THE DESIGN OF AN UNDERGROUND DISTRIBUTION SYSTEM FOR THE UNIVERSITY OF TENNESSEE.

by

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INTRODUCTION

The present distribution system of the University of Tennessee having proved inadequate due to the increased demands for power, a need has been felt for a system that will supply the present demands and also provide for supplying an increased demand in the future.

It is also inefficient, and although it was considered good design at the time it was installed (and the system is still used to a considerable extent), the present tendency is toward high voltage distribution even for short distances.

Aside from being inadequate and inefficient, the present distribution system is unsightly. The poles and the masses of wire mar the beauty of the campus.

The object, then, of the present work is to design a system that will meet the demands for power, that will decrease the costs of distribution, and, if it does not increase the beauty of the campus, will at least be inconspicuous.

The intention of this study is not to discover new principles of design, but to apply will known principles of design to a particular installation.

The author wishes to acknowledge his indebtedness to Dr. Charles A. Perkins and Prof. Charles E. Ferris for valuable aid and assistance.

CHAPTER I.

GENERAL SURVEY OF THE FIELD.

For some ten or fifteen years after the introduction of electricity for lighting, all transmission and distribution was done by overhead wires. As the distribution systems became more numerous and more complicated there arose an objection to them, especially in large cities. It was due to this demand on the part of the public that wires were first put underground.

The first underground System was the Edison Underground System laid in 1882. The practice was not taken up to any extent however, until about 1890. Due to lack of knowledge of the conditions that would obtain, the first underground installations were not very successful and were looked upon rather as a necessary evil. Then too, the cost of changing from the overhead to the underground system was great and was not warranted except in the built up portions of large cities. Besides the cost there was the difficulty in making repairs. In many cases it was necessary to take up pavement or sidewalk to effect a repair.

The underground line may be considered as made up of two parts, namely the cable and the conduit. For single phase or two wire direct current systems the cable consists of a single conductor either solid or stranded, covered with either rubber or paper insulation and the whole encased in a lead sheath.

For three phase or three wire direct current systems the cable consists of three conductors insulated from each other and from the lead sheath.

The conduit should be made of some protective material not readily effected by water and air. In many cases of European practice no conduit is used. The cable is covered with an armor similar to that used on American submarine cables and laid directly in the ground. This method has several advantages. It affords better cooling. It is flexible and can more easily be laid around obstacles. The initial cost of laying such a cable is also less. Its disadvantages are that the armor is exposed to the earth and is attacked by rust and electrolysis. The life of such a cable is not as long as that of one placed in a conduit.

Conduits of various materials have been manufactured and sold. All of them have some advantages and some disadvantages. The first conduits were made of wrought iron or cast iron pipe embeded in coarse concrete. This makes a very strong but expensive conduit. It will resist crushing due to the pressure of the earth and is not apt to be broken by workmen when making excavations. The joints may easily be made water tight which is very desirable. It is attacked by rust and electrolysis however. It also offers another disadvantage for alternating current lines due to self induction in the conductor.

Clay and tile conduits are also used and are somewhat cheaper than wrought iron or cast iron pipes but are easily broken.

Wooden conduits have been used but it was found that the disintegration of the wood formed acetic acid which corroded the lead sheathing of the cable.

The latest development in conduits is the fibre conduit. The advantages claimed for it are numerous. It is light and easily handled and possesses sufficient strength to prevent its being crushed by the pressure of the earth. It will not corrode the lead sheathing as wood will. It is a nonconductor and a break in the insulation will not necessarily cause a"ground". It is doubtful whether or not this last is an advantage however, as it makes it more difficult to locate a break in the insulation. It is not attacked by the acids in the soil or by electrolysis.

The present practice in America is to embed the conduits in cement. The mixture should be two parts cement, three parts fine aggregate, and five parts coarse aggregate. The coarse aggregate should pass through a one and one half inch mesh screen. The trench should be wide enough so that there will be at least one and one half inches of cement between conduits and between the outside conduits and the sides of the trench. The depth of the trench should be such that the tops of the ducts will be at least two feet below the surface of the earth. For clay or tile conduits the depth should be slightly greater than this to avoid its being crushed by the pressure due to wheels of vehicles.

Where a large number of ducts are laid in one trench manholes should be constructed every two or three hundred feet. Where only a few ducts are laid, hand holes will be sufficient. The manholes are constructed of brick or cement and if water tight, should have a drain at the bottom connecting with a sewer. Where constructed in sand or loam the floor may be omitted for the soil will afford drainage facilities.

The cable is drawn through the ducts after the construction is completed. This may be done by pushing a wire through from manhole to manhole, then drawing a rope through with the wire and finally drawing the cable through with the rope.

So far, only the construction features of underground distribution have been considered. The electrical features are similar to those of overhead construction and cannot be taken up in detail here but a brief review of them will be given.

