A STUDY OF THE PASADENA POWER AND LIGHT SYSTEM

Thesis by

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INTRODUCTION

Due to its rapid growth in the last ten years, the Pasadena Municipal Light and Power Department has had difficulty in maintaining good operating performance at all times, and overloading of the system has caused undesirably wide voltage variations and uneven loading of transformers and feeders. The study of this condition and remedies for it constitute the substance of this report.

The present conditions were studied by means of load charts of various kinds. These load charts were then correlated to an analysis of the future growth of Pasadena, thus obtaining a definite idea of the conditions of the present and the likely conditions of the future. A study of various types of distribution systems showed only two feasible solutions and these have been discussed at length and their application described.

HISTORY OF THE DEPARTMENT

Before starting on the present system let us hastily review the growth of the Department(1)*. In 1906, a bond issue of $125,000 provided a 250 H.P. unit and a street lighting system, which replaced the system then in use. In 1908, another bond issue of $50,000 was used to extend the street lighting system

* References are listed on Page 26

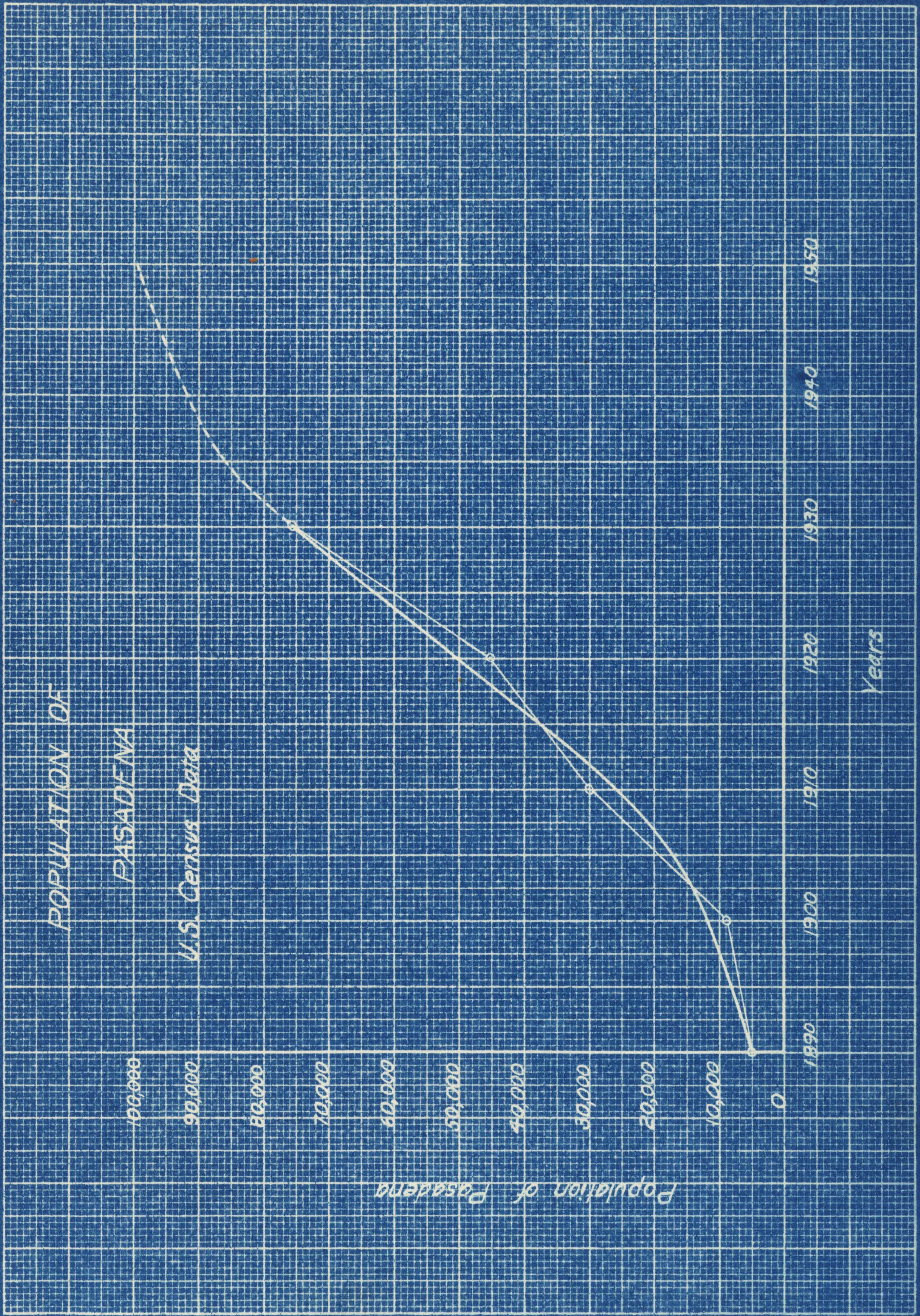
and to provide for distribution to the public, and in 1909, a bond issue of $150,000 was used to install a 1000 H.P. unit and to enlarge the distribution facilities. These units were soon too small and in 1914, a 1250 kw. Westinghouse, and in 1916, a 3000 kw. Allis Chalmers unit were added in order to care for the rapidly growing load. In 1920, a bond issue of $500,000 provided for the purchase of the Southern California Edison Company's system within the city limits, a very wise step, securing better coordination of the system and eliminating undesirable operating conditions. When Pasadena annexed Lamanda Park, this policy of eliminating competition was continued and $65,000 of bonds bought out the Southern California Edison Company's interest in this region. With these purchases, readjustment and expansion of the system was necessary and $350,000 of bonds provided new substations, distribution facilities, and auxiliary equipment. In 1924, this was augmented by a 10,000 kw. Allis Chalmers unit provided by an issue of bonds totaling $250,000. This unit was unable to satisfy the needs of the Department for long and a 15,000 kw. Allis Chalmers unit was added in 1928, this machine being purchased from current earnings. By 1931, the load had grown so that more capacity was needed and a 25,000 kw. Allis Chalmers unit is now being installed which as can be seen from the production curves given in the next article, will carry the system for a considerable length of time.

As we shall see, the rate of growth of Pasadena is decreasing, and the future demands on the power system, while increasing constantly, will not have the sky-rocketing characteristics of the last ten years, so that with ample generating capacity provided and a distribution system expanded to care for the present load and allowing for future growth, the Department will be able to give steady electrical service at a minimum expense.

