was capable of dealing with the discharge of the battery at the 1-hour rate—that is, at 6,000 amperes. It was capable of being moved from end to end without damage and without what may be called any serious sparking with a current of 5,000 amperes. I think there is very little doubt that the efficiency to be obtained by the use of regulating switches is very much higher than it possibly is in the case of boosters, because, as Mr. Taylor shows in his paper, the units lost through all-day running of boosters really amounts to quite a good deal in the course of a year, and those units are wasted in the booster just at the time when they are the most expensive to produce, namely, at the time of peak load; whereas a booster, although relatively small, when necessary for charging, is used at a time when the units cost the least, namely, in the valleys of the load, and in the small hours of the morning. The extent to which batteries are used by the Berlin Electricity Works is really startling as compared with our English practice. The figures given by Mr. Taylor in his paper are rather on the small side. I see they are stated on a 3-hour rating. I was informed that the capacity of the batteries installed at the various sub-stations in Berlin was 35,000 k.w. for two hours, and that in the case of a breakdown, they were capable of maintaining the whole supply of the city for period of two hours. I inquired the reason why they considered it necessary to make such very large provision in the way of batteries, and they said, in the first place, batteries were a considerable source of economy—coal is very expensive in Berlin—and that the considerable reduction in the peak which they were enabled to effect, reduced their standby losses in the boiler house very considerably; and, in the second place, they were under very heavy penalties to the local tramways, the underground

Mr. Shawfield. railways, tubes, and also to the Municipality of Berlin in the event of any failure of supply, and, therefore, the batteries were very largely installed as an insurance against the possibility of their being mulcted in a very heavy bill for penalties. That is a state of affairs which does not very often occur in this country. I do not know of any case where a supply has to be given under penalties for failure other than the purely nominal penalties imposed by the Board of Trade. Therefore, I think batteries can only justify their existence in so far as they actually tend to reduce the cost of generating. There is no doubt they can be used with very great advantage in that direction, but the advantage is limited entirely to their use on a 2- or 3-hour rate, according to the size of the peak, and provision should not be made for dealing with heavier currents than that. With regard to the Exide cells, I wish Mr. Taylor had given some further details of those, as I understood him to say in his opening remarks that they were suitable only for emergency purposes, and not for regular use. If that is so, I do not quite see why he has apparently suggested their use for the first peak in Fig. 19. I take it that that peak is one of regular occurrence, and, therefore, the batteries would have to be used daily to meet it. Then, with regard to the figures which Mr. Taylor has sketched on the blackboard, I am afraid I have not been able to follow them. It would appear he makes the standing charges for 11,200 k.w. of steam plant at £43,500 per annum. Surely they should be something like half that amount. £3·89 per kilowatt per annum must represent an expenditure of over £30 per kilowatt, whereas a modern steam plant can surely be put down for a figure of £12 per kilowatt. I think, therefore, the comparison which he has made is really not quite accurate, and I shall be glad if he will amplify it.

Mr. Pearce. Mr. S. L. PEARCE: As the author has referred in two or three places in his paper to the large battery which has been put down in Manchester, a few facts and figures relating to the first complete year of working will, I think, be of some interest. In the first place, I would like to correct the figure which appears at the top of page 394, that the coal bill has been reduced by some 25 per cent. That was true of three months in the summer of last year, but the average for the completed twelve months is 13 per cent. I will come back later on to the actual savings which have been made by the installation of this battery, but perhaps it would be well at first to describe in a few words its main features and functions. Originally, when installed, we intended to charge the battery up off the traction busbars, and to discharge it purely as a peak-load battery over our heavy winter lighting "peak." The capacity of the battery at the 1-hour rate is approximately 3,000 k.w. The arrangement of boosters I shall refer to later, but it is quite possible—and this perhaps meets a point which has been raised by previous speakers—to drive the booster motors off the traction busbars instead of the lighting busbars. This is of value when the traction and lighting peaks are not coincident. Although it was intended normally to charge the battery from the traction bars and to discharge

Mr. Pearce.

on the lighting, it is so arranged that both the charge and the discharge can be used entirely on the lighting system. The results of the year have shown that the greatest benefit and the most economical results are obtained by keeping it entirely on the lighting system. Possibly the conditions at Manchester are ideal for a battery of this capacity and for this use. We have the high-tension station at Stuart Street and the two direct-current city stations (which for all practical purposes may be considered as one) in Dickinson Street and Bloom Street, and the connecting link between the two systems is the large 3-phase sub-station installed at Dickinson Street. This gives a very flexible arrangement. For example, if we have very dark weather in the morning and take a more or less complete discharge out of the battery, owing to the fact that the Stuart Street load is dropped some 7,000 or 8,000 k.w between 12 noon and 2 p.m. (due to the large industrial works leaving off for dinner) it is quite possible to get a very good charge into the battery again at midday from the sub-station, and it is then available for the winter evening lighting peak.* So that the conditions for getting more than one discharge per day out of the battery are more or less ideal.