Direct current was formerly used for lighting and small power purposes. The current was delivered at a potential of 110 volts and was generated at a voltage equal to 110 plus the voltage drop in the line. Current could not be transmitted for any considerable distance because the amount of copper required to keep the line drop within suitable limits was prohibitive. The Edison three wire system which is now in use at the University of Tennessee reduced the amount of copper required to about one third.

Two windings are used on the armature of the generator giving a potential of 220 volts across the two main leads and 110 volts from each main lead to the neutral wire. The load is distributed between the two main leads and the neutral wire. If the loads on the two sides of the neutral are nearly balanced, only a small current flows in the neutral wire, so it may be made of smaller wire than the two main leads.

The present practice is to supply three phase alternating current from a central station or substation at 2200 volts. Near the premises where the current is to be used the voltage is transformed from 2200 volts to 110 volts and the current is delivered for lighting purposes at 110 volts. Where three phase current is required for power purposes, two transformers are connected in open delta across the mains and current supplied at either 110 volts or 220 volts as may be desired. The load is distributed across the three phases as evenly as possible.

By this system a great saving in copper is obtained. Since the voltage drop in the line is proportional to the square of the current, if, by raising the voltage the current required to deliver the same power is reduced to half, the voltage drop in the line will be reduced to one fourth. Therefore with the same voltage drop the line need only be one fourth as large.

The transformers are an added cost but they require practically no attention and if not overloaded will last for an indefinite time. There is a small magnetizing

current in the primaries of the transformers at all times but it is of low power factor and does not consume much power. Then too, alternating current generators can be built more efficient than direct current generators because commutators are unnecessary.

CHAPTER II.

GENERAL THEORY.

It is not the purpose of this thesis to investigate the financial side of the proposed improvement; the cost of equipment, installation, and depreciation; or the saving due to increased efficiency of distribution. These are matters demanding a more thorough investigation than would be waranted by the limited time and opportunities available, and would require more knowledge of prices and costs of construction than the writer possesses.

For these reasons the purpose of this investigation shall be to make recommendations regarding the general type of construction deemed favorable under existing conditions, to determine the kind and amount of equipment required and to make recommendations regarding the location of lines and equipment.

The solution of a problem of this kind may be divided into three general parts.

(1) A general survey to determine the conditions to be met and the demands to be supplied. This survey should include:

The making or obtaining of a map of the territory to be supplied.
The number and location of all buildings to be supplied.
The location of the taps leading into the buildings.
The system by which the buildings to be supplied are wired.
The total connected lighting load of each building.
The connected motor load and the kind of motors to be supplied, i.e., whether induction motors or synchronous

motors, single phase or three phase.
Data should be collected to determine the probable demand factor, or, if none is available, it should be estimated.
A study of the terrain noting the conditions that will effect the location of the lines.
A survey of the works of culture on the territory to be supplied, such as paved roads, concrete walkways, other lines, etc, that may effect the location of underground lines.

(2) A study of the survey to determine the method by which the conditions shown in the survey may best be met. In making this determination the following points should be considered:
The lines and equipment should be so placed that they will not endanger the lives of persons coming near them and they should not add to the fire hazard of the property.
The size of lines and equipment selected should be large enough to take care of an increase in load in the future.
The transformers should be located as near as possible to the center of the load to be supplied by them.
The equipment should be easily accessible and should be placed so as to occupy space of as little value as possible.
The lines and equipment should be selected so that maintainance and depreciation are a minimum.
The length of secondary lines should be kept as short as possible.

(3) Having determined the best method by which the conditions may be met, the third step in the problem is to calculate the details. The details will include the following:

The size of each transformer required.
Probable maximum current in each portion of the line.
Length and size of wire required for the primary line.
Length and size of wire required for each secondary line.
Amount and size of conduit that will be required.
Number of junction boxes, crosses, etc.
The number of manholes and handholes that will be necessary.

In the following pages the writer will endeavor to show how the preceeding outline has been carried out.

CHAPTER III.

RESULTS OF PRELIMINARY SURVEY.

Fig. 1 is a map of the territory to be supplied showing the location of the various buildings. The location of the taps leading into each of the buildings is marked with a small circle. All of the buildings are wired with the two wire system except the Library, Ayres Hall and Morrill Hall. The load on all of the buildings with the exception of Estabrook Hall and a small motor load in Science Hall, is a lighting load and will have a power factor of 100%. The lighting load on each building is as follows:

Ayres Hall	34.0 K.W.
Estabrook Hall	28.0 K.W.
Science Hall	13.5 K.W.
Jefferson Hall	9.5 K.W.
Morrill Hall	8.7 K.W.
Library	6.8 K.W.
Carrick Hall	5.8 K.W.
South College	5.0 K.W.
Barbara Blount Hall	4.8 K.W.
Y.M.C.A. Building	4.2 K.W.
Humes Hall	3.8 K.W.
Reese Hall	3.8 K.W.
Infirmary	2.5 K.W.
Ayres House	1.8 K.W.
Turner House	1.0 K.W.
Total	133.2 K.W.