GROWTH OF PASADENA

When we began our study of present conditions, an investigation into the probable future growth of Pasadena was undertaken. On the first chart there is shown a curve of population of Pasadena drawn through the five points given by United States Census Figures for each decade. The curve has been fitted according to the theory of population of Dr. Raymond Pearl(2) and its extension into the future has been according to the same theory. For a detailed discussion of the biological and mathematical basis for this treatment, the reader is referred to Dr. Pearl's works. The major point of interest in this curve is the decrease of the

Chart 1

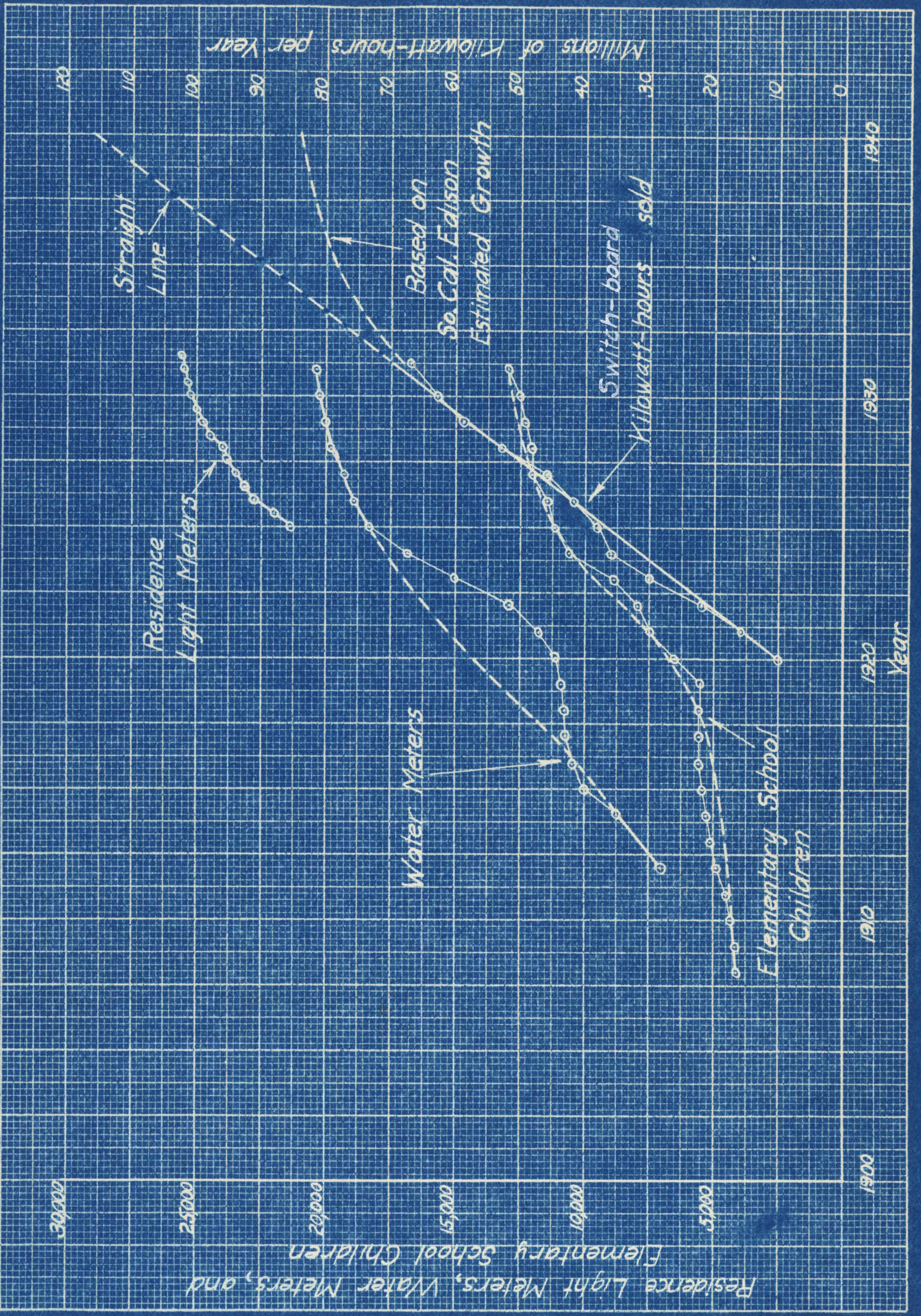


POPULATION OF
PASADENA
U.S. Census Data
Years
1890
1900
1910
1920
1930
1940
1950
Population of Pasadena
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000

rate of growth. To follow out this point, the four curves of Chart 2 were plotted.

The first curve, school children, emphasizes strongly the decreasing slope observed in the first chart. In the next two curves, light meters and water meters, we see the reason for this population trend. Both of these curves are tending to become asymptotic and when these curves were shown to Mr. W. E. Alworth of the Planning Commission, he stated that the reason for this saturation is the fact that around 90 percent of the lots in the city limits were occupied by one or more residences, leaving only 10 percent of the building sites available for future expansion. From this it follows that future growth can come in only one way, namely, the development of apartment houses or duplex bungalows. At the present time there is a local prejudice against this type of construction so that the growth for the near future will come only from a slow using up of the little vacant property and a slow infiltering of apartments. During the meantime there will be fewer new meters installed, most of the electrical growth being shown in increased use per capita. The fourth curve of this group is the generated power of the Pasadena Municipal Light and Power Department, this including purchased power less bulk sales to

