ELECTRIFICATION PROJECT
THE ILLINOIS CENTRAL RAILROAD COMPANY
SUBURBAN SERVICE AT CHICAGO, ILL.

BY TRACY W. SIMPSON
ELECTRIFICATION PROJECT
FOR彈力發電機化電力供應
TRIENAL SERVICE AT CHICAGO, ILL.

In
CHICAGO, ILLINOIS.

A STUDY
SUBMITTED TO THE FEDERAL AND MARITIME
OFFICERS OF NAVAL ENGINEERING
AND
ADMIRAL OF THE NAVY

MAY 1909
To the Council and Faculty of the Department of Electrical Engineering of Argonne Institute of Technology, Chicago, Ill.

Gentlemen:

I have the honor to submit herewith a thesis for the degree of

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

This thesis is a study of the suburban system of the Illinois Central Railroad Co. at Chicago, Ill., with particular reference to its operation by electric motive power. In addition it is an exposition of certain methods of procedure for attacking a problem of this kind, and also it includes various studies of engineering interest that are related to the general question of the electrification of steam railroads. In these last respects the work necessarily differs from an engineer's report to the railroad company as client; but as far as possible, these technical descriptions of method etc. have been included as appendices.

Respectfully submitted,
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The suburban service at the晖辉on the Illinois Central railroads is at the present time, the best example of such service operated by steam locomotives to be found in the United States. It has long been regarded by the railroad company as an important and integral part of the company’s business and the excellent manner in which the equipment is operated and maintained, and the general comfort of the suburban service is operated show conclusively the successful operation under which it is operating. These conditions are in distinct contrast to the policy of some suburban steam railroads who allow the suburban service to take one of last, sometimes as it actually happens very good locomotives are sure to any service to have available.

Certain conditions following the completion of the 1893 World's Fair led the company to consider the opportunity to institute a suburban service in advance of the Chicago system, and took the opportunity and engaged one of the centers of railroad history. The far sighted policy ever begun one has continued along many lines ever. Perhaps the most apparent example of this has been the construction of the multiple tie four suburban car in 1893, a type to which all indications point of the next design of small transit service.

In view of the success attained upon the recent change to electric operation on some portions of the New York Central, Long Island, Pennsylvania, and Erie railroads, it is particularly important to indicate at this time regarding the applicability and operating results.
to be expanded due to a decrease from climatic electric operation for the suburban service of the Illinois Central Railroad Company. In
1904, the company explored a commission to investigate the feasibility of electric operation for the service, but owing to the incomplete state of development of electric railways and theory, the commission was satisfied with a short report only. Since that time electric railways equipment has attained a high degree of excellence, and although many questions of machinery policy still are close to argument, the way is very clear for a final decision to be made and some operating results to be received by the public.

ILLINOIS CENTRAL

For the short line, a territory served by the
1. . . . . 1. electric service, from Hammond to Grand Junction
the railroads traversed are mostly settled residential districts providing
a heavy passenger traffic. From Great Crossings to Hammond, the country
is mainly unoccupied and has not been developed or occupied into the ice
elevation. At Hammond are all that the extensive scope of the railroad.
Mineral and manufacturing districts are noted. Hammond is the headquarters of the Illinois Central Railroad which runs to New Orleans, on the Mississippi River, and into New York. It is also the headquarters of the Chicago Lake Shore and South
Sand. A high class interurban electric railroad operating a single
track road to South Bend, Hammond the Big Bend, Gary, and Michigan City.
That portion of the road from Hammond to Hammond is owned by a
subsidiary Illinois Central corporation, — the Hammond and Eastern.
The railroad uses single phase current and operates single car trains on a one hour headway at maximum speeds approaching 50 m. p. h.

South of Kensington the town of Survey has 6000 inhabitants and is a thriving residential and manufacturing town. From Survey to the terminus of the suburban service at Rossmoor, the country is rolling and above the Chicago Plain. The chief town is Homewood of 6000 inhabitants. At Rossmoor is situated the Homewood Country Club. For east of the region south of Grant Crossing to Survey, a great development is expected when the Calumet Drainage Projects are completed; but at present the tendency is to retrogression in most of the Calumet region. South of Survey the country is undergoing healthy development as a high class suburban residence district.

The South Chicago branch remains a combined residential and industrial territory. Here are situated the Illinois Steel Co. South Works, and the Dearing Works of the International Harvester Company. The Blue Island branch reaches excellent suburban country west of Kensington. East Bullman in the chief town. Here are the Pneumatics Works of the International Harvester Company, etc. Blue Island has 6000 inhabitants, but is well served by the South Island suburban system.

Following is a table of distances in miles from Buckingham St., the distances between stations for all points on the S. C. I. R. suburban system.
Train service from Van Buren St. is divided as express or local.

Express trains run from Van Buren St. to Hyde Park without stop, on the east pair of tracks of the right of way. These have been isolated from the other trains, not halted at interchanges or crossovers so that delays rarely occur. From Hyde Park to 67th St. these separate tracks are used for the express service. At 67th St. the express trains
continue to South Chicago, Florsmoor, or Blue Island as the train may be designated. Local trains run from Van Buren St. to Woodlawn on the west pair of tracks. Local trains stop at all stations shown on Fig. 1 between these points. Local trains are made up of multiple side door cars, whereas all other trains are the older type car with end doors.

Various classes of train service are provided, some details of which are shown in Table II. This line is compiled from a summer week-day schedule. In winter some Florsmoor trains run only as far as Harvey. In addition to the trains noted in Table II, there are a few trains during the rush hour which cannot be included in the classification of Table II. Usually one express each to Joliet, West Pullman, and Hazel Crest is provided. These trains have been considered as regular trains to Florsmoor and Blue Island in compiling the table. A service of four trains a day each way is provided on the Rockford Division, between Randolph St. and Addison, 24.1 miles. These leave city via St. Charles Air Line. Further details of the present steam schedule are included in the printed time table of the service a copy of which is included herewith as Table III and from which Table II has been compiled.

**Table II**

**DETAILS OF TYPICAL PRESENT STEAM SERVICE**

<table>
<thead>
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<th>Distance (Miles)</th>
<th>Local</th>
<th>Express</th>
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<tbody>
<tr>
<td>7.2</td>
<td>12.9</td>
<td>16.0</td>
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<tr>
<td>10.3</td>
<td>14.3</td>
<td>16.3</td>
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<tr>
<td>14.3</td>
<td>18.3</td>
<td>20.3</td>
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<tr>
<td>20.3</td>
<td>22.3</td>
<td>24.3</td>
</tr>
</tbody>
</table>

**Schedule Speed (M.P.H.)**

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<table>
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<tr>
<th>Service Type</th>
<th>Weekly Cost</th>
<th>Daily</th>
<th>Midday</th>
<th>Evening</th>
<th>Morning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus at 67th</td>
<td>$42</td>
<td>$15</td>
<td>$10</td>
<td>$10</td>
<td>$10</td>
</tr>
<tr>
<td>Express academy</td>
<td>$30</td>
<td>$20</td>
<td>$20</td>
<td>$20</td>
<td>$20</td>
</tr>
<tr>
<td>Express academy</td>
<td>$20</td>
<td>$20</td>
<td>$20</td>
<td>$20</td>
<td>$20</td>
</tr>
<tr>
<td>Total number of rides per day each way</td>
<td>119</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note:
- Includes 18 right transfers within local to prevent and continue to Connecticut.
- Midday service only.
- evening service only.
- Includes all stops except Daniel and Second, and other than including 63rd and 72nd.
- Includes all stops except 63rd and 72nd.
- Includes all stops except 63rd and 72nd.
- Includes all stops except 63rd and 72nd.

For more details, contact the proposed site via email or call 123-456-7890.
At the present time midday locals are two car side door trains, and midday express trains average four cars. Rush hour locals are either three side door cars or six end door cars. Rush hour expresses are usually made up with seven end door cars.

**TRACK AND ROADWAY.**

Figures 2, 3, and 4 show profile and alignment for the suburban tracks as well as other features of permanent way; - types of ballast, and weight and age of rails. Fig. 5 shows in greater detail the yards of the company at Chicago terminal as far as they are related to the suburban service. From Kensington south to Florence, the suburban trains operate on main line tracks; but from Kensington to Randolph St., they occupy tracks devoted exclusively to suburban service. From Van Buren St. to 67th St., east tracks are used for express trains and loading platforms separate from the local platform are provided. Express tracks are cut into by crossovers only at 27th St. and 43d St., in the entire 7 miles between 12th St. and 67th St. At 12th St. all incoming express trains stop for signal at the combination switch before proceeding across the yard tracks to track 2. The yards of the company are arbitrarily divided at this point so that it is only on rare occasions that a train is delayed due to freight switching. Under agreement with the City of Chicago, that portion of the right of way extending from 12th St. to Randolph St. must contain no structures reaching above the retaining wall marking the edge of Lake Front Park. When the new outer parkway is completed, the right embodied in this agreement is liable to be most carefully guarded. This fact has an important bearing on the question of proper structures for a power distributing system with electric operation.
There are no grade crossings north of Drexel. From 61st St. to Drexel the tracks are elevated and streets are crossed on viaducts of the usual plate girder type. It is as yet undecided whether there shall be separation of the grades of the Illinois Central R. R. and the Pennsylvania R. R. at Grand Crossing. All grades are very light, and there are no curves for which a slow down in speed is required by suburban trains.

The total track mileage operated in the suburban service is 30.0 miles including sidings at Randolph Street.

STATIONS.

The type of station employed usually consists of a frame or brick depot built adjacent to the right of way with a loading platform, usually of the island type, to which admission is had by means of turnstile at the ticket seller's window. The platforms are raised to the level of the car floor (4 ft. above rail), and are provided with shelters and canopy roofs. South of Kensington, where main line tracks are used, the platforms are at rail level and hence egress from car is by means of steps. At Randolph St., six tracks are served by three island platforms admission to which is by means of steps leading from an overhead covered bridge spanning all the tracks. At Van Buren St. a suburban station has been provided, comprising a station building 300 ft. long and 60 ft. wide, as well as platforms aggregating about 1000 ft. in length along each side of tracks 1 and 2. Two trains can be loaded at once at Van Buren St. The main depot of the railroad is
located at 12th St. Electric trains do not enter this station. There
is located, however, near it, a complete local suburban station but it
is operated independently. The average length of station platform is
250 ft. This will permit loading a train of eight standard suburban
cars or all five side door cars.

The stations, approaches, and platforms, including also the
several offices at central station, are lighted by incandescent and are
larger supplied with current from a separate service plant of 20th
St. All suburban stations as far north as Lansing Road are supplied
from this system (not until Orleans branch). Transmission is from
600 to 1,100 kw and 1,000 to 2,200 kw generator at 4600 volts 60 cycle 3 phases to transformers at local substations.

WILLIAM STOOG

There are in use 40 locomotives of the rear tank type built
especially for suburban service. The various classes now in use and
various items concerning them are given below in Table IV.

<table>
<thead>
<tr>
<th>CLASS</th>
<th>SPECIFICATIONS</th>
<th>I. C. N. R. SUBURBAN LOCOMOTIVES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C-248</td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>No. of use</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>16222</td>
<td>17x24</td>
</tr>
<tr>
<td></td>
<td>16x22</td>
<td>16x24</td>
</tr>
</tbody>
</table>
Under bad weather, the train is delayed.

<table>
<thead>
<tr>
<th>Section</th>
<th>Time</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4-2</td>
<td>143</td>
<td>143</td>
</tr>
<tr>
<td>4</td>
<td>163</td>
<td>163</td>
</tr>
<tr>
<td>8</td>
<td>183</td>
<td>183</td>
</tr>
<tr>
<td>16</td>
<td>203</td>
<td>203</td>
</tr>
<tr>
<td>20</td>
<td>223</td>
<td>223</td>
</tr>
</tbody>
</table>

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These are obtained from stop watch tests of the time required for a train to travel various distances up to its own length. In all cases best performances are tabulated. The performances agree fairly well with calculated results on the basis of adhesion. The observed accelerations are not continued for any length of time, almost immediately after a train had traveled about 300 ft., the process of notching up was begun which reduced the rate of acceleration. The speed at which this notching up of the link mechanism is begun is about 17 m.p.h. This is about the point of maximum horse power of the locomotive. On this basis the net horse power of the various locomotives appears as from 500 N.p. for the 2-4-4 type to 400 N.p. for the 2-8-2 type.

From data of Table V and from other time-distance tests, Fig. 6 is derived. This is a speed-time curve from run of 0.616 miles as performed by present steam equipment. It is the estimated best performance of a 2-6-4 locomotive hauling three side door cars loaded, and also represents fairly well the best performance of a 2-4-4 locomotive hauling two side door cars.

The cars used for the Pullman service are of two types, the multiple side door car and the standing 6 door day. The side door car is at present used on the regular local trips. If of these cars are used in trip, Table VI shows comparative data regarding these types of cars.

<table>
<thead>
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<th>Table VI</th>
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</thead>
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<td>COMPARATIVE PERFORMANCE, M.P.H. AND TON MILES FOR 90 M.P.H.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Multiple</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side Door</td>
<td>61</td>
<td>61</td>
</tr>
<tr>
<td>Length over all Ft.</td>
<td>71</td>
<td>71</td>
</tr>
</tbody>
</table>

- 20 -
The side door cars are strongly built. A complete steel
framework is provided composed of four longitudinal 5 in 11 lb. I
beams (see transverse 6 in. 7 in. 16 lb. I beams between two and sills
of 3 in. 25 lb. gauged). Diagonal bracing and gusset plates are used
all corners for 11 rod bolster support. The floor is 1/4 in. deck plates
placed directly on circular. The super structure is semi steel
construction. The side doors are operated by compressed air and an
electric signal control is arranged so that when all doors on train are
closed, the bell is immediately communicated to the engineer. These cars
have been in use for five years and have given good satisfaction in hand-
ling trains. The signal device works perfectly, contradicting the
assertions of certain railway engineers that such a device is impracti-
nical. The cars are necessarily heavy an account of the necessity of
comprising all supporting strength in the underfloor; it being impossi-
able to frame around the side above.

The short above note regarding the use of those side door cars
is a matter of importance in car service. The writer has frequently
seen a three or four car train of side door cars loading at Van Buren St.
during the rush hours when 100 to 200 people board the train. Duration

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of goods ever went as 10 seconds were heard elapsed and 5 or 10 feet and the
writer observed 12 seconds to be unusual. The other stations did
receive as well as satisfactory, that at 12-15 seconds sufficient
for a complete station also saving real time. With a train of about
3000 and 1000 cars, the rotation of station stop at 30 miles an
hour from 10 to 15 seconds, depending on other train composition. At these
stations, the trains are from 10 to 15 seconds during real time.
The train doors are opened to more than 60 to 70 seconds per stop as compared
with the usual 5 or 6 sec. one enormous advantage would deserve at
the time of the train traffic just when such a saving is the most desirable.

Another distinct advantage of this type of car is the impossibility
of any personal collision as well as of any personal injury
involves the train. This eliminates personal injuries as a factor
of operation. The greater safety in the event of accident to the
heavy construction also does not in an important consideration, but is not so
dangerous in the case of the modern train, as for the average train operating
at higher speeds. A collision or rear end collision in the
heavy train, to back such a train up, where it stopped is approximately
10 miles, would be extremely disastrous with present and near cars and,
for this service, one is available that is filling at least.

Henry W. Millard

Besides the six loading tracks at Washington St., there is provide
the storage track available for additional cars, a capacity 7000 ft.
In length. This will provide room for 20 side door cars. The loading
are two in number, extending from Randolph St. to Harrison St., and are directly east of tracks 1 and 2 as shown in Fig. 5. If the outer suburban terminal ample storage siding are available which can be easily extended. Light ray clearing and inspection is done on the downtown storage tracks. The locomotive storage yard, clearing and inspection sheds are at 36th St.; with an auxiliary clearing station at Randolph St. It is customary to dispatch locomotives released at Randolph St. to 36th St. immediately.

The main line repair and locomotive shops are at Burnside at the general company shops.

**SIGNAL SYSTEM.**

The present suburban tracks are protected by electric block signals of the Hall Manjo type. The suburban tracks are controlled at the point points on the main line tracks by means of signals mounted on overhead bridges spanning the entire set of tracks. In addition to these, other signals are provided where necessary, mounted on standards adjacent to the track controlled. These signal positions are indicated in Figs. 3, 4 and 6. Simple block signaling only is provided, no overlap signals being used.

**CONCLUSION OF PRESENT SUBURBAN SERVICE.**

The preceding paragraphs have briefly described the physical equipment of the present suburban service. The writer has been unable to obtain figures of earnings and operating costs,
the omission of which leaves need to be desired. A general statement that about 1,000,000 passengers are carried per annum must suffice to show the extent of the present traffic. There are, however, certain facts evidencing the need that are plainly apparent. The suburban traffic is decreasing on account of the competition of the rehabilitated lines of the Cudahy City Railway and of the South Side Elevated R.R., Fig. 7 shows the relations of these lines to the I. C. R. R. stations in 1905 and in 1906.

The Chicago City Railway has in use 40 ft. double truck cars each having 4-40 H.P. motors, which have been substituted for the cable equipment and single truck electric cars. The speeds have been increased and routes provided that permit travel to the city from Illinois Central territory without transfer. The lines on which these cars operate are in direct competition with the Illinois Central R. R. at Grand Crossing, 67th St., 47th St., and 49th St. In addition, it parallels the I. C. R. R. from 39th St. to Randolph St. From each of these points a through run can be boarded at least every 5 minutes during the day, and for a five cent fare.

The operation of these improved cars has had a very depressing effect on the earnings of the South Side Elevated Railway, and it is reasonable to expect that an even greater effect is felt by the Illinois Central Railroad.

The South Side Elevated R. R. has instituted an express service during the rush hour between 43rd St. and the Union long without stop. This decreases by 5 minutes the running time from all stations south of 43rd St., into the city. This service attracts many passengers who would otherwise use the Illinois Central Railroad from Woodlawn station. The elevated road has also built a line tapping the
residence section of Eversmo with a terminal at 3rd St. and the I. C. R. R. right of way. This line connects with the 3rd St. station and utilized stations for traffic. Space is provided express service from the line into the city during rush hour, and direct local service during the day. The Eversmo branch carries 4,000 passengers a day from the five stations, three of which are within easy walking distance of the 3rd St. or various stations of the I. C. R. R.

Table VII shows the comparative running times for the United Loop in the case of the 3rd St. line to the Sherman St. station in the case of the I. C. R. R. as noted for the years 1900 and 1908. This illustrates the advance of the so-called Lake St. or a factor in the development for traffic.

**TABLE VII.**

<table>
<thead>
<tr>
<th>Station</th>
<th>3rd St.</th>
<th>3rd St. Local</th>
<th>3rd St. Express</th>
<th>3rd St.</th>
<th>3rd St. Local</th>
<th>3rd St. Express</th>
</tr>
</thead>
<tbody>
<tr>
<td>43rd St.</td>
<td>10 min.</td>
<td>20 min.</td>
<td>30 min.</td>
<td>40 min.</td>
<td>25 min.</td>
<td>30 min.</td>
</tr>
<tr>
<td>43rd St.</td>
<td>15 min.</td>
<td>20 min.</td>
<td>30 min.</td>
<td>45 min.</td>
<td>25 min.</td>
<td>30 min.</td>
</tr>
</tbody>
</table>

In addition to the improved running times as noted in Table VII, the Lake W. L. elevated provided the passengers at least two blocks nearer the business district than does the Illinois Central.

In addition the train service is more frequent and cleaner, and the
rate of fare is 8 cents as compared with 10 cents on the I. C. R. R.

The effect of this acute competition of the street and elevated railroads is not greatly apparent at any express station, except Woodlawn, during the rush hours. For stations between Woodlawn and Hyde Park the effect is a decrease in the area from which the I. C. R. R. draws its patrons. Persons living a considerable distance from the stations now take the street railway when formerly they walked to the I. C. R. R. station.

The local service has suffered extremely from this competition. The introduction of the side door car has not seemed to make more attractive the suburban system when compared with other modes of travel.

The Woodlawn branch of the 50th St. Elevated R. R. has taken practically all the suburban business away from Oakland and 43rd St. stations. The Woodlawn (49th St.) station appears to be the only station on the entire suburban local line that provides a vigorous business. The local platforms at stations from Woodlawn to Hyde Park, and also largely at Madison Park, have for a long time been filled only with those who have "just missed the express".

The competition of the surface and elevated lines is most apparent during the middle of the day. At this time the I. C. R. R. trains are operating on a 20 minute headway whereas elevated trains at 43rd St. leave on a 5 minute headway, so that from the 43rd or Oakland district it is an even chance that a passenger will arrive in the city as quick by the elevated as by the I. C. R. R. During the rush hour the service
of the elevated is almost certain to reach the city quicker. The surface lines divert a greater percentage of traffic from the I. C. R. during the middle of the day than they do during the rush hour. This is for the reason that the time of journey is of less importance during the middle of the day than during rush hours; and convenience, cleanliness, and frequency of service are uppermost in the mind of the patron.

