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TRANSMISSION OF ELECTRICAL ENERGY AT 220,000 VOLTS

BY

ROBERT WILHELM AHLQUIST

A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree of

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

Rolla, Mo.

1924.

Approved by ....I. H. Lovett........

Associate Professor of Electrical Engineering

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Head of Physics & Elec. Eng'r'g Department

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PART I.

GENERAL.

1. TRANSMISSION(History).

Numerous means and devices have been used for the transmission of power. Belts,ropes,shafts,hydraulic pressure,compressed air have been used with various efficiencies. The most universal means for transmission of power for the past three decades has been by means of the electrical transmission line.

The first systems were direct current of relatively low voltages and short distances. It was soon found that a great advantage lay with the use of alternating current,because of the fact that the voltage could be stepped up or down at will by the use of transformers.

In 1887 Tesla pointed out the advantages of the three phase system over the single phase system, but it was not until 1891 that the first commercial three-phase transmission line was put into service. This was the Lauffen-Frankfort line supplying a lighting load to the city of Frankfort. The power-house installation consisted of one 225 kw. three-phase generator driven by a water wheel operating under a head of ten feet. The line voltage used was 12,000 volts.

The first polyphase transmission system in this country was placed in operation in California, in 1893, by the Redlands Electric Light & Power Co. (Now the Southern California Edison). The plant consisted of two 250 kw. 2400 volt three-phase generators. The power was transmitted a distance of 7 miles. In the same year 400 kw. was transmitted 11 miles at 5000 volts at Hartford Connecticut.

Since that time the voltages used have steadily increased. In 1896, the 25,000 volt system of the Pioneer Electric Co. of Utah was thought to be a high tension system, but by 1908 the Au Sable Electric Co. had placed in operation a 110,000 volt system. In 1913 the 150,000 volt system of the Southern California Edison began the task of transmitting 150,000 hp. over a distance of 240 miles. With every increase of power and distance higher potentials have been used, giving greater economy than would be otherwise possible.

2. Statement of Scope of this Paper.

A. E. Silver at the Annual Convention of the A.I.E.E. in 1919 gives some of the reasons why 220,000 Volt transmission is a logical and feasible commercial proposition. He also gives some of the main features of the undertaking.

" (1) Such a voltage does not step beyond present voltage into uninvestigated fields, but that the problem of development and design can be approached with full confidence of early commercial solution.

(2) Such a voltage is in accordance with the long established practice of standardization in multiples of 11,000.

(3) The field is limited to large blocks of power and long distances.

(4) It is to be transmitted from energy sources to terminal substations at important load centers.

(5) The load factor must be high. 220 kilovolts to supply the base load, and the peak load being left to the local generating stations.

(6) It is the ultimate aim to make the 220 kilovolt system as dependable as the local generation of power."

A study of this kind should cover:

(1) The fields where the demand is large enough to warrant this high voltage.

(2) The points of generation where it is possible to generate large blocks of power.

(3) A study of the apparatus that has been designed and tested to generate and transmit this power.

(4) A discussion of the systems where this high voltage has been tried out.

Owing to the great scope of this paper it has been thought necessary to generalize on the discussion of the first two topics and to treat the next two in more detail.

PART II

EXISTING HIGH TENSION SYSTEMS.

PLATE 1 not only shows the proposed superpower districts, but it also shows the present high voltage systems supplying energy over considerable distances. These systems are owned by many companies. Some of them are Hydro-electric, some are steam and others are a combination of the two. Many of them are interconnected for the mutual transfer of power from one system to another, thereby effecting a saving to the systems concerned.

Systems with over 100,000 K.W. Capacity are listed below.

Company	Hydro or Steam	Kv.	Present Capacity	Ultim. Capacity
Gt West. Co.	Both	165	105,000	500,000
S.Cal. Edison	Hydro	220	110,000	750,000
Tenn. Power Co.	"	120		
Ala Power Co	Both	110 44	130,000	148,000
Georgia Rl'w'y and Power Co	"	110 66	124,200	
Pac. Gas & Elec	"	110 104 60	194,975	
Ontario Power Co.	Hydro	110	150,000	225,000
Miss.River P. Co.	"	110	112,500	225,000
Montana Power Co	"	100	212,000	

Company	Hydro or Steam	Kv.	Present Capacity	Ultimate Capacity
Southern P. Co.	Both	100 40	280,900	
Phila. Elec. Co.	Steam	66	216,600	276,600
Duquesne L. Co.	Steam	66	153,650	453,650
Montreal Power Co.	Hydro	66	130,250	190,250
Detroit Edison	Both	48	236,775	300,000

It will be noticed that the Ultimate Capacity of nearly all of the systems given provide for a great expansion in generating capacity.

At Niagra Falls approximately 200,000 K.V.A. is now being developed with both vertical and horizontal shaft turbines. About 195,000 K.V.A. is being installed at the present writing. The city of Buffalo, though it is very near to the Falls has an installation of nearly 100,000 K.V.A. in steam power to take care of its power requirements over and above the power received from the Falls. Another large block of power developed on the Canadian side of the Falls supplies part of Buffalo, Rochester, Syracuse and other cities.

In Pennsylvania, the principal load centers are Philadelphia and Pittsburgh. The companies that supply Pittsburgh with power are the Duquesne Light Co. and the West Penn Power Co. In June 1919, the Power rating of this district was 773,000 kw . This includes the cities of Cleveland,Newark,Pittsburgh, Wheeling,Windsor,and others. Indications are that by 1927,the total peak load of this district will be about 1,400,000 kw . This includes about 100,000 kw . for Steel companies,and about 200,000 kw for railway electrification. In this section of the country most of the plants are steam operated and located on large rivers so as to have an ample supply of water for condensing purposes. In June 1923 the West Penn Systems included 154 high-tension substations, having a transformer capacity of 175,882 kw. Through the lines of this systems interconnections are made with the Wheeling Traction Company,and indirectly to the systems of the Duquesne Light Co. Interconnections are made over the lines of the Ohio Power Co. to Canton and East Liverpool,the Northern Traction Co. at Akron,the Massillon Electric Company and other points in Ohio.

In the State of New York the largest part of the generating capacity exclusive of Niagra Falls is concentrated in the Metropolitan District of New York City. This amounts to about 700,000 kw., and the peak load for this district is nearly 1,400,000 kw. including Railway electrifications. The Hell Gate Station has an ultimate capacity of 300,000 kw., and at the present time has an installed capacity of one half that amount.

In the northeastern portion of the United States there is an interconnected group of power transmission lines reaching from Long Island Sound to Lake Champlain and covering all of Massachusetts, Southern New Hampshire, Eastern Conneticut and Rhode Island. In this section there is a continuous connection, Boston and the system of the New England Power Co. tying together about 500,000 kw. in steam and Water power stations. The two largest systems in this district are the New England Power Co. and the Edison Electric Illuminating Co. of Boston. Most of the plants of the former company are located along the Deerfield River.

In the Northwestern part of the United States the system of the Montana Power Co., composed of Hydro-electric plants, reaches westward into Idaho, and a short gap has recently been closed which connects it with the Washington Power group, which ends at the Pacific coast. Energy is supplied to the Chicago Milwaukee & St Paul Electrified portion of its system from the Montana and Washington power districts. This power is supplied at 100,000 volts. to the transmission lines. Connection into Canada is made from Bellingham to the Western Canada Power Co. Many of the Power stations of Washington are Hydro-electric.

California has been foremost in the development of high-tension transmission lines. It has an installed capacity of 1,129,000 hp. in waterwheels. It is the only state which is transmitting energy at the high pressure of 220,000 volts. The state has ample Hydro-Electric power to supply industry and agriculture for many years. Developments aggregating 325,000 kw. have been completed recently. Four large developments are projected, will add 1,500,000 kw. The table given below shows some of the large water developments and the existing power.

	Developed and under const.	Proposed Dev. for 1926	Near Future
Pitt River	None	200,000 kw.	500,000 kw.
Feather River	100,000 kw.	200,000 "	300,000 "
Big Creek	100,000 "	300,000 "	500,000 "
Colorado River	None	None	200,000 "
Total	200,000 kw.	700,000 kw.	1,500,000 "

The demand for the Sacremento Valley,San Francisco Bay district,Fresno,Bakersfield,Los Angeles,Barstow, Needles ,including Railroad Electrification is estimated at 1,040,000 kw. The Southern California Edison,one of the larges companies in the country, has delivered to the Los Angeles district from the Big Creek plants, a total of 1,200,000,000 kw. hours,a distance of 240 miles,at an average efficiency of 87.5% and a 45% load factor. This energy was transmitted at 150 kv.,but these lines are now operating at 220 kv.