Chart 1

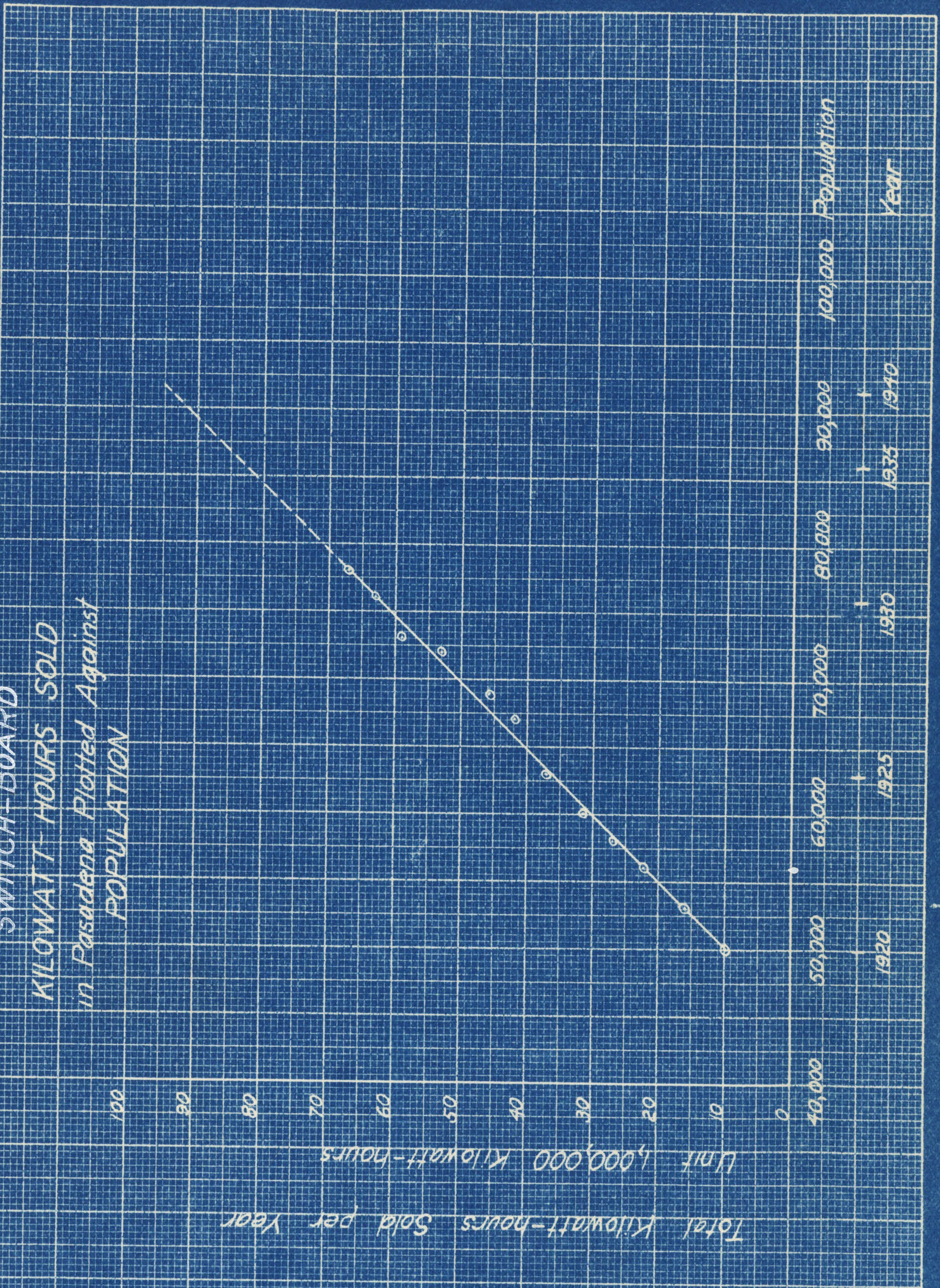


Millions of Kilowatt-hours per Year
Residence Light Meters, Water Meters, and Elementary School Children
Year
Straight Line
Based on So. Cal. Edison Estimated Growth
Switch-board Kilowatt-hours sold
Residence Light Meters
Water Meters
Elementary School Children

other systems. Since this curve is of vital importance in our study, we have projected it into the future. This projection has been done in two ways, first, it was drawn as a straight line since the past points follow a straight line, and secondly, the 1940 value was estimated as a ratio based on the Southern California Edison Company's estimated gain and a smooth curve was drawn between 1930 and 1940. The estimation on the Southern California Edison system was obtained from Mr. N. B. Hinson's paper(3) on population growth. In estimating kw.-hr. demand Mr. Hinson has reverted to Dr. Pearl's theory of the logistic curve. Mr. Hinson's estimation is the only scientific estimate of the two projections, there being no basis for a straight line projection. It is given only to show the extremely high value that is obtained within a few years.

In Mr. Hinson's article kw.-hr. is plotted against population, obtaining a straight line. Taking values from the curves of population and kw.-hrs. we have plotted in Chart 3 these values, and obtained a straight line relation which has been projected to the abscissae of population of 91,500 giving an ordinate of 95,000,000 kw.-hrs. The value of91,500 for population is taken from Chart 1 for the year 1940. The value of 95,000,000 kw.-hrs. agrees with the value of 85,000,000 which was

Chart 3


SWITCH-BOARD
KILOWATT-HOURS SOLD
in Pasadena Plotted Against
POPULATION
Total Kilowatt-hours Sold per Year
Unit 1,000,000 Kilowatt-hours
0
10
20
30
40
50
60
70
80
90
100
40,000
50,000
60,000
70,000
80,000
90,000
100,000
Population
1920
1925
1930
1935
1940
Year

used for curve 4 on Chart 2, the latter value having been obtained by proportion from another chart.

These curves taken as a group lead to several conclusions, first, the growth of Pasadena as a city will be at a much slower rate in the future; second, the growth of generated kw.-hrs. will tend to be a function more and more of kw.-hrs. per capita; and third, the future load will not require the continual increasing of distribution facilities that have been necessary in the past. From the power generation curve we see that if the present system is modified so that the present conditions are alleviated and provision for future expansion of a normal rate is made, the system should be able to prevent future unbalancing with only minor adjustments.

PRESENT DISTRIBUTION SYSTEM

The power supply for Pasadena is supplied from the steam power plant located in the south west portion of the city. The present machines generate at 11,000 and 2400 volts which is transformed to 16,500 volts before going to the main bus, while the alternator now being installed will generate at 16,500 volts and will go to the main bus direct. Located in the northern and the eastern parts of the city are substations which receive power from a loop line which comes from the 16.5 kv. bus. This arrangement is shown in Chart 4 which shows also the switching diagrams for these stations and the tie-in lines with the Southern California Edison system. At both substations and the power plant are transformers which supply 2400 volt busses from the 16.5 kv. busses, and from this 2400 volt bus there are feeders which supply the load in a designated portion of the station's district. There are 22 of these radial feeders and the district served is shown in Chart 5. There are six from the Lamanda Park substation in the eastern part of the city, six from the Raymond substation in the northern part of the city, and ten from the Power Plant. When new load was added in a district it was connected to the feeder through step-down transformers, with the result that as districts have grown the load on the feeders has increased, not uniformly, but as the growth of the districts. Voltage regulation on the 2400 volt feeders has not always been sufficient to prevent "lamp flicker". Adjustment of this condition has been attempted by changing transformers to nearby feeders, giving temporary relief but causing confusion of the feeders.

LOAD SURVEY

Since more permanent reform is needed, an extensive survey of the load conditions on these feeders and district was made. To do this we investigated four sets of load data, (1) kva.load per feeder, (2) connected kva.transformer capacity per feeder, (3) kva. load per block, and (4) the kva.density per square mile by blocks.

In determining the load per feeder, data was obtained from the Power Department on all of the feeders. It has been found from previous experience that the peak load of the system comes at the end of December. This made it possible to find the peak from an examination of the data taken in December and the beginning of January. The data included the current, voltage, and power factor on each feeder. In all but a few exceptions the time of reading the instruments was at 6:00 P.M., approximately the point of peak demand at this time of the year. The information obtained is given in Table 6 in a condensed form. The kva. transformer capacity of each feeder was obtained so that conditions of unequal distribution of load on transformers could be determined, thereby giving an indication of where the load was increasing beyond the feeders capacity and to help in the rearrangement

Chart 6.

Distribution Feeders

District	Date '30	Current	Max. Kva.
A	12-22	135	557
B	11-14	71	293
C	12-23	115	510
D	11-19	150	697
E	12-22	125	542
F	11-10	195	933
Orange Grove	12-23	189	835
Los Robles	12-23	185	801
Washington	12-23	185	833
Lincoln	12-23	157	680
Villa	12-24	196	891
Elizabeth	12-23	190	823
2	12-22	264	1210
3	12-18	300*	1380
4	12-22	240	1055
5	12-24	177	750
6	12-24	151	648
7	12-10	190	823
8	12- 5	208	973
9	12-24	150	660
10	12-18	183	847

* Meter read off scale

Chart 6.