The considerations in this section are of course incomplete without tabulated figures of traffic and ticket sales, but it is believed that such figures if provided would merely indicate the degree of the conclusions noted above, rather than to controvert any of them.

CONCLUSION

Provided the facts are as above stated it seems advisable to undertake the complete rehabilitation of the suburban service in order to regain its former patronage and to receive the full benefit from the ever-growing population along its lines.

Rehabilitation along the lines suggested below will be sufficiently complete to securing the desired result.

1. Double the frequency of train service over all lines during the middle of the day.
2. Reduce rates of fare on the suburban local trains to a uniform 3 cent fare.
3. Provide more rush hour trains with greater seating capacity.
I. Operate express trains on Sundays, and in the evening.

2. Increase schedule speed 20% or more.

The best method of obtaining these results, and in fact the only feasible method with present physical limitations of terminals and locomotives, is to change the motive power of the train from present steam locomotives to electric operation by means of motor distribution throughout the train, and controlled by a multiple unit system. It will be shown that the results desired can be obtained with a simpler equipment and power distribution system which is economical, reliable, and in accord with best modern practice. In addition, it will be shown that this method of operation has decided advantages as far as operating expenses are concerned which in themselves are almost sufficient to recommend the adoption of an electric system. The chief argument for electric operation, however, is that it will permit applications of service as regards frequency of trains, speed, and reliability as to cause a decided increase in traffic—a result obtained by no other method except electric operation of trains.

It is necessary to establish certain working assumptions regarding the service as a whole, to be used in the investigation of the proposed electric equipment. These assumptions are considered below in detail.

APPENDIX B: PROPOSED EQUIPMENT

I. Complete estimates are prepared relating to the equipment of the entire subway service with the exception of the service to
II. In addition, there are prepared estimates relating to equipping the entire suburban service with the exception of the Addison Line, but with a total car miles per annum equal to that now operated. Amplification of service as regards frequency and speed of trains is the same as for Estimate I, but the number of cars per train is decreased to accord to present requirements. Page 34

III. An estimate is prepared for the equipment of the Woodlawn local service only, with the idea that a uniform five cent fare be instituted on this line. The peculiar advantages of electric traction would be most noticeable for this type of local service, and the installation would be advisable as preliminary to the equipment of the entire suburban service. Page 35

IV. Finally an estimate is given for the equipment of the Woodlawn local service and of the express tracks from Van Buren St. to South Chicago and Grand Crossing. These are worked out on a basis similar to Estimate I, but with the idea that there would arise no particular advantage in extending the electric zone beyond this point. Suburban passengers are to be transferred to steam operated trains at this point. Pages 36 and 37.
An important question of engineering policy relating to the system of electric traction arises when there is considered the probability of more extensive electrification of our future date. The state of Illinois will undoubtedly bring pressure upon all the incoming railroads to operate electrically inside its city limits. In addition, certain engineers have predicted that long sections of trunk line railroads would soon be equipped with electric locomotives for freight and passenger service. Their argument is largely that of decreased operating expenses that more than warrant increased capital charges with electric equipment.

If either of these possibilities should occur in the case of the I. E. R., the fact should be considered in determining the best system of electric operation for the suburban service; since the system giving best results for trunk line service or for heavy terminal service, is not necessarily the one best adapted for the suburban service. If there is any reasonable assurance of future extension along these lines, it would undoubtedly be desirable to sacrifice some features of the suburban service equipment in order that there may be unity of system and flexibility of operation at some future date when all extensions are completed.

It is not the intention of the writer to investigate the probability of trunk line electrification or of heavy terminal electrification for the suburban service. As a matter of fact the assumption is made that the probability of trunk line electrification...
is too remote in the sense of the R. R. Co. to warrant any consideration. There is some possibility of the occurrence of the terminal electrification of the through service with the idea of eliminating smoke nuisance; hence the system of electric traction to be adopted must be such as to be adapted to this terminal service if necessary. Moreover, the influence of this consideration on the design of suburban equipment is taken as very slight; and that system of electric traction giving best results for suburban service is assumed the proper one to use for the terminal service as well.

THE DE HAB

It is assumed that the standard 61 ft. multiple car type can be used for the electric service. (Fig. 71.) Notice of tenders for additional cars for main line trains, the side doors will not be used since the usual ground level platforms prevail. Entrance and egress will be by the means of the usual steps at the end of each car. The traffic at these stations is comparatively light; and the absence of the sliding gate principle will have but little effect on the function of station stops. The arguments in favor of this type of car in the usual local line have been noted and the adoption seems advisable for the entire electric service. It is practically a fire-proof car, a desirable feature when electric operation is used. The adoption of this type permits the equipment of the present side door cars with electric motors and apparatus to convert them into standard electric multiple cars. The objection to adopting this type of car is that platforms at Cheltenham, South Shore and Blue Island must be relocated since the side door cars cannot
will be loaded on a curved platform with a curvature exceeding 2 degrees.

Certain changes in construction of the side door cars are necessary to adapt it for electric operation, but these are of a minor nature.

**MAIN OPERATION.**

This study is based on the operation of side door cars in trains equipped with motors throughout the train, the whole controlled by one motorman by means of multiple unit control. This is the universal practice of elevated and subway railways, and is followed by the electrified suburban lines of the New York Central, Long Island, West Jersey and Sea Shore Railways, etc.; and by all interurban railways that operate cars in trains. The advantages of this method as compared with operation by electric locomotives are briefly as follows:

1. Increased rate of acceleration due to greater weight available for traction.
2. Decreased total train weight.
3. More efficient terminal service.
4. Increased motive power proportionate to increase of length of train.
5. Less wear on track due to distribution of weight.
6. Permits the use of one and two car trains to be run economically during slack hours.

In order to provide interchangeability of suburban equipment it is necessary that all motor cars shall have identical equipment as regards motor equipment and gear ratio.
The maximum speed of the present express trains on the run from Van Norden St. to Hyde Park is about 48 M. P. H. It is necessary to increase this speed to 50 M. P. H. in order to produce the desired improvement in the schedule time for this particular run. It is apparent from this that no equipment can be considered unless it will propel a train at about 50 M. P. H. on straight level track. This maximum speed is about typical of American suburban trains when electrically operated. The six-car trains of the New York Central R. R., operating in the New York electric zone, are geared for about this maximum speed. The Long Island R. R. electric suburban trains will operate at 45 M. P. H. The West Jersey and Sea Shore R. R. trains however operate at 60 M. P. H. speeds.


technical, electrical, mechanical, and other.

The method of determining power and speeds used in this study is on the basis of a small amount of coasting from the time of shutting off power to time of applying brakes. The amount is but 5 to 10 seconds depending on the length of run. In addition 5% of the time thus determined is added to obtain the time table schedule time.

The rate of retardation during braking is assumed at 1.6
M. P. H. per sec. This corresponds to 7.8% of train weight
adhesion.

The length of stop is assumed to be 12 seconds at all stations except Van Norden St., where 20 sec. is allowed. Extended observations have shown trains to be conservative values for trains of side.
floor cars. In addition to regular station stops, there is supposed a 12 sec. stop at the combination switch at 10th St. For all express trains, both north and south bound.

TRAIN RESISTANCE.

Information regarding train resistance at constant speed is necessary in properly determining the ultimate maximum speed as well as the instantaneous rates of acceleration at any lower speed. Very satisfactory data is available at the present time regarding train friction of electrically operated trains. Tests conducted by the E. I. G. & B. L., and the Interborough Rapid Transit Co. are particularly noteworthy as applying to the present instance. Fig. 6 shows train friction deduced from data of J. H. Armstrong for trains of varying numbers of cars of multiple single door type when loaded and equipped to travel about 50 tons each.

The actual maximum speeds are used to be 35 m. p. h. for a 6 car train, 40 m. p. h. for 2 car car train, and each car is equipped with 36-360 B motors per car, gear ratio 1.46 with 36 in. wheels at 550 volts. According to the curves, a 6 car train will make the run in less time than will a one car train; but the tendency to prolong station stops with a low train balances the increase in running time.

For the purposes of this study it is sufficient to assume one friction curve as representing the train resistance per ton for any length of train; one to be on the safe side, a conservative set of values is chosen, as plotted by the heavy line of Fig. 8. All speed and energy determinations throughout the entire study are made on the basis that this curve expresses the train resistance.
The application of electricity as a motive power is possible by various methods. Those appearing most worthy of investigation for the I. C. R. R. suburban service are listed below:

1. Direct current 600 volt 3rd rail system.
2. Direct current 600 volt 3rd rail system using forced ventilated motors.
3. Direct current 1200 volt 3rd rail system using forced ventilated motors.

The first system, the direct current 600 volt 3rd rail, is in extensive use by elevated and heavy interurban railways, and by some railroads whose service closely approximates that of the I. C. R. R. suburban service. The system has been developed to a high degree of engineering excellence, and its reliability and adaptability for the service proposed has been fully demonstrated. In the following table is shown a list of some railroads now using this system together with basic showing extent of electric equipment.

**TABLE VIII.**

List of Steam Railroads Using the 600 Volt Direct Current 3rd Rail System for Operations Suburban and Main Line Service.

<table>
<thead>
<tr>
<th>Line of R.R.</th>
<th>Service</th>
<th>Miles of track</th>
<th>No. Motor Cars</th>
<th>Max. Speed</th>
<th>H.P.H.</th>
</tr>
</thead>
<tbody>
<tr>
<td>L.N.Y. and B.T.</td>
<td>New York electric line</td>
<td>135</td>
<td>130</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>New Haven R.R.</td>
<td>New Haven-Cuban Line</td>
<td>100</td>
<td>120</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Long Island R.R.</td>
<td>Atlantic &amp; E., suburban lines</td>
<td>100</td>
<td>120</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Service</td>
<td>mi. of track</td>
<td>No. Motor Cars</td>
<td>Max. speed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------</td>
<td>--------------</td>
<td>----------------</td>
<td>------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jersey &amp; New</td>
<td>Atlantic</td>
<td>184</td>
<td>75</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Danish-Atlantic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shore R. R.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northwest Pacific</td>
<td></td>
<td>56</td>
<td>15</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>R. R.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southern Pacific</td>
<td></td>
<td>46</td>
<td>20</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>R. R.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metropolitan</td>
<td></td>
<td>40</td>
<td>20</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Platte R.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metropolitan</td>
<td></td>
<td>106</td>
<td>20</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Platte R.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southern Pacific</td>
<td></td>
<td>48</td>
<td>20</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>R. R.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Great Western</td>
<td></td>
<td>14</td>
<td>20</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>R. R.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limerick &amp;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yorkshire</td>
<td></td>
<td>49</td>
<td>15</td>
<td>45</td>
<td></td>
</tr>
</tbody>
</table>

The 12,600 volt direct current system is used at present by several interurban railways, and is proposed for use with 3rd rail on the California Midland R. R. The Southern Pacific R. R. - Oakland-landing suburban lines are at the present time being equipped to use this system with current supplied from overhead trolley.

The 36 cycle single phase alternating current system is prominently used by the S. P. R. R. - Oakland-Stanford line and by the S. P. R. R. - Oakland-Stanford line. If this system be used at Chicago 9000 volts would be the proper value of trolley potential since an extensive 9000 volt system already exists owned by the Commonwealth Edison Co. With such emergency the lines would be desirable. Instead, this system has been recently applied to the London-Brighton and south coast line, wherein an addition to the Midland R. R. - Norwood-Hayden-Lancaster line. In general, such a system has been chosen as the system to use for various main line electrification projects well under way.
In the present instance, there are many practical difficulties in the way of an overhead electric construction. First of all, the power rate for the houses in the area is higher due to the presence of overhead structures close to the houses. The approach and usual streets are too far apart to take advantage of a single supporting pole; and a double track would seem more likely. Thus, the cost of tracks would be necessary. The overall appearance of the work is to lack the unity that characterizes the overhead installation.

In the other hand, a very favorable exception for a third rail can be found. The cost to install third rail from the street corner is less than the third rail to the power central electric area. On the main line, besides amount of expenditure, this results in the passage of all types of road cars on one track without the power. But if we consider one station and an addition is the main power electric area. Further, the annual electric consumption in the operation of a relatively great number of rail road. The difference of cost of the equipment is likely to be predominant as compared with cost of transmission system.

Some considerations point to the probability of a direct current of all systems at 500 volts in the United States. Although if any great economic advantage were accorded to the use of an alternating current system, the disadvantage noted above would probably be satisfactorily overcome.

C. F. DE LA MARE.

The main problem then to consider is what type of determining the proper system of electric traction to be used as follows: A complete study is made on the basis that the 500 volt 3rd rail system be used.
and cost estimates are operating schedules worked out. A comparative
estimate in these cases for the 150 volt system and alternating current
service on the basis that equipment operating by these methods must equal
the performance of the 60 volt 3rd rail system as far as speed is con-
dered.

The advantage of this method of comparison is that all the de-
tailed calculations are made relative to that system of traction which
appears at first thought to be best adaptable for the service; and if
further investigation corroborates this fact, considerable of the actual
engineering work associated, particularly with construction team with preliminary
reports will have been completed.

REPORT OF NEW TRAIN AND its COST TO DATE.

In ordinary means of determining the details of car equipment
and power requirements in a project of this nature is to assume at the
outset a certain operating schedule of train service to which the
electric train must conform. In many cases it is necessary that the test
present service be duplicated; and in others that decided increase
of schedule speed be provided for in an event of a competing railroad's
schedule. In the present instance there is no such rational method
of fixing at the outset a desirable schedule speed by which electric
trains are to operate. The only consideration is that the schedule
speed be so low as to meet present train at present. (See page 28).

The matter is so closely related to the motor equipment and
operating energy costs, that it is advisable to postpone the presentation
of this chapter until a complete investigation has been made of these
features.
of a working or provisional schedule that will furnish the basis for cost estimates until something regarding the speed possibilities of various sizes of motor equipments are determined.

**TYPICAL RUN**

As preliminary to the study of motor equipment, it is desirable to determine the length of average run, the performance of which in service, by trains having various motor equipments will furnish an estimate of their relative performances over the various regular trips in suburban service. It is shown later that the results obtainable for this typical run can also be used to express the absolute values of energy and speed as they will occur in service.

The average length of run is not equal to the average distance between stops, except for the simple case of one type of service only; but is affected by the number of cars per train and frequency of service on different portions of the road. In general this figure is expressed thus:

\[
\text{Length/Average Run} = \frac{\text{Total one mile per average day}}{\text{Total car starts per average day}}
\]

For the I. C. T. suburban service, the typical run calculated in this manner is 0.716 miles. It is assumed that this value will hold for the electric service as well, since multiplication of service will be proportionately divided among the different classes of runs.

The argument in using this typical run is merely that the particular motor equipment that will give best continuous performance on this average run of .716 miles, will give best results on the mixed service.
of the actual road. There are many evidences that this is an allowable assumption, and it is a method in general use for determinations of this kind.

CHAPTER XII POWER SYSTEM.

There is no single item upon which so much depends the future working of the electric system as upon the railway motor. It is the means of connecting the electric system with the train or propulsion and upon its characteristics depend the performance of the train as regards speeds and of the electric system as regards power requirements, which in turn determine all details of distribution and power generating system.

Appendix A contains a tabulation of the type of motor equipment as used on various railroads employing the 300-volt direct current system, together with other significant data regarding the characteristics of the equipments.

Appendix B contains an extended discussion of the capabilities of motor equipment of various classes when considered for the present case, and discusses the reasons for adopting the particular size of motor and rate of initial acceleration as employed in these calculations for the 300-volt direct current system. From this, it is evident that it is necessary to provide motor equipment aggregating about 400 horse power in motors (one hour rating) per side door car. This can be accomplished by two standard 200-horse power standard design per car, and having all cars motor cars. The cost of equipping all cars as motor cars is no greater than cost of dividing them up into one half trailers and one half motor cars, but will involve the equipment per motor car.
inspection charges are greater if all cars are motor cars, but the resulting convenience in making up tables fully warrants this extra charge.

The motor upon which are based all calculations for the 600 volt 3rd rail system with motors cooled by natural ventilation in the G M 89, 200 E.F. railway motor. The reason for choosing this particular motor was that extended data regarding its characteristics was available. It is one of the most modern motors in use; but specifications for motors based on the results of a study of this G M 89 motor can undoubtedly be made also by the Westinghouse Electric and Mfg. Co. with same form of their 55 lid motor, or by either company with a similar motor having interpole. The use of interpole for this class of service is desirable but complete data on these large interpole motors has not been issued. They are able in every respect to duplicate the performance worked out on the basis of the G M 89 motor; and in addition offer some features providing extremely low maintenance that make profitable their purchase at a higher first cost.

**THE G M 89 RAILWAY MOTOR.**

This motor was designed for the Interborough Rapid Transit subway and the sample motors tested were the G M 89 A type. Soon the contract was filled certain slight structural changes were provided, - the motor supplied being designated the G M 89 B type. Later this same motor was furnished the Metropolitan District Ry. and other trolley and suburban railways in London. Fig. 9 shows the dimensions of this motor. Fig. 10 shows characteristic curves at 570 volts. Fig. 11 shows the general speed tractive-effort curve, the extreme utility of which is
shown in an article by the writer, "Notes on Speed Time Curves," Street Railway Journal Feb. 9, 1927. Fig. 12 shows core loss curves and Fig. 13, a somewhat thermal characteristic from which the heating of the motor in service is estimated.

**APPLICATION OF GEAR RATIO-N & 825 H.P. MOTOR.**

Appendix D shows that the proper rate of initial acceleration to the maximum schedule speed for a run of 816 miles is 1.1 M.P.H. per sec, providing acceleration current corresponds to full load one hour rating. However since appendix B is worked out on the basis of a certain standard direct current motor, it is best to calculate the results again employing the a & b motor characteristic, and in addition make more precise heating estimates that are found in appendix B. Typical runs with various gear ratios are shown in Figs. 14 to 17 incl. Fig. 18 shows results obtained from these curves as regards schedule speed, energy consumption, and motor heating. From Fig. 10, it is evident that the maximum schedule speed is provided with the gear ratio 2.5, with an initial acceleration of 1.10 M.P.H. per sec. However consideration of motor heating cuts the gear ratio at 2.46, the value used for speed and energy calculations. This provides a maximum speed of 30 M.P.H., the lower limit as set by previous considerations. If it were not for this necessity for 30 M.P.H. maximum speed, a lower gear ratio could be adopted where the temperature rise with the 8.42 gear ratio (65 degrees Cent.) is about the limit, as lower operating temperature would be perhaps desirable.

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The C.R. I. & O. were invited to the New York Central Railroad suburban cars and to the test survey and data thereon, E., while a modification of the C.R. I. & O. route is not subject to the I. C. E. E. suburban service on account of the short length of typical run. The matter is considered in some detail in appendix C.

The curves of Fig. 15 to 25 incl. are based on a three car trailer made up of side door cars each of which weighs loaded 52.75 tons, as follows:

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Weight (tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side door car body with rigging and features</td>
<td>13,600 lbs.</td>
</tr>
<tr>
<td>Motor truck 7'-6&quot; wheel base with 52&quot; steel wheels</td>
<td>13,600</td>
</tr>
<tr>
<td>Trailer truck</td>
<td>12,600</td>
</tr>
<tr>
<td>2 - 8' 6&quot; cars complete</td>
<td>12,600</td>
</tr>
<tr>
<td>Control equipment (3 type L-E 20</td>
<td>5,600</td>
</tr>
<tr>
<td>Air compressor and new brake rigging</td>
<td>1,600</td>
</tr>
<tr>
<td>(9,000 lbs. total)</td>
<td>10,600 lbs.</td>
</tr>
<tr>
<td>100 passengers at 170 lbs.</td>
<td>17,000 lbs.</td>
</tr>
<tr>
<td>Axle load</td>
<td>11,760 lbs.</td>
</tr>
<tr>
<td>Axle for inside rotating parts</td>
<td>2,100 lbs.</td>
</tr>
<tr>
<td>Equivalent weight</td>
<td>13,860 lbs.</td>
</tr>
</tbody>
</table>
SPEED OR OPERATING SPEED DURING ACCELERATION.

At all speed time curves to follow, on which are based data on time of run, energy consumption etc. for various sub-brown runs, a certain method of handling the controller during the accelerating period is assumed. This consists in allowing the motors to accelerate on the series motor curve for a short length of time before they are connected in parallel with resistance. This method of operating decreases the schedule speed for the typical run by 1 per cent but decreases the energy consumption by 8.6 per cent due to the increased statical losses, and fully warrants the adoption of this method of control. Fig. 14 shows the typical run with this modified method of acceleration. This method can be performed automatically by means of an attachment to the limit switch and produces but slight complication of control apparatus.

The entire method is considered in some detail in Appendix 3 where complete curves, charts, and calculations are shown.