PART III Super-Power System.

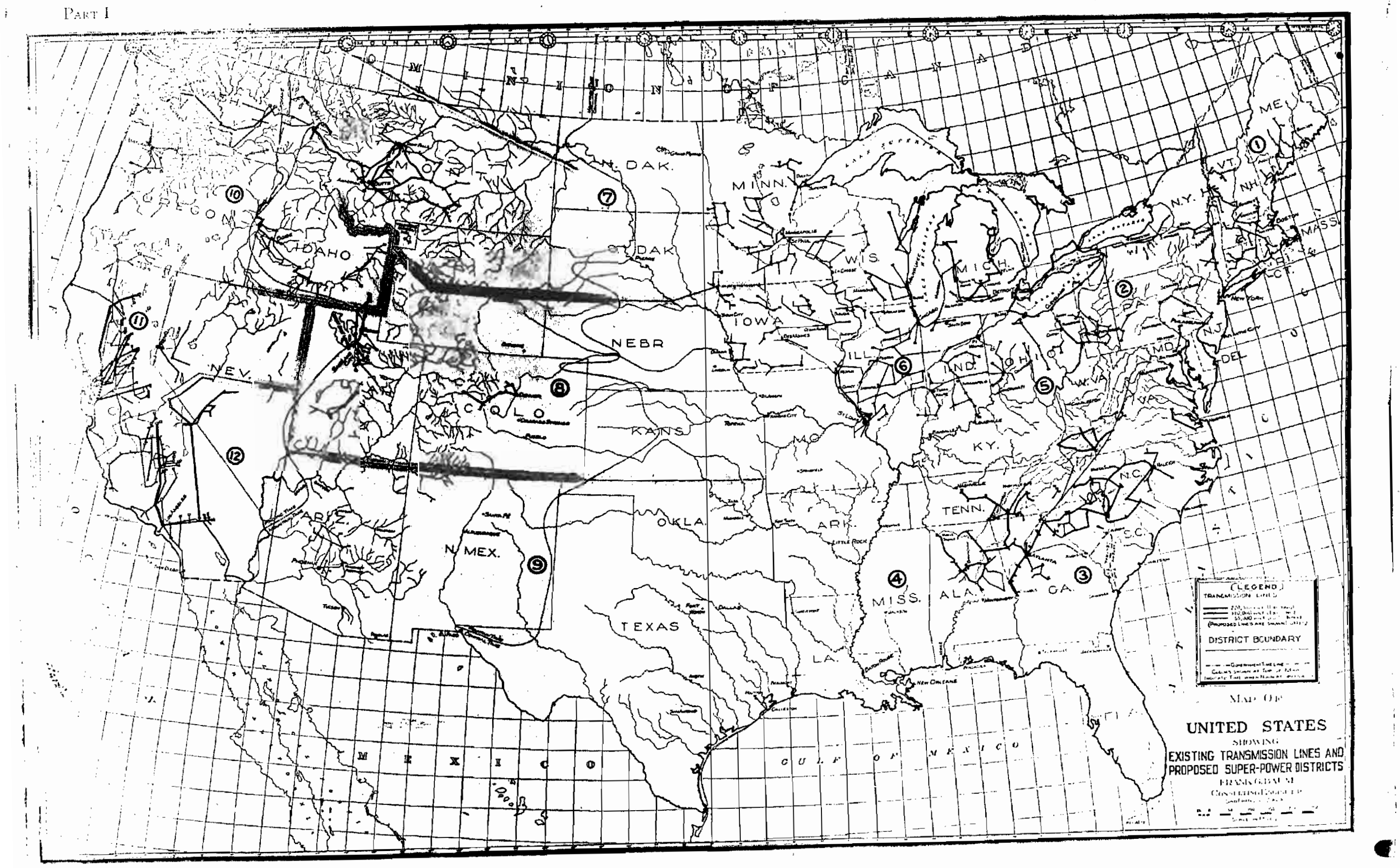
1. Power Districts.

Secretary of Commerce Hoover, speaking before the representatives of Public Service commissions in ten northeastern states concerning the super-power system states: " This new era of advanced projects is no theorists' or promoters' dream. It is a basic fact unanimously supported by our engineers; agreed to by the responsible men in the industry...... The electrical companies, under the regulation of the Public Service Commissions, have already made excellent progress in the application of superpower principles in many localities."

Mr. Frank G. Baum, Consulting Engineer at San Francisco, after making an extensive study of the power demand over the whole of the United States proposes a super-power system. Plate 1 shows the existing lines and the proposed super-power districts. The power developement and transmission system in each region should be under one concern, which will sell the power to smaller distributing companies. The regional power districts should be divided into economical subdivisions, thru means of public service commissions to form distributing units of such sizes as

Plate 1.

PROPOSED SUPER-POWER DISTRICTS.



would give economic management, and management close enough to the power consumer to be responsive to the districts served.

The regional power districts that are shown in plate 1 comprise the following regions:

#1 covers the New England States.

#2 comprises New York, New Jersey, Pennsylvania east of the Alleghenies, Maryland and Delaware.

#3 is east of the Appalachians and includes Virginia, North Carolina, South Carolina, Georgia and Florida.

#4 comprises the states of Alabama, Mississippi, Arkansas and Louisiana.

According to Mr. Baum Districts 1 to 5 have enough desirable water power in each region to form with large steam plants systems for power production and transmission.

#6 includes Illinois and Indiana.

#7 Includes the Drainage valleys of the Missouri and Columbia rivers for the Western Railroad systems, and the states of Minnesota and Wisconsin.

#8 comprises the upper Colorado river, and the states of Utal, Colorado, Nebraska, Kansas and part of Wisconsin and Wyoming together with Iowa and Missouri.

#9 includes the states of Oklahoma,Texas, New Mexico and Arizona. In this group is included the main power of the Colorado river and possible power from the oil and Gas fields of Oklahoma,Texas and Kansas.

#10 includes the states of Washington, Oregon and Idaho. These three states contain very large power resources,and it will be a long time before all of the power of this region can be absorbed either in Railway hauling or in manufacturing lines.

#11 Comprises Northern California and Nevada.

#12 included Southern California and Western Arizona(Part of the power of the Colorado river).

In the Super-power system large blocks of power will be generated in each district at very high voltages and supplied to the present power systems thru transformers. Under this system interconnection will be universal. There are many benefits arising from the interconnection of power systems.

(a) It conserves fuel in a steam station tied into a hydroelectric system without adequate pondage by allowing the waterplant to care of the light load periods up to the full capacity of the water power that would otherwise go to waste.

(b) The hydro-electrical plants with pondage can store up water while the steam plants are able to carry the load so that the plant with water storage can carry load during the heavy peak load period.

(c) Waste power can be saved by taking advantage of the diversity of water flow on different water sheds,particularly at the time of early spring floods.

(d) Large and efficient plants can operate on the base loads using the less efficient plants for peak loads.

(e)The interconnection of systems often permits the postponment by some companies of the building of new plants,thus conserving capital charges.