With regard to the savings which I estimate we have effected during the first complete year of working, they are as follows: Dealing with the coal first, a reduction from 3·33 to 2·89 pounds per unit generated has resulted—that is, a reduction of 0·44 of a pound—which on the output of the city stations—namely, 30,000,000 units—accounts for £3,348. There are other savings in the works costs, which latter amount in all to 0·064 of a penny, comparing the year ending March 31, 1911, with the previous year, and which, as far as I can see, are wholly due to the battery. This reduction of 0·064d. on 30,000,000 accounts for £7,762. Altogether, after allowing for full capital charges on the battery, and for the full maintenance, there has been a saving on the first year of £3,041. That takes no account whatever of any saving on capital charges, and if it be admitted that this battery at the 1-hour rate can be fairly compared with steam plant at the Stuart Street station, plus high-tension mains, plus converting plant at Dickinson Street, we get these figures: £13 per kilowatt installed for the steam scheme, that is, steam plant plus high-tension mains, plus converting plant, which I put at £13 a kilowatt and £8 for the complete cost of the battery—that is, battery boosters, switchgear, cabling, housing, and everything complete. This shows a difference of £5 per kilowatt. Taking 8½ per cent. on the £5, and at the 3,000-k.w. rate over the 1-hour—viz., £15,000—that gives a further saving of £1,950. We have therefore a saving on running and fixed costs of, roughly, £3,000, and on capital charges a saving of £2,000, or a total of £5,000. That figure does not differ very materially from the hypothetical case worked out by Mr. Taylor on the board.

A few other particulars might be of interest. We estimated the

* The maximum charging rate for the battery is 6,000 amperes and the normal rate 4,000 amperes.

Mr. Pearce. daily steam plant load factor in the winter would be increased from 32 to 43½ per cent. due to the lopping-off of the peak. As an average, I think, the figure of 47 per cent. might be substituted for 43½, but on some days we have reached as high as 60 per cent.—that is the daily steam load factor. The "commercial" or "over-all" efficiency of the battery—that is to say, the efficiency after deducting all booster and battery losses—works out for the year at 71 per cent., which I think is a very fair figure. On page 416 the author refers to there being a sufficient gain in saving and standby losses of boilers and engines; in other words, that the coal saving is fully equal to that lost in the inefficiency of the battery. Mr. Shawfield also made a point of that. Our figures are as follows: The total units lost in the battery and lost in the boosters were, roughly, 700,000. The coal saved was £3,348, so that the lost battery units are covered four times over by the coal saving. With regard to this question of rapid discharge rates, perhaps the figures of the Tudor battery at Manchester might be of interest. These are the actual figures we have obtained in practice, and are not the manufacturers' figures. We got 8,400 amperes at the 1-hour rate, 13,000 at the ½-hour rate, and 17,000 for 5 minutes. On that question of the high-discharge rate for the short periods and the design of the switches, I can assure you that the satisfactory operation of these large switches, even for 17,000 amperes, makes one wonder how the Americans successfully deal with this 40,000-ampere rate of discharge which we have heard of to-night. With regard to the question of using the battery as standby or emergency, I entirely agree with the author's remarks on page 418, where he says: "It will not be found advisable to put in batteries exclusively for standby or emergency purposes." I am rather sorry to see that in Appendix III. Mr. Taylor seems somewhat to hedge on the point, and suggests that a double arrangement should be put in, "a standby" and "an ordinary battery," as shown on the curve on the wall. It seems to me that a battery which will be large enough, as a substitute for a peak load steam plant, to give that economy in working which makes it a sound commercial investment, has all the emergency qualities necessary for the purpose. I agree with the author when he suggests that for ordinary commercial purposes it is quite good enough to put in a battery to "buffer" the demand in foggy weather so as to give time to get away the steam plant. As a matter of fact, that is how we do use the battery. With regard to the booster equipments, I think the author, unconsciously perhaps, has done us an injustice. He speaks about the Manchester booster plant being insufficient for discharging the battery at "emergency" rates. That is not correct. As a matter of fact, the booster equipments are three in number, and, collectively when operated in parallel, they are sufficient to give a current corresponding to the 5-minute maximum discharge rate of the battery at maximum boost. We have divided the boosters up into three sets, partly because, as I have explained before, the battery was intended for traction working as well as lighting, in which case the two boosters in series are run off the traction bars, or at times of discharging on heavy lighting peak the boosters are all paralleled. No difficulty is experienced with the series-parallel arrangement. Mr. Jenkin has already referred to that, and I do not propose further to labour the point; but it seems to me that that is quite easily arranged—in fact, the diagram of connections of the Manchester battery which has been published shows clearly the arrangement of the switches and busbars, and no complications whatever are introduced. It is quite easy to go from series to parallel without any complicated change-over switch such as Mr. Taylor puts forward in his paper. **Mr. Pearce.**