Besides these there are lights distributed about the campus amounting to 1.5 K.W. These will need to be controled by a separate switch at the power plant. There will also be required 3 K.W. of three phase power at Science Hall to drive a motor generator set to furnish direct current for laboratory use.

The connected motor load at Estabrook at present consists of direct current motors and is as follows:

Electrical laboratory	50 H.P.
Machine shop	34 H.P.
Hydraulics laboratory	40 H.P.
Materials laboratory	4 H.P.
Pattern shop	20 H.P.
Foundry	5 H.P.
Forge shop	26 H.P.
Total	179 H.P.

Of these the Pattern Shop, Forge Shop and Foundry will not be running at the same time and only two motors in the Hydraulics Laboratory will be needed at any one time. The maximum motor load that is likely to occur is as follows:

Electrical Laboratory	27 H.P.
Machine Shop	34 H.P.
Hydraulics Laboratory	,25 H.P.
Materials Laboratory	3 H.P.
Forge Shop	26 H.P.
Total	117 H.P. or 87 K.W.

All of these will probably be supplied by three phase 220 volt induction motors except the Electrical Laboratory which may be supplied with a synchronous motor.

Other conditions noted in the survey are as follows: Ayres Hall, Science Hall, Morrill Hall and Carrick Hall have basements containing room for transformers. Carrick Hall however, is an old building and would not be a suitable place for a transformer. There is a steam line leading from Estabrook Hall to Ayres Hall and manholes have been constructed along it approximately every 100 feet, and also one from Science Hall to South College. The vertical distance between the first floor of Ayres Hall and the floor of the Power Plant is about 140 ft.

It will be seen from the foregoing data and the map Fig. 1. that the most favorable route for the primary line from Estabrook Hall to Ayres Hall is to follow the old steam line. Since manholes have already been constructed along it they could be used for the distribution line as well. Since the heaviest load is in Ayres Hall the transformers supplying the buildings near the top of the hill should be placed there. These transformers if placed in the basement under the West end of Ayres Hall could supply the following buildings:

Ayres Hall	34.0 K.W
Library	6.8 K.W.
Reese Hall	3.8 K.W.
Jefferson Hall	9.5 K.W.
Turner House and Infirmary	2.5 K.W.
Total	56.6 K.W.