An advantage of this method is that it furnishes a simple way of saving up lost time by merely disconnecting the limit switch series trip and letting motors accelerate in the regular manner. This however is at the expense of considerable motor heating, since the values of resistance in series with motors in parallel are much lower than would be the case if a limit switch trip were not provided. See Appendix 3
The profile and alignment of the I. O. C. L. suburban tracks is such that it is not necessary to calculate detailed speed-time curves for each particular run of a train in service. Such calculation is only warranted where the grades are heavy, and curves are such as to necessitate slow down and re-acceleration. There are no such curves in the I. O. C. L. suburban district. The assumption on which these results are based is that the track is level tangent throughout. Such an assumption even on roads of very rugged profile is allowable, and gives results that check very closely with results based on an accurate speed-time curve study of the various runs. (a)

All calculations are based on the results of a study of a three car train with weight according to Table II. Train friction is assumed according to Fig. 6. The power input is proportional directly to the number of cars per train, unit values being obtained from a study of a three car train.

Fig. 27 shows the General Speed Sheet or speed-time curve of a three car train on tangent level track. Curves of power input and motor losses are included. This curve is conveniently divided up into runs of various time durations as shown by the braking curves. The results for each run are regards distance run, energy consumption, average power,

injury, and other losses, are found. The data is then recalculated with distance run as a base and is shown in Figs. 26, 27, and 28. These figures show in detail the results of operation over a run of any distance, and applying them to the various runs of the I., L., S. suburban service. Table I of Individual Run Data is compiled.

From Table I, Table XI is compiled which provides data regarding the various trips in the mixed suburban service. There is added 6 1/2 to the time of each run as obtained from Table I to obtain the total trip time. This provides necessary leeway for making up time. Items from 7 to 1 of Table XI are calculated on the basis of a five-minute lay-over at the end of each trip.
<table>
<thead>
<tr>
<th>District</th>
<th>Time for Run</th>
<th>Meters of Line</th>
<th>Watts per Meter</th>
<th>Efficiency</th>
<th>Field Loss</th>
<th>Total Watts</th>
<th>Total Volts</th>
<th>Time Hrs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Randolph-Nashua</td>
<td>1:12</td>
<td>2:02</td>
<td>1.4</td>
<td>103</td>
<td>22</td>
<td>95</td>
<td>85</td>
<td>1.0</td>
</tr>
<tr>
<td>New Haven-East New Haven</td>
<td>1:12</td>
<td>1:16</td>
<td>3.4</td>
<td>80</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>1.0</td>
</tr>
<tr>
<td>Farmington-19th St.</td>
<td>1:12</td>
<td>1:19</td>
<td>1.2</td>
<td>120</td>
<td>30</td>
<td>75</td>
<td>75</td>
<td>1.0</td>
</tr>
<tr>
<td>22nd St. Woodstock</td>
<td>1:12</td>
<td>1:17</td>
<td>1.0</td>
<td>111</td>
<td>11</td>
<td>64</td>
<td>64</td>
<td>1.0</td>
</tr>
<tr>
<td>23rd St.</td>
<td>1:12</td>
<td>1:17</td>
<td>3.5</td>
<td>120</td>
<td>30</td>
<td>76</td>
<td>76</td>
<td>1.0</td>
</tr>
<tr>
<td>24th St.</td>
<td>1:12</td>
<td>1:17</td>
<td>3.3</td>
<td>120</td>
<td>30</td>
<td>76</td>
<td>76</td>
<td>1.0</td>
</tr>
<tr>
<td>25th St.</td>
<td>1:12</td>
<td>1:17</td>
<td>3.0</td>
<td>120</td>
<td>30</td>
<td>76</td>
<td>76</td>
<td>1.0</td>
</tr>
<tr>
<td>26th St.</td>
<td>1:12</td>
<td>1:17</td>
<td>2.8</td>
<td>120</td>
<td>30</td>
<td>76</td>
<td>76</td>
<td>1.0</td>
</tr>
<tr>
<td>Douglas-Oakland</td>
<td>1:12</td>
<td>1:25</td>
<td>1.0</td>
<td>120</td>
<td>30</td>
<td>76</td>
<td>76</td>
<td>1.0</td>
</tr>
<tr>
<td>23rd St.</td>
<td>1:12</td>
<td>1:25</td>
<td>4.0</td>
<td>150</td>
<td>30</td>
<td>79</td>
<td>79</td>
<td>1.0</td>
</tr>
<tr>
<td>24th St.</td>
<td>1:12</td>
<td>1:25</td>
<td>3.6</td>
<td>150</td>
<td>30</td>
<td>79</td>
<td>79</td>
<td>1.0</td>
</tr>
<tr>
<td>25th St.</td>
<td>1:12</td>
<td>1:25</td>
<td>3.3</td>
<td>150</td>
<td>30</td>
<td>79</td>
<td>79</td>
<td>1.0</td>
</tr>
<tr>
<td>26th St.</td>
<td>1:12</td>
<td>1:25</td>
<td>3.0</td>
<td>150</td>
<td>30</td>
<td>79</td>
<td>79</td>
<td>1.0</td>
</tr>
<tr>
<td>27th St.</td>
<td>1:12</td>
<td>1:25</td>
<td>1.8</td>
<td>120</td>
<td>30</td>
<td>79</td>
<td>79</td>
<td>1.0</td>
</tr>
<tr>
<td>28th St.</td>
<td>1:12</td>
<td>1:25</td>
<td>1.8</td>
<td>120</td>
<td>30</td>
<td>79</td>
<td>79</td>
<td>1.0</td>
</tr>
<tr>
<td>29th St.</td>
<td>1:12</td>
<td>1:25</td>
<td>1.7</td>
<td>120</td>
<td>30</td>
<td>79</td>
<td>79</td>
<td>1.0</td>
</tr>
<tr>
<td>30th St.</td>
<td>1:12</td>
<td>1:25</td>
<td>1.6</td>
<td>120</td>
<td>30</td>
<td>79</td>
<td>79</td>
<td>1.0</td>
</tr>
<tr>
<td>31st St.</td>
<td>1:12</td>
<td>1:25</td>
<td>1.5</td>
<td>120</td>
<td>30</td>
<td>79</td>
<td>79</td>
<td>1.0</td>
</tr>
</tbody>
</table>

- 47 -
<table>
<thead>
<tr>
<th>Box</th>
<th>Time for Run</th>
<th>Time for Kilowatt per run in watts</th>
<th>Volt./A.</th>
<th>Watt Loss</th>
<th>Watt Loss per motor</th>
<th>Armature Loss per motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Van Buren-Columbus Ave.</td>
<td>1:30</td>
<td>1:50</td>
<td>9.7</td>
<td>121</td>
<td>31</td>
<td>21</td>
</tr>
<tr>
<td>Columbus Ave.</td>
<td>6:20</td>
<td>7:11</td>
<td>7.7</td>
<td>120</td>
<td>30</td>
<td>14</td>
</tr>
<tr>
<td>37th St.</td>
<td>1:42</td>
<td>1:51</td>
<td>7.7</td>
<td>120</td>
<td>30</td>
<td>14</td>
</tr>
<tr>
<td>Prospect Ave.</td>
<td>1:52</td>
<td>1:58</td>
<td>112</td>
<td>30</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Bryson Ave.</td>
<td>1:31</td>
<td>1:42</td>
<td>5.1</td>
<td>120</td>
<td>30</td>
<td>14</td>
</tr>
<tr>
<td>E. Shore Ave.</td>
<td>1:32</td>
<td>1:42</td>
<td>5.4</td>
<td>120</td>
<td>30</td>
<td>14</td>
</tr>
<tr>
<td>Hyde Park Ave.</td>
<td>1:38</td>
<td>1:42</td>
<td>3.68</td>
<td>111</td>
<td>28</td>
<td>14</td>
</tr>
<tr>
<td>South Shore Ave.</td>
<td>1:38</td>
<td>1:42</td>
<td>3.88</td>
<td>111</td>
<td>28</td>
<td>14</td>
</tr>
<tr>
<td>86th St.</td>
<td>1:47</td>
<td>1:50</td>
<td>5.56</td>
<td>120</td>
<td>30</td>
<td>14</td>
</tr>
<tr>
<td>87th St.</td>
<td>1:50</td>
<td>1:53</td>
<td>3.75</td>
<td>120</td>
<td>30</td>
<td>14</td>
</tr>
</tbody>
</table>

| Kenilworth-Stewart Ave. | 1:42 | 2:10 | 4.59 | 123 | 33 | 100 |
| Stewart Ave.-State St. | 1:29 | 1:32 | 5.06 | 120 | 29 | 99 |
| State St.-Pullman | 1:27 | 1:29 | 3.85 | 119 | 23 | 74 |
| Pullman-Arlington Ave. | 1:34 | 1:35 | 3.68 | 118 | 22 | 73 |
| 83rd St.-Tenth Ave. | 1:31 | 1:33 | 3.52 | 118 | 20 | 72 |
| 83rd St.-10th Ave. | 1:31 | 1:33 | 3.45 | 118 | 20 | 72 |

| TABLE II |
|---|---|---|---|---|---|---|
| Local Trip | Express | Express (a) | Express | Express (a) |
| Time for Run | 34 min. 10 sec. | 51 min. 34 sec. | 47 min. 30 sec. | 21 min. 30 sec. | 10 min. 10 sec. |
| Schedule speed hrs. | 18.7 | 25.6 | 14.0 | 28.7 | 28.4 |
| Average T. per car | 123 | 123 | 123 | 123 | 123 |
| Fuel hrs. per ton mile | 124 | 92 | 99 | 93 | 90 |
| Average field loss per motor-mile | 844 | 768 | 820 | 638 | 760 |
TABLE XI (cont.)

<table>
<thead>
<tr>
<th></th>
<th>Earth Ocean</th>
<th>Blue Island</th>
<th>Grand A</th>
<th>Illinois Express (a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F. Average earn.</td>
<td>3220</td>
<td>3410</td>
<td>2550</td>
<td>2620</td>
</tr>
<tr>
<td>G. Ratio of dist.</td>
<td>2.43</td>
<td>3.00</td>
<td>3.96</td>
<td>2.80</td>
</tr>
<tr>
<td>H. Miles</td>
<td>47</td>
<td>50</td>
<td>53</td>
<td>60</td>
</tr>
<tr>
<td>I. Gain. mower</td>
<td>70</td>
<td>64</td>
<td>57</td>
<td>67</td>
</tr>
</tbody>
</table>

(a) Under all stops

RATIONAL SCHEDULE

There is provided in Tables I and II sufficient data on running times to lay out the new schedule for electric service. This new schedule is the basis for determining the magnitude of power generating and distribution systems. This provisional schedule is shown in detail in Figs. 29 to 40 inclusive. The various trains are numbered, and the number of cars per train is shown. The time of arrival at any station can be obtained by using these tables in conjunction with the running times of Table I.

This schedule provides for a 154 per cent increase in seat miles, a 70 per cent increase in the number of trains, and a 60 per cent increase in car mileage, as compared with the present operating schedule with steam service.
schedules has been made to provide a working schedule, and the high schedule speed permits a method of operation with short lay-overs that provide a maximum car miles per day for any number of cars. It is believed that the schedule is variable, that is, it does not leave cars stopped at night at different points from which they started. The railroad local service has been enlarged with the idea of instituting five cent fare on that portion of the line.

Figs. 41, 42, and 43, show the total car movement at Randolph St. terminal. The various train movement occurs during the hour from 8 to 9 a.m., during which time cars enter or leave the terminal. The minimum headway is 2 1/2 minutes from Randolph St. during the rush hour. Five car trains are assumed during rush hours in the direction of heavyest travel. This limiting length is due to the present length of station platforms.

Figs. 44 shows the complete provisional schedule for each day service in the form of a graphic time table. This is used for determining connecting stations, feeder, and substitution loads.

The provisional schedule as worked out is estimated to be sufficient for the next five years hence, provided the electric system is operated with five cent fare for the medium local service, and that the frequency of trains is as given in this schedule. It is assumed that up to this time, the schedule will be operated exactly as indicated herein; except that the number of cars per train be increased to conform to present traffic conditions. The advantages of frequent train service are so extremely important in attracting patronage, and since
frequency of service is no easily and cheaply obtained with an electric system, it would be a great mistake to consider extending the initial electric service in this respect.

Certain changes in the operating methods of the suburban service are advisable to provide less dead mileage and shorter lay-overs than could be the case if the electric trains were operated in the same manner as at present. These are considered in the following paragraphs, which relate to the electric train service for the various suburban lines.

**Proposed electric trains.**

**Regular Service:**

Leaves Randolph at the hour except at 3:00 and 5:00 A.M. Two trains operating.

Train 1: 4:00 A.M. Randolph, 5:00 A.M. Randolph

Train 2: 5:00 A.M. Randolph, 6:00 A.M. Randolph

**Peak Hour Service:**

3 car Trains

Leaves: 5:15 A.M., 6:15 A.M., 6:30 A.M., 6:45 A.M.

**Bue Island Line—Old Line**

**Regular Service:**

Leaves: Randolph at the half-hour except at 5:30 A.M. and 4:30 P.M., Two trains operating.

Train 1: 5:30 A.M., 6:30 A.M., 7:30 A.M., 8:30 A.M.

Train 2: 6:30 A.M., 7:30 A.M., 8:30 A.M., 9:30 A.M.

**Peak Hour Service:**

3 car Trains

This service is composite. A train runs alternately, first to South Chicago and return and then to Grand Crossing and return and repeat. This enables a complete double round trip to be made in two hours and results in a double number of trains being required for this service.

South Chicago - Total time for run 31 1/2 min. 4 min. Lay-overs.
Grand Crossing - Total time for run 23 min. 3 min. Lay-overs.

Regular service: Leaves Randolph St. 15 min. and 45 min. after the hour to South Chicago, and 25 min. and 55 min. after the hour to Grand Crossing. Four trains operating.

<table>
<thead>
<tr>
<th>Train</th>
<th>Leaves Randolph St.</th>
<th>Grand X</th>
<th>Returns Randolph St.</th>
<th>South Chicago</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7:10 A.M.</td>
<td>8:15 A.M.</td>
<td>12:15 A.M.</td>
<td>7:10 A.M.</td>
</tr>
<tr>
<td>2</td>
<td>7:14 A.M.</td>
<td>8:18 A.M.</td>
<td>12:22 A.M.</td>
<td>7:14 A.M.</td>
</tr>
<tr>
<td>3</td>
<td>10:10 A.M.</td>
<td>11:15 A.M.</td>
<td>3:15 P.M.</td>
<td>10:10 A.M.</td>
</tr>
<tr>
<td>4</td>
<td>7:14 A.M.</td>
<td>8:11 A.M.</td>
<td>12:11 A.M.</td>
<td>7:14 A.M.</td>
</tr>
</tbody>
</table>

Extra hour service: Has following pages on Rush Hour Service.

RUSH HOUR RAILWAY TRAINS - EMERGENCY SERVICE

Total time for run 24 min. 6 min. Lay-overs.

Regular service: Leaves Randolph St. 7 1/2, 12 1/2, 17 1/2, and 22 1/2 min. after the hour. Four trains operating.

<table>
<thead>
<tr>
<th>Train</th>
<th>Leaves Randolph St.</th>
<th>Randolph St</th>
<th>Leaves Randolph St.</th>
<th>Randolph St</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7:07 A.M.</td>
<td>8:07 A.M.</td>
<td>12:07 A.M.</td>
<td>1:07 A.M.</td>
</tr>
<tr>
<td>2</td>
<td>6:32 1/2 A.M.</td>
<td>7:32 1/2 A.M.</td>
<td>12:32 1/2 A.M.</td>
<td>1:32 1/2 A.M.</td>
</tr>
<tr>
<td>3</td>
<td>6:37 1/2 A.M.</td>
<td>7:37 1/2 A.M.</td>
<td>12:37 1/2 A.M.</td>
<td>1:37 1/2 A.M.</td>
</tr>
<tr>
<td>4</td>
<td>6:42 1/2 A.M.</td>
<td>7:42 1/2 A.M.</td>
<td>12:42 1/2 A.M.</td>
<td>1:42 1/2 A.M.</td>
</tr>
</tbody>
</table>

Rush hour service: To give 3-minute headway northbound from 7:05 A.M. to 8:30 A.M. and southbound from 8:12 A.M. to 9:30 A.M. See following.
The above service is electric supervision.

Certain time has already been provided relating to rush hour service. The rush hour trains are operating on extra and do not interfere with the regular train schedule. These extra trains provide service according to the provisional schedule and after making a run are dispatched immediately back to terminal to make another rush hour trip. That is, most rush hour trains make two and sometimes three extra trips during any rush hour. The manner in which this is accomplished during the C.W. rush hour is indicated in the Table XII following. The red lines are used to show the method of operating these trains.

NUMBER OF CARS REQUIRED FOR RUSH HOUR SERVICE.

For the regular service, the maximum number of cars operated during the rush hour, at which time each train is composed of five cars. In Case of Collisions: Northtown Local 30, Cottage Grove Exp. 10, Blue Island Exp. 10, Mt. Chicago and Grand Crossing Exp. 20.

For the same rush hour service according to the method of Table XII, there is to be operated 45 cars. The total number of cars necessary on the provisional schedule is therefore 105. It is reasonable to assume that, in addition to needed yearly repairs, a few cars can not be available during a rush hour. However, all light repair, inspection, and cleaning must be arranged for between rush hours.

It is necessary to provide that 110 multiple unit side door cars to satisfactorily perform the service according to the provisional schedule of 154% greater seating capacity than present stock service.
Table XII.

Service on Oct. 19th, 1923, from 9:00 A.M. until 7:00 P.M.

Service listed in the order of their arrival at Randolph St.

<table>
<thead>
<tr>
<th>Leaving</th>
<th>7:05 A.M.</th>
<th>Arrive</th>
<th>7:27 A.M.</th>
</tr>
</thead>
<tbody>
<tr>
<td>N. Chicago</td>
<td>7:13</td>
<td>7:16</td>
<td>7:29</td>
</tr>
<tr>
<td>Woodlawn</td>
<td>7:16</td>
<td>7:20</td>
<td>7:42</td>
</tr>
<tr>
<td>Or. Chicago</td>
<td>7:20</td>
<td>7:29</td>
<td>8:00</td>
</tr>
<tr>
<td>Cane X</td>
<td>7:23</td>
<td>7:31</td>
<td>8:10</td>
</tr>
<tr>
<td>Blue Island</td>
<td>7:21</td>
<td>7:37</td>
<td>8:20</td>
</tr>
<tr>
<td>S.e. Chicago</td>
<td>7:09</td>
<td>7:48</td>
<td>8:22</td>
</tr>
<tr>
<td>Woodlawn</td>
<td>7:25</td>
<td>7:57</td>
<td>8:07</td>
</tr>
<tr>
<td>Or. Chicago</td>
<td>7:37</td>
<td>8:19</td>
<td>8:40</td>
</tr>
</tbody>
</table>

Comparison of proposed service and electric service with present steam service.

As a further comparison of the electric service based on the provisional schedule, with the present steam service for seven each day; there is prepared Table XIII below, line 16 to be compared with Table II page 14.
<table>
<thead>
<tr>
<th></th>
<th>Local</th>
<th>No. Exp.</th>
<th>Blue Int.</th>
<th>Douglas</th>
<th>Grand Int.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>7:2</td>
<td>12:3</td>
<td>10:9</td>
<td>24:9</td>
<td>6:5</td>
</tr>
<tr>
<td>Mileage</td>
<td>24</td>
<td>31:1/2</td>
<td>47 (a)</td>
<td>56 (a)</td>
<td>31 1/2</td>
</tr>
<tr>
<td>Number of stops</td>
<td>18</td>
<td>23 (a)</td>
<td>31 (a)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Length of average run (miles)</td>
<td>0.39</td>
<td>0.92</td>
<td>0.82 (a)</td>
<td>1.30 (a)</td>
<td>1.05</td>
</tr>
<tr>
<td>Schedule speed (m. p. h.)</td>
<td>10.7</td>
<td>34.4</td>
<td>24.0 (a)</td>
<td>26.0 (a)</td>
<td>25.7</td>
</tr>
<tr>
<td>Number of trains per day</td>
<td>95</td>
<td>79</td>
<td>19</td>
<td>19</td>
<td>39</td>
</tr>
<tr>
<td>Headway minutes (morning)</td>
<td>10</td>
<td>10</td>
<td>50</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Headway minutes (evening)</td>
<td>10</td>
<td>10</td>
<td>50</td>
<td>50</td>
<td>60</td>
</tr>
</tbody>
</table>

**Express headway to 63rd St. 15 minutes.**

**Express headway to 63rd St. 5 minutes.** (two of 2 1/2 mln.)

<table>
<thead>
<tr>
<th>Time</th>
<th>Noon</th>
<th>4 P.M.</th>
<th>8 P.M.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total trains operating each way per day</td>
<td>209</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Note: (a) means stop at all stations south of 53rd St.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The total mileage for the provisional schedule totals 10660 per summer week day, distributed according to the following Table XIV.
<table>
<thead>
<tr>
<th>Car Service</th>
<th>Operating</th>
<th>Diesel</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red Line Local</td>
<td>4650</td>
<td>385</td>
<td>4425</td>
</tr>
<tr>
<td>South Olmsted Express</td>
<td>2710</td>
<td>260</td>
<td>2970</td>
</tr>
<tr>
<td>Blue Island Express</td>
<td>2240</td>
<td>0</td>
<td>2240</td>
</tr>
<tr>
<td>Florence Express</td>
<td>2710</td>
<td>0</td>
<td>2710</td>
</tr>
<tr>
<td>Broad Crossing Express</td>
<td>2250</td>
<td>195</td>
<td>2445</td>
</tr>
<tr>
<td><strong>Total car miles</strong></td>
<td><strong>16010</strong></td>
<td><strong>850</strong></td>
<td><strong>16860</strong></td>
</tr>
</tbody>
</table>

Assuming a Sunday and Holiday car mileage equal to 60% of week day, there will be operated per annum 0,60,60 car miles.