I am inclined to think, after carefully considering this paper, that the sub-division of the booster units in the manner in which we have done it is even preferable to the arrangement which the author puts forward. With the latter arrangement all one can stand to gain is the annual charges on extra capital expended on the booster plant, at the expense of additional losses when charging, and, seeing what an extremely important function of the battery the booster plant is, I think outlay on the booster is money exceedingly well spent. What is wanted is absolutely reliable and sufficient plant to enable the battery to discharge up to its greatest capacity. With regard to Fig. 15, that seems to me to be a purely hypothetical case, which is hardly likely to occur in actual practice. I suggest that a maximum discharge is always coupled with the question of maximum boost. There is another point which is of interest—at any rate to engineers in charge of local authorities' stations—namely, the question of loan periods granted for batteries. It is the practice of the Local Government Board to grant seven years. Seeing that battery makers are now perfectly willing to give maintenance periods, say, on an 8½ per cent. basis for fifteen years, I think, if the Local Government Board can see their way to extend that term, it would be a further inducement to local authorities to take up batteries.

Mr. A. H. SEABROOK: There is no doubt that Mr. Taylor's persistent advocacy of batteries, in season and out of season, has caused a number of supply people to look more closely into the question. It has had that effect upon me, and I have given a lot of time during the last eighteen months to this subject. We in St. Marylebone have a problem to get over during the next year, or the year after, of supplying an additional 3,000 k.w., which has to be carried about 2,800 yards from our generating station to our principal distributing centre. Our generating station is at St. John's Wood, on the Regent's Canal, and our principal load belt is a few hundred yards north of Oxford Street, from Marble Arch to Tottenham Court Road. Three-quarters of our output is required there. On going into figures for additional steam plant and cable capacity, I found the capital cost was £57,000, and the cost for a storage battery for 4,000 k.w., at the 1½-hour rate was £25,000 or £26,000. There is thus a big saving on capital, apart from the improvement of the plant load-factor station, and the undoubted economies which may be obtained, and which we know can be obtained from our present experience with the comparatively small **Mr. Seabrook.**

Mr. Seabrook.

batteries we are using at present. In connection with that, the point as to loan periods made by Mr. Pearce is most important. We have just entered into a twenty years' maintenance contract for batteries, and, if a twenty years' maintenance guarantee can be given by the makers, there is surely no reason why the loan should not be granted for that period. In addition to that, the scrap value of a battery is very much greater than the scrap value of ordinary electrical plant. The overall commercial efficiency (71 per cent.) mentioned by Mr. Pearce is rather startling to me, and I shall have to look into some of our figures. I have taken out the kilowatt-hour efficiency of our battery without booster loss for last year, and I found it amounted to 74 per cent. The overall efficiency, including boosters and everything, was 54 per cent. Did Mr. Pearce refer to the ampere-hour or the kilowatt-hour efficiency? [Mr. PEARCE: Commercial over-all efficiency in kilowatt-hours.] Then that figure of 71 per cent. is an exceedingly good figure. With regard to the author's remarks on regulating cells, I do not think they are to be passed over in favour of boosters quite as readily as the author does. It is interesting to hear from Mr. Shawfield that regulating cells are used in America and on the Continent to a considerable extent. On our two existing batteries in Marylebone we found that, owing to the watts required to discharge by means of boosters, we were justified in spending a considerable amount of money in putting in additional end cells, to do away with the boosters during discharge time on peak load. We shall in future, I hope, get some figures which will show an improvement on the overall battery efficiency of 54 per cent. According to the author, the capital cost of end cells as against capital cost of boosters does not amount to very much, but it would be interesting to know if any one has any figures as to the working efficiency in kilowatt-hours as between using boosters and using end cells. It is significant that during the last year or two battery makers have been prepared to extend their maintenance to regulating cells, which they would not do some six or seven years ago. I do not know whether the author can give any information with regard to the number of cells which can be lumped together for each step in regulating. We have tried some experiments, jumping three cells at a time, which has not had any effect on the pressure of distribution. There was no fluctuation in the light supply. There is another point in favour of end cells, namely, that they are more reliable than boosters. The booster is the weak point in the charge and discharge arrangement. The switchgear is much less complicated by using end cells, and the class of men to look after a sub-station need not be so intelligent.