Distribution Feeders

District	Con. Kva.	Con. Kva. / Sq. Mile	Max. Kva. / Con. Kva.	Max. Kva. / Sq. Mile
A	1203	830	.462	385
B	1464.5	2810	.200	561
C	405.5	707	1.260	887
D	2048.5	3970	.340	1001
E	494.5	3015	1.100	3300
F	2519.5	3230	.371	1180
Orange Grove	1471	1635	.576	927
Los Robles	627	866	1.280	1120
Washington	715.5	1125	1.165	1310
Lincoln	1245.5	458	.546	235
Villa	757.5	2005	1.175	2360
Elizabeth	894.5	1058	.921	970
2	2856.5	26700	.423	12900
3	1004.5	10260	1.326	14100
4	893	7780	1.185	9200
5	699	2210	1.075	2370
6	1454.5	1820	.446	810
7	2823.5	10300	.392	3000
8	2875.5	15150	.339	5120
9	1473	2190	.448	983
10	1442.5	5800	.586	3400

of feeders if necessary. The data was obtained by carefully compiling the transformer capacity of each district fed by the individual feeders. This data was taken from maps upon which all distribution transformers are marked by the engineering department. The transformer capacity found on each feeder is listed in Chart 6 and there is also given on this same chart the ratios of kw. per kva. of connected transformer. This may be called the percentage load or overload on the transformers.

The kva. load and the kva. density per block were obtained, as they gave a basis upon which comparison between different systems of distribution could be made. The load density is also important in the consideration of the arrangement of feeders in any kind of power distribution. The only figures available for this study were the monthly meter readings of the customers. As the compilation of the data involved the record of every meter in the district to be studied, it was decided to use only figures for the most heavily loaded section of the city. This included the area bound on the north by Orange Grove Avenue, on the east by Allen Avenue, on the south by Del Mar Street, and on the west by Vernon Avenue. This district is indicated on Chart 5. The highest value of kw.-hr. used in one month was chosen from the readings for the year 1931 for each meter and the total for each block was obtained.

In changing from kw.-hrs. per month to kva. of load a factor of 200 was used in residential districts and 250 in industrial and business areas. These factors h have been obtained by the Light Department from experience and are used by the Department in determining transformer capacity to be used to supply loads. The data was then compiled by blocks and charted on a map of the district. The area of each block was then found and with its corresponding kva. the load density was obtained. Another map was then made up with all of the blocks tabulated as to density of load. These maps are shown in Charts 7 and 8.

An examination of the data shows that some feeders are over-loaded to a considerable extent. The rated current of these primary feeders is 200 amperes. Feeders 2,3,and 4 are carrying heavy overloads. Those in the outlying sections will have to be rearranged or new ones installed. As the areas served are in some cases quite large there is not much possibility of rearrangement. The low density of load is such that any but the radial type of distribution system is out of question at present. Zoning laws are such that industrial areas will invade but very few of the sections in the future,so expansion will have to take place by installing new feeders in the old system.

Chart 7


MAXIMUM
K.W.-HOURS per MONTH
by Blocks for the year 1930
Brainard = 25834
ALLEN
HILL
HOLLISTON AVE
CHESTER AVE
MICHIGAN
WILSON
CATALINA
MENTOR
LAKE
HUDSON
OAK KNOLL
EL MOLINO
MADISON
OAKLAND
LOS ROBLES
EUCLID
GARFIELD
MARENGO
BROADWAY
RAYMOND
SUMMIT
PEARL
CHESTNUT
WALNUT ST
COLORADO
GREEN
VERNON
PASADENA
LINCOLN AVE
SUNSET AVE
MOUNTAIN
CHAPMAN
GLEN
BLAKE ST
CALIFORNIA
GRAND AVE
DEL MAR
WAVERLY DR
BELLEVUE
PALMETTO DR
FAIR OAKS
PICO
FILLMORE ST
STREET
ALPINE ST
KNOLL CIRCLE
VILLA
GROVE
ORANGE
PARKE ST
MASONIC
HOLLY
UNION
MARY ST
DAYTON
VALLEY
ARCADE ST
HENRIETTA
GRANT ST
BURTON CT
HERKIMER
BRAINARD
PACIFIC
MILLS
KNOX
FAIR DR