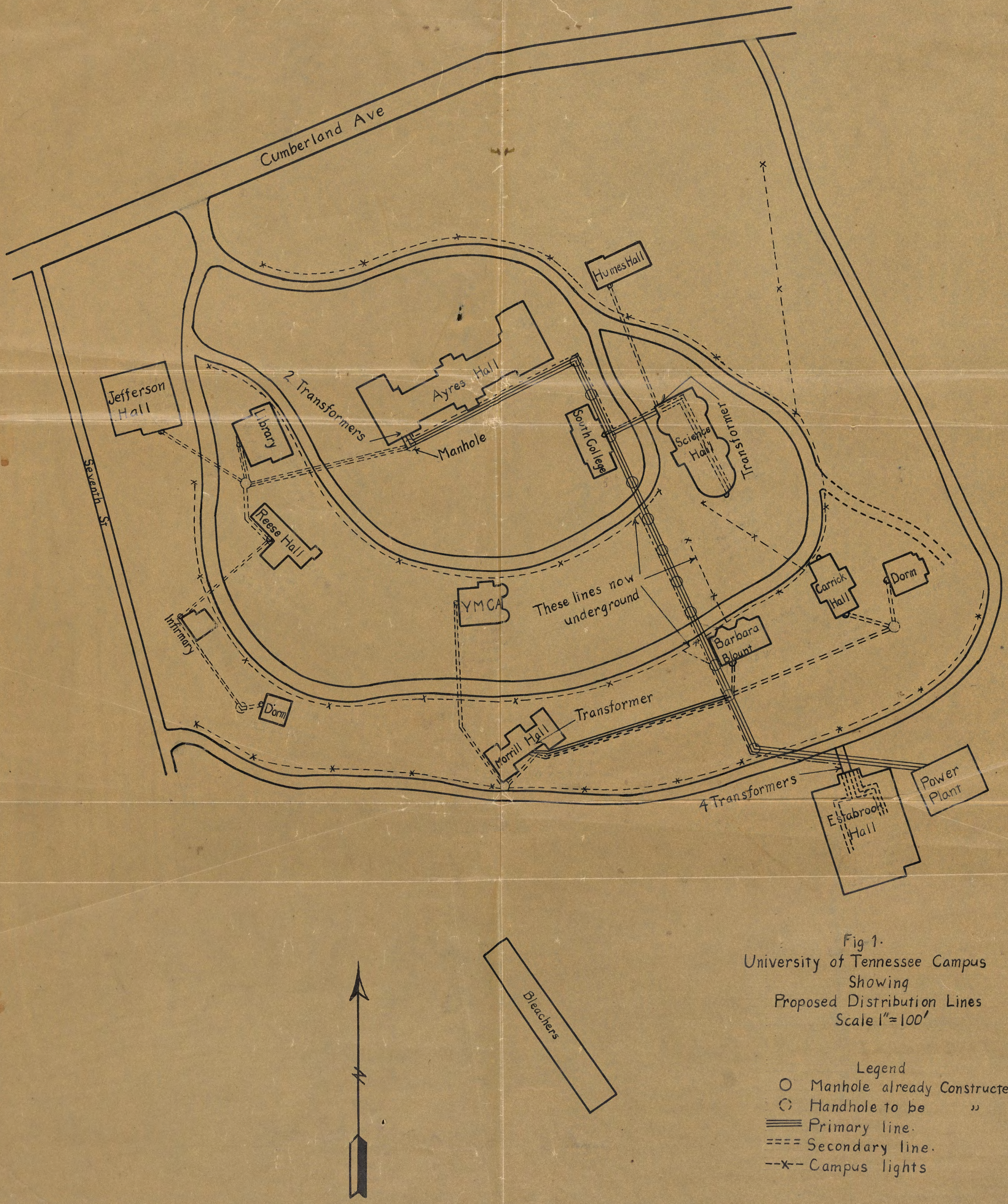


Fig 1.
University of Tennessee Campus
Showing
Proposed Distribution Lines
Scale 1"=100'

Legend
- ○ Manhole already Constructed.
- ◌ Handhole to be " .
- ═══ Primary line.
- ==== Secondary line.
- --x-- Campus lights

Since there would be six buildings supplied by the secondaries, it is not likely that more than 90% of the total load would be on at any one time. This would require that two 25 K.W. transformers be used.

A transformer placed in the basement under the North end of Science Hall would supply the following buildings:

Science Hall	16.5 K.W.
South College	5.0 K.W.
Humes Hall	3.8 K.W.
Total	25.3 K.W.

In this case, since only three different buildings would be connected to the secondary circuit it is possible that all of the load might be on at one time and the transformer should be large enough to carry the entire connected load. Therefore a 25 K.W. transformer would be required here. In order to supply three phase current to the Physics Laboratory it would be necessary to run one wire from one transformer at Ayres Hall.

One transformer placed in the basement of Morrill Hall would supply the following buildings:

Morrill Hall	8.7 K.W.
Y.M.C.A. Building	4.2 K.W.
Barbara Blount Hall	4.8 K.W.
Carrick Hall	5.8 K.W.
Ayres House	1.8 K.W.
Total	25.3 K.W.

One 25 K.W. transformer would supply these, and since all of the load would seldom be on at the same time, it would allow for an increase of at least 5 K.W. without adding another transformer.

A 30 K.W. transformer placed under the entrance ot Estabrook Hall would supply

Estabrook Hall lighting load	28.0 K.W.
Campus Lights	1.5 K.W.
Total	29.5 K.W.

The secondary of this transformer would be connected to the wiring system of the building at the present switchboard.

The power load of Estabrook Hall could be supplied by three 30 K.W. 2200-220 volt transformers connected in closed delta and placed under the North entrance to Estabrook Hall. The secondary line from these transformers would be connected to the switch board in the Machine Shop and would be distributed through the building from there.

The general location of the lines and transformers is shown on the map, Fig. 1. In Fig. 2 the distribution system is shown in diagramatic form.

CHAPTER IV.

CALCULATIONS.

The folowing calculations are based upon the resistance of the wire only. Since the distances involved are so short the reactance and capacitance of the lines are neglected. Then too, the wide variation of the load and the error involved in estimating what the maximum current will be makes this refinement unwarranted.

The safe carrying capacities are given for paper insulation. They were taken from the catalogue of the Westinghouse Co. and correspond to the N.E. Code rating. The resistance of the wire was taken from the Manual for Engineers, compiled by Chas. E. Ferris.

Where a single building is supplied by a line the maximum current in the line was taken to be the current required for the full connected load. In the case of a line supplying several buildings the maximum current was assumed to be 80% of the current required for the full connected load

The lengths of the various lines were measured from the map, Fig.1, an allowance of ten feet being added for each lead-in to a building.

The voltage drop from the transformer to the load was limited to 3.5% except where a larger drop would not be a serious disadvantage. For example, the line from Ayres Hall to Jefferson Hall was calculated for a total drop of 5%.

Ayres Hall Transformers.

(1) From Ayres Hall to the junction box near the Library. Distance 275 ft. Permissable drop 1.5% x 220 = 3.3 volts. Allowing a demand factor of 80% the maximum current will be I = 128.8 x 80% = 103 amps. Resistance of the wire per 1000 ft. = $\frac{3.3 \times 1000}{103 \times 550}$ = 0.058 ohms.
The will require No. 00 B&S. Capacity 180 amps.
For the middle wire the maximum current will be 27.3 amps. This will require No. 10 B&S. Capacity 30 amps.

(2) From junction box to Library. Distance 95 ft.
Permissable drop = 2% x 220 = 4.4 volts.
I = $\frac{6800}{220}$ = 31 amps. Resistance of the wire per 1000 ft should be = $\frac{4.4 \times 1000}{31 \times 190}$ = 0.725 ohms.
This will require No. 8 B&S gauge. Capacity 40 amps.
For the neutral wire, No. 14 with a capacity of 18 amps. should be sufficient.