Mr. Andrews

Mr. LEONARD ANDREWS: In reading through Mr. Taylor's paper, my attention was attracted by an apparent discrepancy between the first items in Tables B and C (page 410). The capital cost of the extra 1,540 k.w. of steam plant is given in Table A as being £19,500. Interest and sinking fund at 6½ per cent. on this sum amounts to £1,270, or £1,670 less than the amount the author has included in

Mr. Andrews.

Table C for standing charges on the steam plant. The author makes Mr. Porter and myself responsible for the higher figure by quoting from our paper of two years ago on gas engines,* but I can find no justification in that paper for the figure quoted of £1·91 per kilowatt of maximum demand, which I agree with Mr. Shawfield appears to be much too high. I conclude that the author arrived at this figure by adding to the 6½ per cent. on the capital cost of the 1,540 k.w. of plant, 25 per cent. for additional standby plant, and a *pro rata* charge for increased labour and repairs. [Mr. TAYLOR: The details of that £1·91 are given above Fig. 23. Interest and sinking fund at 6½ per cent. £1·09, repairs 0·5, labour 0·32, total £1·91.] I had noticed these details, but 6½ per cent. on £19,500 only amounts to £0·877 per kilowatt, which led me to conclude that to arrive at the £1·09 per kilowatt Mr. Taylor must have included the interest and sinking fund charges on 25 per cent. of standby plant, which is probably quite justifiable. I contend, however, that it is altogether erroneous to assume that the extra labour and repairs will be directly proportional to the maximum demand upon the generating plant. If, for instance, the labour and repairs on an 8,000-k.w. steam plant amounted to £5,600—the figure given in the revised estimate contained in the reply to the discussion on our paper referred to—and the maximum demand on the steam plant was reduced to 6,500 k.w. by carrying 1,500 k.w. of the peak load on batteries, I am of opinion that the maximum reduction it would be reasonable to expect on the labour and repairs item would be £350 per annum. I consider therefore, that the standing charges on the steam plant should not be taken as being higher than—

| | £ |
|---|---|
| 6½ per cent on £19,500 ... ... ... ... | 1,270 |
| + 25 per cent. extra standby ... ... ... | 318 |
| Extra labour and repairs ... ... ... ... | 350 |
| | 1,938 |

Or £1·26 per kilowatt of maximum demand instead of £1·91.

With this amendment, and accepting Mr. Taylor's figures for the other items, I consider that the correct total fixed and running charges for the generating plant should be :—

| | Fixed Charge per Kilowatt Maximum Demand. | Running Charge per Kilowatt-hour. |
|---|---|---|
| | £ | d. |
| For steam plant ... ... | 3·20 | 0·2210 |
| For gas plant ... ... | 2·98 | 0·0825 |

* *Proceedings of the Institution of Electrical Engineers*, vol. 43, p. 3, 1909.

Mr. Andrews.

These figures still show that a very substantial saving will be effected by installing batteries to deal with the peak load, as recommended by the author. In the general principal of attacking the standby losses as being the most vulnerable spot in modern power station costs, I am entirely in agreement with Mr. Taylor, and his recommendation of combining batteries with steam, gas, or oil engines, as local conditions may dictate, appears to be quite the most promising method of dealing with the difficulty. That standby losses are responsible for a very large proportion of the operating charges of a modern generating plant every one agrees, though opinions differ as to the extent of such losses. Taking the banking of boilers and radiation losses alone, we gave in our paper a figure which corresponded to 0·89 tons of coal per annum per kilowatt of maximum demand, and in the discussion on that paper Mr. Pearce gave results of some tests at Manchester, which appeared to confirm our figure; on the other hand, Mr. S. Donkin quoted results of a 16½-hour test, which showed a consumption equivalent to 0·2 ton of coal per annum per kilowatt of maximum demand. These conclusions are all based on comparatively short trials made under test conditions, and may therefore be misleading when applied to actual working conditions over long periods. On my way through Canada a few months ago, I visited a plant where a battery of boilers was kept under steam for the sole purpose of serving (in conjunction with two 2,000-k.w. steam turbo-generators) as a standby to a hydro-electric supply. I was interested to learn that the banking and radiation losses of this plant amounted to approximately 3,600 tons of coal per annum, or 0·9 ton per kilowatt of maximum demand.

Mr. Duncan.