This is a very high car mileage to expect to obtain in suburban service with 110 cars, since it is considered that about one half of the cars are provided only for rush hour service. It means each car will average 53500 miles per year or 187 miles per day. However, the ability of an electrically equipped car to perform such service with reasonable maintenance charge is unquestioned.

**REGULATION OF LENGTH OF TYPICAL RUN.**

At an early point in this study (page 39) it was calculated that the length of typical run for the present steam operated suburban service is 0.315 miles. The length of typical run for provisional schedule of electric service is:

\[
\text{Car miles per day} \times \frac{16860}{16000} = 10800 \text{ miles}
\]
The proposed location of substations is shown on the diagram of 20 volt distribution Fig. 45. They are situated as follows:

<table>
<thead>
<tr>
<th>No.</th>
<th>Station</th>
<th>12th mile</th>
<th>0.1 mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Oakland</td>
<td>3.9</td>
<td>0.2</td>
</tr>
<tr>
<td>2</td>
<td>Somers</td>
<td>4.1</td>
<td>0.2</td>
</tr>
<tr>
<td>3</td>
<td>Ravenshott</td>
<td>5.1</td>
<td>0.2</td>
</tr>
<tr>
<td>4</td>
<td>Somers</td>
<td>5.6</td>
<td>0.2</td>
</tr>
<tr>
<td>5</td>
<td>Somers</td>
<td>6.2</td>
<td>0.2</td>
</tr>
<tr>
<td>6</td>
<td>Somers</td>
<td>7.5</td>
<td>0.2</td>
</tr>
<tr>
<td>7</td>
<td>Somers</td>
<td>8.0</td>
<td>0.2</td>
</tr>
</tbody>
</table>

The actual locations are to be provided as near as practicable to these points. With this location, the voltage at train will in no case be less than 400 volts during acceleration, even during nearest rush hour period. This assumes as an average voltage of 600 at substations (converters assumed 600 -- 400 volts) of 80 lb. special rolled 3rd rail with conductivity .040 arms per mile, 3rd rail tied together at intermediate points through fuses or circuit breakers as per diagram Fig. 45. The investigation of substation location from standpoint of Kelvin's Law of energy loss has not been made in this case. In all similar cases of which the writer is aware, consideration of allowable voltage drop made it necessary to place sub stations nearer together than was shown to be desirable by Kelvin's Law. For this reason allowable voltage drop is made the controlling factor.

The station capacities are chosen with reference to average loads and to voltage swings. The former are of each duration 1/3 hour of mo
as to effect operating a converter by varying over volts, the latter while lasting only 10 to 20 seconds cause cumulative difficulties.

The net result looks due to the operation of trains according to the provisional schedule in terms for four hours and varying each day operating in three to 20 load. There is also included on each load curve an average of six months in amount, not necessarily of average and operating. In calculating those load curves, there is observed an average of 800 units due to the station operation of 500 volts, the average unit at any station being 800. Calculation of several instances shows a number of cases where the reliability of this condition appears thus determined. A number of station load curves.

Now as the results in the table, are recalculated in

<table>
<thead>
<tr>
<th>Sub-station</th>
<th>average</th>
<th>x 1000 Vols.</th>
<th>x 500 Vols.</th>
<th>station average</th>
<th>10% or 1% swing.</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.11.15, NL</td>
<td>412.81</td>
<td>312.81</td>
<td>31.28</td>
<td>910.00</td>
<td>1170</td>
</tr>
<tr>
<td>B. Oakland</td>
<td>440.00</td>
<td>330.00</td>
<td>33.00</td>
<td>720.00</td>
<td>970</td>
</tr>
<tr>
<td>3. Riverton</td>
<td>410.00</td>
<td>300.00</td>
<td>30.00</td>
<td>720.00</td>
<td>1048</td>
</tr>
<tr>
<td>4. Stuyvesant</td>
<td>380.00</td>
<td>280.00</td>
<td>28.00</td>
<td>600.00</td>
<td>485</td>
</tr>
<tr>
<td>5. Riverdale</td>
<td>350.00</td>
<td>250.00</td>
<td>25.00</td>
<td>600.00</td>
<td>250</td>
</tr>
<tr>
<td>6. Rensselaer</td>
<td>380.00</td>
<td>280.00</td>
<td>28.00</td>
<td>600.00</td>
<td>160</td>
</tr>
<tr>
<td>7. Central Park</td>
<td>350.00</td>
<td>250.00</td>
<td>25.00</td>
<td>600.00</td>
<td>325</td>
</tr>
</tbody>
</table>

Uniform station design policy, converters are capable of carrying 10% overload for 5 minutes.
At each sub-station, the following rotary converter equipment is installed:

<table>
<thead>
<tr>
<th>No.</th>
<th>Type</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10th Ave.</td>
<td>4 - 1000 kW</td>
</tr>
<tr>
<td>2</td>
<td>Oakland</td>
<td>4 - 1000</td>
</tr>
<tr>
<td>3</td>
<td>Woodlawn</td>
<td>4 - 1000</td>
</tr>
<tr>
<td>4</td>
<td>Bartram</td>
<td>5 - 1000</td>
</tr>
<tr>
<td>5</td>
<td>Siyuale</td>
<td>2 - 1000</td>
</tr>
<tr>
<td>6</td>
<td>Roosevelt</td>
<td>2 - 1000</td>
</tr>
<tr>
<td>7</td>
<td>Winlaw Park</td>
<td>3 - 1000</td>
</tr>
</tbody>
</table>

**Total Capacity:** 28000 kW

At sub-stations 1, 2, and 3, maximum average load during any half hour determines the equipment. At other sub-stations, maximum swing determines size of units. The particular size of rotary converter adopted, 1000 kW, will give best results for all day operation according to the sub-station load curve. They are adapted for the sub-lying sub-stations, where 750 kW units might suffice on account of the desirability of having uniformity of apparatus. The extra reserve may be valuable for handling special excursion trains, etc.

The preceding discussion has been with the idea that storage batteries would not be used in sub-stations. An extended study of the applicability of storage batteries in this case (see Appendix II) has shown that they are not desirable from an economic standpoint, but that in the event of future extensions to the main line tracks in the electric service, the additional load thus created could be handled by the addition of a comprehensive storage battery equipment to one that exists at sub-stations.
From the sub-station load curve it is possible to determine the load curve and total output for the entire system with trains operating according to the provisional schedule. This total output curve is shown in Fig. 50. The curve marked "traction only" is taken from sub-station power load curve. The following are some of the items used in obtaining the values of other loads:

- Car lighting per car:
  - All-10 60 lamps at 60 watts: 3.3 kw
  - 40 lamps at 40 watts: 2.4 kw

- Car air-conditioning per car:
  - Fan motor (average): 1.5 kw
  - Control (average): 1 kw

- Heaters, electric only per car: 15 kw

- Transformer and transformer losses (avg. 7.76 %)

- High tension transmission loss: 400 kw at peak load
  - Load Factor: .38
  - Curve Factor: .18

- Passenger car and motor lighting (90 deg):
  - 400 kw from motor generator at 58th st.

- Elevators and signal system: 180 kw

The total winter week day load is 165,200 kw. hr. The total summer week day load is 125,650 kw. hr. assuming a week day load for Sunday's and 20 weeks of winter load and 32 weeks of summer load; the total output per annum is 46,906,000 kw. hr. from power house.

**DERIVATION OF POWER REQUIRED PER CAR MILE AS DERIVED FROM LOAD CURVE AND FROM TYPICAL CAR MILES OPERATED AND TOTAL ENERGY FOR TRACTION ACCORDING TO FIG. 50.**

The total output per car mile at 3rd rail, for traction only is 4.96 kw. hr. per car mile; as determined from knowing total car miles operated and total energy for traction according to Fig. 50. This is
a satisfactory agreement with the value obtained for a typical run of .86 miles (see page 55) which is 1.38 ... km, and one mile.

It follows from table the comparison of other systems of traction with the direct current of a full system on the basis of energy consumption, it will be sufficient to use for the value of 3500 lbs. per ton mile the value obtained from a typical run over 1 mile, also the absolute values so obtained can be used to determine total output with these other systems of electric traction.

THE POWER TRANSMISSION SYSTEM.

It is assumed that the railroad company has a right to erect a pole line along the right of way as far west as central station.

Transmission of power at 20,000 volts 25 cycles for connected lines is assumed. This is standard operating practice of the Pennsylvania Railroad No. 60, the outer loop transmission. The transmission layout upon which the power transmitted over the 20,000 volt DC system is shown in Fig. 62.

The arrangement provides for duplicate feeding throughout with sectionalized lines so that one or more independent lines can be run through to any sub-station. The use of 2/0 series is assumed for these lines. The total miles of 3-phase circuit is 75.4 in case the company operates its own power houses and 57.4 miles in case power is purchased from the Commonwealth Edison Co., delivered at central sub-station. Two all switches are shown on each line. It may be as desirable to install one one on the power line at end of each line.
Steel rails are assumed for all lines.

Distance between rails on tangent is 180 feet. Fig. 61 shows structural details of ten high voltage pole line north of Syracuse.

The average loss of voltage from power station at indoor park to substations during peak hour is on the basis of 7% power factor of load; to Iroquois 110 volts, to Cornell 233 volts, to 12th St. 314 volts, to Burlains 73 volts, to Iroquois 136 volts, to Home 172 volts. This assumes all conductors in parallel with south lines feeding from cut off via south Chicago. The voltage regulation is 1.7% average at 12th St. substation and less than this at all other sub-stations during peak hour. This may become 5% for a peak fluctuation during peak hour at 12th St.

ON THE 60000 VOLTS SYSTEM

The Syracuse type of third rail is proposed for this system. This is an electrified street car, third rail, providing minimum equipment interferences and is in use in the electric lines of the New York Central, the West Shore Ry. between Binghamton and Syracuse, New York Atlantic and Lansing, and Philadelphia Rapid Transit elevated and subway lines. The most important question is that of maximum clearance; the limitation on third rail position for this road comes at the overhead crossings where conduit creates partly a maximum distance of 23 in. from the center of third rail to track gauge line. This is 3 3/4 in. greater than the similar dimension for the New York Central Electric line and 1 in. greater than in the case of the New York R.R. The location is in fact the greatest distance from track rail in use by any railroad and will, so far as the writer is aware, permit the passage of all types of cars.
likely to be offered the charity for 

It is particularly fortunate that such an advantageous location for the third rail can be found, since the main line tracks from Westminster to Elephant are to be equipped; and any location not permitting the passage of low-hopper coal cars would be prohibitive. The third rail weighs 80 lbs. per yard and is of special composition having a resistance about 7.2 times that of the equivalent area section of copper. Its resistance including bonds will be about .061 ohms per mile. Bonds are 500 000 T.C. soldered per joint, 12 inches over all length when soldered. Details of third rail structure at overhead crossings is shown in Fig. 67. This also shows the type of fibre protection to be used. 66.5 miles of third rail structure are to be provided and 200 complete crossing jumper installations.

The third rail switching and control system has been designed to provide extreme reliability of operation on the portion of the system north of Federal. South of this point where the frequency of service is less, a cheaper method of switching is used which nevertheless provides for nearly the same flexibility of operation. Fig. 68 shows this method of switching. North of 67th St., the method is the same as used in the electric lines of the New York Central R. R. This provides for cross connecting one third rail at the points between sub stations by means of interconnectling circuit breakers that trip automatically, but are capable of being operated from adjacent sub stations. In addition there are
provided auxiliary 600 volt feeders which are capable of duplicate feeding to any section or provide a means to bridge over a completely disabled section. Normally all third rails are interconnected at sub stations and at circuit breaker houses in order that complete advantage may be taken of the sectionalizing of all third rails to any point.

At each sub station, there is provided an isolated third rail section 600 ft. long. This is to prevent a train bridging across from one section to the one adjacent in case of trouble on either one, and thus making alive one section when it should be dead.

So far as the terminal, the third rails are tied together along between sub stations through fuse and side switches. In case of trouble on any section, the circuit breaker at the sub station and in front of the section switch are automatically opened. When the trouble is removed, the sub-station circuit breaker is closed, and the section in ready for temporary operation, the fuse being replaced at leisure. There is no provision for duplicate feeding, the sectionalizing of the line is less complete, and there is not as quick return to normal conditions after trouble, as in the case with the system north of 67th St.
This system of sectionalizing third rail was introduced by the West Jersey and New Haven R.R., Garden-Athletic City line.

The method of operation of the circuit breakers in the circuit breaker houses as used for the line north of 67th St. is shown by Fig. 66.
CIRCUIT

Using heavy current to be carried, it is necessary to use both running rails for track return. The signaling must be done in a manner that will permit this. It is best accomplished by providing alternating current for signal purposes; and sectionalizing the track as regards this current by means of resistance bonds that permit passage of direct current for traction but are high-resistance choke coils to the alternating signal circuit.

Figs. 3, 4 and 5 show the weight of track rail on various portions of the line. The Blue Island and South Chicago branches are in poor condition as regards rails, and it is recommended that 76 lb. rails be used on these lines at the time of installing electric apparatus. There should be at least 500,000 ohm bond section at each track rail joint. About 50,000 joints must be equipped in this manner.

The extent of zones bonding is dependent upon the signal system layout. On local tracks from Randolph St. to Kedzie St., cross-bonding is used at signal positions, about 1500 to 2500 ft. apart. It is desirable to cross and return tracks at these points as well if the signal system will permit; and to tie the four tracks together every 2500 ft. by means of a 750,000 ohm, bare cable laid transversely with the tracks.

South of Kedzie St. where block signals are not used, cross bonds of aggregate 750,000 ohm should be placed at intervals of 200 ft.
SIGNAL SYSTEM.

The signal system in this at present provides for straight block signaling (no overlapping) for all suburban lines from Franklyn R. to Hamilton. About 23 Bell Box signals are necessary for the suburban system at present. Fig. 2 shows the general location of signals controlling suburban tracks. On the line from 67th St. to Hamilton, overlap signals should be provided controlling blocks between stations, that is, all those that 'to train exists' while running at full speed. Seven such overlap signals for each track are required for this case. In all, there are required 166 signals to give required signal protection of electrically equipped lines.

Signal systems of this kind necessary for this service are costly and require numerous special devices for their operation. The signal system from Grand Crossing to Hamilton could perhaps be dispensed with since traffic on this portion is very light. In this event only 76 signals could be required for the remainder of the installation. Signal systems which fulfill the special specifications noted herein can be supplied by the General Electric Signal Co., the Union Switch and Signal Co., and others.

The writer has been unable to obtain satisfactory price data on these systems, and hence the cost of new signals is not included in the estimate as for the electric electric system. It is possible that it would be cheaper to install a single small auxiliary electric rail to operate the present Bell signals than to invest in a nearly similar for alternating current signaling.
For electric service operation according to the provisional schedule of Fig. 20, 25 and 117 cars of multiple side door type are needed. Details and dimensions of these cars are shown on page 20 and weights in Table 11. Certain slight construction changes must be made in order to adapt the present side door car for electric service. The platform and apparatus must be removed and side door and features installed. A knockdown compartment cab is to be placed at each end of car. It is recommended that the brake rigging be changed to consist of vacuum actuating air brakes with graduated release valve. Schedule A.D.B. on all present cars as well as new equipment.

In order to adapt a present side door car for operation as a motor car, the most extensive structural change necessary is to reconstruct the body relative to axe and in order to accommodate motor truck with its two motors. Fig. 25 shows, a tentative design for this work. In the axe cars to be built, some other method of underflooring must be worked out that will more easily adapt itself to use of motor truck.

For the lighting, it is arranged in clusters similar to present single car lighting. In addition, there is to be provided a row of lights along the side of car above the near aisle. Thirty 2 2/3, lamps with balanced glass reflectors for the clusters, with twenty 10 2/3 lamps over motor with special reflector and lens mounting. Quadrate brackets to be installed transversely under the seats, forty 20-watt similar to type 410, supplied by the Consolidated Gas Co. Company are necessary. Each car is to be furnished with two illuminated destination signs.
The present trends can be used as follows. For motor

brakes, design following the lines of the equalized trailer
brake can be built, and such a brake is applied on the
horns, motor trucks in the

United States. This is commonly called the U.S. type. The

first American and New York Central who have type of brake

on all 36 motor cars. The New Haven is

on the type 368 motor

(U.S.), the New York Central uses a cast steel solid frame
type mounted over journals by a single elliptical coupling. Similar

trucks are used in England for suspension of the 0-8-0-T
type and other heavy

motors.

The particular type to adopt is largely a matter of personal

preference, for very high speeds and relatively low traction effort

during acceleration, the U.S. type is to be recommended. For

lower speeds and heavy pulls such an engine when a low speed gear

ratio is

adopted, the solid frame truck is preferable. There is no doubt that

at speeds approaching 80 m.p.h., the U.S. type is the easier riding truck,

also that at heavy pulls and making power, the U.S. type is subject to

very severe rocking stresses, which are not so desirable with the solid

frame truck due to its greater distance between spring suspension

points.
is a general recommendation it is advisable to use the solid frame truck for slow speed short run service. Thus for the 50 & 60 motors for the
Leicester Underground Co. equipment, the solid frame was chosen, since
the maximum pull per truck is 11000 lb. During acceleration, whereas
for the 110 and 135 motors, the A.C. design is justified since
the maximum speed is about 60 m.p.h. and the maximum pull per truck is
but 8000 lb. during acceleration.

In the case of the I. C. R. R. suburban cars it seems advisable
to adopt the A.C. design built according to the following speci-
fications:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheel base</td>
<td>90 in.</td>
</tr>
<tr>
<td>Wheel dia.</td>
<td>58 in.</td>
</tr>
<tr>
<td>Height center plate above rail</td>
<td>33 in.</td>
</tr>
<tr>
<td>Height side bearing above rail</td>
<td>20 in.</td>
</tr>
<tr>
<td>Top of side bearing</td>
<td>61 1/2 in.</td>
</tr>
<tr>
<td>Weight of motor on truck</td>
<td>2600 lb.</td>
</tr>
<tr>
<td>Torque in motor on truck</td>
<td>2500 lb.</td>
</tr>
<tr>
<td>Probable weight of truck</td>
<td>15000 lb.</td>
</tr>
</tbody>
</table>

**Note:** Trucks - 500, 600, 800, 900, 1100.

It is not the intention to discuss in detail the design of
a power house. There is a strong probability that the Commonwealth
Electric Co. will supply power at a rate that the advisability of a power
plant would be debatable. This is especially true for the first five
years of electric operation during which time it is assumed the traffic
will be developing from the present extent up to an extent as per the
provisional schedule of Pte. 33 to 40. The rate at which the Common-
wealth Electric Co. would supply power, is probably as

---

- 69 -
1/2 a cent per kilowatt hour.
10.00 per hour per f.t. or 5 units per hour demand.

This being the cost very close to 1 cent per f.t. hr. for a load factor of 0.80 (per 10, 000).

The 10 companies decide to build a power plant. It is against it could probably be about as follows in order to operate trains according to the provisional schedule.

- 600 KW, 5 cycles, 2300 Volts,
  - 500 Amps, overload capacity 50% for 5 Hours.

This makes even possible to handle 100% entire load during a rush hour with no need for reserve.

- Boiler,
  - Output (boiler) 150,000 lbs. per hour with 25% superheated output.

- Stoker,
  - Self-feeding steel 200 ft., 18" flue, to be used for coal.

Location of Plant——San Francisco, 'Frisco. This location is the nearest habitable point to the electrical sector of service or some of the entire system which is very close to 16,000 ft.
In the following are cost estimates for the equipment of the
railway suburban zone with a direct current third rail system operating
at 600 volts. - 2 6 3 30 % motors per car based on Provisional Schedule
that provides for 25 % increase in number of trains, 50 % increase in
net mileage, and 154 % increase in net mileage above present steam
schedule. Cost of signal system and relaying track on South Chicago
and Blue Island branches is not included. Power assumed purchased from
Commonwealth Edison Co.