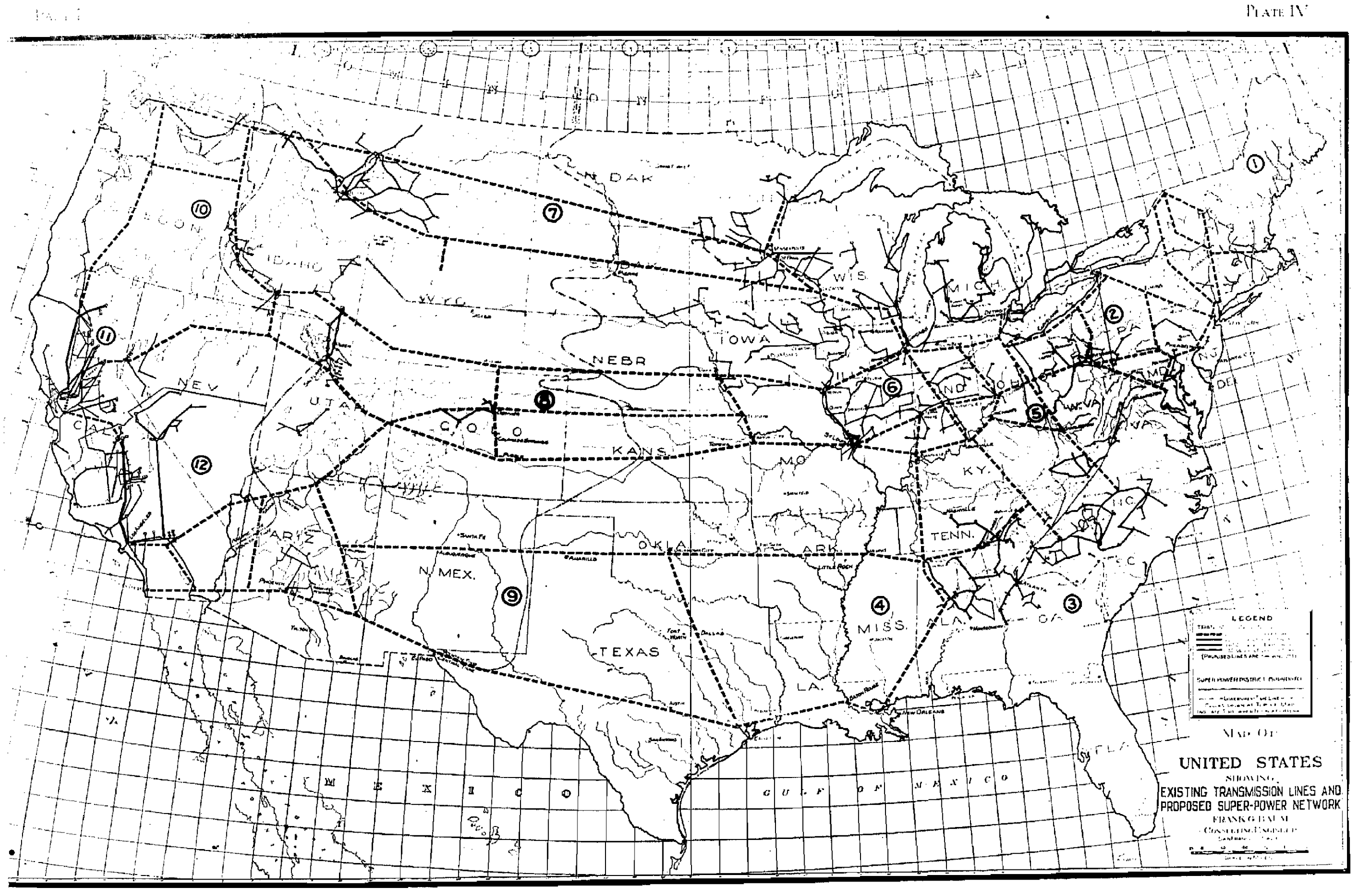
(f) When two systems are tied together advantage may be taken of the fact that the peak load occurs at different times of the day, and one system may act as a reserve for the other one.

2 Proposed Lines.

Figure 2 shows the super-power net work as proposed by Mr. Baum. The heavy dotted lines show the main power lines that would carry the large blocks of power. The explanation of Mr. Baum in regard to his map throws many side lights on the power situation of the country.

Plate 2.

PROPOSED SUPER-POWER NETWORK.



Referring to plate number 2.

The Adirondacks to New York connection to District #1 is made because the New England states are short of Hyrdro-electric power. # 1 may in time secure power from Canada. From the Adirondacks lines would extend back to the St. Lawrence river and a second line would take St, Lawrence river power to New York thru Utica.

A line from Niagara to New York and connected with the Susquehanna river power at Holtwood is interconnected with the industrial regions west of New York through to Philadelphia. A second line from Niagra Falls goes thru Erie,Cleveland,Toledo and connects with the large steam stations on Lake Michigan. Steam reserve from #2 can subsequently come from #5.

A line from Pittsburgh is shown running to Columbus,Dayton,Cincinnatti and Louisville with the understanding that water power is to come from the branches of the Allegheny,Monongahela and Yonghogheny rivers.

A line is shown running easterly from Cincinnatti and Columbus to Charleston,West Virginia and thence connecting with the Southern Power Co.

The upper Kanawha and New rivers can be developed to justify a double circuit transmission line. This line could feed power into #5 and act as a steam reserve for #3. No 220 kv. transmission lines are shown for #3 except those that will bring power from districts #4 and #5. From Louisville another trunk line goes to the Tennessee river where considerable Hyro-electric power can be developed.

Louisville and St Louis are both fed from a line connected to Muscle Shoals, Alabama. It seems logical that the power from Muscle Shoals should be used in district#4, but it will take some time for a market to develop in that district, as no large power is demanded except in Alabama. However, with the reclamation of the Mississippi river lands large amounts of power will be required. Lines also connect to Memphis and Oklahoma, and to New Orleans, Baton Rouge and westerly to district #9.

Power for district #9 can come largely from the gas and oil fields.

District #6 on account of the large coal fields located here will be a steam district, but it may finally receive power from from Minnesota and Manitoba.

From power available on the upper Missouri river, trunk lines are shown going easterly which can supply the three northerly railroads with power to electrify these roads.

Three lines are shown going from the power resources of the Colorado river. One follows the Santa Fe railroad, one the Union Pacific and the third lies intermediate between the two.

In district #10 the market for power has not developed sifficiently to show the main trunk lines.

Districts #11 and 12 should interconnect as shown. A short line is also shown interconnecting the Pacific Gas and Electric Co. with the Southern California Edison Co. at 220 kv.

A survey of the power conditions show that the main power problem seems to be:

(1) to develop hydro-electric power and supply the demands of #2.

(2) To develop hydro-electric power on the Ohio and supply #5.

(3) To find a market for the excess power in the Rocky Mountains.

(4) To find the market for the power in #10.

3 Super-power as applied to the Eastern States.

In 1921 an appropriation of $125,000 was made to the United States Geological Survey for the survey of power production and distribution in this country, and a special investigation of the possible economy of fuel, labor and materials resulting from the use in the Boston-Washington district of a super-power system. The territory where the study was made included parts of the states of Maine, New Hampshire, Vermont, New York, Pennsylvania, Delaware and Maryland and all of Massachusetts, Rhode Island, Connecticut, and New Jersey. This industrial region is the great finishing shop of American industry. This zone has relatively small hydro-electric resources and maximum power requirements. However, great deposits of coal lie near this region.

The super-power system recommended by the Geological Survey comprehends a plan of power production that includes the generation of electricity by steam at tidewater and on inland rivers where a sufficient supply of condensing water can be commercially obtainable, and also the utilization of all hydro-electric power that is obtainable in the zone or within transmission distance of it. The electric power so generated will be coordinated thru a system of interconnected lines,the potentials of which will be of the order of 220,000 and 110,000 volts.

Under the present condition of operation there is at present 558 electric utility plants with an average capacity of 7,900 kw. Under the projected super-power system the number of power stations required to supply the zone in 1930 will be only 273,of which 218 of these will belong to the existing power utilities. The capacity of the base load steam plants will range from 60,000 to 300,000 kw. This system will not seek to compete with the existing systems or to supplant them,but it would only serve to coordinate and supplement these utilities. Load centers will be established where economy dictates. At these centers,power will be coordinated with power generated at the existing utility plants,and distributed by transmission and distributing systems.

The market for super-power energy will be furnished by the electric utilities,the industries and the railroads. The estimated market demand is given as 31,000,000,000 kilowatt hours for 1930. This energy can be supplied thru a super-power system at an annual cost of $239,000,000 less than it could with the uncoordinated system. Studies of operation at each load center have shown that a great quantity of coal can be saved annually under this scheme. This amounts to about 50,000,000 tons per year for the three groups given above.

PART IV.

FEATURES OF THE PROPOSED 220,000 VOLT LINES.

1. Performance of Theoretical Lines.

The principal elements that are considered in designing a transmission line are length,amount of energy to be transmitted,frequency,voltage,corona, reactance,condensance,cost of energy,cost of operation,and value of energy that is finally delivered.

The length of line is determined by the location of the power house from the demand.

The amount of energy transmitted depends upon the demands of the market or the capacity of the generating plant.

The frequency is nearly always 60 cycles.

The voltage discussed here will be 220 kv.

Corona limits the size of a conductor, since there is a definite critical voltage for every size conductor depending upon spacing, arrangment of conductors, elevation and climatic conditions. Up to about 2000 feet above sea level the minimum diameter of a conductor is about 0.95 inches for 220,000 volts.

The fundamental elements that determine the losses and performance of a line are resistance, reactance and capacitance.

Resistance of a wire depends upon its length, cross section and its material composition.

Reactance varies with the frequency, length, size, arrangement, and spacing of conductors. Reactance is one of the factors limiting the amount of energy that can be transmitted at one particular voltage.

Capacitance or condensance determines the charging current, and it depends on the spacing, diameter of the conductors, arrangement, frequency and the length of the transmission circuit. If the receiving end is open, the charging current may rise to the full value of the load current. The charging current, being leading, tends to make the generator self exciting, and it may cause the generator to go beyond the point of field control.