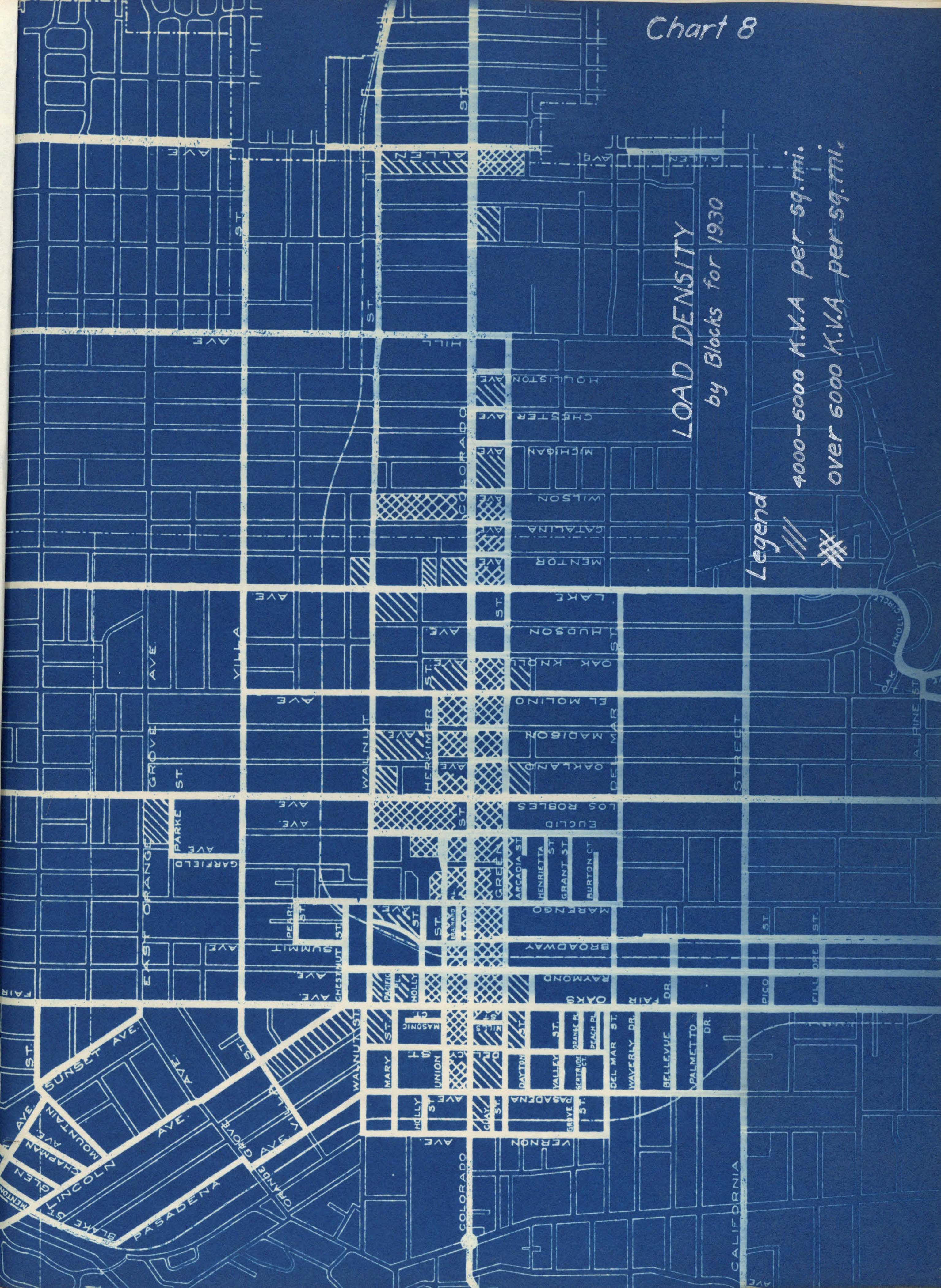


Chart 8
LOAD DENSITY
by Blocks for 1930
Legend
4000-6000 K.V.A per sq. mi.
over 6000 K.V.A per sq. mi.
COLORADO ST.
ALLEN AVE
HILL AVE
HOLLISTON AVE
CHESTER AVE
MICHIGAN AVE
WILSON AVE
CATALINA AVE
MENTOR AVE
LAKE ST.
HUDSON AVE
OAK KNOLL AVE
EL MOLINO AVE
MADISON AVE
OAKLAND AVE
LOS ROBLES AVE
EUCLID AVE
MARENGO AVE
BROADWAY
RAYMOND AVE
FAIR OAKS AVE
PASADENA AVE
VERNON AVE
WALNUT ST.
HERKIMER ST.
DEL MAR ST.
STREET
CALIFORNIA
PICO ST.
FILLMORE ST.
VILLA ST.
GROVE AVE.
PARKE ST.
GARFIELD AVE
EAST ORANGE GROVE AVE
SUMMIT AVE
PEARL ST.
CHESTNUT ST.
ARCADIA ST.
HENRIETTA CT.
GRANT ST.
BURTON CT.
GREEN ST.
MASONIC CT.
MARY ST.
UNION ST.
DAYTON ST.
VALLEY ST.
ORANGE PL.
PEACH PL.
WAVERLY DR.
BELLEVUE DR.
PALMETTO DR.
GERTRUDE CT.
HOLLY ST.
SUNSET AVE.
MOUNTAIN AVE.
CHAPMAN AVE.
LINCOLN AVE.
GLEN AVE.
MENTOR AVE.
BLAKE ST.
PASADENA AVE.
ORANGE GROVE AVE.
ALPINE ST.
OAK KNOLL CIRCLE
FAIR

FUTURE DISTRIBUTION POLICY

The district wherein the load density was calculated offers a different situation. Feeders 2,3,and 5 are overloaded and should be relieved. These are all in the heavily loaded district with a load density of over 6000 kva.per square mile. This part,at the present time,is all served from the Power House over 2,300 volt feeders. The load is now at such a point that it is not feasible to continue to supply future growth from there, so the section will have to be supplied from another source and the feeders rearranged for a more even load distribution.

In the development of a local distribution system the load density at certain points tends to increase to such a degree that the increasing use of power can more economically be supplied by a higher voltage. One method of doing this is by placing a substation at the center of the increased load density. The substation involves an investment in real estate(or a rental charge),transformers,switchboards,etc. and an operating expense for attendance and repairs. On the other hand the feeders running into a district to be served by the substation occupy valuable duct or pole space and require a large investment in conductors.

The Power and Light Department has at the present time property near the corner of Los Robles and Colorado

Street which is in approximately the center of the overloaded district. The project of placing a substation on this property has been given consideration. The present feeders would be disconnected and left in place to be used as emergency lines. This would eliminate the present congestion but the defects of a radial system would still be present. If the load is underestimated then obsolescence expense is incurred, while if the load is over-estimated, or the growth slower than expected, excess capital is invested without returning proper revenue. There is a delay in restoring service to miscellaneous lighting and power consumers in time of outage. As the load increases the voltage regulation becomes poorer. Feeders must be rearranged at intervals as the load changes. Service to the consumer must be discontinued when a feeder is killed for repairs or the men must work on the feeder while alive. There may be the necessity of duplicating feeders to supply a bulk load. In the present case the substation would have to be a three story building due to lack of ground space. This may cause difficulty with the neighbouring business men. There is also the objection of placing a substation where it will be subject to the complaints of residence owners in the immediate vicinity. The people of Pasadena would be averse to having any unsightly apparatus in the open and this would necessitate increased expense in a substation. There would be numerous complaints if a circuit breaker should explode. The initial investment will be high and will not be utized completely until the load has grown up to the substation capacity. The fixed investment in a company should be kept as low as possible.

Within the last five years the use of networks has increased rapidly in distribution practice and soon after work on this project was started,the suggestion was made that the possibility of using a network in Pasadena be considered. The load in Pasadena comprises a very high percentage of residential and commercial lighting,a load which requires closer regulation than the average commercial load. The alternating current network gives this needed regulation and is the most satisfactory permanent solution. With a network,units are added as needed so that investment cost and charges are kept as low as possible. However,a network can be added to as frequently as desired without being over-loaded. By its nature the network does not require any substation and this is an importatnt point when it eliminates downtown substations. Up to the last year most of the Pasadena distribution system has been overhead but with a large group of laborers in the organization as their part of the unemployment program the Department has placed a number of ducts underground, so that the installation of a network would be more of changeover than a new construction program. While the underground lines were being constructed, underground vaults have been installed and these have been constructed of ample size to hold the necessary low voltage transformers for a network. However before discussing their application to this problem it has been thought desirable to include a discussion of networks and their operating principles.