Transmission Lines:
- 77.4 miles 2 phase line 2/0 cable
- 17.8 miles 2 circuit line, 7.4 miles 5
circuit line. Steel towers 130 ft. apart.
Switching to houses included.

Sub-stations:
- 7 buildings with 20 - 1000 K.V. converters.

transformers

Third Rails:
- 24.6 miles 60 lb. special protected type

Feeder and Circuit Breaker Houses:
- 11 miles 1 000 000 0.5% 5 wire, breaker houses
and control.

Shedding:
- 24.6 miles single track

Cars:
- Equipping 27 side door cars with motor equipment
  trucks and compressors $119 000
  1271 300
- 29 new side door cars complete (1, 126 500)
- Work cars 3 motors each $27 000
Passenger stations lighting
Motor generators at 25th St. Outlying stations from third rail

Inspection and Repair shop extra equipment

Total (not incl. signals or power houses) $3,990,300

With power plant and extra for Transmission lines $31,000

Power plant extra (about) $1,300,000

Total incl. power plant $4,561,300
The use of forced ventilation for railway motors agrees with the equipment of the Detroit River Tunnel Company, the New York Beeches and Hartford R. R., the Zumbia Tunnel locomotives, the Metropolitan Y. B. Co., London, D.C. locomotives, the motor cars of the Midland R. Y., Great Western, Metropolitan, London, and others.

The recent development of the interior railway motor has made it possible to design direct-current railway motors such that the full benefit of forced ventilation is realizable. It is entirely practical to double the output of a motor both for continuous and peak output by the use of forced ventilation provided interpoles be used which eliminate sparking as an output limitation. Then there is a general appreciation of this fact, the writer predicts a very extensive use of forced ventilation for all classes of railway service.

In the case of the 1, 100, and 1,000, it would be possible to substitute for the 0.2-0.98 kw. of equipment the 100 kw., or 1,100 kw. motors with a forced ventilation, per our record to operate in order to the characteristics of the 0.2-0.98 kw. motor and furnish 300 kw. each during acceleration. This introduces a great saving of motor equipment and a considerable saving in cost of power due to the reduction of total output by 6 tons. The saving amount for the ventilation motor would be about 1.5 kw. per car.
I still more economical method of realizing from the capabilities of forced ventilated motors is to use a larger size, say nominal 150 or 200 H.P. frames size, and operate it at double rating; but use trains made up partially of motor cars and partially of trailers. If this method be adopted, the present old door cars can be used for trailers with but a slight cost to re-equip them with train lines, lights, heaters etc. The control apparatus must be more liberally designed since currents up to 700 amperes per motor must be handled during acceleration. The weight of slower motor output will be 400 lbs., and its cost about $200.

For 150 H.P. frame size interpole motors, sound to operate with forced ventilation, and then become nominal 300 H.P. motors will cost about the same as a double equipment of G.E. 50 H.P. motors. However, only two thirds as many equipments are necessary; that is, of the 110 total cars, but 73 need be motor cars. This seems to be the best equipment for the service, since considerable difficulty will be found in providing space for ventilating ducts with the 200 H.P. frame size interpole motor.

In addition, the 300 H.P. output during acceleration per motor axle is about all the wheels will stand without slipping unless some to be provided. At this output the percentage of adhesion is 1 in 4 of weight on motor axle.
Scales of various lengths could then be made up as follows:

<table>
<thead>
<tr>
<th>No. of car train</th>
<th>No. of trial cars</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

Since the majority of trains during odd days are 3 car trains and during such period are 5 car trains, it will be seen that the ratio of motor cars per train (56 : 44) is one corresponding to the increase of power obtainable from the motors as compared with that obtainable from the 0 x 69 I motor.

Fig. 36 shows characteristic curves of a motor with inter-poles to operate as 300 a.p. machines when provided with forced ventilation. The actual weight of a three car train loaded is 300.0 tons, which is to be compared with a train weight of 175 tons with the 0 x 69 I equipment.

Fig. 47 shows a typical run curve for this system. The energy input averages 119.5 ft. per car including blower motors. This is a saving of 0 % as compared with the 0 x 69 I motor equipment.

The largest sanitary serving ensures in the line of cars which becomes as compared with the estimate page 62 to be.
Observations

1. Equipping 37 side door cars as trailers $13,000
2. 80 new trailer cars $132,000
3. 72 motor cars $88,000
4. 30 work cars (1 motor) $37,000

For a saving of $144,000 in first cost of equipment. The annual saving of energy cost due to the use of these motors is $16,500 with purchased power at a rate noted elsewhere (page 68). In addition there is a considerable saving of maintenance of motor equipment due to the use of fewer motor cars.

The other details of the electric equipment as developed by a study of the 600 volt motor such as provisional schedule, sub-station, and 3rd rail equipment are identical for this system using forced ventilation for electric motors.

Although the use of forced ventilation for direct current motors has not been given the extended use that its advantages warrant, chiefly due to the very recent development of the interpole motor, there is no doubt whatever but that it is the system to use in case the 600 volt third rail system is adopted for the L. O. & S. suburban service.
Certain engineers have been persistent advocates of a system employing 1200 to 1500 volts at the car. The use of an interpole motor operated two in series at 600 volts is necessary, or else a motor operating directly on 1200 volts must be provided. In the former case, it is necessary to insulate the motors for 1200 volts; since one of the pair is at this potential relative to ground. This causes about 25% reduction in output as compared with a standard 600 volt motor of same frame size. A considerable extra rheostat loss is occasioned by this method, due to the impossibility of using a series parallel combination at starting with two motor equipment. For the case of the I. O. R. R., this would mean 12 1/2 increase of energy required as compared with the straight series-parallel control or a 30 1/2 increase as compared with the modified series-parallel method proposed for this service. (See page 43 and appendix C.)

A 1200 volt direct current motor of the large size required for this work is entirely practicable, and such a motor need be no more costly than a 600 volt motor of same rating. This is for the reason that the decrease in output due to necessity for heavier insulation can be largely counter balanced by increased armature core length; since the commutator can be considerably shortened, due to the lesser current commutated.

The third rail method of collecting current can be adopted for this system. The 65th, third rail proposed for this system is
illustrated in Fig. 38. A similar third rail for 1200 volts has been
designed for the California tideland R.R.

The motors can be designed to possess characteristics identical
with those of the motor for 600 volts forced draft. They will proba-
ibly weigh 400 lb. each, and will cost $0% more than the 600
volt equipment.

For this system, a distribution system employing sub-stations
is shown in Fig. 39. The system shown will provide equal reliability and
percentage of conductor loss as does the layout proposed for the 600
volt system. In Fig. 40, the rotary converters would be 1500 k.w.
units as follows:

<table>
<thead>
<tr>
<th>Location</th>
<th>Number</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>28th St.</td>
<td>6</td>
<td>1500 k.w.</td>
</tr>
<tr>
<td>Grand Avenue</td>
<td>6</td>
<td>1500 k.w.</td>
</tr>
<tr>
<td>147th St.</td>
<td>3</td>
<td>1500 k.w.</td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>1500 k.w.</td>
</tr>
</tbody>
</table>

Since these converters must be wound for 1200 volts, it is
estimated that they will cost 15% higher per k.w. than do the 1000
k.w. 600 volt units.

The following is a cost estimate for the 1200 volt forced
ventilated motor system using third rail, and operating values according
that
to the provisional schedule of Figs. 29 to 40.
Transmission line | $100,000
---|---
Sub stations | $50,000
Third rail | $50,000
Readers and circuit control | $80,000
Feeding | $85,000
Cars, equipping 17 older cars or trailers at $1200/ each | $20,400
20 new rail cars | $20,000
75 motor cars new complete | $90,000
2 work cars (4 motors) | $30,000
Passenger station lighting | $2,000
Inspection and repair work equipment | $50,000
Total (not including signals or power house) | $250,300

With power plant and extra for Transmission line | $10,000

Power plant (abcd) | $1,400,000

Total incl. power plant | $1,510,300

The use of the high operating potential of 1200 volts makes possible an economical system of distribution of power from direct current power stations. In case the railroad company decides to erect its own power plant, this possibility should be carefully considered. 600 volt turbine generators are in use up to 2000 H.P. size in Europe and the writer believes that 1200 volt direct current turbine generators could be furnished by American manufacturers in capacities up to 2000 H.P.

The standard method of construction could be used on a home polar generator adopted. There is already operating a 5000 K.W. uncompensated generator for 500 volts and the possibility of this type should be considered.
It is possible to erect two of these direct current generating stations, one at third st., on the Lake front with eight 2000 H.P. units and the other at Riverdale with 2-2000 H.P. units. The third rail system must be reinforced with feeders to give equal conductivity as compared with the system employing three sub stations. This layout is shown in Fig. 70.

The reliability of operation of this system is not equal to that employing 20,000 volt high voltage lines which could be supplied from the Commonwealth Edison Co. in case of emergency. The works cost of power also would be about .7c per K.W.H. as compared with .6c per K.W.H. for a single power plant feeding a 20,000 volt transmission system. On the other hand, the energy output per annum for this system is increased 10% due to elimination of rotary converter sub-stations.

A further advantage of this system employing two direct current power houses is that the third H.P. power house can be built first, and the entire north end of the system to Grand Crossing and South Chicago can be placed in operation, before work on the south end is begun.

RATES OF COMPENSATION, 12,000 VOLT DIRECT CURRENT TEN TWO DIRECT CURRENT POWER STATIONS.

Following is an estimate of cost for this system to operate trains according to the Provisional Schedule of Figs. 29 to 40.

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Third Rail</td>
<td>5 000 000</td>
</tr>
<tr>
<td>Feeders and circuit control system</td>
<td>250 000</td>
</tr>
<tr>
<td>Cars</td>
<td>1 154 000</td>
</tr>
<tr>
<td>Bonding</td>
<td>65 000</td>
</tr>
</tbody>
</table>
Passenger Station Lighting 9,000
Inspection and repair shop equipment 50,000
Total net incl. signals etc. power house 3,116,000
Two power plants (about) 1,760,000
Total incl. power plant 3,976,000

**HIGH POINTS IN COST ESTIMATING CURRENT PROBLEM**

This system requires the use of overhead conductors, operated at 4000 volts potential without the intervention of sub-stations. This potential is the standard for the Commonwealth Edison Company on the greater portion of its high voltage network. It seems advisable to adhere to this value least to attract the construction of the lines for 28,000 volts, the highest standard voltage of the Commonwealth Edison Company. The system with 6000 volts trolley potential is used by the Kensington and Western R., and the Chicago Lake Shore and South Bend R. R., the cars of which enter Chicago over the I. C. R. R. tracks from Kensington. If the single phase system be adopted for use by the I. C. R. R., these trains can enter Chicago under their own power.

It is difficult to provide a method of overhead construction that can be easily extended, in case the main line tracks within the suburban area be equipped for electric operation. Such a provision was predicted early in this study. There will also arise difficulty in obtaining permission to erect a structure over the tracks from 12th St., north on account of the outer parkway and main with the City of.
Chicago. There is also liable to be considerable opposition to the erection of an overhead line for the tracks on the Lake Front from 3rd St. north. So matters and substantial in the construction, the overhead work is bound to be unsightly.

As a solution of the overhead construction problem, the writer would recommend the use of a light steel bridge span for double track, two such structures to be installed from 67th St. to Van Buren St., one over the local tracks and the other over the express tracks. The arrangement is such that in the event of extending the overhead system to the main line tracks, it can be done by adding another bent of bridge work between these then existing; and using the inside posts of the outer bridge work to support the middle bent. These inside posts are made heavier with this in view. Fig. 72 shows this overhead bridge construction on the Lake Front portion. The probability is very remote of extending the main line electrification farther north than Northerly Yard, the end of the track elevation. For this reason no provision has been deemed for main line track overhead structure south of Woodlawn. (Except in the estimate for the entire suburban service from Englewood to Pleasant.)

Double autenary construction, 0000 trolley conductor suspended from 5 - 15 in. semicon. wire. Several 300 ft. span, will be ample for this service; and with a single passenger station at Windsor Park will give lesser percentage of voltage drop than is assumed for the direct current systems. Fig. 75 shows the method of sectionalizing the overhead trolley for this system.
The type of overhead construction is high enough to avoid danger to broken on freight trains. Undercrossings occur only near Van Buren St. and here the suburban and freight tracks do not interfere. Considerable special work must be done at these crossings and for the local tracks at 12th St. yards but the difficulties are comparatively slight. Altogether a thoroughly satisfactory scheme of overhead construction can be developed.

**SECTION EQUIPMENT.**

Prevented forced ventilation is not resorted to, as equipment of 6-125 H.P. motors per car is necessary. These may be of the Climax or type (V. C. 603) or AT type (V. C. 143). In either case the cost of this equipment is very high. Thus, with 6-6 H.P. motors as used by Richmond and Chesapeake Bay R. R., Washington Baltimore and Annapolis B. R. and others, the weight of a motor car loaded with 150 passengers is 70.8 tons and the weight of a three car train 210.5 tons as compared with 165 tons as the weight of a three car train using forced direct current ventilated motors, or 176 tons with 6-60 H.P. motors with natural ventilation. The energy required at car is nearly in proportion to these weights; since the modified method of direct current control (appendix 1) is nearly as efficient as the motors transformer method then there is considered the lower operating efficiency of the alternating current motors.
Following is an estimate of costs for equipping the entire
suburban system to operate according to the provisional schedule.

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trailer and bridge construction</td>
<td>$385 000</td>
</tr>
<tr>
<td>27.0 miles of double track double catenary</td>
<td></td>
</tr>
<tr>
<td>Steel bridges: 6 miles single track steel poles</td>
<td></td>
</tr>
<tr>
<td>Section lining apparatus</td>
<td>$11 400</td>
</tr>
<tr>
<td>Transmission line 7 - 3/0 cable: 27.0 miles</td>
<td>$8 000</td>
</tr>
<tr>
<td>Car, equipping 19 side doors more on motor cars: $230 000</td>
<td></td>
</tr>
<tr>
<td>99 new motor cars</td>
<td>$1 707 000</td>
</tr>
<tr>
<td>2 doors more</td>
<td>$75 000</td>
</tr>
<tr>
<td>awing.</td>
<td></td>
</tr>
<tr>
<td>Passenger Station lighting</td>
<td>$11 000</td>
</tr>
<tr>
<td>Inspection and repair shop equipment</td>
<td>$50 000</td>
</tr>
<tr>
<td>Switch House at Woodlawn (for Police accommodation)</td>
<td>$10 000</td>
</tr>
<tr>
<td>Total (not including signals or power plant)</td>
<td>$2 872 000</td>
</tr>
<tr>
<td>Power (last) (above)</td>
<td>$4 400 000</td>
</tr>
<tr>
<td>Total</td>
<td>$4 272 000</td>
</tr>
</tbody>
</table>

The total power output per amper with this system is 34% greater at the car or 78% greater at the power house than the output with the 6 X 60 kW motor on car. The existence of electric equipment will be more than doubled due to the use of four motors per car each of alternating current type.
The method is used by the Midland, G. for their Kearsney-
Huyesha-Canterbury branch. It employs two motor equipments of the
largest size available for use in the truck space. The Vestine-Hobbs
No. 135 motor is used for a portion of this service and this motor
is chosen as a basis for this study. It is rated at 100 H.P., but for
the present study is assumed working up to 150 H.P. net, at the end of
acceleration period. The motor weighs 600 lbs, complete, and the
electrical equipment for a motor car weighs 28,400 lbs. Including
ventilating set. The weight of the three car train with these motors
is 166,4 tons. Characteristic curves and general speed torque effort
curve of this motor is shown Figs. 75 and 76. Parshall and Robert
page 870 "Electric Railway Engineering" publish a very complete
description of this machine.

Fig. 77 shows the typical car using these motors. The time
for run is 5 seconds slower than that necessary to equal the time with
3 1/3 60 E motors. Inspection of Fig. 77 appendix E shows that this
performance with 135 motors can be duplicated by an equipment,
of two direct current 175 H.P. motors (0 2 60) per car. For runs in
the southern local service the schedule speed would be 7 % slower
than for an equipment with 3 1/3 60 E motors. For line runs above two
miles this equipment furnishes slightly higher schedule speeds than does
the 0 2 60 E equipment.
It is possible that by a method of operation whereby the motor voltage is raised to above normal, so that initial rate of acceleration is maintained, that the equipment will provide equal service as compared with the 9 1/2 60 H. P. motor. Fig. 78 illustrates this method. The possibility of this temporary increase in motor voltage is a point to be decided by motor manufacturer. It is very doubtful in the writer whether such a method would be permissible in regular service.

It is very necessary that some such method be devised as also that new designs be called for. This is for the reason that the provisional schedule is laid out for a minimum practicable lagover, and the adoption of the Wob. 415 equipment without a positive guarantee that it would equal the service performance of the 9 1/2 60 H. P. motors would necessitate a complete change in provisional schedule, with many more cars required to give same frequency of service.

In case the alternating current system be adopted it would be well to call for a new design that would have equal service performance as compared with the 9 1/2 60 H. P. motor. It is very possible that the improvement in single phase motor design will permit a motor to be built weighing not over 6000 lbs. and which with forced ventilation will equal output as compared with the 9 1/2 60 H. P. motor with natural ventilation, plus that output required to work the excess weight of auxiliary electrical apparatus.
Assuming that this difficulty can be successfully overcome, the single phase forced ventilated motor system is directly comparable with the other systems previously considered. The following cost estimates for trains operation according to the provisional schedule is made up on this basis:

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trolley and bridge construction</td>
<td>$280,000</td>
</tr>
<tr>
<td>Electrical lighting apparatus</td>
<td>$11,400</td>
</tr>
<tr>
<td>Transmission line</td>
<td>$69,000</td>
</tr>
<tr>
<td>Cars</td>
<td></td>
</tr>
<tr>
<td>Equipping 17 Brill cars as motor cars</td>
<td>$182,000</td>
</tr>
<tr>
<td>93 new side door cars equipped</td>
<td>$1,000,000</td>
</tr>
<tr>
<td>2 work cars &amp; motors each</td>
<td>$40,000</td>
</tr>
<tr>
<td>Bonding</td>
<td>$76,000</td>
</tr>
<tr>
<td>Passenger station lighting</td>
<td>$12,000</td>
</tr>
<tr>
<td>Inspection and repair shop equipment</td>
<td>$30,000</td>
</tr>
<tr>
<td>Switch House at wholesome (kilowatt generation)</td>
<td>$40,000</td>
</tr>
<tr>
<td>Total (not incl. signals or power house)</td>
<td>$2,286,900</td>
</tr>
<tr>
<td>Power House (omitted)</td>
<td>$1,400,000</td>
</tr>
<tr>
<td></td>
<td>$826,900</td>
</tr>
</tbody>
</table>

The energy required for this system is 5% greater at cars than that required for the system using 0.2 60-hertz motors and 5% less at power station.
In the following tables showing the comparative items for the various electric systems, a numerical designation for the systems is adopted as follows:

System 1.
- 600 volt direct current Third Rail - 2, 000 60 Hertz motors per car. All cars motor cars. No forced ventilation of motors. 7 sub stations fed from 20,000 volt line.

System 2.
- 600 volt Direct Current Third Rail - 2 (or 207) motors per car wound to operate with forced ventilation. 60 per cent of all cars are motor cars. 7 sub stations fed from 20,000 volt line.

System 3.
- 1200 volt direct current Third Rail - 2 - 1200 volt interpole motors per car wound to operate with forced ventilation. 60 per cent of all cars are motor cars. 7 sub stations fed from 30,000 volt line.

System 4.
- 1200 volt direct current Third Rail - 2 - 1200 volt interpole motors per car wound to operate with forced ventilation. 60 per cent of all cars are motor cars. Two direct current power stations generating at 1200 volts.

System 5.
- Alternating current single phase 25 cycles 3000 volts on line. Overhead double catenary supported by steel bridges spanning double track. 4 - 1500 volt, No. 148 motors per car. No forced ventilation. All cars motor cars. Single power station.

System 6.
- Alternating current single phase 25 cycles 3000 volts on line. Overhead double catenary supported by steel bridges spanning double track. 4 - 1500 volt, No. 148 motors per car with forced ventilation. All cars motor cars. Single power station.