(3) From junction box to Jefferson Hall. Distance 170 ft.
Drop 3.5% (making 5% from transformer) = 3.5% x 100 = 3.85
I = $\frac{9500}{110}$ = 86.5 amps.
Resistance per 100 ft. = $\frac{3.85 \times 1000}{86.5 \times 340}$ = 0.129 ohms.
This corresponds to No. 1 B&S. Capacity 126 amps.

(4)From junction box to Reese Hall. Distance 120 ft.
Allowable drop = 2% x 110 = 2.2 volts. I = $\frac{7300}{110}$ = 66 amps.
Resistance per 1000 ft. = $\frac{2.2 \times 1000}{66 \times 240}$ = 0.139 ohms.
This corresponds to No. 1 B&S. Capacity 126 amps.

(5) Reese Hall to the Turner House. Distance 240 ft.
Allowable drop = 2% = 2.2 volts. I = $\frac{3500}{110}$ = 31.8 amps.

Resistance per 1000 ft. $= \frac{2.2 \times 1000}{31.8 \times 480} = 0.144$ ohms.

This corresponds to No. 2 B&S. Capacity 100 amps.

(6) From transformer in Ayres Hall to fuse box.

Distance 50 ft. Allowable drop = 3.5% = 7.7 volts.

$I = \frac{3400}{220} = 155$ amps. Resistance per 1000 ft. should be

$\frac{7.7 \times 1000}{155 \times 100} = 0.45$ ohms. This corresponds to No. 6 wire but this has a capacity of only 60 amps. Therefore No. 0 having a capacity of 156 amps. should be used.

(7) From Ayres Hall to Science Hall to supply three phase current. Distance 700 ft. Allowable drop = 3.5% = 3.85 volts.

$I = \frac{3000}{\sqrt{3} \times 110 \times .90} = 17.7$ amps. for 90% power factor.

The resistance of the wire per 1000 ft. $= \frac{3.85 \times 1000}{17.7 \times 1400} = 0.153$

Size of wire No. 2 B&S. Capacity 100 amps.

Science Hall Transformer.

(1) Science Hall to Humes Hall. Distance 210 ft.

Allowable drop = 3.5% = 3.85 volts. $I = \frac{3800}{110} = 34.5$ amps.

Resistance per 1000 ft. $= \frac{3.85 \times 1000}{34.5 \times 420} = 0.266$ ohms.

Size of wire No. 4. Capacity 85 amps.

(2) Science Hall to South College. Distance 90 ft.

Allowable drop = 3.5% = 3.85 volts. $I = \frac{5000}{110} = 45.5$ amps.

Resistance per 1000 ft. $= \frac{3.85 \times 1000}{45.5 \times 180} = 0.47$ ohms.

Size of wire No. 6. Capacity 60 amps.

(3) Science Hall transformer to lead-in at Science Hall.

Distance 150 ft. Allowable drop = 3.5% = 3.85 volts.

$I = \frac{13500}{110} = 123$ amps.

Resistance per 1000 ft. $= \frac{3.85 \times 1000}{123 \times 300} = 0.104$ ohms.

Size of wire No. 0. Capacity 156 amps.

Morrill Hall Transformer.

(1) Morrill Hall to Y.M.C.A. Distance 385 ft.

Allowable drop = 3.5% = 3.85 volts. $I = \frac{4200}{110} = 38.2$ amps.

Resistance of wire per 1000 ft. $= \frac{3.85 \times 1000}{38.2 \times 770} = 0.130$ ohms.

Size of wire No. 1. Capacity 126 amps.

(2) From Morrill Hall to manhole near Barbara Blount Hall.

Distance 330 ft. Allowable drop = 3% = 3.3 volts.

Total $I = \frac{12,400}{110} = 113$ amps.

Assuming a demand factor of 80%, I = 113 x 80% = 90.4 amps.

Resistance per 1000 ft. $= \frac{3.3 \times 1000}{90.4 \times 660} = 0.055$ ohms.

Size of wire No. 000. Capacity 220 amps.

(3) From manhole to Barbara Blount. Distance 60 ft.

Allowable drop = 0.5% = 0.55 volt. (Total drop from transformer 3.5%) $I = \frac{4800}{110} = 43.5$ amps.

Resistance per 1000 ft. $= \frac{0.55 \times 1000}{43.5 \times 120} = 0.105$ ohms.

Size of wire No. 0. Capacity 156 amps.

(4) From manhole to Garrick Hall and Ayres House.