The cost of transmission depends upon the efficiency of the transmission line, fixed charges and maintenance costs. Tables below show the efficiencies of several lines. These lines are theoretical, but they express actual conditions as far as the performance of the lines are concerned with a voltage of 220,000 volts.

	Line #1	Line #2
Power transmitted	300,000 kw.	300,000 kw.
Voltage Rec. end	220,000	220,000
Cycles	60	25
Length	350 mi.	350 mi.
Number tower lines	2	2

Table continued

	Line #1	Line #2
Size of conductors cm.		
Aluminum	605,000	605,000
Steel Core	78,000	78,000
Emergency Load	150,000 kw.	150,000 kw.
Normal Load per circuit	75,000 kw.	75,000 kw.
Power factor of load	85%	85%
Power factor gen. end.	.893 lead	.884 lead
Power factor rec. end	.983 lag	.934 lead
Power factor generator end for emergency load	.983 lag	.983 lag
Power factor receiving end for emergency load	.879 lead	.894 lead
Synchronous condenser k v-a. at normal load	152,000	90,000
Line losses	29,800 kw.	36,360 kw.
Transformer losses	4,500 kw.	6,000 kw.
Syn condenser losses	6,100 kw.	3,600 kw.
Total losses	40,000 kw.	45,960 kw.
Efficiency of transmission	88.1%	86.7%

Transmission line #3

Length 300 mi. Voltage 220 kv. Load 120,000 kw.

Section 600,000 cm. copper Full load amperes 400

Efficiency 90.25% Transformer loss 1.25%

Condenser loss 0.5%

For 100 miles with same conditions Efficiency is 95%

Transmission line #4

Assumptions

Steel core copper cable 450,000 copper 398,200 steel

20 foot horizontal spacing

Constant receiver volts 200,000

Constant generated volts 230,000

Load delivered at 75 % power factor

Transformer banks 50,000 kw. capacity

Calculated losses include line, transformers and synchronous condensers.

Calculation Results.

Rec. KW.	Condenser	Receiver		Generator		Losses	
		Kv.	PF %	Kv.	PF %	KW.	%
0	49,000 lag	209	.18 lag	230	5.48 ld.	2704	
50,000	7,600 lead	207	78 "	230	96.8 "	2691	5.4
100,000	81,600 lead	203	98 "	230	99.7 "	11,843	11.8

Efficiency of transmission 50,000 94.6%

100,000 89.2%

Transmission line #5

Assumptions

Steel core aluminum cable 716,000 al. 92,900 steel

Constant generated volts 230,000

Constant receiver volts 200,000 (includes trans.)

Transformer banks each 50,000 kw. capacity

Losses include line, transformers and condensers.

Calculation Results

Receiver Kw.	Condenser Kv-a.	Receiver Kv.	pf	Generator Kv.	pf	Losses Kw.	%
0	49,800 lg.	209	.18 ld.	230	.04 ld.	2646	
50,000	7,500 lg.	207	.78 lg.	230	.96 ld.	2786	5.6
100,000	81,000 ld.	203	.98 ld.	230	100	11,927	11.9

Efficiency line 50,000 kw. 94.4 %

Efficiency line 100,000 kw. 89.1 %

2 Discussion of Equipment for 220,000 volt Lines.

Generating station arrangement.

Simplicity should be the dominating principle. Generators and transformers should be operated as a unit. In contrast to modern practice,there should be no low voltage bus,and no low voltage paralleling. It is preferrable to have a specific bank of transformers and generators for each 220 kv. circuit

Towers.

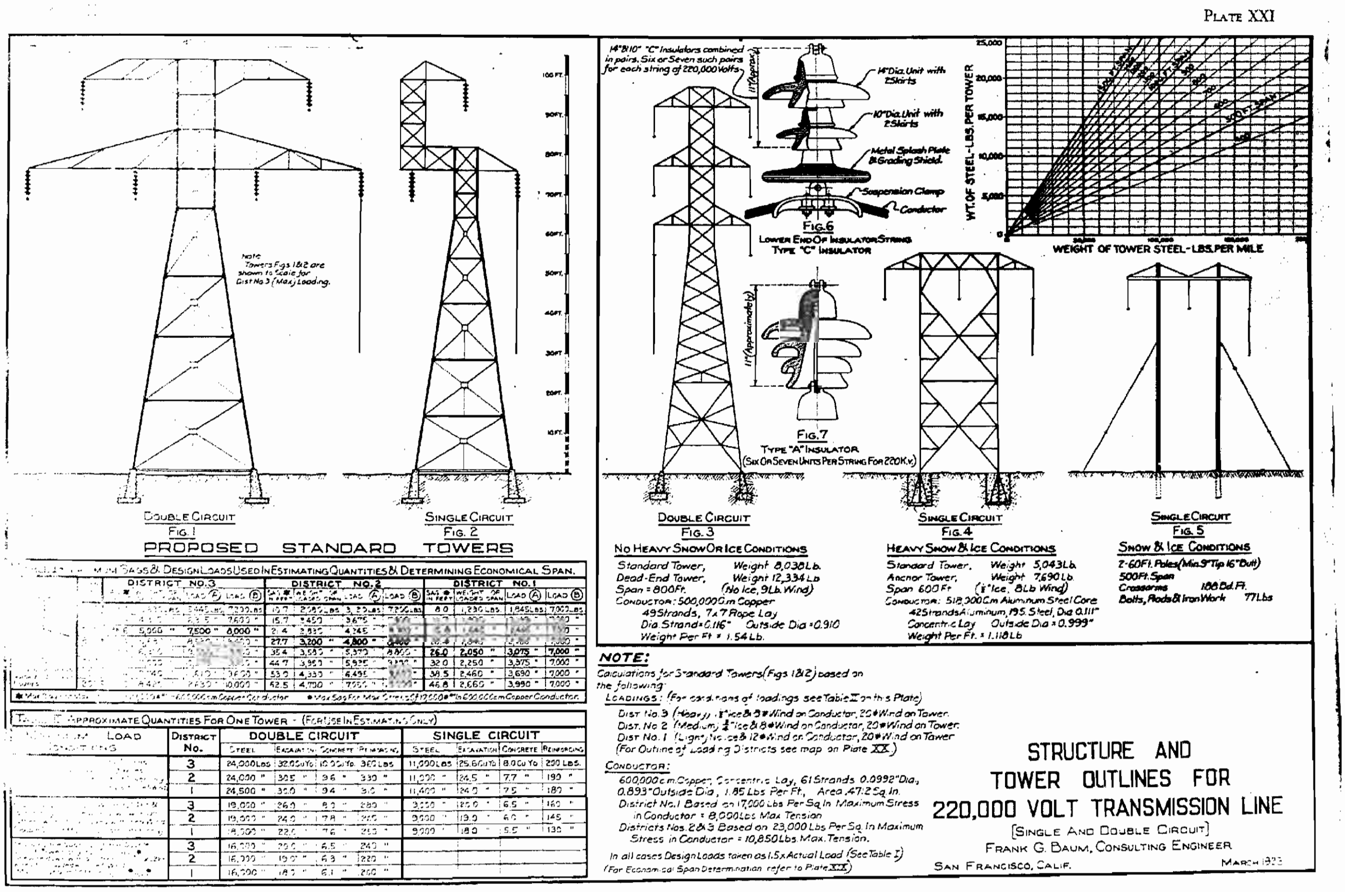
Plate 3. shows outlines for different types of towers that F.G. Baum recommends for 220 kv. transmission. Figure 1 and 2 show towers that would be used under very severe weather conditions. The Delta spacing takes care of ice that may short circuit in the vertical spacing shown in figure 3. Figures 4 and 5 show towers that may be used where snow and ice is prevalent. The tower shown in figure 5 will give very good service where poles can be secured cheaply as in the northwestern part of the United States. The cost of the towers will vary from $9,000 to $19,500 per mile.

Main Substation arrangement.

On account of switching operations it will be necessary to have low and high voltage buses. Synchronous condensers must be provided for each transformer bank.

Plate 3.

STRUCTURE AND TOWER OUTLINES.



DOUBLE CIRCUIT
FIG. 1

SINGLE CIRCUIT
FIG. 2

PROPOSED STANDARD TOWERS

FIG. 6
LOWER END OF INSULATOR STRING
TYPE "C" INSULATOR

FIG. 7
TYPE "A" INSULATOR
(SIX OR SEVEN UNITS PER STRING FOR 220K.V.)