Mr. E. MacGregor Duncan: Mr. Pearce has mentioned his battery at Manchester, and says he discharges twice a day. I should like to know whether the makers allow him to discharge the batteries under a maintenance contract once, twice, or oftener a day, or do they restrict him to any limited number of discharges?

Mr. Cooper.

Mr. W. R. Cooper (*communicated*): Mr. Taylor's paper, coupled with the remarks of speakers in the discussion, emphasises the importance of working a battery for dealing with peak loads under the most economical conditions, not merely in combination with boosters, but also in regard to the batteries alone. The extremely fine figure of 71 per cent. given by Mr. Pearce for the over-all efficiency at Manchester, including boosters, compared with the much lower figure of 54 per cent. given by Mr. Seabrook for the battery at St. Marylebone, leads me to think that a good deal must depend upon the conditions under which the battery is worked apart from the boosters. This view is borne out by the fact that a buffer battery works more efficiently than a battery used under the usual lighting conditions. Mr. J. S. Highfield* obtained a figure of 84 per cent. for the former and 74 per cent. for the latter. The higher efficiency of the buffer battery is doubtless due to the small range of the charge and discharge curves

* *Proceedings of the Institution of Electrical Engineers*, vol. 30, p. 1070, 1901.

over which working mostly takes place. The most efficient result is likely to be obtained by working over what may be termed the flat parts of the normal charge and discharge curves as far as possible, so as to approach buffer battery conditions. It would be interesting if Mr. Pearce would give full particulars of the method of working at Manchester, so as to show whether these conditions are approached. Mr. Cooper.

Mr. A. M. TAYLOR (*in reply*): Mr. Jenkin remarks that "if we increase the number of the cells sufficiently, the whole of the cell output is available on the busbars," but I must entirely disagree with this. Particularly is this not the case when very rapid rates of discharge from the cells are comtemplated. Let us, however, consider first the 1-hour rate of discharge. Referring to Fig. 4, it will be noticed that, for a 1-hour discharge, 303 cells are required. Of these cells, Nos. 1–275 are fully discharged, Nos. 276–285 are discharged on the average for $\frac{7}{8}$ hour, Nos. 286–290 for $\frac{5}{8}$ hour, Nos. 291–295 for $\frac{3}{8}$ hour, Nos. 296–297 for $\frac{3}{16}$ hour, Nos. 298–300 for $\frac{1}{8}$ hour, and Nos. 301–303 for $\frac{1}{16}$ hour. The battery is thus only equivalent at the peak of the load to 290 cells; in other words, there is 4 per cent. of the current locked up in the cells. The case would, of course, be much worse if we took the 365 cells (see Fig. 4). Mr. Taylor.

Now, with the booster arrangement some 3 per cent. of the battery current is, with the most efficient arrangement, taken up on the average by the booster motor during the discharge; but out of this energy some 2 per cent. is returned to the battery circuit by the booster, the actual loss therefore being only 1 per cent. as against the 4 per cent. of ampere-hours locked up in the regulating cells. There is therefore a net gain of 3 per cent. in the size of the battery by the employment of boosters; with the additional very great advantage that the whole of the cells are equally charged and discharged.

It has been stated in the discussion that the battery makers are prepared to undertake the maintenance at the same rates where regulating cells are employed. It must, however, be remembered that the additional labour and inspection involved in attending to these regulating cells falls entirely on the central station and not on the battery makers; and the labour and inspection charges on a battery installation may become quite considerable and can only be kept down by reducing all items connected with battery maintenance to a minimum. The author knows of two batteries of equal output in the same station, and worked under the same conditions, in which the labour charges were respectively £150 and £450 per annum. These sums were exclusive of the battery manufucturers' maintenance contract. In cases where the batteries are likely to be discharged at higher rates than the 1-hour rate, the above remarks apply with increased force, there being more regulating cells and greater inequality of discharge among them. It may not be out of place to remark that Fig. 9 does not represent the limit of economy attainable before changing to the arrangements shown in Figs. 15, 16, and 17. Mr. Jenkin has apparently taken Fig. 14 to refer to the curves given in Fig. 15, but this is wrong; Fig. 14 being