Distance 280 ft. Allowable drop = 2% = 2.2 volts. (Total drop from transformer = 5%)

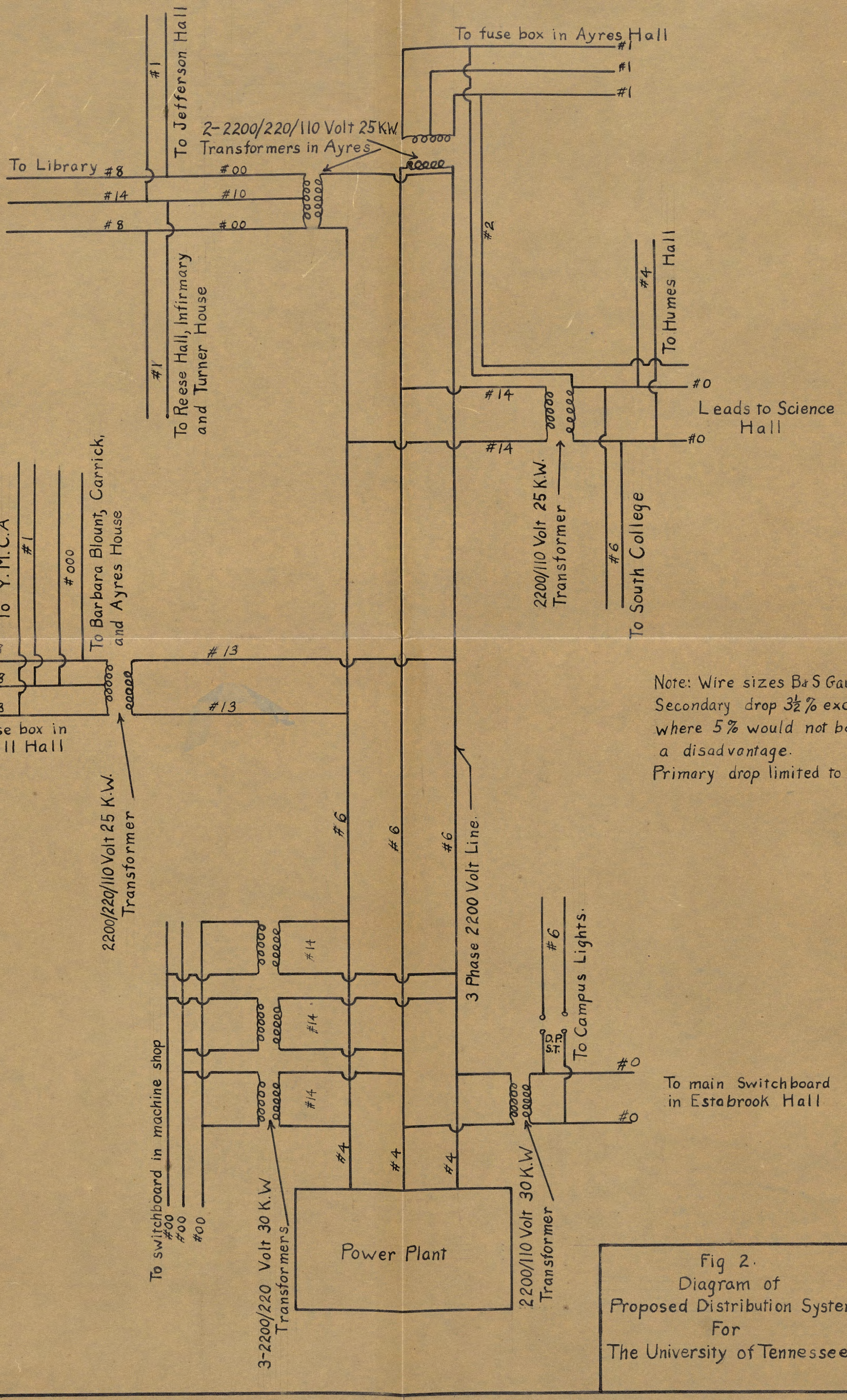
$I = \frac{7600}{100} = 69$ amps.

Assuming a demand factor of 90%, I = 69 x 90% = 62 amps.

Resistance per 1000 ft. $= \frac{2.2 \times 1000}{62 \times 560} = 0.063$ ohms.

Size of wire No. 000. Capacity 220 amps.

Leads into Ayres House should be No. 8 wire.



Note: Wire sizes B & S Gauge.
Secondary drop 3½% except where 5% would not be a disadvantage.
Primary drop limited to 1¼%

Fig 2.
Diagram of
Proposed Distribution System
For
The University of Tennessee.

Estabrook Hall Transformers.

(1) From lighting transformer to main switch-board.

Distance 75 ft. Allowable drop = 3.5% = 3.85 volts.

$I = \frac{28,000}{110} = 255$ amps.

Resistance per 1000 ft. $= \frac{3.85 \times 1000}{255 \times 150} = 0.101$ ohms.

Size of wire No. 000. Capacity 220 amps.

(2) From Estabrook lighting transformer to campus lights.

Distance 575 ft. Allowable drop = 5% = 5.5 volts.

$I = \frac{1500}{100} = 13.6$ amps.

Resistance per 1000 ft. $= \frac{5.5 \times 1000}{13.6 \times 1150} = 0.352$ ohms.

Size of wire No. 6. Capacity 60 amps.