DOUBLE CIRCUIT
FIG. 3
NO HEAVY SNOW OR ICE CONDITIONS

Standard Tower, Weight 8,038 Lb.
Dead-End Tower, Weight 12,334 Lb
Span = 800 Ft. (No Ice, 9 Lb. Wind)
CONDUCTOR: 500,000 C.m Copper
49 Strands, 7x7 Rope Lay
Dia. Strand = 0.116" Outside Dia = 0.910
Weight Per Ft = 1.54 Lb.

SINGLE CIRCUIT
FIG. 4
HEAVY SNOW & ICE CONDITIONS

Standard Tower, Weight 5,043 Lb.
Anchor Tower, Weight 7,690 Lb.
Span 600 Ft (½" Ice, 8 Lb Wind)
CONDUCTOR: 518,300 C.m Aluminum Steel Core
42 Strands Aluminum, 19 S. Steel, Dia 0.111"
Concentric Lay Outside Dia = 0.999"
Weight Per Ft. = 1.118 Lb

SINGLE CIRCUIT
FIG. 5
SNOW & ICE CONDITIONS

2-60 Ft. Poles (Min. 9" Tip 16" Butt)
500 Ft. Span
Crossarms 188 Bd. Ft.
Bolts, Rods & Iron Work 77 Lbs

[illegible] SAGS & DESIGN LOADS USED IN ESTIMATING QUANTITIES & DETERMINING ECONOMICAL SPAN.

	DISTRICT NO.3				DISTRICT NO.2				DISTRICT NO.1			
[illegible]	[illegible]	[illegible]	LOAD Ⓐ	LOAD Ⓑ	SAG * IN FEET	WEIGHT OF LOADED SPAN	LOAD Ⓐ	LOAD Ⓑ	SAG * IN FEET	WEIGHT OF LOADED SPAN	LOAD Ⓐ	LOAD Ⓑ
[illegible]	[illegible]	[illegible] Lbs.	3,445 Lbs.	7,200 Lbs.	10.7	2,380 Lbs.	3,[illegible] Lbs.	7,200 Lbs.	8.0	1,230 Lbs.	1,845 Lbs.	7,000 Lbs.
[illegible]	[illegible]	4,[illegible]	6,[illegible] "	7,600 "	15.7	2,450 "	3,675 "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	5,000 "	7,500 "	8,000 "	21.4	2,830 "	4,245 "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	8,[illegible]	[illegible]	27.7	3,200 "	4,800 "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	6,[illegible]	[illegible]	[illegible]	35.4	3,580 "	5,370 "	8,[illegible] "	26.0	2,050 "	3,075 "	7,000 "
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	44.7	3,950 "	5,925 "	[illegible]	32.0	2,250 "	3,375 "	7,000 "
[illegible]	[illegible]	[illegible]40	[illegible]	9,600 "	53.0	4,330 "	6,495 "	[illegible]	38.5	2,460 "	3,690 "	7,000 "
[illegible]	[illegible]	8,420	[illegible]	10,000 "	62.5	4,700 "	7,050 "	[illegible]	46.8	2,660 "	3,990 "	7,000 "

* Max [illegible] 600,000 Cm Copper Conductor. * Max Sag For Max Stress Of 17,000 #"In 600,000 Cm Copper Conductor.

TABLE II APPROXIMATE QUANTITIES FOR ONE TOWER - (FOR USE IN ESTIMATING ONLY)

[illegible] LOAD [illegible]	DISTRICT No.	DOUBLE CIRCUIT				SINGLE CIRCUIT			
		STEEL	EXCAVATION	CONCRETE	REINFORCING	STEEL	EXCAVATION	CONCRETE	REINFORCING
[illegible]	3	24,000 Lbs	32.0 Cu Yd	10.0 Cu Yd.	360 Lbs.	11,000 Lbs	25.6 Cu Yd	8.0 Cu Yd	200 Lbs.
	2	24,000 "	30.5 "	9.6 "	330 "	11,000 "	24.5 "	7.7 "	190 "
	1	24,500 "	30.0 "	9.4 "	310 "	11,400 "	24.0 "	7.5 "	180 "
[illegible]	3	19,000 "	26.0 "	8.0 "	280 "	9,000 "	20.0 "	6.5 "	160 "
	2	19,000 "	24.0 "	7.8 "	265 "	9,000 "	19.0 "	6.0 "	145 "
	1	18,000 "	22.0 "	7.6 "	250 "	9,000 "	18.0 "	5.5 "	130 "
[illegible]	3	16,000 "	20.0 "	6.5 "	240 "				
	2	16,000 "	19.0 "	6.3 "	220 "				
	1	16,000 "	18.0 "	6.1 "	200 "				

NOTE:

Calculations for Standard Towers (Figs 1&2) based on the following:

LOADINGS: (For conditions of loadings see Table II on this Plate)

Dist No. 3 (Heavy) ½" Ice & 8 # Wind on Conductor, 20 # Wind on Tower.
Dist. No 2 (Medium) ¼" Ice & 8 # Wind on Conductor, 20 # Wind on Tower.
Dist No. 1 (Light) No Ice & 12 # Wind on Conductor, 20 # Wind on Tower
(For Outline of Loading Districts see map on Plate XX.)

CONDUCTOR:

600,000 c.m. Copper, Concentric Lay, 61 Strands 0.0992" Dia., 0.893" Outside Dia, 1.85 Lbs Per Ft., Area .472 Sq. In.
District No. 1 Based on 17,000 Lbs Per Sq. In Maximum Stress in Conductor = 8,000 Lbs Max Tension
Districts Nos. 2&3 Based on 23,000 Lbs Per Sq. In Maximum Stress in Conductor = 10,850 Lbs. Max. Tension.

In all cases Design Loads taken as 1.5 x Actual Load (See Table I)
(For Economical Span Determination refer to Plate XX)

STRUCTURE AND
TOWER OUTLINES FOR
220,000 VOLT TRANSMISSION LINE
[SINGLE AND DOUBLE CIRCUIT]
FRANK G. BAUM, CONSULTING ENGINEER
SAN FRANCISCO, CALIF. MARCH 1923

These condensers will be connected to a tertiary winding. This winding takes care of the third harmonic of the magnetizing current,unbalanced ground current in case of line faults,and at the same time supplies the synchronous condensers which are used for line regulation.

Transformers.

At the present stage of the art of manufacturing transformers,manufacturers advocate that transformers be not attempted with greater capacities than 60,000 kva. for three-phase units,and 35,000 to 40,000 for single phase units. Transformer cores and windings for these capacities can be sent from the factory assembled.

According to A.E. Silver,three-phase transformers are preferable..

(1) Simplicity and cheapness of installation.

(2) Factory cost and efficiency about the same as an equivalent bank of single phase transformers.

(3) High trust should be placed in main units rather than trust to spare units.

A.E. Silver recommends that the oil in the transformers be externally cooled for the following . reasons:

(1) Tanks for transformers are smaller due to elimination of space required for cooling coils.

(2) Positive circulation to the points needed.

(3) More effective cooling.

(4) Oil may be filtered each time before it enters the cooling coils.

Plate 4 shows a typical connection for transformers. The transformer banks of transformers are connected in Y on the high tension side with grounded neutral,giving 127,000 volts to ground.

High Voltage Switching.

All line switching should be done on the high tension side of the lines,due to the enormous current capacity that would be required for oil switches on the low tension sides.

Oil Circuit Breakers.

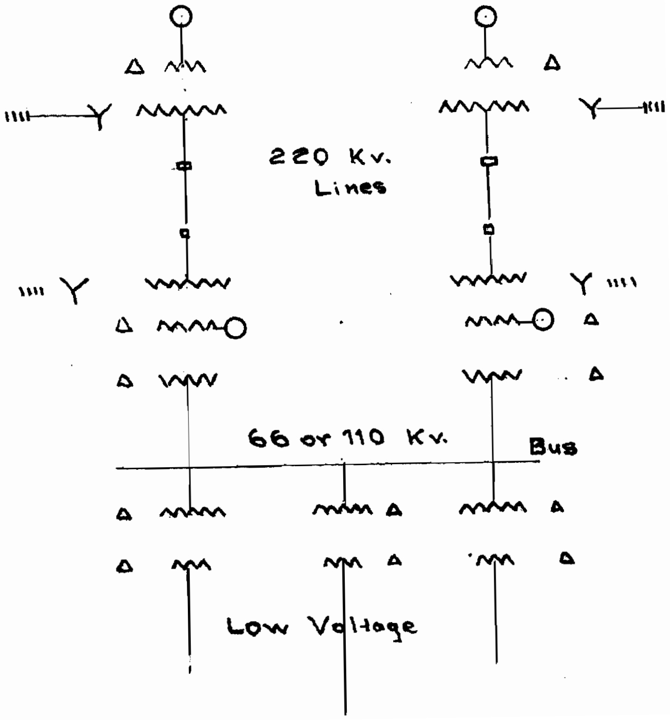
The duties of the circuit breakers may be from 1,000,000 to 1,500,000 kva. The leading manufacturers of the country are ready to provide these.