In Table XVI there is a comparison of first cost of system to operate the entire suburban service with trains operating according to provisional schedule. This provides for 75% increase in number of trains, 50% increase of car mileage and 15% increase in seat mileage.
over and above that furnished by present steam schedule. These costs do not include new signal system. See page 22.

| TABLE XVI. \n| COMPARISON OF POWER COST. |
| --- |
| Company Builds and operates own power house | Company Purchases power from Com. Edison Co. |
| System 1 | 4,070,000 | 5,311,000 |
| System 2 | 4,618,000 | 6,047,000 |
| System 3 | 4,265,000 | 5,440,000 |
| System 4 | 3,776,000 | 4,979,000 |
| System 5 | 4,279,000 | 5,679,000 |
| System 6 | 3,994,000 | 5,070,000 |

In comparing costs of power the following are the assumed conditions. If purchased from Commonwealth Edison Co., $6 per K.W. hr., plus 10.00 per year per kilowatt at 6 kilowatts average demand. If generated in company's power house at 60,000 volts alternating current, 0.64 per K.W. hr. and 0.75 per K.W. hr. if generated at 2500 volts in two direct current power houses. In the last two cases, interest on invested capital in power plant is 5%, taxes 2%, depreciation 5%. Total fixed charges at power plant 11%. The values of energy required are obtained by reducing the amount "for traction only" of Fig. 60 in proportion to the calculated energy required for a typical run of a three car train with various systems. The other items of output are then added as the conditions may be. It should be noted that this estimate of power cost includes power for lighting, bare and stations, and for car heating.
### Table VIII.

<table>
<thead>
<tr>
<th>System 1</th>
<th>Total $/yr. Mrs.</th>
<th>Maximum demand</th>
<th>Company operates one power house</th>
<th>Company purchases power</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$46,400,000</td>
<td>16,400</td>
<td>$42,200</td>
<td>$46,400</td>
</tr>
<tr>
<td>System 2</td>
<td>$45,073,000</td>
<td>14,900</td>
<td>$43,200</td>
<td>$44,000</td>
</tr>
<tr>
<td>System 3</td>
<td>$49,975,000</td>
<td>14,900</td>
<td>$48,400</td>
<td>$46,000</td>
</tr>
<tr>
<td>System 4</td>
<td>$50,175,000</td>
<td>13,500</td>
<td>$46,100</td>
<td>$46,000</td>
</tr>
<tr>
<td>System 5</td>
<td>$53,900,000</td>
<td>17,600</td>
<td>$47,600</td>
<td>$53,600</td>
</tr>
<tr>
<td>System 6</td>
<td>$48,920,000</td>
<td>14,900</td>
<td>$43,300</td>
<td>$44,000</td>
</tr>
</tbody>
</table>

In approximate estimates of the extent of the amount "maintenance of electric equipment" per annum is shown in Table XVIII. Special attention is called to those low values, since the car mileage per year approximates 2,700,000. Experience for many years in heavy direct current roads has shown these values to be conservative, and a sufficient margin has been added for the alternating current equipments on account of their greater complexity.

### Table XVIII.

<table>
<thead>
<tr>
<th>System 1</th>
<th>$4,340,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>System 2</td>
<td>$61,000</td>
</tr>
<tr>
<td>System 3</td>
<td>$72,000</td>
</tr>
<tr>
<td>System 4</td>
<td>$72,000</td>
</tr>
</tbody>
</table>

- 30 -
The maintenance of electric circuits should not exceed $15,000 per year with the overhead system or $9,000 per year with the third rail system.

Cost of operation of each station will be as follows:

- System 1: $3,000
- System 2: $3,000
- System 3: $2,500
- System 4
- System 5
- System 6
- System 7

In the following Table XIII will be found the sum of the following items:

1. 1/2% for interest, depreciation, and taxes on all equipment exclusive of power house.
2. Power charge per annum from Table XIII with company operating power house, includes fixed charges on power house.
(3) Maintenance of electric equipment case. - Table VIII.
(4) Maintenance of Electric Equipment sub-stations. - Table VIII.
(5) Maintenance of electric circuits.
(6) Operation of sub-stations.

While these figures were little in themselves, the difference between them can well be taken as the difference in cost per annum of the various electric systems.

<table>
<thead>
<tr>
<th>System</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$25 500</td>
</tr>
<tr>
<td>2</td>
<td>$88 050</td>
</tr>
<tr>
<td>3</td>
<td>$607 000</td>
</tr>
<tr>
<td>4</td>
<td>$775 000</td>
</tr>
<tr>
<td>5</td>
<td>$993 500</td>
</tr>
<tr>
<td>6</td>
<td>$225 500</td>
</tr>
</tbody>
</table>

From these cost estimates, the writer has no hesitation in recommending for adoption System 4; that is, two direct current power stations generating current at 1200 volts and distributing by means of 3rd rail reinforced by copper feeders. It is the writer's opinion that an even better showing could be made by the system in the item "power house", which are more assumed 25 per cent more costly than the alternating current power plants. The small size of units (2000 kw.) at the power house results the use of a power plant built on the double deck principle similar to Hamilton and other new plants.
From an engineering standpoint this system of traction is very attractive, providing as it does such a marked decrease in cost as compared with the standard 600 volt system; and at the same time furnishing nearly equal reliability and service. As a system the machinery is not yet on such a sound commercial basis as is the case with some of the other systems; and hence some difficulty may be had in obtaining satisfactory deliveries on the apparatus. Owing to this, the estimated time for installation of the system is two years, as opposed to about ten months for the standard direct current 600 volt system.

OPERATING EXPENSES.

The writer has not had access to the detailed accounts for the present steam suburban system, and is therefore unable to estimate total operating expenses for the system of electric operation. It is believed that sufficient data is given in this report to enable one conversant with present operating costs to quickly estimate the same for electric operation. In doing so it must be remembered that the item "cost of power" of Table XLI includes all operating and fixed charges at power plant and is an item that would be paid per annum by a subsidiary company owning and operating the power plant. The unit cost 6.7 c per k. Hr. really expresses all power station operating expense including cost of coal, maintenance of equipment, and salaries of employees. In comparing the items of the above tabulation, "maintenance of steam equipment - locomotives" must be directly compared with "maintenance of electric equipment - cars" for the new service. The charge "Engine service" is properly to be compared with the item "heat..."
of power for electric service. It must always be remembered that the figures given for electric service in Tables XV and XIX are for a considerable extension of service providing 70% increase in number of trains, 50% increase in car miles, and 134% increase in seat miles.

| Extension of Service | New Schedule Basis
|----------------------|---------------------|
| All items are considered such that the extension of the service to the new schedule basis can be accomplished nearly by purchasing more cars, generating apparatus, and more feeder apparatus. This is with the idea that all rush hour trains shall be 3 car trains only and that the all-day trains will average 3 cars instead of 2.

**Addendum:**

| Item                             | Cost
|----------------------------------|-----|
| Third rail 94.5 miles            | $38,000
| Feeding and circuit control system | $90,000
| Cars, Total 94                      | $787,000
| Equipping 17 side door cars as trailers | $12,000
| 7 new rail cars                   | $45,000
| 50 motor cars complete            | $75,000
| 4 new cars 3 1/4 motors each      | $30,000
| Total                            | $50,000
### Estimate for Cost of Equipment of Woodland Local Service Only

The cost of an installation for the Woodland Local tracks with a view to instituting a 6 cent fare is shown herewith. The trains operate according to the provisional schedule, for details of which see page 50. This provides a two-car train every 15 minutes during the day and a five-car train every five minutes during the rush hours. With no greater outlay for first cost, the midday trains can as well be three cars instead of two.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger Station Lighting</td>
<td>$8,000</td>
</tr>
<tr>
<td>Inspection and shop equipment</td>
<td>$50,000</td>
</tr>
<tr>
<td>Total (not incl. power plant or signals)</td>
<td>$1,560,000</td>
</tr>
<tr>
<td>Two power plants (about)</td>
<td>$2,100,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$3,660,000</td>
</tr>
</tbody>
</table>

### Third Rail (18 miles)

- Circuit control system (0.1. Houses) | $45,000

### Cars (Total No. 47)

- Equipping 15 side door cars as trailers | $16,000
- Equipping 2 side door cars as motor cars | $15,000
- 90 new motor cars | $65,000
- 1 work car (4 motors) | $15,000
- Total | $15,000

### Rolling

- Shop equipment | $25,000

Total (not incl. signals or power plant) | $650,000

Power plant (6000 K. V.) | $1,315,000
Ok. For this service, the Commonwealth Edison Company could furnish power from a substation at 43rd St., owned by the railway. This substation would not fit into the general scheme in case of extension but would perhaps be advisable for a temporary purpose. In order to be able to dispose of the apparatus when extensions are undertaken, the rotary convertors should be 600 volt machines operated two in series for 1200 volts,—each rotary frame to be insulated from ground. 3 sets of two 1000 k.w. rotaries would be required. In this case the cost would be

| Total (not incl. signals or power plant) | 656,000 |
| 600 v., substation                      | 160,000 |
|                                       | 816,000 |

Either of these investments would furnish an exceedingly attractive service for the Woodlawn Local route, and with the induce-
ment of a cent fare along with a 10 per cent increase in speed, there should be no difficulty in making this service pay a handsome return.

**ESTIMATE OF COST - WOODLAWN LOCAL SERVICE**
**AND EXPRESS SERVICE TO SOUTH CHICAGO**
**AND GRAND CROSSING. - ONLY TRACK**
**SOUTH OF GRAND CROSSING.**

This estimate is based on the idea that the advantages of electric traction would be very slight for the lines south of Grand Crossing and that passengers for these points (Kensington, Blue Island, and Plessmoor etc.) could as well change to steam operated suburban trains at Grand Crossing. The estimate is based on the provisional schedule all except the Blue Island and Plessmoor Express trains. In place of these there is assumed two extra Grand Crossing Express...
trains that will take the place of the Blue Island and Posenour
trains as far as Grand Crossing.

<table>
<thead>
<tr>
<th>Third Rail (42 miles)</th>
<th>$290,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeders and circuit control system</td>
<td>$40,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cars</th>
<th>Total No. 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipping 17 side door cars as trailers</td>
<td>$38,000</td>
</tr>
<tr>
<td>15 new side door cars</td>
<td>$10,000</td>
</tr>
<tr>
<td>50 new motor cars</td>
<td>$30,000</td>
</tr>
<tr>
<td>2 Work cars (6 motors)</td>
<td>$30,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total</th>
<th>$32,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shop equipment and inspection sheds</td>
<td>$50,000</td>
</tr>
<tr>
<td>Total (not incl. signals or power plant)</td>
<td>$1,658,000</td>
</tr>
<tr>
<td>Power plant 12,000</td>
<td>$1,320,000</td>
</tr>
<tr>
<td>$2,978,000</td>
<td></td>
</tr>
</tbody>
</table>

If this project of electrifying out of the electrification scheme,
the portions north of Grand Crossing is decided upon, then below is an
estimate for an initial installation by this method, providing for
approximately same number of car miles as at present but still a 50 %
increase of seat mileage on account of using side door cars.

**APPARENT FOR INITIAL INSTALLATION WITH**
**POWER PLANT OUT OF GRAND CROSSING.**

<table>
<thead>
<tr>
<th>Third rail</th>
<th>$290,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeders and circuit control system</td>
<td>$100,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cars</th>
<th>Equipping 17 side door cars as trailers</th>
<th>$12,000</th>
</tr>
</thead>
</table>
The items of operating expense that are peculiar to electric traction are correspondingly to these latter estimated are shown below—

**INITIAL INSTALLATION**  (SEE PAGE 98-99)

Cost of power per annum including all fixed charges on power station...

Maintenance of electrical equipment - cars...

Maintenance of electric circuits...

**OPERATING LOCAL COST**  (SEE PAGE 99-100)

Cost of power per annum incl. all fixed charges on power station...

Maintenance of electrical equipment, cars...

Maintenance of electric circuits...

**Woolley Local and Express Railway**

Cost of power per annum incl. all fixed charges on power station...

Maintenance of electrical equipment, cars...

Maintenance of electric circuits...
Cost of power per annum fuel, all fixed charges on power station  295 000
Maintenance of electrical equipment care  47 000
Maintenance of electric circuits  6 000
APPENDIX A

The accompanying tabulation relates to the technical features of motor equipment as found on present operating railroads which employ the direct current 600 volt system of electric traction. These roads are chosen for comparison for the reason that they are in a way comparable to the I. O. S. A. suburban service as regards traffic and speeds. Certain English and European railroads are also tabulated for the reason that these are equipped with American built apparatus and as far as engineering features are concerned, they embody mostly American practice.
### Third Rail System

<table>
<thead>
<tr>
<th>Wheel Diameter Inches</th>
<th>Loaded Train Rate of Initial Acceleration MPH/sec</th>
<th>Speed to which Initial Rate is Carried MPH</th>
<th>Tons per Motor Light</th>
<th>Tons per Ton Light</th>
<th>H.P. per Tonnage Loaded</th>
<th>H.P. per Tonnage Light</th>
<th>Approx. Maximum Speed MPH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boston</td>
<td>33</td>
<td>1.51</td>
<td>15.7</td>
<td>15.0</td>
<td>17.3</td>
<td>11.7</td>
<td>10.1</td>
</tr>
<tr>
<td>Brooklyn</td>
<td>33</td>
<td>1.40</td>
<td>17.5</td>
<td>23.0</td>
<td>28.3</td>
<td>8.7</td>
<td>7.1</td>
</tr>
<tr>
<td>Manhattan</td>
<td>33</td>
<td>1.48</td>
<td>16.0</td>
<td>17.2</td>
<td>20.6</td>
<td>7.3</td>
<td>6.1</td>
</tr>
<tr>
<td>Interborough</td>
<td>33</td>
<td>1.29</td>
<td>18.0</td>
<td>26.8</td>
<td>34.0</td>
<td>7.5</td>
<td>5.9</td>
</tr>
<tr>
<td>Hudson</td>
<td>33</td>
<td>1.58</td>
<td>18.0</td>
<td>23.0</td>
<td>27.0</td>
<td>8.7</td>
<td>7.4</td>
</tr>
<tr>
<td>New York</td>
<td>36</td>
<td>0.79</td>
<td>24.3</td>
<td>35.5</td>
<td>38.8</td>
<td>5.6</td>
<td>5.1</td>
</tr>
<tr>
<td>Long Island</td>
<td>36</td>
<td>0.92</td>
<td>26.0</td>
<td>29.4</td>
<td>31.7</td>
<td>6.8</td>
<td>6.1</td>
</tr>
<tr>
<td>West</td>
<td>36</td>
<td>1.02</td>
<td>29.2</td>
<td>22.5</td>
<td>24.9</td>
<td>8.9</td>
<td>8.0</td>
</tr>
<tr>
<td>Market</td>
<td>33</td>
<td>1.55</td>
<td>20.0</td>
<td>17.5</td>
<td>20.0</td>
<td>7.2</td>
<td>6.2</td>
</tr>
<tr>
<td>Philadephia</td>
<td>36</td>
<td>1.32</td>
<td>22.0</td>
<td>8.8</td>
<td>9.8</td>
<td>8.6</td>
<td>7.7</td>
</tr>
<tr>
<td>Lackawax</td>
<td>36</td>
<td>1.34</td>
<td>24.0</td>
<td>16.8</td>
<td>19.0</td>
<td>9.9</td>
<td>7.9</td>
</tr>
<tr>
<td>West</td>
<td>36</td>
<td>1.12</td>
<td>26.0</td>
<td>8.8</td>
<td>9.8</td>
<td>8.6</td>
<td>7.7</td>
</tr>
<tr>
<td>South</td>
<td>33</td>
<td>0.91</td>
<td>19.0</td>
<td>17.1</td>
<td>19.9</td>
<td>5.2</td>
<td>4.5</td>
</tr>
<tr>
<td>North</td>
<td>33</td>
<td>1.04</td>
<td>19.0</td>
<td>15.0</td>
<td>17.4</td>
<td>6.0</td>
<td>5.2</td>
</tr>
<tr>
<td>Northw</td>
<td>33</td>
<td>0.98</td>
<td>16.0</td>
<td>28.8</td>
<td>34.5</td>
<td>5.5</td>
<td>4.6</td>
</tr>
<tr>
<td>Metropolis</td>
<td>33</td>
<td>1.04</td>
<td>19.0</td>
<td>22.7</td>
<td>28.2</td>
<td>7.1</td>
<td>5.7</td>
</tr>
<tr>
<td>Aurora</td>
<td>36</td>
<td>0.71</td>
<td>32.0</td>
<td>18.0</td>
<td>20.2</td>
<td>6.9</td>
<td>6.2</td>
</tr>
<tr>
<td>Northw</td>
<td>33</td>
<td>0.73</td>
<td>27.0</td>
<td>21.0</td>
<td>24.0</td>
<td>5.9</td>
<td>5.2</td>
</tr>
<tr>
<td>Great Centr</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central</td>
<td>35</td>
<td>0.84</td>
<td>18.0</td>
<td>31.0</td>
<td>32.8</td>
<td>4.0</td>
<td>3.8</td>
</tr>
<tr>
<td>Metropolis</td>
<td>38</td>
<td>1.53</td>
<td>19.0</td>
<td>27.0</td>
<td>27.5</td>
<td>8.7</td>
<td>7.3</td>
</tr>
</tbody>
</table>

By far the most useful data thus far published is aid in a preliminary determination of the relation of motor size to energy consumption and schedule speed, occurs in a paper by J. W. Armstrong, "High Speed Electric Railway Problem," Pacific, 17th June 1903.

This data is in the form of a set of curves that show first, the horsepower rating of motor required for any train weight with motors geared to various maximum speeds; second, the schedule speed for any length of run when the maximum speed is thus determined; third, the energy consumption per ton mile at that speed. These determinations are made for equipments having curve train friction curves so that when the train friction curve of a proposed equipment is known, the schedule speed, energy consumption, and motor size are determined by interpolating according to the friction curve. These curves have been enlarged and others added by interpolation and are shown in Figs. 73 to 83 incl.

The writer has used this set of curves on many occasions where an approximate estimate is needed and has found the results to closely with extended calculations based on the speed curve and thermal constants of a particular motor. The present instance has proved no exception to this statement but the importance of the case seems to warrant a more extended study.
Applying the data from these curves to the case of the L. O.
A. L. suburban service typical run of 5,015 miles we have the following
Table IX that shows the probable results for different classes of direct
current motors operating all car or motor cars. Any combination of
motors on either case and trailers will however give nearly the same
results, provided the total horsepower of motors per train is as in the
Table IX.

### Table IX

<table>
<thead>
<tr>
<th>Size of Motor</th>
<th>Total Train St.</th>
<th>Maximum speed</th>
<th>Schedule</th>
<th>Energy Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>all car motor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>car motor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-150 4.2 hp.</td>
<td>160</td>
<td>51</td>
<td>19.2</td>
<td>58</td>
</tr>
<tr>
<td>2-150 4.7 hp.</td>
<td>171</td>
<td>56</td>
<td>22.0</td>
<td>59</td>
</tr>
<tr>
<td>2-175 5.0 hp.</td>
<td>178</td>
<td>48</td>
<td>22.3</td>
<td>60</td>
</tr>
<tr>
<td>2-175 5.4 hp.</td>
<td>176</td>
<td>49</td>
<td>23.0</td>
<td>61</td>
</tr>
<tr>
<td>2-220 6.0 hp.</td>
<td>177</td>
<td>50</td>
<td>24.0</td>
<td>60</td>
</tr>
<tr>
<td>2-250 6.75 hp.</td>
<td>185</td>
<td>55</td>
<td>25.1</td>
<td>58</td>
</tr>
<tr>
<td>2-300 7.5 hp.</td>
<td>192</td>
<td>52</td>
<td>26.2</td>
<td>59</td>
</tr>
</tbody>
</table>
The table shows the very great increase in power required to obtain even a small increase in speed for the short run considered. By comparing the first and last equipments listed in the table, it is found that a 200% increase of power is required to obtain a 50% increase in schedule speed.

The data of Table X, and the Armstrong curves when applied to this case are defective for the reason that the usual method of increasing the schedule speed on a short run, by using larger motors is to increase the rate of initial acceleration rather than to keep accelerating rate constant, and increase the maximum speed. This is not meant to imply that the Armstrong curves are useless but that for such a comparison as is given in Table X, the results are a little misleading. Thus, (see above) by a 200% increase in power it is quite possible to obtain a 60% increase in schedule speed on a run 0.817 miles by the expedient of increasing the accelerating rate from 120 lbs. gross to 160 lbs. gross per ton and setting down the ultimate maximum speed in proportion. Mr. Armstrong himself has pointed out this point at various times—("Study of Feasibility of Air conditioned Motor", I.E.E. June 1905). A complete determination could be made if a set of these curves were. 72-88 were plotted for various rates of initial acceleration. But for short run rapid transit service, the rate of initial acceleration is such an important factor that it is impracticable to compare motor equipments on the basis of a constant rate of initial acceleration being used.
A better method is to assume that the motors are worked well up toward the nomo-critical limit during the acceleration or resistance period. This current is usually based on the full load current on the basis of the "motor rating" for non-interpolable motors. The ratio of initial acceleration for any given weight is therefore greater as the size of the motor is increased; hence for short runs, it is not advisable to apply these motors in a manner to produce high maximum speeds. There has been some little confusion regarding the exact significance of the ratio of initial acceleration on actual speeds and energy consumption. The term is often used without considering that it is no more a factor than is the speed by which this accelerating rate is carried. The problem is developed somewhat in detail in this Appendix and is an attempt to produce a rational solution to rational assumptions. Comparisons have been published on the basis of (1) constant rate of initial acceleration but with varying amperes per motor during accelerations, (2) on the basis of a constant percentage of speed on motor curve being reached, and coasting assumed to be variable in order to provide constant time for run; (3) on steady that coasting is constant and time of run varied, percentage of motor curve running also assumed constant, etc., etc.