Mr. Taylor. suitable either for the curves of Fig. 13, or the intermediate higher limit of economy just referred to. He has also misunderstood the employment of regulating cells as shown in Fig. 9. The cells here shown are not really "regulating cells" at all, but "floating" cells. Their function is merely to prevent the battery discharging into the busbars during that part of the day when no discharge is being taken out of the battery and when, for purposes of economy, the main boosters are shut down. The battery, to be available at all times as a standby, must, of course, be kept floating on the busbars. In addition to their employment for "floating purposes," however, these cells also serve the function of compensating for any heavy out-of-balance load, which the static balancer is unable to do. Mr. Jenkin's proposed arrangement of combined regulating cells and boosters is extremely ingenious. As the author understands Mr. Jenkin's proposal, he keeps the current in the regulating switch branch to zero during charge, and during discharge he runs the booster as an inverted motor in such a way as to cause every cell to give the same current. Without going into this proposal in detail the author believes it will be found impracticable to make the charge and discharge ampere-hours of the regulating cells balance out in this happy way, with the result that we are no better off than if we had regulating cells alone. Another difficulty that will probably be incurred is the following: Where a battery is used partly as a standby, it is desirable that at the end of the peak discharge there should still be, perhaps, half of its discharge left in the battery. Now, according to the time of year this will be a continually varying quantity, and it would seem that Mr. Jenkin's booster arrangements could not possibly be accommodated to suit the cells under all conditions; whereas if we rigidly keep the boosters in series with the cells the acme of simplicity is attained. Then, as to the question of the regulating switch being suitable for taking unexpected emergency discharge rates, it has yet to be proved that a regulating switch with its many heavy connections will not be very expensive when it has to be designed to move over a very large number of contacts and to carry, while moving over the contacts, currents approaching the 5-minute rate of the battery discharge. These conditions will, I believe, be more simply met by an automatic switch which short circuits the booster busbars (where the boosters are in series with the battery), and at the same time wipes out the booster field and opens the circuit of the booster motor. The money to be spent is thus restricted to dealing with a single pair of contacts instead of having to deal with the same current perhaps 30 or 40 times over.

Mr. Shawfield complains that the paper does not deal sufficiently with the coal economics. On this point I may explain that this is because I am in substantial agreement with Mr. Andrews' treatment of the the subject in his paper on "The Use of Gas Engines for Generating Electric Power." * Mr. Andrews there adopts a method of calculation

* *Proceedings of the Institution of Electrical Engineers*, vol. 43, p. 3, 1909.

Mr. Taylor.

which lends itself to any load factor and any station. In my reply to Mr. Andrews, Mr. Shawfield will find further particulars as to boiler stand-by losses. I do not agree with Mr. Shawfield that there is no advantage in being able to discharge the battery at higher rates than the 1-hour rate. It seems to me that this is entirely a matter of the proportion of the station output borne by the battery at its 1-hour rate. If, in a station having a 20,000-k.w. maximum demand, batteries are only put in for, say, 4,000 k.w. for 1 hour, it might be exceedingly inconvenient to be unable, for, say, ¼ hour, to increase this to 12,000 k.w. If, on the other hand, they were put in for 8,000 k.w. for 1 hour, it would be equally useful if they could be employed at a correspondingly higher rate for only half an hour. I know of a large station in this country where probably this would have just saved a serious breakdown. Mr. Shawfield questions my total of £43,500 for the fixed charges for a station of 11,200-k.w. maximum demand, as in Fig. 19. The figure of £3·89 per kilowatt on which it is based is given in detail in Table C of the paper, and consists of the following items: Interest, etc., sinking fund, labour, and repairs at generating station = £1·91 per kilowatt; rates, taxes, and insurance = £0·25 per kilowatt; "standby coal" = £0·79 per kilowatt; interest, etc., on E.H.T. mains, rotaries, etc. = £0·42 per kilowatt; repairs on E.H.T. mains and in sub-stations = £0·195 per kilowatt; labour in sub-stations = £0·097 per kilowatt. As regards the item £1·91, I must refer Mr. Shawfield to Mr. Andrews' paper (see also my reply to Mr. Andrews, *loc. cit.*). The item for rates, taxes, and insurance is based on the assumption that if the batteries are put down only at the sub-stations and are paid for out of revenue, the observed maximum demanded at the generating station would remain stationary, and there would be no justification for an increased rating (see also article in the *Electrician* for December 4, 1907, for further consideration of this point *). In taking only £0·25 per kilowatt per annum for rates and taxes, I am taking only one-quarter of the figure obtained upon the whole undertaking at Manchester. The standby coal is, no doubt, debateable; but here again the author is only following Mr. Andrews, whose figures do not greatly disagree from some obtained by a different method (see *Electrician, loc. cit.*). Mr. Shawfield is evidently thinking only of the plant at the generating station, whereas I am considering the cost of delivering direct current to the sub-station bars 1 mile away, which adds another £7 per kilowatt to the capital cost, as shown in Table B. Mr. Andrews considers that I have not quoted him correctly. My figures were, however, taken from Mr. Andrews' paper, and I have since verified the items challenged, and find them quite correct. The figure of £1·91 per kilowatt is deducible directly from Mr. Andrews' own figures. If we add together £2,590 (labour), £4,000 (repairs), and £9,050 (interest, etc., on capital), and divide by 8,000, k.w. we get £1·91 per kilowatt per annum. The £9,050 is obtained by taking 6½ per cent. on Mr. Andrews' own figures of £13·95 per kilowatt. The other

* *Electrician*, vol. 62, p. 395, 1908.