There are two types suggested:

(1) Tank units,4 breaks in series for heavy duty. These can stand heavy pressure,but not explosions.

Plate 4.

TRANSFORMER CONNECTIONS



(2) Tanks,4 breaks in series in seperate explosion chambers. Each type will give satisfactory service.

Overhead Ground Wires.

The line designs provide for 2 overhead cables 5/8 inch in diameter with strength at the elastic limit of 16,000 lbs. per square inch. The justification of ground wires for 220,000 volt transmission is debatable,but in view of its great importance,according to A.E. Silver,it is best to be conservative until further experience has been obtained.

Insulation.

There is no insulator on the market that has demonstrated its ability to give reasonable service under all conditions. The insulation for this particular service can be made as safe as with the commercial voltages now in use.

The designs of A.E. Silver provide for 10" cemented cap and pin type insulators placed in a string of 15 units. The dry arc over voltage is the controlling feature in the design of these insulators.

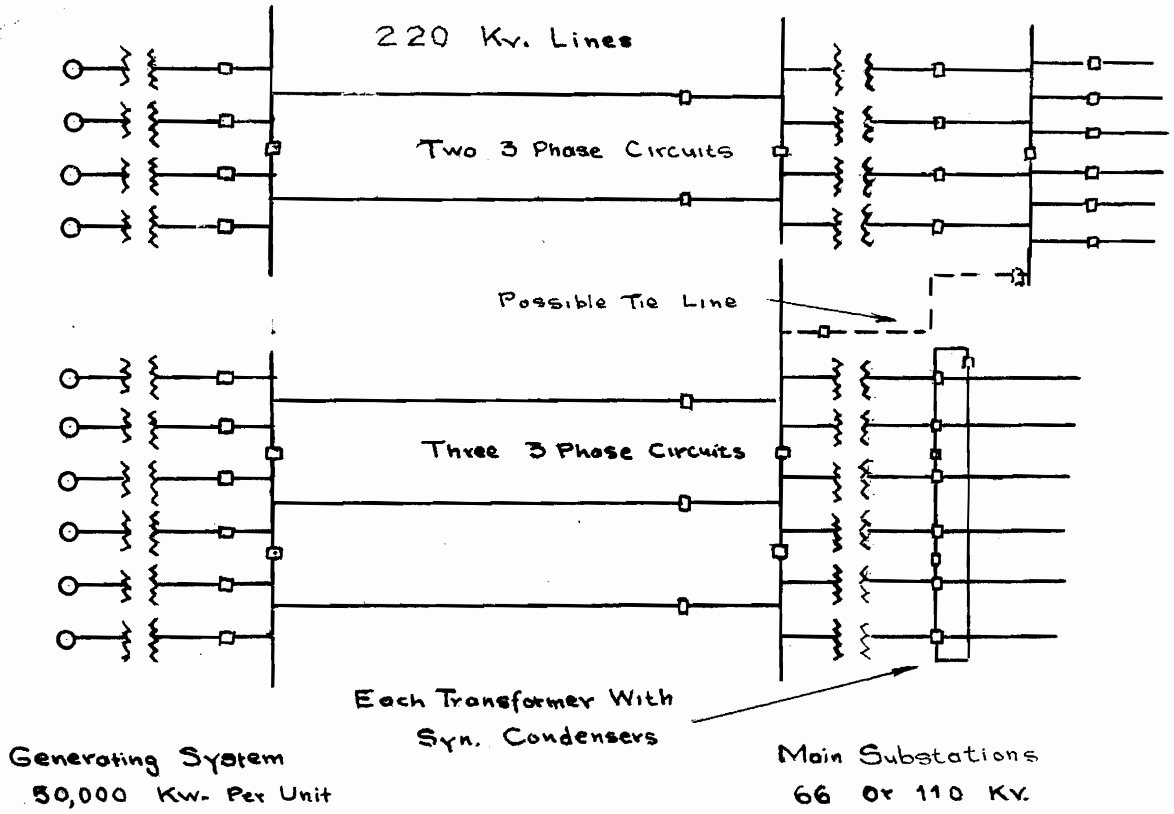
Arc horns are to be used with the insulators to protect the insulator from the heat of the arc over. The working stress of these insulators are about 2500 lbs. per sq. inch. Two strings are to be used in parallel for spans up to 700 feet, and three strings in parallel for spans over that length.

Stations and Substations.

The economic features of this high voltage demand and make feasible generating stations of several hundred thousand kilowatts. Interconnected systems of the magnitude of one half to one million kilowatts are possible. The principal problems are the design of switching devices and apparatus to withstand the great stresses that would come from short circuits. Writers on this subject recommend that simplicity and intrinsic strength of the equipment be considered first before flexibility and external protective measures. A typical system is shown by plate 5.

Plate 5.

STRAIGHT LINE DIAGRAM FOR A TYPICAL SYSTEM.



MAIN FEATURES. Reduction superflous oil switches with no spare units either generator or transformer.

PART V.

EXPERIENCE WITH 220,000 VOLTS IN CALIFORNIA.

The Two Systems Employing this Voltage.

The Pit River Line of the Pacific Gas & Electric Company extends from the Pit River plant #1 in Northern California to the Vaca Substation in the Lower Sacramento Valley, a distance of 202 miles. The conductors consist of seven strands of copper cable, each cable which in turn is made up of seven strands of single wire. The cross sectional area is 500,000 cm. and it weighs approximately 8,400 lbs. per mile. Six of these conductors, constituting two circuits, are strung on each tower. The towers are spaced seven to the mile, and their height varies from 60 to 97 ft. The cost of the line alone, exclusive of substations, was about $33,000 per mile. The power from this line is used to supply the Bay district adjacent to San Francisco.

The Big creek lines of the Southern California Edison operate over a distance of 240 miles. Operating at 150 kv., these lines had a capacity of 150,000 hp. With the addition of Big Creek #1 and the construction of Big Creek #2, it was necessary to provide to a great extent additional facilities, either by constructing a duplicate set of 150 kv. lines or reconstructing the latter for a higher voltage. It was found that approximately $7,000,000 could be saved if the lines were reconstructed for 220 kv., instead of building a duplicate set of lines such as already existed.

In making this change many difficulties were encountered. The additional insulators decreased the clearances to ground so that it was necessary to raise the towers in many cases. Banks of 150 kv. to 220 kv. were installed at each 150 kv. power house. After many laboratory tests it was found that sufficient insulation could be obtained for 220 kv. After these tests a 27 mile section of one of the Big Creek lines was taken out of service, and after adding two insulators to the existing strings and equipping the insulator next to the conductor with shield rings, this section of line was energized at 280,000 volts. This voltage was later lowered to 240,000 volts where it maintained for five months. After these tests, work was started for the reconstruction of the lines to 220 kv.