DESCRIPTION OF THE ALTERNATING CURRENT NETWORK

The low voltage alternating current network is formed by combining all low voltage lines into a grid, the grid being supplied with power at the intersections from high voltage sources. When networks were originally started protection was obtained with fuses but they were inadequate so that the network protector was developed. The protector consists of a circuit breaker actuated and controlled by relays operating on reverse power flow. These protectors are used on large systems very successfully but on smaller systems fuses are still used in the low voltage mains with circuit breakers in the feeders. A feeder fault may trip out any feeder with its transformer banks which are supplying part of the alternating current network and that part of the network must then be supplied from the adjacent feeders and their transformer banks. Upon a short circuit in the network all transformers remain in the circuit and assist in supplying current to burn off the fault. A network fault close to a transformer may burn out the fuse in the network protector although the duration and severity of the network faults are seldom of such magnitude. Obviously it is necessary to limit the size of conductors used in the network so that sufficient current is always available to burn off a fault. Also slow burning off of the fault may overheat and destroy a long length of cable. The cable sizes usually used in the alternating current network have been 250,000 and 500,000 c.m. Tests(4) however have shown that cables larger than 250,000 c.m. have sometimes failed to burn off quickly enough so that the latest designed networks have used 250,000 c.m. cables almost exclusively. If when new load is added to a network the nearest transformers become overloaded, a new feeder is brought into the district and a new unit added and the system gives the new load as good service as the rest of the system. With these general facts of a network system let us consider Pasadena in particular.

A LOW VOLTAGE NETWORK IN PASADENA

Refering to Charts 6, 7, and 8, we see that feeders 2, 3, 4, and Villa have caused overloading up to

Oakland Street; knowing that the trend in growth of the system is eastward on Colorado Street it is evident that feeder 8 also will soon have to be relieved. Therefore figures from Chart 7 have been taken for three different districts and compared.

(1) Walnut, Lake, Green, DeLacy.

(2) Villa, Lake, Green, DeLacy.

(3) Villa, Hill, Green, Delacy.

District.	Area sq. mile.	Kva.	Kva. per sq. mile.
(1)	.384	3,657	9,520
(2)	.827	4,167	5,040
(3)	1.218	5,075	4,160

Since these figures include only the load within these streets, it is estimated that district No. 2, which is the largest district having a satisfactory load density for networking, would have a total load of 5,000 kva. As the system has a total load of 25,000 kva. at the peak, the removal of this portion of the load with a redistribution of present feeders would provide adequate distribution for the future. Furthermore the area covers that portion of town in which future commercial growth will most likely take place, so that future loading would be easily cared for from the network. This area still has overhead distribution in parts and this will soon have to go underground so that this item of expense will be incurred with any system of distribution.

The primary feeders into this district could be either 2400 volt or 16 kv. since both voltages are in use. 2400 volts would be more convenient in that it allows the use of much more of the present equipment, however, the distance from the power house and the two substations is very long and the capacity of the feeders would be small if the losses are to be kept at a reasonable figure. A variation of this would be to change to a Y connection thus giving 4000 volts and reducing the losses to some extent, but it is doubtful if the saving would be worth the extra cost of changeover. The 16 kv. feeders would be more desirable because of avoiding the large voltage drop. If 2400 volt feeders were used, the feeders would be used as radials, that is, they would go direct to the transformers from the power house, but if 16 kv. is used, these feeders can be run either radial or ring. The ring feeder goes from the source of supply to one unit through to another unit, and to as many as it can supply, then returns to a source of supply. This provides a two way feed, and when a fused secondary is used in the network, the ring feeder is an aid in stable operation.

A 16 kv., 4/0 feeder would be able to supply 7 transformer vaults, thus requiring 3 feeders for the network. These feeders can be run from one substation to another substation if costs and reliability indicate this to be the best method rather than bringing the feeder back to the original point, however, the 16 kv. busses at both stations must have a good tie-in to prevent the loss of a feeder during time of trouble.

The present street vaults are of sufficient size to hold 3- 100 kva. transformers, and since many networks have found this to be a satisfactory unit, it would be logical to continue with this arrangement. Since the loss of a transformer vault does not impair the efficiency of a network, 3 phase transformers are often used because of the saving in space and first cost. Their use is generally governed by the size of the manhole since the 3 phase transformers are larger than the single phase transformers and frequently they can not be handled conveniently. The cables used on the network could be 250,000 c.m., an accepted standard, with fuses in the low voltage mains just before they go into the network. Cables of a larger size can not be used for fear of failure to burn off quickly on a secondary fault, while smaller cables although satisfactory for the present might not be able to care for future loads.

When considering the item of relative costs we were hindered by lack of time and of experience in making cost comparisions, but we accepted as comparable the results from other systems. The costs(5) as determined for an alternating current network for Portland, Oregon are given in the following table.

	Construction Costs Per Installed Kva.	Carrying Charges Investment 14% Per Kva.	Energy Losses Per Kw-Yr.	Total
2.4 kv. radial	$101.00	14.15	5.00	19.15
2.4 kv. radial primary network secondary	117.00	17.00	5.00	22.00
11 kv. radial primary network secondary	77.00	10.80	2.20	13.00
11 kv. duplicate primary radial secondary	68.00	9.50	2.20	11.70
11 kv. duplicate primary network secondary	79.00	11.10	2.20	13.30
11 kv. primary radial secondary	67.50	9.45	2.20	11.65
11 kv. primary network secondary	78.50	11.00	2.20	13.20

As shown the costs of all the high voltage systems ran approximately equal. The duplicate primary system gives improved voltage regulation and increased reliability but it is best suited to serve heavy concentrated loads and would not be needed for load such as is present in Pasadena. Network protectors are used in this system and increase the relative cost for the networks. In the Electrical World for March 5, 1932 an article gives comparative costs for networks compared to radial systems. This article is unsigned, and the amount of load and the location is not given so that the article is of use only as a general comparison.

	Secondary Network Supplied from the Generating Station.	Radial System Supplied from Substation.	Network from Substation.
Investment %	100.00	110.30	115.60
Energy Loss at Annual Peak	100.00	393.10	395.00
Total Annual Loss	100.00	281.00	281.90
Total Annual Cost of Losses	100.00	315.70	317.40
Total Annual Cost	100.00	125.20	130.40

These figures show the big saving in energy loss obtained by the elimination of the substation. The Spokane, Washington system gives cost data(6) as follows.

	4,000 volt Ring	4,000 volt Radial	13,200 volt Ring	13,200 volt Radial
Feeders	7	8	2	3
Vaults	56	56	56	56
Trans.	16,800	16,800	16,800	16,800
Feeder	14,000	16,000	14,000	21,000
Load	14,000	14,000	14,000	14,000
% Cost	100.00	92.84	103.39	99.45

The load of 14,000 is the estimated load in 1940 for this system, the present load being about 3,300 with 7,000 kw. of direct current soon to be converted. This system used the fused secondary and in many respects is quite similar to the local situation. The ring system was adopted in Spokane, Washington because it improved operating conditions even though the cost was somewhat higher. The 4000 volt system was used because the substation was within 2000 feet of the load center whereas in Pasadena, the sources of supply are 6500 feet from the load center. This excessive distance would improve the cost ratio of the higher voltage system. Considering the future need of underground duct construction with the need of relief from present overloads, it seems that a network will not cost any more than the necessary extensions to the present system and it would provide for future growth in a more satisfactory manner.