(3) Leads from power transformers to switch-board in machine shop. Distance 75 ft.

Load = 87 K.W. at power factor of 90%.

$I = \frac{87,000}{\sqrt{3} \times 220 \times .90} = 257$ amps.

Allowable drop = 3.5% x 220 = 7.7 volts.

Resistance per 1000 ft. $= \frac{7.7 \times 1000}{257 \times 150} = 0.199$ ohms.

This corresponds to No. 3 wire having a capacity of 95 amps. The capacity of this wire is too small and No. 0000 having a capacity of 260 amps should be used.

Primary Line.

Under conditions of full load the current in the primary winding of each transformer is as follows:

Transformer supplying Ayres Hall	15.5 amps.
Transformer supplying, Library, Jefferson Hall, etc.	10.7
Transformer in Science Hall	11.5
Transformer in Morrill Hall	11.5
Estabrook Lighting transformer	12.7
Each power transformer	14.6

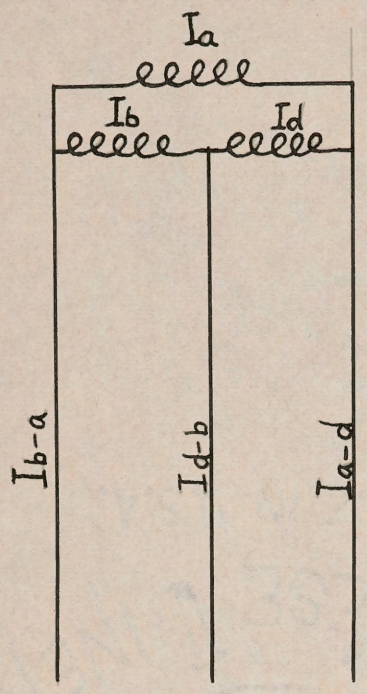


Fig 3.

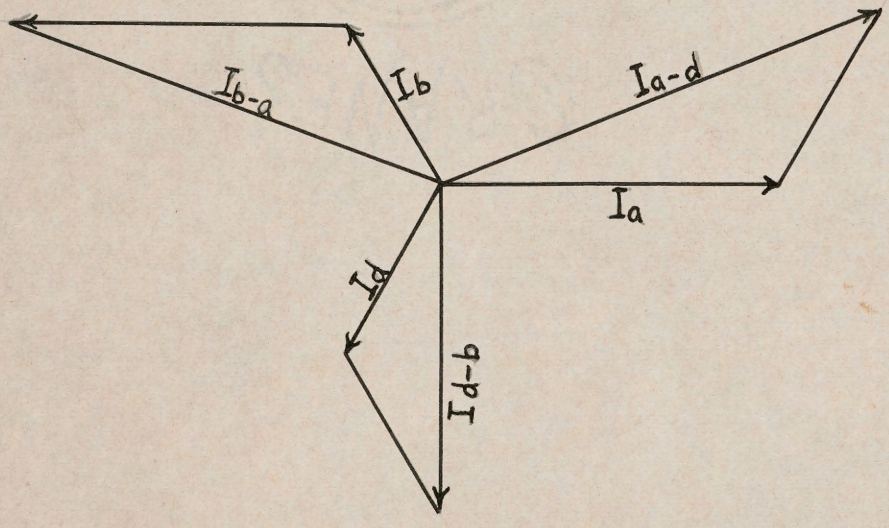


Fig 4.

Considering that portion of the line between the Power House and Estabrook Hall. The method of loading is shown in Fig. 3, and the phase relations of the currents in Fig. 4. Refering to the diagrams Figs. 2 and 3:

$I_a = 14.6 + 11.5 + 10.7 = 36.8$ amps.

$I_b = 14.6 + 11.5 = 26.1$ amps.

$I_d = 14.6 + 15.5 + 12.7 = 42.8$ amps.

From Fig. 4, by the Law of Cosines;

$I^2_{a-d} = \overline{36.8}^2 + \overline{42.8}^2 - 2 \times 36.8 \times (-0.5) \times 42.8$

$= 1355 + 1835 + 1660 = 4850$

$I_{a-d} = \sqrt{4850} = 69.5$ amps.

$I^2_{b-a} = \overline{26.1}^2 + \overline{36.8}^2 - 2 \times 26.1 \times 36.8 \times (-0.5)$

$= 681 + 1355 + 960 = 2996$

$I_{b-a} = \sqrt{2996} = 54.7$ amps.

$I^2_{d-b} = \overline{42.8}^2 + \overline{26.1}^2 - 2 \times 42.8 \times 26.1 \times (-0.5)$

$= 1835 + 681 + 1116 = 3632$

$I_{d-b} = \sqrt{3632} = 60.2$ amps.

Using No. 4 wire which has a capacity of 85 amps. and is sufficient for the larger current, the voltage drop for the 125 ft. will be:

$$E = \frac{69.5 \times 0.2525 \times 250}{1000} = 4.4 \text{ volts.}$$

$$\text{The percentage drop} = \frac{4.4}{2200} = 0.2\%$$

Considering the portion of the line between the Estabrook transformers and the leads to Morrill Hall. The conditions of full load are:

$I_a = 11.5 + 10.7 = 22.2$ amps.