2. Electrical Equipment Used.

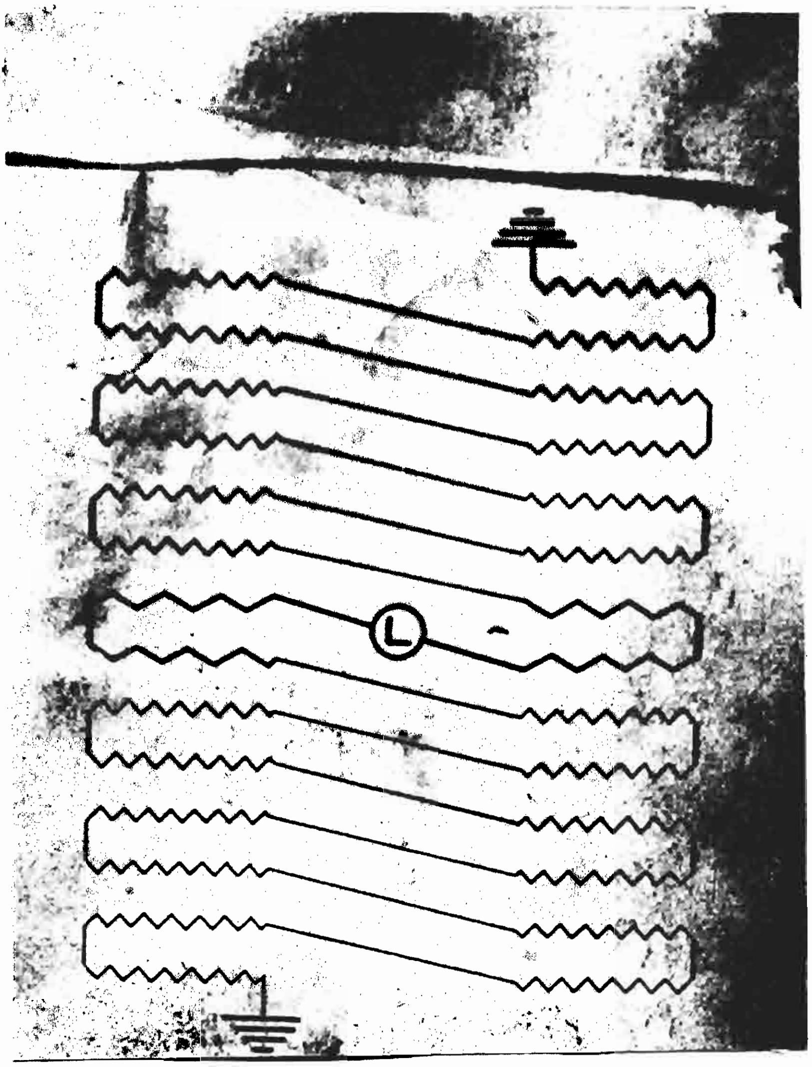
Towers used by Southern California Edison Co.

	Type SA	Type SC	Type M	Type 098
	Single circuit		Double Circuit	
Height	55.5'	55.5	97'	98'
Width				
At Base	20'x20'	20'x20'	20'	20'
At Cross Arm	4'x20'	4'x20'	6'	6'
Cond. Sep.				
Phases	19'	19'	15'	15'
Circuits	19'	19'	24'	24'
Conductor				
Max. size cu.	500,000	500,000	500,000	500,000
Loading	8 lb. Wind 1/2" ice		8 lb. Wind No Ice	
No. Broken	3	3	3	3
Nor. Span	500'	500'	800'	800'
Insulator	Suspension		Suspension	
Weight Tower	5100#	7270#	8440#	12,950#

Transposition on the Pitt River line is of the rolling type with the intermediate or transposition towers offset to reduce the side deflection of the insulators to a minimum.

Plate 8

CONNECTION DIAGRAM FOR SINGLE PHASE TRANSFORMER



Line enters at L.

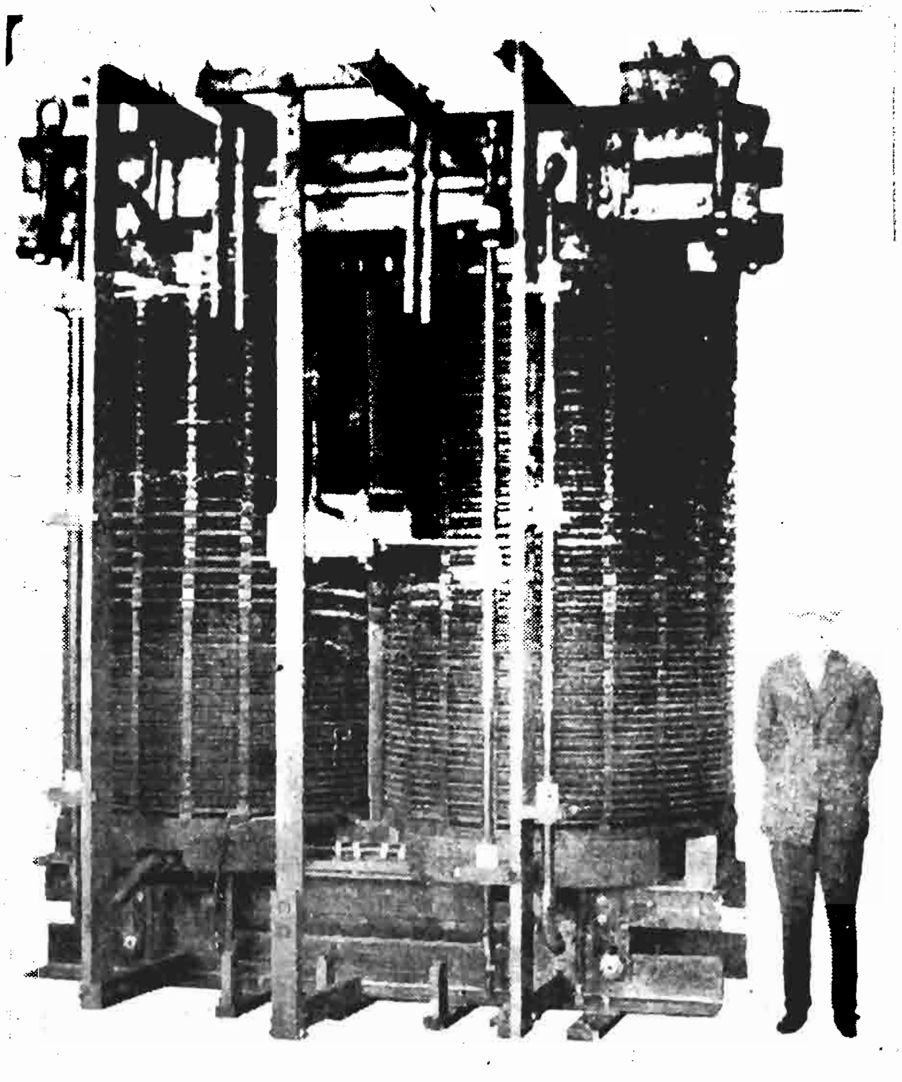
Transformers.

The Pacific Gas and Electric Company have had a 100,000 volt system in the San Francisco District for many years, and it was planned to bring the power from the Pitt River at 220 kv, and transform this at the Vaca Subsation to 100 kv. For this purpose 7 auto-transformers were used. The transformers are connected in two banks with one spare, and each bank has a rating of 50,000 kw. They are connected star-star and are provided with a tertiary winding which takes care of the third harmonic of the magnetizing current, unbalanced ground current in case of line faults, and at the same time supplies the synchronous condensers which are used for potential regulation.

The Southern California Edison Company had been operating their lines from Big Creek at 150 kv., and the two original Big Creek plants and the Eagle Rock step-down substation were all eqipped with 150 kv. apparatus. A considerable saving was effected by allowing this eqipment to stand and obtain the 220 kv, by transformation. The high tension lines were connected to the auto-transformers star-star and a tertiary winding was used for the same purpose as the above mentioned Vaca subatation except that no synchronous condensers were connected to this winding.

Figure 7.

CORE AND COILS OF 20,000 KVA. 220 KV. TRANSFORMER



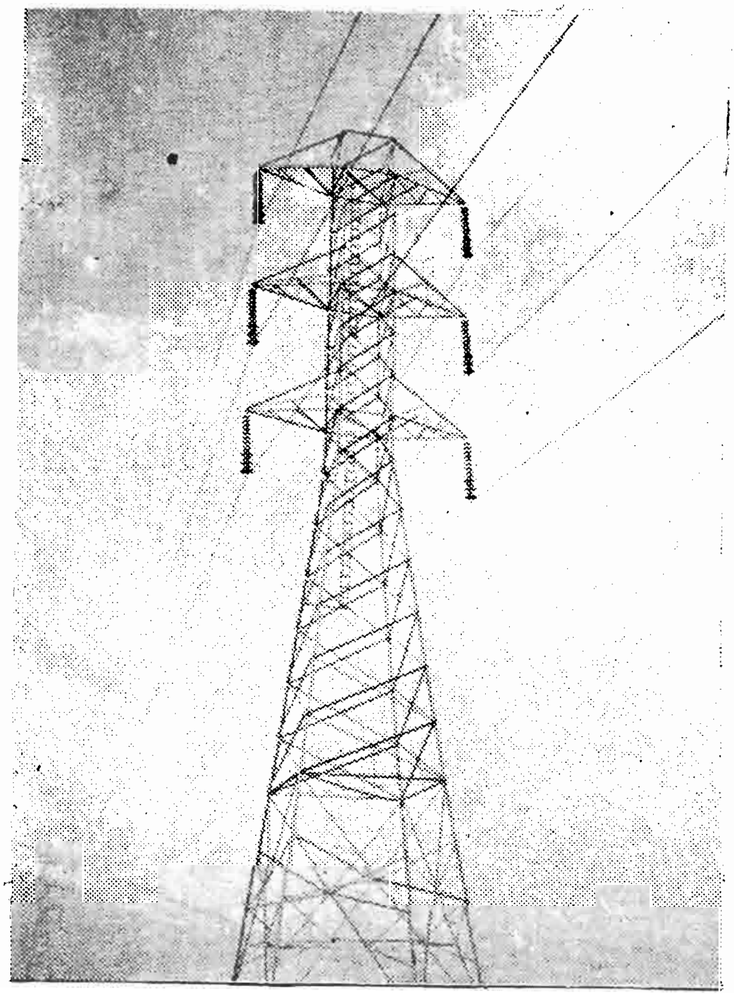
According to the G.E. Review of June 1923 the present transforming capacity is:

Pacific Gas & Electric CO.	200,000 kva.
So. California Edison CO.	523,500 kva.