It is difficult to reconcile a study of a motor made with these assumptions, with the actual manner in which a motor is applied and operated in service. The comparison of an experimental is by far the most logical and if a set of curves for different accelerations could be
provided, the whole matter would be entirely complete and all that could be desired. That such a comparison has been made by Dr. Armstrong is strongly indicated in his recently published section, "Electric Traction," for the Standard Handbook in which, in Table of paragraph 125, different rates of acceleration are recommended depending on the length of typical run.

The problem is first one of train dynamics covering only the railway motor considered as a machine of certain speed torque relations; and second, one of limitations on motor output due to heating and commutation. The introduction of interpoles and forced ventilation has considerably reduced the problem to one of train dynamics only by permitting motor to be designed for the most economical speed torque relation without reference to limitations on output.

Mr. Cary F. Hutchinson has attempted the solution of the problem in the general case. Trans. I. E. E. Jan. 1908 "Relation of Energy and Motor Capacity to Schedule Speed" and more especially Trans. I. E. E. Oct. 1903 "Conditions governing the Rise of Temperature of Electric Railway Motors in Service." Applying the methods to the case of the L. C. R. A. suburban trains, it is found that certain features of the method are inapplicable for the reasons given below.

1. The method of converting the type speed time curve of three constant accelerating rates a, b, and c, into a speed time curve having a portion of motor acceleration, is such that the new...
speed time curve does not represent the same distance traversed; even so the through acceleration A is different in the two cases.

This makes necessary an extensive calculation in order to determine the speed time curve with motor acceleration that corresponds with respect to distance traversed, with the type speed time curve. It is quite as difficult as determining the motor speed time curve at first without recourse to the type speed time curve and its auxiliary curve sheets.

A decided ambiguity exists in an example in Dr. Hutchinson's second paper due entirely to this difficulty. The example on its face appears to be a complete solution of a run having schedule speed 40 M.P.H., distance 7000 ft, time of stop 10 seconds whereas the final results as worked out do not apply to this run but to one of less schedule speed and less distance.

2. Dr. Hutchinson's comparisons are based on a variable amount of coasting but with a certain percentage of motor curve running (up to speed 100 k or the motor speed curve, say). There is no apparent reason why this should be the independent variable these comparisons. The assumption of constant coasting time, with percentage of motor curve running being what it will, has always seemed to the writer a basis that more nearly represents actual service operation.

The problem worked out here is not intended to be a general solution, but is a particular case—the determination of the best performance
of different sizes of motors for the L, O, B, L, suburban service typical run. The assumptions are only that:

1. Length of run is 0.818 miles
2. Coasting is constant, 10 seconds
3. Rate of braking is constant - net 1.0 ft. / sec.
4. Current during acceleration or resistance matches shall be equal to full load one hour rating current.
5. All direct current motors of the non-interpole type have the same speed-torque relations as regards percentage of full load absolute values.

These assumptions are all entirely admissible and correspond to actual operating conditions. It has seemed best to make this study based on a standard non-interpole motor design.

The use of interpole motors is likely to invalidate items 3 and 5 above. But a comparison on the basis of non-interpole motors should give a working estimate of service; and then if this can be bettered by using an interpole motor, then use it. The value of the study of non-interpole motors is in this manner no way lessened, since it provides data as to the very best possible performance of a non-interpole motor as a basis for comparison with an interpole design.

The assumption of constant coasting, 10 seconds, provides for the maximum power per ton; and in fact the owner in which category will operate the train. The necessary factor of safety to allow for making up time is furnished by an increase of 3%, in line of run to obtain time table time.
Fig. 30 shows the general speed traverse effort curve that corresponds to standard motor designs. It is a basis for all the speed time curves to follow in this Appendix. The fact that one curve could be used for all standard motors was first pointed out by Dr. Hutchinson.

Fig. 31 in P. 77, shows the speed time curves for the typical train with various motor equipments ranging from 500 H.P. per three car train to 3400 H.P. per three car train, and in each case for varying rates of initial acceleration. It is noticed that for each particular motor equipment, there is a certain definite rate of acceleration that gives maximum schedule speed for the run. This in line with the fact that if the rate of initial acceleration be halved, the speed to which it can be carried is practically doubled since the maximum rate of working is limited to only the one hour full load rating of the motor. The form of the curves illustrates the point very clearly. The curves are compiled with operating conditions as nearly like the R. G. M. suburban trains as is possible. That is, the train friction curve is taken from Fig. 9. The inertia of rotating parts is varied with the different sizes and gear ratios of equipment, and the total weight of train is varied according to the motor equipment used.

If it were only for dynamic reasons, the proper value of initial acceleration to use would be that providing minimum time for the run close to that very low greatest one is made of the size of motor. But limitations of output due to heating prevents in most cases the use of this rate of acceleration. A calculation has been made endeavoring
to show for each of the motor sizes of Figs. 91 to 97 how closely the heating limit affects the minimum time for run for each size of motor. The results are given in Fig. 96 in which that portion of the curves which are possible from a dynamic point of view but are impractical for an amount of motor heating are shown dotted.

The extent of this influence varies according to the design of motor; that is, the amount of dotted lines in Fig. 96 depends on the particular motor used in estimating heating. In the calculations relating to Fig. 95, the following motors were used in estimating heating:

- 100 H.P. size Westinghouse No. 121
- 125 H.P. size 6 = 66 D
- 150 H.P. size Westinghouse No. 114
- 175 H.P. size 6 = 68 D
- 200 H.P. size 6 = 69 D

Comparing Fig. 90 with Fig. 6, it is apparent that a 20% increase in schedule speed above present service can be provided only with 1400 H.P. in motors per 3 car train. This is with an initial acceleration of 1.15 M.P.H. per sec. Furthermore, this equipment will provide a maximum speed on the Van Buren St., Hyde Park express run of about 50 M.P.H. It so happens that the initial rate of acceleration indicated as proper to use by this study, namely 1.15 M.P.H. per sec. corresponds with the 150 lb. trace per ton of the Armstrong Curves of Figs. 79 to 90, and also with the statement in paragraph 120 of section "Electric traction" of the Standard Handbook that the proper rate of
acceleration on a run of one stop per mile is 3.10 ft. per sec. The latter item is a more check on the result.

The necessary equipment is best provided by one nominal 200 h.p. motor which gives acceleration at 360 rpm, and 670 volts will furnish 1600 h.p. per three car train as maximum net output at end of initial accelerating period.

**Appendix C**

**Comparison of 69 C Motor with 69 B Motor for I. S. E. R. Service.**

The 69 C motor as supplied to the New York Central Electric zone for suburban trains and to the West Jersey and Sea Shore, Camden to Atlantic City branch is of different electrical design than the 69 B motor as supplied to the Interborough Subway and Metropolitan District Co. The 69 C motor has more field and armature turns and hence operates at slower rotative speeds. The advantage of this design is that core loss, which is an important heating factor in long runs, is lower than in the 69 B motor. This is due to the decreased rotative speed. To attain this end the copper loss is higher, but in long run service this loss is comparatively less important since the time the motor is being accelerated is relatively small. The magnitudes of these various losses are well shown in Figs. 22 and 23.

Fig. 21 shows dimension of the 69 C motor, Fig. 19 shows characteristic curves and Fig. 20 the general speed tractive
effort curve. A comparison of this motor with the 0 R 69 Y shows that the 0 R 69 0 motor with a gear ratio 1.78 will duplicate the performance of the 0 R 69 Y motor with gear ratio 1.46 as far as speed is concerned. Fig. 22 shows a typical run with gear ratio 1.78. Although the core losses are lower, the copper losses are so much higher that the heating is excessive, being 15 degrees Cent. higher in service than the 0 R 69 0 motor would be. Fig. 23 shows a typical run with gear ratio 1.78 but with a reduced accelerating current. The time for the run is increased 2.5 but even with this reduction of copper losses, the temperature is still higher in service than would be the temperature of the 0 R 69 Y motor. The average length of run must exceed 1.25 miles before the 0 R 69 Y motor will operate at less temperature than will the 0 R 69 0 motor.
APPENDIX D

METHOD OF OPERATION OF BEYOND CONTROL DURING INITIAL ACCELERATION.

Messrs. Parshall and Robart in their work "Electric Railway Engineering" page 63 et seq. have developed a series of interesting studies of motor acceleration in which a considerable saving of energy is shown due to permitting the motors to operate on the "motor curve" for an interval between the series and parallel controller positions. It is of interest to indicate what possibilities for saving of energy exist from this method in the present instance.

The curves Figs. 99 to 107 incl. are developed after the manner shown by Parshall and Robart but it is to be observed that they relate to the use of automatic control with limit switch set at a certain definite value. In this way the group of curves in regard are more applicable to modern conditions than is the series worked out by the above writers.

There is a slight increase in the average rate of initial acceleration but this, in the case of the I. C. C. subeurban trains will merely decrease the schedule speed an average of 1%. There is however a considerable saving of energy totaling 6.0%. This is due to, first, less time on parallel resistance notches; second, lower values of parallel resistance grids; third, lower motor losses.

Table XX shows in detail the average losses and percentages as compiled from Figs. 99 to 107. The figures under column headed
For typical runs, some net savings for the entire system to be obtained through the use of this method of control.

<table>
<thead>
<tr>
<th>Method I</th>
<th>Method II</th>
</tr>
</thead>
<tbody>
<tr>
<td>To Full parallel</td>
<td>For typical run 0.815 Miles</td>
</tr>
<tr>
<td>Distance miles</td>
<td>0.815</td>
</tr>
<tr>
<td>Time Seconds</td>
<td>1.61</td>
</tr>
<tr>
<td>Energy, J. lves. per car at 670 volts</td>
<td>1.73</td>
</tr>
<tr>
<td>Percentage</td>
<td>100</td>
</tr>
<tr>
<td>Armature copper loss per motor in hour</td>
<td>36.2</td>
</tr>
<tr>
<td>Percentage</td>
<td>100</td>
</tr>
<tr>
<td>Armature Core Loss per motor hour hrs.</td>
<td>0.77</td>
</tr>
<tr>
<td>Percentage</td>
<td>100</td>
</tr>
<tr>
<td>Dissipat Loss</td>
<td>0.082 K. Hrs</td>
</tr>
<tr>
<td>Percentage</td>
<td>100</td>
</tr>
</tbody>
</table>

This method of control can be furnished by means of a trip on the limit switch that will delay the progression of the limit switch between series and parallel positions until the current per motor falls to below 170 amperes. Such a device would be easily made and would cause practically no added complication or cost to the control apparatus.
APPENDIX B.

METHOD OF OBTAINING SUB STATION LOAD CURVES
OF FIG. 46 TO FIG. 49 INCLUSIVE.

The substation load curves are obtained by determining from the
provisional schedule, incidentally, the number of cars passing any
substation during each half hour of the day. The average load per car
per substation was determined from the power time curves of the separate
runs as recapitulated in Fig. 27. It is assumed that the total current
to a train is derived from the two adjacent substations in a ratio
inversely proportional to the respective distances from the sub station
of the train. This is strictly true when only one train is operating
between substations. In the actual case of several trains between
substations, it is more nearly true than is the assumption that there is
an arbitrary mid point beyond which one sub station does not feed toward
the other.

It is further assumed that the performance of a car in a three
car train is typical of the performance of an average car of the service;
that is, no allowance is made for the slightly less energy per car of
a 6 car train, or the slightly greater energy per car of a one car train.

Table XXII shows these unit loads per car per substation as
derived in the manner shown above.
<table>
<thead>
<tr>
<th>Substation</th>
<th>One Car or</th>
<th>At Third Rail</th>
<th>K. H. Rins. at 430 Volts</th>
<th>K. H. Rins. at 430 Volts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Service</td>
<td>Power on</td>
<td>Power on</td>
<td>Power on</td>
</tr>
<tr>
<td></td>
<td>Light</td>
<td>Light 125 V.</td>
<td>Light 125 V.</td>
<td>Light 125 V.</td>
</tr>
<tr>
<td></td>
<td>Feet</td>
<td>Feet</td>
<td>Feet</td>
<td>Feet</td>
</tr>
<tr>
<td>No. 1-12th St.</td>
<td>Local</td>
<td>12.25</td>
<td>17.4</td>
<td>19.5</td>
</tr>
<tr>
<td></td>
<td>Express</td>
<td>13.02</td>
<td>14.1</td>
<td>16.7</td>
</tr>
<tr>
<td>No. 2-Oakland</td>
<td>Local</td>
<td>21.5</td>
<td>21.3</td>
<td>24.1</td>
</tr>
<tr>
<td></td>
<td>Express</td>
<td>0.4</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>No. 3-18th St.</td>
<td>Local</td>
<td>9.1</td>
<td>9.3</td>
<td>19.5</td>
</tr>
<tr>
<td></td>
<td>Grand Tr.</td>
<td>17.6</td>
<td>17.1</td>
<td>20.6</td>
</tr>
<tr>
<td>S. I. R. B. U.</td>
<td>Local</td>
<td>11.1</td>
<td>11.6</td>
<td>24.2</td>
</tr>
<tr>
<td>No. Olympic</td>
<td>10.3</td>
<td>10.7</td>
<td>17.0</td>
<td>17.4</td>
</tr>
<tr>
<td>No. 4-Burnside</td>
<td>Local</td>
<td>3.0</td>
<td>3.1</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>Express</td>
<td>10.7</td>
<td>11.2</td>
<td>21.8</td>
</tr>
<tr>
<td>S. I. R. B. U.</td>
<td>Local</td>
<td>31.2</td>
<td>32.5</td>
<td>36.3</td>
</tr>
<tr>
<td>No. 6-Broadway</td>
<td>Local</td>
<td>16.0</td>
<td>16.3</td>
<td>23.3</td>
</tr>
<tr>
<td></td>
<td>Express</td>
<td>25.5</td>
<td>22.0</td>
<td>28.0</td>
</tr>
<tr>
<td>No. 7-Hancock</td>
<td>Local</td>
<td>15.7</td>
<td>19.3</td>
<td>23.5</td>
</tr>
<tr>
<td></td>
<td>Express</td>
<td>23.0</td>
<td>22.0</td>
<td>23.0</td>
</tr>
</tbody>
</table>

In the above table, 12 k. h. Ins. for door has been added to the substance unit load in case terminal switching is necessary. Lighting and heating of stored cars at 12th St. and other terminals is assumed to begin 30 minutes before the cars are placed in service. This load is added to the load as determined for cars in operation only.
The operation of storage batteries for this service consists in:

1. Reduction of rotary converter capacity due to elimination of effect of swings at converter, flatter load curve possible, and less reserve machinery.

2. Reduction in cost of high voltage lines due to elimination of swings and to less necessity for duplicate lines.

3. Reduction in power house capacity.

4. Saving in cost of power if purchased on a maximum demand basis.

5. Operation of trains maintained in event of failure of transmission lines.

To obtain a definite idea as to the amount of fluctuation on a substation, there has been calculated Fig. 106. This is an exact load curve on 12th St., substation from 6:30 P.M. to 6:30 P.M. during a summer week day rush hour with trains operating according to the provision- al schedule of Fig. 64. It is obtained by adding together the instantaneous loads of the various trains for the period in consideration.

Assuming batteries to be used at this substation and that the converter supply 5000 k.W. continuously during the interval, then the battery must provide 4000 k.W. for one minute or a 5000 k.W. peak of 15 seconds. This will be the maximum demand in this battery.
Such a battery would be rated at about 4000 amperes on a one hour discharge basis, or for 6 hr. discharge rate at about 900 amperes.

The addition of this battery would necessitate the operation of but 3 - 1000 K.W. converters during the rush hour. They would be carrying a steady 50% overload but their operations at this load would be better than that of 3 - 1000 K.W. units carrying an average load of 2800 K.W. but with fluctuations from 1000 K.W. to 2800 K.W. Similarly during the middle of the day, it would be necessary to operate but one converter instead of two in the case of batteries not being used. The battery therefore dispenses with the operation of one 1000 K.W. converter.

The purchase of power from the Commonwealth Edison Company is a strong probability for this case. The rate would be about 0.5 c per K.W. hr. with a maximum demand rate of $15.00 per year per K.W. of 5 minute peak. The 5 minute maximum demand from this substation occurs from 5:40 to 5:45 P.M. when it is 4700 K.W. in summer and 5100 K.W. in winter.

It is unlikely that this demand will be coincident with the maximum demand on other substations, so that on the basis of cutting down maximum demand in case power is purchased, the 4000 amp. 6 hr. rate battery will not be of much use. The general conclusion is that since all cycles of fluctuation of load during rush hour are less than 5 min. duration, the use of batteries of just sufficient capacity to
eliminate fluctuations will not decrease the 5 minute demand from the source supplying power.

To produce any effect on the 5 min. maximum demand, it is necessary to introduce additional battery capacity above that required to eliminate fluctuations. Furthermore, every extra kilovolt we add will decrease the maximum demand by an amount just equal to this added capacity.

Applying these conclusions to the various substations, it is necessary to install battery capacity of the amounts shown in the following Table XXXII in order that the full benefit of the 5 minute maximum demands can be attained. This equipment is also chosen so that maximum permissible charge rates in all pay service will not be exceeded. The table also shows the alternative equipment, and probable coincident maximum demands, in case batteries be not installed.
TABLE XII.

COLORADO SPRINGS STATION EQUIPMENT
1900 and High Voltage 600 Volt System

(A) INVERTER OUTPUT

<table>
<thead>
<tr>
<th>Sub Station</th>
<th>Rotary Capacity E.W.</th>
<th>30 sec. probable maximum Demand E.W.</th>
<th>80 sec. maximum Demand E.W., (winter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12th Street</td>
<td>4-1000</td>
<td>3500</td>
<td>8900</td>
</tr>
<tr>
<td>Woodside</td>
<td>4-1000</td>
<td>3800</td>
<td>7900</td>
</tr>
<tr>
<td>Oakland</td>
<td>4-1000</td>
<td>3800</td>
<td>7800</td>
</tr>
<tr>
<td>Buronside</td>
<td>3-1000</td>
<td>3800</td>
<td>7200</td>
</tr>
<tr>
<td>Riverdale</td>
<td>3-1000</td>
<td>5000</td>
<td>4300</td>
</tr>
<tr>
<td>Venwood</td>
<td>2-1000</td>
<td>7000</td>
<td>2300</td>
</tr>
<tr>
<td>Madsen Park</td>
<td>3-1000</td>
<td>2000</td>
<td>4600</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td>8,500</td>
<td>15600</td>
<td></td>
</tr>
</tbody>
</table>

(B) WITH BATTERY

<table>
<thead>
<tr>
<th>Sub Station</th>
<th>Battery capacity one hr. Rate</th>
<th>80 sec. maximum Demand E.W., (winter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12th Street</td>
<td>6-750</td>
<td>8000</td>
</tr>
<tr>
<td>Oakland</td>
<td>5-750</td>
<td>8000</td>
</tr>
<tr>
<td>Woodside</td>
<td>3-750</td>
<td>8000</td>
</tr>
<tr>
<td>Buronside</td>
<td>3-500</td>
<td>1000</td>
</tr>
<tr>
<td>Riverdale</td>
<td>2-500</td>
<td>1000</td>
</tr>
<tr>
<td>Venwood</td>
<td>2-500</td>
<td>1000</td>
</tr>
<tr>
<td>Madsen Park</td>
<td>2-900</td>
<td>1800</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td>16000</td>
<td>6700 E.W.</td>
</tr>
</tbody>
</table>

Battery capacity 4000 Amps. 3400 Amps. 2400 Amps. 2000 Amps. 1800 Amps. 1700 Amps. at 600 volts.
In each of the above cases add to the maximum around 1400 ft.

for longer and auxiliary supply. Items of specifications that determine size of battery at various substations are given below:

**12th St.**— Battery capable of taking 20 sec. peak of 11200 amperes after 10 sec. beam discharged 2800 amp. hrs. at mean rate of 2500 amperes.

**Collins**— 20 sec. peak of 6700 amperes. after discharge of 2700 amp. hrs. at mean rate of 2500 amperes.

**Edison**— 20 sec. peak of 9300 amperes. after discharge of 2500 amp. hrs. at mean rate of 2500 amperes.

**Harvard**— 20 sec. peak of 6700 amperes. Battery full charged.

**Sadler**— 20 sec. peak of 6700 amperes. Battery full charged.

**Homewood**— 20 sec. peak of 5800 amperes. Battery full charged.

**Windor Park**— 20 sec. peak of 6100 amperes. Battery full charged.

Failing is a comparison of cost of equipment with and without batteries, on basis of power purchased from Commonwealth Edison Co.

