# MOUNTAIN RAILWAY ELECTRIFICATION

BY ALLEN H. BABCOCK

ABSTRACT OF PAPER

The paper is a study of the relative merits of steam and electric equipment for a mountain division of the Southern Pacific R.R. The two slopes to the summit of this division are 49.5 and 18.3 miles long, respectively, with average grades of 1.14 and 1.33 per cent, and ruling grades of 2.2 per cent on each slope. Assumption is made of a 2400-volt, third-rail system using 100-ton electric locomotives capable of handling train units of 500 tons for freight, and 150-ton locomotives for passenger service. On the basis of present traffic it is shown that electrification of this division would not be justified from a financial viewpoint, whether the power was "home-made" or purchased.



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*(Subject to final revision for the Transactions.)*

# MOUNTAIN RAILWAY ELECTRIFICATION

## A STUDY OF THE TEHACHAPI PASS

BY ALLEN H. BABCOCK

During the past ten years the Southern Pacific Company has investigated the question of electrification of its three outlets from the central valleys of California, north, over the Siskiyou, east, over the Sierra, and south, over the Tehachapi. The earlier reports, inspired directly or indirectly by manufacturers as a part of their propaganda program, were favorable to electrification. The railway company then began studies of the subject, independently. The conclusions of its officers were unanimously opposed to electrification, by reason of the financial results to be anticipated; however, some of its lines have been electrified, and other electric lines have been acquired for good reasons.

Lately there has been a constant and persistent pressure put upon the company officials, by both power companies and consulting engineers, to reconsider decisions adverse to electrification, decisions that were made after patient and thorough study, and in the face of the fact that to be connected with any such important engineering work as these installations would be, could but fire the professional imagination of any engineer worthy of the name. Just how much of this agitation has been due to the application of general statements regarding the benefits to be secured by electrification, to the particular problems presented by west coast mountain railroading, is hardly susceptible of direct determination. It is possible, however, that much of it is due to the effect that such hypothetical studies and papers as have been published recently, have produced upon executives, who, however skilled they may be in their specialties, only in rare instances are sufficiently experienced technically to be capable of forming independent opinions on engineering matters. It is a fact that reports adverse to electrification in the hands of these same executives, often cause disappointment and sometimes arouse criticism.

Here, then, are two opposing parties; the one with things to sell, (apparatus, power, engineering skill), the other with a service to be maintained, at decreased cost if possible, but maintained at any cost it must be: the first reports favorably upon projects that the second considers unfavorably with equal positiveness. Some things must be unknown to both. Either the radicals have not all the facts upon which to work, or the conservatives cannot interpret their facts correctly.

Words have been multiplied with reference to the subject until aspiring authors well may pause before adding fuel, not to say fat to the fire; but it is with these thoughts in mind this paper is written, not with the intent to offer anything original in the study of such problems but to give the facts of a typical west coast mountain railroad district and their interpretation as seen by one whose reports heretofore have been responsible for many adverse decisions in such matters.

It is not intended to be the final word on the subject of electrification of this district, but it is the result of a study recently made to determine whether there was such a reasonable chance for profitable electrification as would warrant a very considerable expense in time and money, such as was incurred a few years ago in an exhaustive and final study of the Sierra problem, for example.

If through the facts given herein, and in the discussion thereof, a better mutual understanding will be reached, its purposes will have been served.