With a network installed the feeders would have as a group only 75 percent of their former load, so that a complete readjustment would be needed, but with that portion of the load which is farthest away from the substations removed, these feeders can be adjusted to give better voltage regulation, more even distribution of transformers, and more uniform balancing of load. At this point we might mention the latest devolopment in network appliances,namely,an overhead network switch for use in overhead distribution systems. This switch can be used for loads of low density, such as 1500 kva. per square mile, which would include a great deal of Pasadena's residential district. This development has not been full described yet and prices are not quoted at date of writing; it may become useful in the near future.

CONCLUSIONS

We believe that a downtown substation would relieve the present congestion, but it will be crowded, expensive,and may prove objectionable to the neighboring business men. The relief will be only temporary, since the radial system tends to become unbalanced unless const ant rearranging is done.

We believe that a low voltage,120-208 volt secondary network fed by 16.5 kv. ring feeders will relieve the congestion,provide for future growth, provide good voltage regulation,at no greater expense.

Appendix: MEDIUM VOLTAGE NETWORKS.

In the previous discussion no mention has been made of the network formed by tying primary mains together and feeding this grid by high voltage feeders. This medium voltage network is generallyn operated at 4000 volts. Standard 2300 volt transformers may then be connected between the lines and a grounded neutral while transmission is at a higher voltage. The medium voltage network may be composed largely of the original feeders reconnected to form the circuits of the network. Power transmission to the transformers is at 11 kv. or higher. A relatively small number of transformer banks are required but these will be of large capacity compared with those which would be distributed over a low voltage natwork covering the same load district. Reliability requires that the network should continue to operate successfully with one transformer bank and its high voltage feeder out of service. As a means of accomplishing this the network is sectionalized by automatic oil circuit breakers in each branch.

The Edison Electric Illuminating Company of Boston has recently installed four 1500 kva. medium voltage network units . The primary network supplied by these units was obtained by reconnecting the former feeders,none of which were smaller than 1/0 cable and no new cables were installed. The transformers are three phase,rated 1500 kva. self-cooled or 2000 kva. with blowers circulating air through the vault from the street above. The voltage rating is 13.8 kv. to 4,330 volts with a provision for tap changing under load in eight steps over a ten percent range. A contact making voltmeter controls the motor driven tap changer, maintaing constant network voltage at the transformer terminals.

The medium voltage network is claimed to be adapted to load densities of 600 to 20,000 kva.per square mile.With that increase in load the short circuit duty kva. on the circuit breakers is said to increase only three times for the above maximum load density with 1500 kva. network units a quarter of a mile apart. In the case of underground cable, reactors may be installed between the network transformers to limit the short circuit kva.

When load densities require the installation of a low voltage network it may be supplied directly from the medium voltage network without voltage regulators. Additional regulation would probably be obtained by transformerswhich reduce the 11 kv. or 16.5 kv. to 120/208 volts for the four wire network. The medium voltage network units with circuit breakers and control would eventually be removed and used elsewhere in the system as the low voltage network progressed.

The primary network while ~~not~~(7)"not eliminating transformer substations,simplifies them by reducing their individual capacity,by building them as factory units and installing them in vaults similar to distribution transformer vaults except for size. Primary feeder lengths are reduced and there are also other economies claimed for primary networks. However, the chief feature is considered to be the improvement of reliability of service by the interconnection of primaries into a sectionalizes network.

Primary natworks appear to be a rather unsatisfactory general solution to the question of economy, although economies may be sometimes shown in individual case s. Also they tend to perpetuate the use of intermediate voltages for primary circuits;that is 4 kv. and 2,300 volts. During recent years such voltages have been found inadequate,in many situations,to serve properly the loads encountered. And with the present trend toward widespread use of major appliances and the steady increase of energy consumption per customer in residential districts it is inevitable that the present more usual primary voltages must give way generally to the higher voltages.

In Pasadena this steady increase has caused the present need for revision of the distribution system so that it is felt that this system would be more of a makeshift nature than of a permanent and that even if it solved the needs for the present, in the near future increased demands would require more revision of the system. For this reason it has not been included in the main body of the report.

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TABULATED DATA

For Chart 1

Year	Population of Pasadena
1890	4882
1900	9117
1910	30291
1920	45354
1930	75875

United States Census Data

For Chart 2

Water Meters in Pasadena

Date	Water Meters
Nov. 1,1912	7279
Jan.30, 1914	8685
" " 1915	10107
" " 1916	10597
" " 1917	10842
" " 1918	10789
" " 1919	10905
" " 1920	11110
" " 1921	11888
" " 1922	12815
" " 1923	14895
" " 1924	16851
" " 1925	18269
" " 1926	18960
" " 1927	19416
" " 1928	19796
" "1929	20052
" " 1930	20346
" " 1931	20460

Elementary School Children in Pasadena

School Year Ending June	Number of School Children
1908	4106
1909	4183
1910	4352
1911	4510
1912	4953
1913	5127
1914	5332
1915	5393
1916	5627
1917	5616
1918	5639
1919	5595
1920	6568
1921	7432
1922	7825
1923	8830
1924	10597
1925	10963
1926	11234
1927	12016
1928	12068
1929	12329
1930	12541
1931	13017

Residence Light Meters

Date	Light Meters
Dec. 31, 1924	21302
Dec. 31, 1925	22766
June 30, 1926	23766
Dec. 31, 1926	23544
June 30, 1927	23787
Dec. 31, 1927	24054
June 30, 1928	24509
June 30, 1929	25017
Dec. 31, 1929	25208
June 30, 1930	25368
Dec. 31, 1930	25519
June 30, 1931	25667
Dec. 31, 1931	25761

Switchboard K.W.-Hours per year sold

Year	K.W.-Hours
1920	10,000,000 Approx.
1921	16,000,000 "
1922	22,000,000 "
1923	29,448,100
1924	35,740,422
1925	37,758,117
1926	42,177,662
1927	46,118,200
1928	52,434,940
1929	57,616,480
1930	62,799,089
1931	65,990,807

Note: Switchboard K.W.-hours per year sold is power generated plus power purchased minus power sold outside of Pasadena.

Sources of Data for Chart 2

Residence Light Meters, switch-board power sold were obtained from the Pasadena Department of Light and Power.

Water Meters - this data was obtained from the Eighteenth Annual Report of the Pasadena Water Department.

Elementary School Children - this data was obtained from the accounting department of the Pasadena Board of Education.

For Chart 3

Year	Population of Pasadena in thousands	Million of Switchboard K.W.-hours per year sold
1920	50	10
1921	53	16
1922	56	22
1923	58	27
1924	60	31.5
1925	63	37
1926	67	42
1927	69	46
1928	72	53
1929	73	59
1930	76	63
1931	78	67

Note: This date for population and power sold were obtained from the curves of chart 2.