Mr. Taylor. two figures are his own.* The way in which I looked at the extra cost of labour and repairs was quite different to what Mr. Andrews suggests. What I contend is, that if, in a station with a steady developing load, we stop putting in steam plant for three or four years and put in batteries instead, we make savings in labour and repairs which are nearly proportional to the reduction in the maximum demand from the demand which would otherwise have obtained. Some time ago I published figures † which showed that, at Manchester, the charges for labour and repairs were a nearly constant figure per kilowatt during the growth of the station demand from 10,000 to 15,000 k.w.; the first item, in fact, rising quite materially above mere proportionality. The charges for rates and taxes kept virtually constant over a very much greater range—actually up to 30,000 k.w. If we think only of the diminution in labour and repair charges caused by putting in batteries (to the small value of 1,450 k.w.) in a station already equipped with the full amount of steam plant to meet its load without any help from the batteries, no doubt Mr. Andrews is right. But, supposing that the station has now a maximum demand, say, 10,000 k.w., and that we now put in batteries to deal with another 5,000 k.w., would it not be right, in view of the Manchester experience, to assume that the labour and other fixed charges on those extra 5,000 k.w. would have been proportional to the kilowatts, and, therefore, would have been entirely saved by employing batteries? It seems to me that it would.

Mr. Andrews accounts for £1,625 out of my £2,940; but if he will take labour and repairs at his own figure of £0·824 per kilowatt he will account for another £1,270, leaving only £45 unaccounted for, which is negligible. Mr. Andrews, in his paper on "Gas Engines," made the "standby engine-hours" and the "banked boiler-hours" account for 5,140 and 3,330 tons of coal respectively, representing money values of £3,850 and £2,485 respectively. This works out at £0·79 per kilowatt of maximum demand per annum, which is the figure quoted by the author in Table C of his paper. In the notes against Fig. 23 of his paper, however, he has, to be safe, taken only two-thirds of this amount, or £0·52 per kilowatt per annum. Some four years ago, when investigating this subject, I obtained a figure equalling the above £0·79 per kilowatt by assuming that the true "running cost for coal during the year should only be that which might have been expected in generating the units turned out during the year under "test" conditions, and that the difference was due solely to standby losses in engines and boilers. It is interesting that Mr. Andrews' figure, obtained in quite a different way, should agree quite closely with the figure so obtained.

I am fully in accordance with Mr. Pearce's remarks, except that I cannot agree with his statement that the boosters at Manchester are put in on the best possible lines. But his arrangements, at the date of carrying out his installation, were undoubtedly the best in the market. As regards my remark about the Manchester boosters being inadequate

* *Proceedings of the Institution of Electrical Engineers*, vol. 43, p. 30, 1910.
† Ibid., vol. 44, p. 647, 1910.

Mr. Taylor.

for discharging the battery at emergency rates, I desire to withdraw this; though the remark was qualified by the phrase "or to draw upon spares," which appears to be correct. At the same time, I think I could undertake to halve the cost of Mr. Pearce's boosters, and so save about £1,000 initial outlay, and also save some £50 per annum in booster losses. I regret having to dissent from Mr. Pearce when he speaks of the "series-parallel arrangement" at Manchester being so successful. He has *no series-parallel arrangement whatever* on his lighting side (according to his published diagrams of connections), and only a "double-series" arrangement on the traction side. This latter feature was quite an accident, and merely got introduced owing to the fact