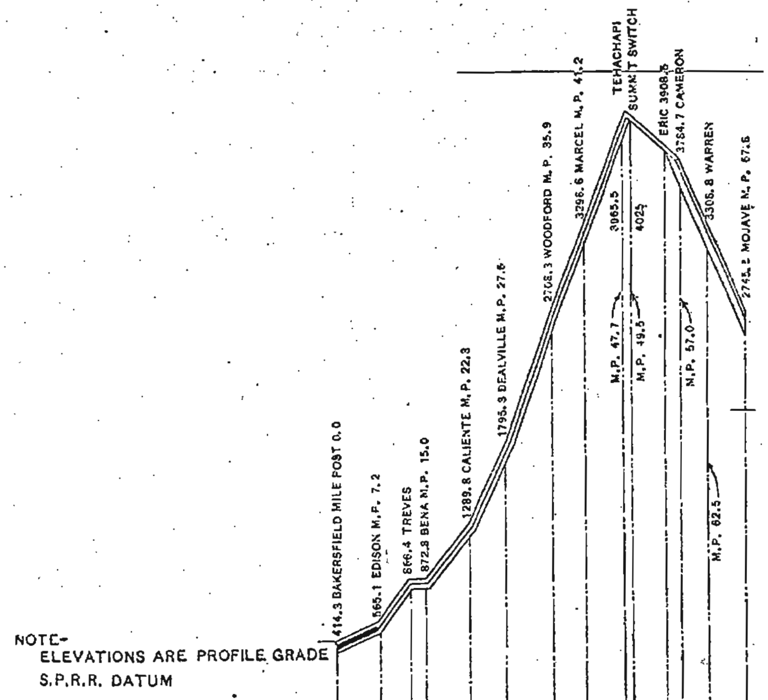
### Physical Characteristics

West Slope, Bakersfield to Summit........................49½ miles
- Vertical rise........................................3764 ft.
- Average grade........................................1.44 per cent
- Average curvature equal to a constant 3 deg. curve.
- Total curvature, 7944 deg., of which 6969 deg. are between Caliente and Summit (27.2 mi.). The loop curve has a total curvature of 566 deg. 33 min. 12 sec.

East Slope, Mojave to Summit........................18.3 miles
- Vertical rise........................................1285 ft.
- Average grade........................................1.33 per cent
- Average curvature (as above)........................0.79 deg.
- Total curvature........................................765 deg.



The ruling grade on each slope is 2.2 per cent, but these grades are not compensated for curvature so that in effect the ruling grade is 2.4 per cent. The maximum grades are long enough to fix the weight and power of the locomotives. The average distance between sidings is three miles, approximately.




| | | | | |
|---|---|---|---|---|
| MAXIMUM GRADE (FEET PER MILE) | | 105.6 | 116.16 | 116.16 |
| CURVED LINE (MILES) | FROM 0° TO 6° INCL. | 11.34 | | 6.44 |
| | " 6°01 " 8° " | 2.38 | | |
| | " 8°01 " 10° " | 7.67 | 2.03 OF 10°01 & OVER | |
| TOTAL ASCENTS EAST (FEET) | | 3686.885 | | 5.5 |
| " " WEST ( " ) | | 76.885 | | 1285.03 |
| TOTAL CURVATURE | | 7944° | | 76.5 |

Fig. 1—Condensed Profile, Tehachapi Pass

In determining energy consumption of trains moving over the mountain the actual characteristics of the line were used, (see Appendix K), but in determining load diagrams and substation spacings and capacity, the following close approximations were made to take care of the ruling grade, curves, etc. (For their application see Appendix A.)

| Section | Miles | Average grade |
|---|---|---|
| Bakersfield to Edison | 7.2 | 0.5 per cent |
| Edison to Caliente | 15.1 | 1.5 " " |
| Caliente to Summit | 27.2 | 2.4 " " |
| Mojave to Cameron | 10.8 | 2.4 " " |
| Cameron to Summit | 7.5 | 0.75 " " |

The average freight train, eastbound, weighs 2000 tons, exclusive of locomotives. Four consolidation type locomotives, or their equivalent in Mallet compounds, are used to haul this train from Bakersfield to Summit. From Summit to Mojave one locomotive is used for supplying air for brake purposes, etc., and the other three return deadhead to Bakersfield. The westbound freight trains are lighter than the eastbound on account of the fact that much of the western movement consists of empty cars. The normal weight is 1250 tons, hauled by three consolidation locomotives, or their equivalent in Mallets; or a 1500-ton train operated by three consolidation or decapod locomotives, or their equivalent in Mallets. The helper engines cut out at Summit and return light to Mojave.