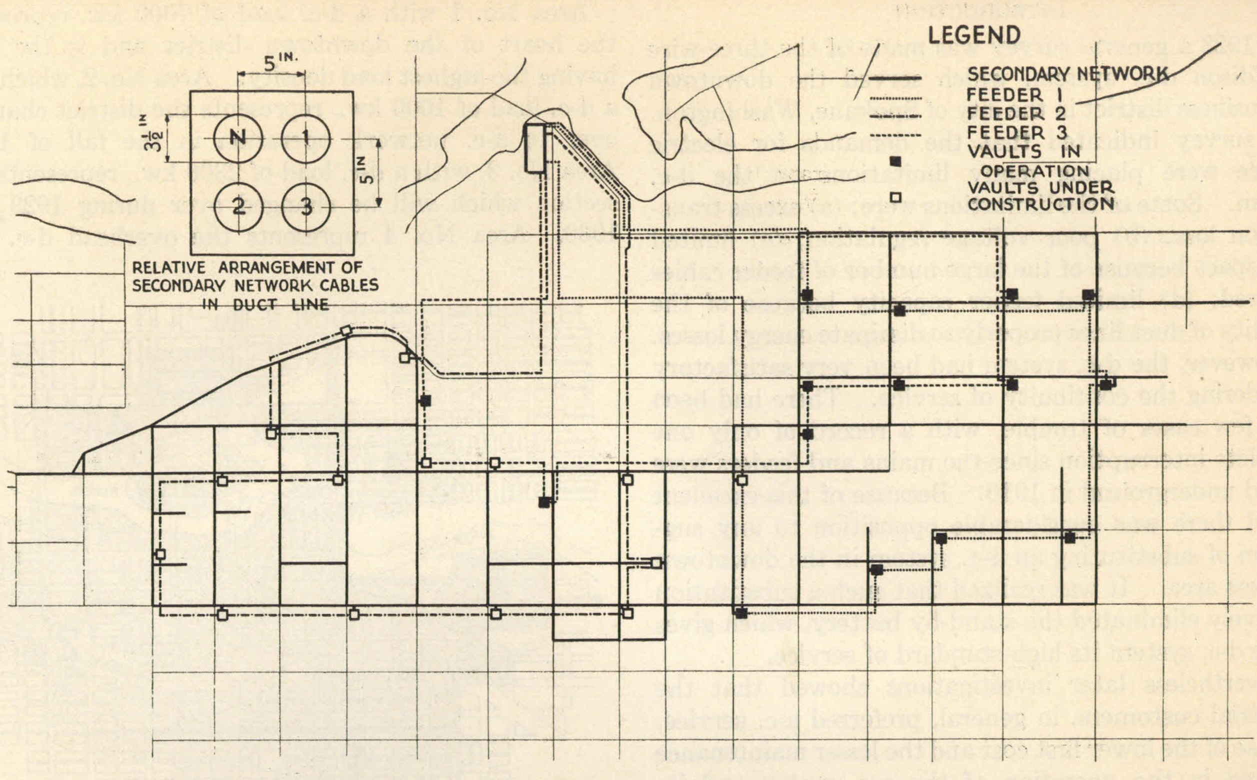

FIG. 1B SECONDARY NETWORK AND PRIMARY FEEDER ARRANGEMENT

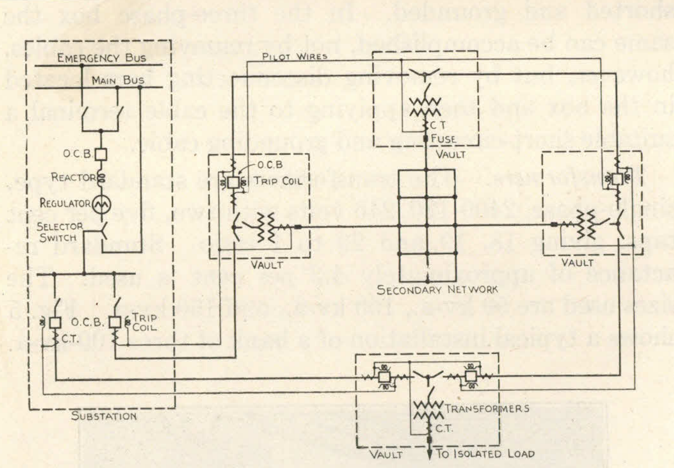

FIG. 2—ONE-LINE DIAGRAM OF ONE PRIMARY RING FEEDER

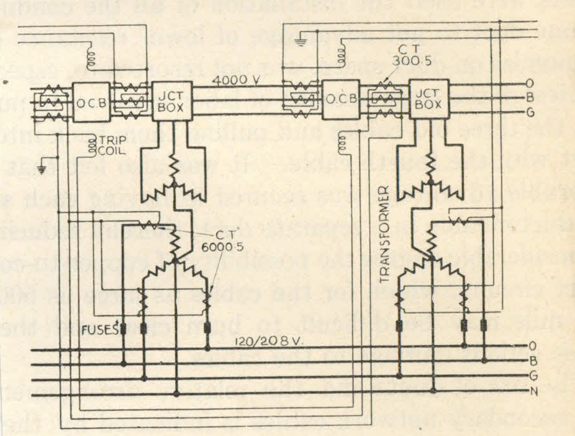

FIG. 7—PILOT-WIRE RELAY CONNECTION DIAGRAM

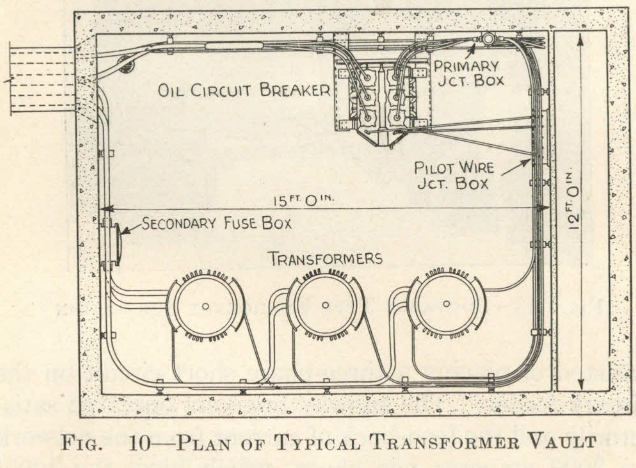

FIG. 10—PLAN OF TYPICAL TRANSFORMER VAULT

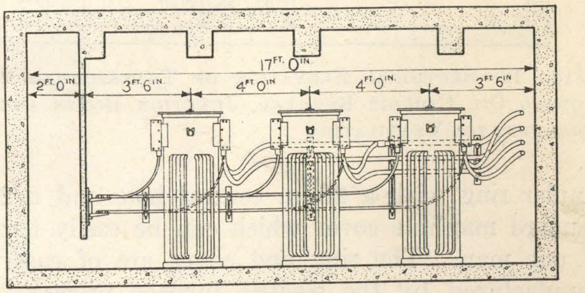

FIG. 11—SECTIONAL ELEVATION OF TRANSFORMER VAULT SHOWING ARRANGEMENT OF TRANSFORMERS

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