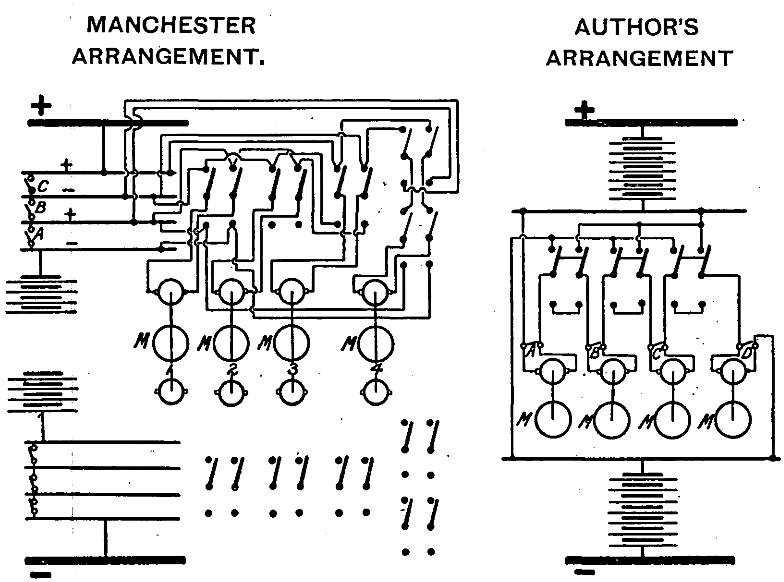


Fig. B.

that, as Mr. Pearce wanted the same battery to do duty for busbars whose respective pressures were 450 volts and 525 volts, the boost on discharge had perforce to be doubled on the traction side. The accompanying diagram (Fig. B) is given in order to illustrate the clumsiness of the "multi-busbar" switching method, where three boosters are working and one is a spare, in the (almost universal) case where it is desirable to keep a connection with the neutral wire of the 3-wire system, as compared with the method proposed in the present paper. Fig. B shows the Manchester method on the left-hand side. It will be seen that this involves four double-ended boosters, whereas my arrangement involves only single-ended ones; it also involves 8 busbars, each equal to the full current output of the battery, 8 short-circuiting

Mr. Taylor. switches, each equal to the full current output, with 2 double-pole single-throw and 8 double-pole double-throw switches, each equal to the output of one booster; whereas the author's proposal only involves 2 busbars and 4 short-circuiting switches, each of only the section for one booster, and 3 double-pole double-throw switches. Even if we sacrifice the neutral connection, Mr. Pearce's scheme involves 4 busbars, 4 short-circuiting switches of full section (8,000/17,000 amperes), 1 double-pole single-throw, and 4 double-pole double-throw switches. It is no easy matter to accommodate these heavy busbars, and 4 switches each for 8,000/17,000 amperes will cost more than double, if not treble, what the same number of switches for 2,000/4,400 amperes would cost. As regards complication, I submit that my method is the simpler. It is, however, quite easy to keep the board simple when only two boosters are employed in series, as at Manchester. It is interesting to hear from Mr. Pearce that his saving in coal pays four times over for the losses due to the inefficiency of the battery. The author in his paper of 1908* before the Incorporated Municipal Electrical Association claimed to demonstrate that this "inefficiency" scare was groundless, and to show that there should be a decided net saving in coal. It has, however, been left to Mr. Pearce's enterprise to demonstrate in practice that this is so, when batteries are used in a really serious way. With regard to Mr. Pearce's remarks on "the additional loss when charging," I do not propose to labour this point, as I think it is demonstrable that there are no additional losses when charging, but, on the other hand, a great gain; and I believe that Mr. Pearce will admit this on fuller consideration. If correct, it would at once discredit regulating cells, on the ground of economy alone.

Mr. Seabrook will find his remarks as to regulating cells dealt with quite fully in my reply to Mr. Jenkin. With regard to Mr. Seabrook's inquiry as to the inefficiency in kilowatt-hours of boosters as against end-cells, I would submit that the question is not here altogether one of efficiency. An unnecessary investment in cells, which take up the attendants' time and also incur maintenance charges out of all proportion to the work done by them, may be quite as inefficient as a booster wasting a definite number of kilowatt-hours.

I am of opinion that boosters will be found increasingly useful as the batteries are used on the higher discharge rates, and regulating cells where the reverse is the case. In any case, either "floating" cells or a "bucking" booster (which can be kept very small) should be used for the periods when the battery has to "float" on the busbars. From a consideration of the charge and discharge curves I feel satisfied that the losses in the boosters, on the triple-series method, will not be more than 1 per cent. of the output on the discharge and another 2 or 3 per cent. on that of the charge, giving a booster efficiency of 96/97 per cent. Regarding the grouping of end-cells for switching purposes, the New York "Exide" batteries employ 32 single-cell and 12 triple-cell con-

* *The Electrician*, vol. 61, p. 480, 1908.

tacts, and the other 82 cells in the main battery; *i.e.*, 150 cells in all, across the outers of the 3-wire system. The arrangement gives one cell per switch-point round about the "floating"-point, and more rapid cutting-in towards the end of an emergency discharge. Good results are stated to be obtained with this arrangement. I understand that a uniform distribution of two cells per point is common practice in Germany. **Mr. Taylor.**