In order to provide a flexible unit it was proposed to use an electric locomotive, capable of handling a train unit of 500 tons, as many per train to be used as the weight of the train requires. The weight of the electric locomotives is assumed at 100 tons.

Passenger train weights vary from 250 tons to 600 tons, for which a single passenger locomotive weighing 150 tons was provided. A maximum freight train movement over the mountain recently consisted of twelve full-size freight trains, eastbound, and eight full-size freight trains, westbound, in addition to the normal passenger movement, which is seven regular trains each way per day, with occasional extras and second sections.

The track, particularly on the west slope, is laid for the greater part of the distance in rough country, in fact between mile posts 326 and 361 all the track, with the exception of a short stretch near Caliente, is in cuts or on fills. It may be said generally that at least half the track is laid in conditions where any overhead contact system would require, necessarily, very expensive steel pole or bridge construction. In addition to the above, there are 18 tunnels, in none of which the vertical clearance is more than $18\frac{1}{2}$ ft., and 60 per cent of their total length is on 10-deg. curves. A detailed list of tunnels is given in Appendix L-1.



Experience with similar earlier reports has shown that, in general, there is little difference in total first cost and annual operating costs, whether an overhead system or the third rail system be considered. A double overhead contact system gives maximum first cost and operating costs for contact system, and minimum weights, costs and maintenance of locomotives; a single overhead contact system gives high first cost and operating costs for contact system, with maximum weights and maintenance of locomotives; the third rail gives high first cost and minimum operating cost of contact system, medium locomotive weights and first costs, with minimum operating costs, but the total costs are brought up to the level of the others by reason of the necessary substation apparatus and attendance. A choice of systems therefore is to be made only after an exhaustive study of all the local conditions.

In a preliminary study, as this is, it matters little what particular system of propulsion is chosen, upon which to base the estimates. For the purposes of this discussion a 2400-volt continuous-current, third-rail contact system was selected for the main line, with an overhead contact system in yards and terminals, at Kern, Bakersfield and Mojave.

In the following, the First Costs are based on the present traffic as shown by the train dispatcher's sheets; the Annual Operating Costs are taken from the reports of the fiscal year ending June 30, 1912, for steam operation, while the same traffic and reports are used, as far as they apply, in estimating the costs for electric operation.

First Costs

| | | | |
|---|---|---|---|
| Substations, | Appendix | A | $1,610,000 |
| Generating station, | " | B | 1,760,000 |
| Transmission system, | " | C | 430,050 |
| Contact system (yards) | " | C | 155,250 |
| " " (line), | " | A | 825,000 |
| Bonding, | " | A | 122,300 |
| Block signals, | " | D | 175,000 |
| Shops and inspection shed, | " | E | 10,000 |
| Electric locomotives, | " | F | 2,085,000 |
| Total | | | $7,172,600 |
| Credit by steam locomotives released for service on other divisions, | Appendix | G | 1,464,900 |
| Net first cost | | | $5,707,700 |

| ANNUAL OPERATING COSTS (Steam-generated power) | | | Steam | Electric |
|---|---|---|---|---|
| Substation labor and supplies, | Appendix | A..... | | $59,700 |
| Power house labor and supplies | " | B..... | | 84,780 |
| Transmission and contact system maintenance, | " | C..... | | 36,576 |
| Maintenance of way as affected by locomotives, | " | H..... | $126,890 | 83,285 |
| Locomotive repairs, | " | I..... | 270,990 | 70,701 |
| Loco. enginemen, (passenger), | " | J..... | 48,300 | 29,100 |
| Fuel, | " | K..... | 240,852 | 100,530 |
| | | | $687,032 | $464,672 |
| Bond interest at 4½ per cent.................... | | | | 256,847 |
| Totals.............................. | | | $687,032 | $721,519 |

Net loss, $34,487

In the above no account is taken of items not affected by character of motive power: freight enginemen, and all train crew wages, repairs to cars and maintenance of way as affected by cars—for example.