According to A. W. Copley of the Westinghouse CO., the design of these transformers do not require any radical departure from designs which have become standard for lower voltages. Both shell and core types are used, and the same types of terminal bushings. It is becoming the practice to have a solidly grounded neutral on the high tension side, and it is possible to effect a considerable saving by the grounding of line insulation from maximum at the line end to a minimum at the ground end. Approximately 35% of the insulation cost is saved by this practice. Plate 6 shows this type of insulation used by the Pacific Gas and Electric Co. on the Pitt River line. Plate 7 shows a picture of a transformer used by the So. California Edison Co.. Each transformer is rated at 20,000 kva. and 2 banks of 3 transformers each and one spare are used at the Laguna Bell substation, transforming from 220 to 72 kv. Each bank has an output of 60,000 kva.

Plate 6.

STRAIGHT LINE TOWER ON THE PIT RIVER TRANSMISSION LINE



Switches used by The So. California Edison Co.

The 220 kv. oil switches which were put into operation May 6,1923 have not as yet been allowed to operate automatically. It is intended that they shall operate automatically and drop out a line whenever trouble develops in it.

Air Brake switches. There are three types; disconnecting switches for oil switches,line sectionalizing,and line parallelling switches.

The disconnecting switches are mounted on top of insulator tripods,which in turn are carried on frame work. Each leg of the tripod is 7 ft. long, and consists of 14 insulator units. The switch blade is 10 ft. 6 in. long. The clear opening of the switch is 81 in.

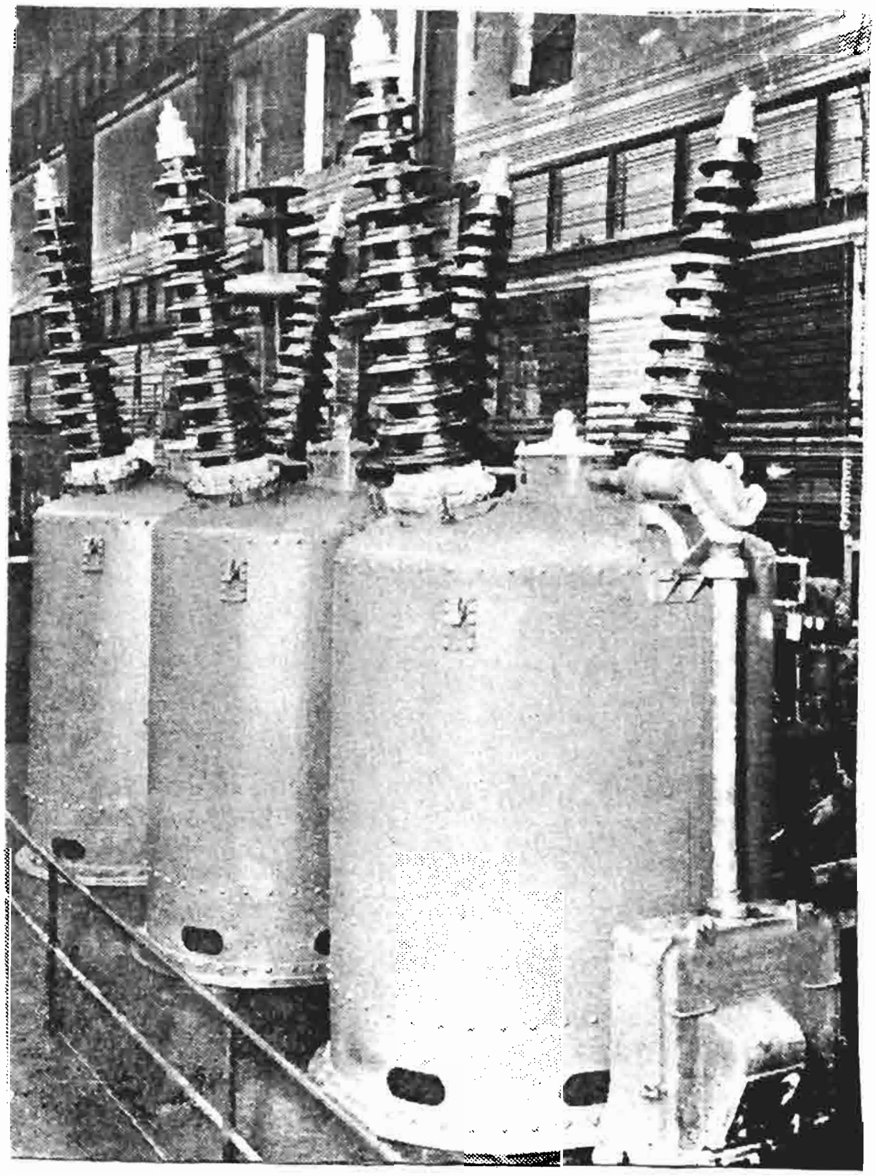
The line sectionalizing switches are connected in series and short circuit a string of 8 pillar type insulators. These switches are not operated on a live line. Plate 9 shows a view of the circuit breakers used by the Mt. Shasta Power Co. These have a rupturing capacity of 1900 amperes at 187,000 volts.

Bushings.

The bushings are either the oil filled types or the condensers types,or compound filled. There have been a few cases of breakdown with either type. There has been some trouble due to the oil leaking from these bushings.

Plate 9.

220,000 VOLT OUTDOOR CIRCUIT BREAKERS



Lightning Arresters.

Some of the stations are equipped with lightning arresters and some are not. Big Creek Power plant has no arresters and it has not been decided yet whether the the ones at Vestal substation will be re-installed. Big Creek #2 operated many months without arresters. Mr. Harold Michener makes the statement that there probably will never be any arresters on the 220 kv. circuits.

Line Insulation.

With a long string of insulators, the unit next to the line carries about 30% of the total voltage to ground, and this percentage is practically constant for strings of any units of above five. Ryan and Peek have both shown that the best way to correct this uneven distribution is by the use of grading the insulators by use of units. Static shields have also the same effect. The Pacific Gas and Electric Co. are using graded insulators.

Synchronous Condensers.

There are two condensers with a rating of 20,000 kva. each at the Vaca substation of the

Pacific Gas & Electric Co. These condensers operate at 11,000 volts from the tertiary winding of the transformers as described, and are started from a special 3,300 volt winding.

Generators.

There are two generators at Pit River #1, each rated at 35,000 kva. at 0.9 power factor lagging. These generators are capable of handling the charging current, not alone as regards the kva. standpoint, but also regarding excitation due to the charging current furnishing magnetizing power. At light load the field excitation for this condition is reduced to a minimum by cutting in resistance in series with the field automatically. The generators are then capable of supplying 90% of its full load current at zero power factor leading, with a terminal voltage of 82% normal. The normal voltage of these generators is 11,000 volts.

In case of the operation of the Big Creek Lines it has been found necessary to handle the lines with two or more generators in parallel in order to divide the charging current between the generators, and secure enough positive field to stabilize the voltage, and keep it within control of the voltage regulators.

PART VI

CONCLUSION

The year 1923 has demonstrated in a practical way that 220,000 volt transmission is as feasible as the lower commercial voltages now being used. With two large commercial companies transmitting the bulk of their power at this voltage,and with other companies contemplating raising their systems to the same pressure,it is fair to assume that other companies will follow the initial lead taken by the two companies in California.

However,transmission at this voltage is not to be regarded as an ultimate goal for all systems transmitting power. Its special field,as stated before,is for the transmission of large blocks of power over long distances. Whether or not a particular system can benefit by the use of this high potential depends very much upon economic considerations, as well as the above factors. For hydro-electric transmission it is a great step in extending the radius of power distribution.

The purpose of this paper has been to show that there is a definite field for this voltage;to point out in a brief way the conclusions reached by leading engineers on the subject before any of the contemplated lines were in existence; and to show that the predictions made by these men were very closely duplicated by the first lines using this voltage.

PART VII

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