$I_b = 11.5$ amps.

$I_d = 15.5$ amps.

In the same manner as determined in the preceeding section

Ia-d = 32.8 amps.

Ib-a = 29.6 amps.

Id-b = 23.4 amps.

Number 6 wire having a capacity of 60 amps. will be sufficient for the larger current and the voltage drop for the distance 250 ft. will be:

$E = \frac{32.8 \times 0.4004 \times 500}{1000} = 6.5$ volts.

The percent voltage drop $= \frac{6.5}{2200} = 0.3\%$

For that part of the line between the Morrill Hall leads and the leads to Science Hall the full load currents will be

Ia = 10.7 amps.

Ib = 11.5 amps.

Id = 15.5 amps.

In the same manner as before, the line currents will be

Ia-d = 22.8 amps.

Ib-a = 19.2 amps.

Id-b = 23.4 amps.

Distance 550 ft. Using No. 6 wire the voltage drop will be

$E = \frac{23.4 \times 0.4004 \times 1100}{1000} = 10.3$ volts.

The percent drop $= \frac{10.3}{2200} = 0.47\%$

For that part of the line between Science Hall and Ayres Hall the full load currents will be

Ia = 10.7 amps.

Ib = 0

Id = 15.5 amps.

The line currents will be

Ia-d = 22.8 amps.

Ib-a = 10.7 amps.

Id-b = 15.5 amps.

Distance 430 ft. Using No. 6 wire the voltage drop will be

$E = \frac{22.8 \times 0.4004 \times 860}{1000} = 7.85$ volts.

The percent voltage drop will be $\frac{7.85}{2200} = 0.34\%$

Total drop from plant to Ayres Hall will be

0.2% + 0.3% + 0.47% + 0.34% = 1.31% under conditions of extreme load.

The maximum current in the leads to Science Hall will be I = 11.5 amps. Distance 80 ft.

Allowable drop = 1.25% - (0.2% + 0.3% + 0.47%) = 0.28%

Drop in voltage = 0.28% x 2200 = 6.15 volts.

Resistance of wire per 1000 ft. = $\frac{6.15 \times 1000}{11.5 \times 160} = 3.34$

Size of wire No. 14. Capacity 18 amps.

Total drop from Power Plant to Science Hall = 1.25%.

The maximum current in the leads to Morrill Hall will be, I = 11.5 amps. Distance 330 ft.

Allowable drop = 1.25% - (0.2% + 0.3%) = 0.75%.

Allowable voltage drop = 0.75% x 2200 = 16.5 volts.

Resistance of wire per 1000 ft. = $\frac{16.5 \times 1000}{11.5 \times 660} = 2.18$ ohms.

Size of wire No. 13. Capacity 21 amps.

CHAPTER V.

CONCLUSIONS.

The distribution system proposed in this thesis will require the following material and equipment:

Transformers.

No. required.	Capacity.	Voltage ratio.
4	25 K.W.	2200/220/110
1	30 K.W.	2200/220/110
3	30 K.W.	2200/220

Cables.

All cables lead covered and paper insulated. The conductor may be solid wire for sizes up to and including No. 6 and stranded for sizes larger than No. 6. Those marked 3C in the table below are three conductor cables. All others are single conductor.

Location	Length. in ft.	Size B&S gauge.	
Power Plant to Estabrook	125	4	3C
Estabrook to Ayres Hall	1355	6	3C
Primary lead to Science Hall	160	14	
Primary lead to Morrill Hall	660	13	
Secondary. Ayres Hall to Junction box	275	00	3C
Junction box to Library	95	8	3C
Junction box to Jefferson Hall	340	1	
Junction box to Reese Hall	240	1	
Reese Hall to Turner House	480	2	
Ayres Hall transformer to fuse box	50	0	3C
Ayres Hall to Science Hall	1400	2	
Science Hall to Humes Hall	420	4	

Location.	Length. in ft.	Size B&S Gauge.
Science Hall to South College	1180	6
From transformer to Science Hall	300	0
Morrill Hall to Y.M.C.A.	770	1
Morrill Hall to manhole	660	000
Manhole to Barbara Blount Hall	120	0
Manhole to Garrick Hall and Ayres House	560	000
Transformer to Estabrook switch-board	150	000
Estabrook to campus lights	1150	6
Power transformers to machine shop	150	0000 3C
Leads to Ayres House , Turner House, and Infirmary	250	14

Conduit. Material -- Fibre.

Total length of conduit ------ 3240 ft.

Inside diameter ---------- 2.5 in.

Junction boxes -------- 5

3 - 45 degree bends.

Type of joint ------ Socket.

300 ft. of wrought iron conduit with screw joints for use in Estabrook Hall and Science Hall. Inside diameter 2 inches.

Additional.

Construction of one manhole at entrance to Ayres Hall.

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APPROVAL.

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

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