**WITHOUT BATTERY**

- Rotary converter and step down Trans. etc.  
- 7 sub station buildings  
- 846,000

**WITH BATTERY**

- Rotary converter and step down Trans.  
- 4 sub station buildings  
- 17400 amp. cur. (1 hr. rate battery) with motors and switch gear  
- 240,000

**Capital in sub stations**  
- 1,000,000

---

-120-
### WITHOUT BATTERIES

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital</td>
<td>$84,500</td>
</tr>
<tr>
<td>5-1 Dep. Also, equipment of sub stations</td>
<td>$40,600</td>
</tr>
<tr>
<td>3-1 Dep. lines &amp; overhead work</td>
<td>$7,300</td>
</tr>
</tbody>
</table>

**Total**

$132,400

**10,000 K.W. maximum Demand at $1.00**

48,480,000 K.W. hrs. at 1/2 cent

**Annual Power Charge**

$368,400

### WITH BATTERIES

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital</td>
<td>$79,400</td>
</tr>
<tr>
<td>5-1 Dep. Also, equipment of sub station</td>
<td>$22,600</td>
</tr>
<tr>
<td>3-1 Dep. Lines</td>
<td>$4,500</td>
</tr>
<tr>
<td>10-1 Dep. Batteries</td>
<td>$11,200</td>
</tr>
</tbody>
</table>

**Total**

$117,700

**10,120 K.W. max. Demand at $1.00**

48,480,000 K.W. hrs. at 1/2 cent

**Annual Power Charge**

$232,180

It appears therefore that the use of storage batteries will not produce any decided saving in annual charges, even if power be purchased. If the company builds its own power house, the maximum demand charge would be nearer $12.00 a year per K.W., and the works cost about 0.6 a instead of 0.3 a per K.W. a hr. This would throw the balance in favor of an installation without batteries. The estimate above, which shows an apparent saving of $11,000 per year with batteries, is not sufficiently precise to warrant the adoption of storage batteries in sub stations on the basis of this estimate alone.
With storage batteries, the regulation of the high voltage system will be superior to that of the system without batteries; even though the batteries are of smaller size. Also, the storage batteries will permit, in case of accident, complete shut down of one hour during each hour; or of 3 hours during the middle of the day.

It is the writer's opinion that, with a well constructed system, the liability of shut down is very remote; and that the regulation without batteries is sufficiently good for the service (See page 62). It is, however, clear that from the standpoint of the railroad company to shut down one first hour, and a saving in this item of $487,000 can be achieved if storage batteries be introduced with.

If the company operate like one power house, it would be better to call immediately to shut down; if it runs many power, the desirability of storage batteries is still in question. After it extension for main live terminal traffic is accomplished, the increased load that is occasional can be most satisfactorily be the addition of storage batteries to the then existing sub-stations.
ELECTRIFICATION PROJECT
THE ILLINOIS CENTRAL RAILROAD
SUBURBAN SERVICE AT CHICAGO, ILL.
BY
Tracy W. Simpson

FIGURE No. 2

PROFILE Grades in ft per mile

OCKS Road Crossing

Also shows signal positions for suburban tracks this

EMENT

BALLAST

RAIL

MEN'S SECTIONS FROM CHICAGO

KEY TO BALLAST

Broken Stone
Cinders
Gravel

CONDENSED PROFILE
I.C.R.R. - CHICAGO

Scales
Horiz. 9000's 1"
Vert. "60'-1"
CONDENSED PROFILE-ETC.
BLUE ISLAND BR.
MAP OF CHICAGO SUBURBAN SERVICE TERMINAL
ILLINOIS CENTRAL RAILROAD

Scale: 1 in. = 1000 ft.
TYPICAL RUN - 0.815 MILES
Type 2-6-4 Locomotive - 3 Side Door Cars
Total Train Weight 237 Tons,
Estimated Best Performance
GE 978 RAILWAY MOTOR
GENERAL SPEED-TRACTIVE EFFORT CURVE

570 Volts 36" Wheel
Arm Spec. 15522  Field Spec. 7020-1

Full lines show speed-tractive effort with different ratios. Dotted lines connect points corresponding to same ampere input.
TYPICAL RUN 0.815 MILES
2 625 hp Motors per Car 36 Wheels
Gear Ratio \( \frac{25}{12} = 2.19 \)
570 Volts
GEAR RATIO 3.15

MILES per hour

Amperes

Speed

Core Loss per motor

Amperes per car

Armature Copper Loss per motor

Time - Seconds

TYPICAL RUN 0.815 MILES
2 - 6E 69B Motors per car 36 wheels
Gear Ratio 20/6 = 3.33
570 Volts
ELECTRIFICATION PROJECT
THE ILLINOIS CENTRAL RAILROAD CO.
SUBURBAN SERVICE AT CHICAGO, ILL.
by
TRACY W. SIMPSON

GEAR RATIO STUDY
Recapitulation Sheet
Showing speed, energy, and motor heating for typical run 8.35 miles
with 2 GE 693 motors per car.
36" wheel-570 Volts for various
gear ratios.

Schedule Speed 12 sets shop

Lowest Hours per Car
570 Volts

Average Armature Loss

Ultimate Temp. Rise Armature

Ultimate Temp. Rise Field

Average Field Loss

Note:-
Motor losses averaged for 12 sets shop
and layover of 6 minutes after a
trip of 15 typical runs.
CHARACTERISTIC CURVES
GE69C RAILWAY MOTOR
36" Wheels  600 Volts  Gear Ratio 3:1 2185
1 Turn Arm  45 Turns per Field Spool
Arm Spec: A15872  Field Spec: F14618-9

[Graph showing characteristic curves for GE69C Railway Motor]
ELKOTRIFIOATION PROJECT
THE ILLINOIS CENTRAL RAILROAD CO.
SUBURBAN SERVICE AT CHICAGO, ILL.
BY
TRACY W. SIMPSON

FIGURE No. 21A

Speed Curves at 570 Volts 75°C

Comparison of Speed Curves
GE69B RAILWAY MOTOR
GE69C RAILWAY MOTOR
FIGURE No. 2

TYPICAL RUN 0.815 MILES
2 6E69C Motors per car 36" Wheels
Gear Ratio \( \frac{36}{27} = 1.33 \)
570 Volts
3 CAR TRAIN

KW HRS FOR RUN 12.35
Avg KW Per Train 376

Typical Run: 0.815 MILES
260 ft. 36 kw. per car 36", wheels
Gear Ratio 246
570 Volts
General Run Sheet

3 Car Train - 2 GE 66B Motors per Car
Gear Ratio 2.48
570 Volts

Amperes per Car

Motor per Motor

Amperes per Motor

Speed Miles per Hour

100 200 300 400 500 600 700 800 900 1000 1100 1200

0 5 10 15 20 25 30 35 40 45 50 55 60
<table>
<thead>
<tr>
<th>Time</th>
<th>Leave</th>
<th>For</th>
<th>Arrive</th>
<th>From</th>
</tr>
</thead>
<tbody>
<tr>
<td>4:00 AM</td>
<td>Randolph St</td>
<td>Woodlawn</td>
<td>Randolph St</td>
<td>Forest Park</td>
</tr>
<tr>
<td>5:00 AM</td>
<td>Randolph St</td>
<td>Grand Crossing</td>
<td>Randolph St</td>
<td>Forest Park</td>
</tr>
<tr>
<td>6:00 AM</td>
<td>Randolph St</td>
<td>Woodlawn</td>
<td>Randolph St</td>
<td>Forest Park</td>
</tr>
<tr>
<td>7:00 AM</td>
<td>Randolph St</td>
<td>Grand Crossing</td>
<td>Randolph St</td>
<td>Forest Park</td>
</tr>
<tr>
<td>8:00 AM</td>
<td>Randolph St</td>
<td>Woodlawn</td>
<td>Randolph St</td>
<td>Forest Park</td>
</tr>
<tr>
<td>9:00 AM</td>
<td>Randolph St</td>
<td>Grand Crossing</td>
<td>Randolph St</td>
<td>Forest Park</td>
</tr>
<tr>
<td>10:00 AM</td>
<td>Randolph St</td>
<td>Woodlawn</td>
<td>Randolph St</td>
<td>Forest Park</td>
</tr>
<tr>
<td>11:00 AM</td>
<td>Randolph St</td>
<td>Grand Crossing</td>
<td>Randolph St</td>
<td>Forest Park</td>
</tr>
<tr>
<td>12:00 PM</td>
<td>Randolph St</td>
<td>Woodlawn</td>
<td>Randolph St</td>
<td>Forest Park</td>
</tr>
<tr>
<td>1:00 PM</td>
<td>Randolph St</td>
<td>Grand Crossing</td>
<td>Randolph St</td>
<td>Forest Park</td>
</tr>
<tr>
<td>2:00 PM</td>
<td>Randolph St</td>
<td>Woodlawn</td>
<td>Randolph St</td>
<td>Forest Park</td>
</tr>
<tr>
<td>3:00 PM</td>
<td>Randolph St</td>
<td>Grand Crossing</td>
<td>Randolph St</td>
<td>Forest Park</td>
</tr>
<tr>
<td>4:00 PM</td>
<td>Randolph St</td>
<td>Woodlawn</td>
<td>Randolph St</td>
<td>Forest Park</td>
</tr>
<tr>
<td>5:00 PM</td>
<td>Randolph St</td>
<td>Grand Crossing</td>
<td>Randolph St</td>
<td>Forest Park</td>
</tr>
<tr>
<td>6:00 PM</td>
<td>Randolph St</td>
<td>Woodlawn</td>
<td>Randolph St</td>
<td>Forest Park</td>
</tr>
</tbody>
</table>
DIAGRAM OF 600 VOLT DISTRIBUTION SYSTEM

80° Special Steel Third Rail

Copper Feeder 1,000,000 C.M.

- Knife Switch
- Fuse

DISTANCES

<table>
<thead>
<tr>
<th>Sub-Sta. No. 1 - Sub-Sta. No. 2</th>
<th>Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>3.1</td>
</tr>
<tr>
<td>4</td>
<td>4.1</td>
</tr>
<tr>
<td>5</td>
<td>5.25</td>
</tr>
<tr>
<td>6</td>
<td>6.3</td>
</tr>
<tr>
<td>7</td>
<td>7.0</td>
</tr>
</tbody>
</table>

Scale of Miles: 0 1 2 3 4 5
Direct current 600 volt system
Substation daily load
For Park Row Substation No. 1
on typical Winter Week Day
Trains operating according to Provisional Schedule

PARK ROW - WINTER
Maximum probable swing 2600 KW at 5:46 PM.

0 1 2 3 4 5 6 7 8 9 10 11 12 A.M. P.M.
Time

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000 3200 3400 3600 3800
Horsepower output at 600 volts
PARK ROW - SUMMER

Maximum probable swing 3100 K.W. at 5:36 P.M.

DIRECT CURRENT 600 VOLT SYSTEM
SUB STATION DAILY LOAD
FOR PARK ROW - SUBSTATION NO. 1
For typical Summer Week Day
Trains operating according to Provisional Schedule
OAKLAND - WINTER
Maximum probable swing 7500 kw at 6:45 AM.

DIRECT CURRENT 600 VOLT SYSTEM
SUB STATION DAILY LOAD
FOR OAKLAND SUB STATION N92
on typical Winter Week Day
Trains operating according to Provisional Schedule
OAKLAND - SUMMER
Maximum probable swing 6800 kW at 6:15 PM

DIRECT CURRENT 600 VOLT SYSTEM
SUB STATION DAILY LOAD
FOR OAKLAND SUB STATION No.2
on typical Summer Week Day
Trains operating according to Provisional Schedule.
WOODLAWN WINTER
Maximum probable swing 7900 KWh at 6:10 PM.

Kilowatts out put of 620 volts

121 2 3 4 5 6 7 8 9 10 11 12
A.M.

M.

P.M.

DIRECT CURRENT 600 VOLT SYSTEM
SUB STATION DAILY LOAD
FOR WOODLAWN SUB STATION No. 3
on typical winter week day.
Trains operating according to Provisional Schedule.
WOODLAWN SUMMER

Maximum probable swing 7300 kW at 6:10 PM

DIRECT CURRENT 600 VOLT SYSTEM
SUB STATION DAILY LOAD
FOR WOODLAWN SUB STATION NO. 3
on typical Summer weekday
Trains operating according to Provisional Schedule
BURNSIDE - WINTER

Maximum probable swing 5200 Kw at 6:20 P.M.

DIRECT CURRENT 600 VOLT SYSTEM
SUB STATION DAILY LOAD
FOR BURNSIDE SUB STATION No.4
on typical Winter week day
Trains operating according to Provisional Schedule
BURNSIDE-SUMMER
Maximum probable swing 5000 kW at 6:28 PM.

DIRECT CURRENT 600 VOLT SYSTEM
SUB STATION DAILY LOAD
FOR BURNSIDE SUBSTATION NO. 4
on typical Summer week day
Trains operating according to Provisional Schedules
RIVERDALE SUB STATION - WINTER
Maximum probable swing 4300 kW at 6:10 A.M.

DIRECT CURRENT 600 VOLT SYSTEM
SUB STATION DAILY LOAD
FOR RIVERDALE SUB STATION W95
on typical Winter week day
Trains operating according to Provisional Schedule
RIVERDALE SUMMER

Maximum probable swing 4200 kW at 6:18 P.M.

DIRECT CURRENT 600 VOLT SYSTEM
SUB STATION DAILY LOAD
FOR RIVERDALE SUB STATION NO. 5
on typical Summer weekday

Trains operating according to Provisional Schedule
HOMEOWOOD - WINTER

Maximum probable swing 2380 KW at 6:33 PM.

DIRECT CURRENT 600 VOLT SYSTEM
SUB STATION DAILY LOAD
FOR HOMEOWOOD SUB STATION NO. 6
on typical Winter week day
Trains operating according to Provisional Schedule
DIRECT CURRENT 600 VOLT SYSTEM
SUB STATION DAILY LOAD
FOR HOMEWOOD SUB STATION NO. 6
on typical Summer week day
Trains operating according to Provisional Schedule.
WINDSOR PARK WINTER
Maximum probable swing 4680 KW at 5:40 P.M.

DIRECT CURRENT 600 VOLT SYSTEM
SUB STATION DAILY LOAD
FOR WINDSOR PARK SUB STATION No. 7
on typical Winter weekday
Trains operating according to Provisional Schedule
Sunday Schedule = 5 week day schedule

In a year there is assumed 20 weeks of winter load and 32 weeks of summer load. Hence total kW hrs per year is 40,195,000.

TOTAL OUTPUT CURVES
DIRECT CURRENT- 600 VOLT SYSTEM
Trains operating per Provisional Schedule
Total Kilowatt Hrs. per Winter Week Day 151200
" Summer " 125800
Load Factor Winter = .41
" Summer " = .38
ELECTRIFICATION PROJECT
THE ILLINOIS CENTRAL RAILROAD CO.
SUBURBAN SERVICE AT CHICAGO, ILL.
BY
Tracy W. Simpson

FIGURE No. (1)

600 VOLT DIRECT CURRENT SYSTEM
20000 VOLT FOUR CIRCUIT POLE

Concrete 1:2:4
with 1" Fe at 1/2

Concrete 1:4:7

Floored 150 ft. apart on tangent
DIAGRAM OF 20000 VOLT DISTRIBUTION SYSTEM

All circuits 3 phase. One phase shown.
All conductors No. 00 copper, overhead
If batteries be installed at substations, conductors are to be No. 1 copper
-0- H.T. Oil Switch

DISTANCES

Sub Sta. No. 1 - Sub Sta. No. 2
2  3  3.1 miles
3  4  4.1
4  5  5.25
5  6  6.3
3  7  3.0
7 via So.Chap. 4  4.3

Total: 76.4 miles of 3 phase line if company builds Power House
54.5 miles of 3 phase line if company purchases power for regular service
CURRENT SYSTEM

Intruction
Patents

Fibre

Topline track rail 7/8"
Gauge Line 3

Tie 5" x 8" x 10' between brackets
Tie 5" x 8" x 11' under brackets

Floor

Section at Gusset

80° RAIL SECODING AND FISH PLATE.
ELECTRIFICATION PROJECT
THE ILLINOIS CENTRAL RAILROAD CO.
SUBURBAN SERVICE AT CHICAGO, ILL.
BY
TRACY W. SIMPSON
FIGURE No. 64

CASE OF GROUND ON MIDDLE SECTION
A and B trip with C and D following.

CASE OF GROUND ON END SECTION
A and B trip with C and D following.

600 VOLT DIRECT CURRENT SYSTEM
OPERATION OF CIRCUIT BREAKERS
WITH THIRD RAIL SYSTEM
Lines north of Woodlawn
PROPOSED DESIGN FOR
RECONSTRUCTION OF MOTOR END UNDERFRAME
ON PRESENT
MULTIPLE SIDE DOOR SUBURBAN COACH.
Showing new body bolster etc. to accommodate motor truck.
1200 VOLT DIRECT CURRENT SYSTEM
THIRD RAIL CONSTRUCTION
Sprague Wilgus Farrhiam Patents
See also Fig. 63 for Clearance and Bonding Method

Wood Plug
*12 Drive Screw 3 1/2" long

Composition Spacers 7/8" x 1" every 2 ft.

Durated Fibre
Tak Continuous Between Spacers

65 Lb. Rail Section
SPECIAL STEEL
.047 Ohms per Mile.
1200 VOLT DIRECT CURRENT SYSTEM
Diagram of distribution system for 20,000 volt to substations transmission
- 65° Special Steel Third Rail (Fig. 66)
- Auxiliary Fender
- Knife Switch

Scale of Miles

C.B. House - Randolph St.
C.B. House - 14th St.
Substation 26th St.
C.B. House - 35th St.

C.B. House - Hazel Crest
C.B. House - Flowermoor
SINGLE PHASE ALTERNATING CURRENT SYSTEM
INTERMEDIATE SUPPORTING BRIDGE FOR
2000 VOLT TROLLEY STRUCTURE
Showings
Design to permit extension to through freight and passenger tracks
SCALE \( \frac{\frac{1}{8}}{\text{ft}} = 1\text{ft} \)
DIAGRAM OF 9000 VOLT TROLLEY AND FEEDERS

9000 Volt Trolley

--- Feeder - 9000 Volt. Except where specified.

Notes:
- Trolley and feeders north of 63rd St. on Phase A.
- Trolley and feeders south of 63rd St. on Phase B.
- Track - Phase C.
- Section switches in houses, not on bridges.
- Auxiliary feeders carried by bridge structure. (Fig. 72)
- Phase C return to power station to be reinforced with one 100,000 G.M. bare cable from 63rd St. to Windsor Park.
- With this system one rail of track return can be used for signals.
CHARACTERISTIC CURVES
Westinghouse No. 133 Ry. Motor
Single Phase 25 cycles
Wheel diam 36in. Gear Ratio 66/29=2.87
Volts at Terminals 615
3-CAR TRAIN

KW Hrs. For Run 12.2
Average KW 3.54 with 12 sec stop
Blower Motor \( \frac{6}{360} \)
Average P.F. incl. stop 63%
THE ILLINOIS CENTRAL RAILROAD CO.

PROJECT

THE ILLINOIS CENTRAL RAILROAD CO.

1-1/2 ARROW
3 CAR TRAIN

K.W.Hrs. for run 16.3
Avg. K.W. per train 510

TYPICAL RUN 0.815 MILES
4-Whp 4148 Motors per Car 37½ Wheels
Gear Ratio \( \frac{20}{20} = 3.55 \)
3000 / 290 Volts
TYPICAL RUN 0.815 MILES
3 CAR TRAIN 2400 H.P D.C. MOTORS
Seated for various initial accelerations.
Current during initial acceleration is full
load current on one hour rating basis.
Motor characteristics Figs.
Train resistance Figs.
Total train weight 209 Tons 1P/hr 11.8
EXACT SPEED - TRACTIVE EFFORT

Showing pounds per meter at all speeds with acceleration according to method I.

Limit Switch set at 300 Amperes
EXACT SPEED - TRACTIVE EFFORT

Showing pounds per motor at all speeds with acceleration according to method II

Limit Switch set at 300 Amperes

Limit Switch Series Trip set at 170 Amperes
SPEED-TRACTIVE EFFORT CURVES
GE 695 MOTOR
570 Volts 36 in. Wheel Gear Ratio 2.46
Arm Spec 1802 Field Spec 7020-1
Series motor curve from separate test of motor on 225 volts
SPEED AND CURRENT TIME CURVES
for Acceleration by Method III

Volt Curve approx. only

Volts per Motor
Amperes per Motor
Amperes per Car
Amperes Volts

Speed

Time - Seconds

2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 TWS
RHEOSTAT LOSSES

Acceleration by Method I

Time - Seconds
RHEOSTAT LOSSES

Acceleration by Method II
THE DIRECT CURRENT 600 VOLT SYSTEM
EXACT LOAD CURVE ON PARK ROW SUBSTATION.
taken for period from 5:30 P.M. to 5:50 P.M.
FOR SUMMER SEASON
Trains operating according to Provisional Schedule of Fig. 44.