The net loss under proposed electric operation is so small that it might be wiped out by a reasonably small change in the assumptions; in fact, at this stage of similar investigations often there is a temptation to search for opportunities to change this, or to modify that, as the necessities of the case demand. This important fact should be borne in mind, however, that in the foregoing no account is taken of taxes and depreciation, both of which must be paid, some time, by some one, to the extent of at least 5 per cent of the net investment, which increases the net loss by approximately $285,000 per year.

It may be asked, why is depreciation not taken into account in the usual manner? The answer is, since there is a loss, or at least no profit shown, and since to add depreciation would be to make a bad matter only worse, nothing is to be gained by entering into the academic discussions that inevitably follow the opening of a subject concerning which opinions reasonably may differ as widely as on this much disputed particular.

But power may be purchased, as is often suggested by those with power for sale, hence it is proper to determine at what rate this power may be purchased and come out even as compared with operation by steam-generated power. Obviously any rate less than this will be profitable.

With purchased power, the total investment will be diminished



by the costs of 20 miles of transmission line and of the generating station, it being assumed that power will be delivered at some one point on the right-of-way, whereas local conditions located the steam station 20 miles off the right-of-way (see Appendix B).

| | | |
|---|---|---|
| The net first cost was.................................... | | $5,707,700 |
| Transmission line, Appendix C............... | $120,000 | |
| Generating station " B.............. | 1,760,000 | 1,880,000 |
| Leaving a net investment with power purchased.......... | | $3,827,700 |

| ANNUAL OPERATING COSTS (Power purchased) | | | Steam | Electric |
|---|---|---|---|---|
| Substation labor and supplies, | Appendix | A.... | | $59,700 |
| Transmission and contact systems maintenance, | " | C.... | | 35,576 |
| Maintenance of way as affected by locomotives, | " | H.... | $126,890 | 83,285 |
| Locomotive repairs, | " | I.... | 270,990 | 70,701 |
| Loco. enginemen, (passenger), | " | J.... | 48,300 | 29,100 |
| Fuel, | " | K.... | 240,852 | |
| | | | $687,032 | $278,362 |
| Bond interest at 4½ per cent.................... | | | | 172,247 |
| Totals................................ | | | $687,032 | $450,609 |

The difference, $236,423, should be decreased by $191,385, (the approximate tax and depreciation rate of 5 per cent on the net investment of $3,827,700), and there is left the wholly inadequate sum of $45,038 with which to purchase 53,000,000 kw-hr. at a load factor of about 20 per cent; with no profit to show for an investment of nearly $4,000,000.

For the sake of the argument let the depreciation be neglected and let it be considered that $236,423 are available for the purchase of power under the operating conditions of the service. At any time there may be four passenger and four freight trains pulling up hill simultaneously, taking a total of 32,720 kw. alternating-current input to the line. This is not the maximum number of trains that is on the mountain regularly, but represents only those taking power. A slight derangement of schedules, or an extra freight movement, citrus fruits or oil, or a blockade, for example, will cause congestion beyond any possibility of estimating. This traffic must be handled as circumstances require. It cannot be spaced conveniently for power demands, as many engineers and power men have suggested, but the terminal yards must be cleared as the cars accumulate. Is there any power company in the west coast country, or even beyond the reach of such a natural power source as Niagara, that would care to undertake such a load for any such yearly return as that named in this paragraph? It would net about $4\frac{1}{2}$ mills; a rate that neither the purchaser nor the seller could afford to consider.

In the face of the foregoing it is difficult to see how any recommendation in favor of electrification can be made, if the opinion is based on the direct financial profit to be realized; in other words, this case is merely another example of the fact often noted, that in the great majority of cases the profits from electrification must be realized indirectly rather than directly,—increased track capacity, postponing second- or double-tracking, or the like.

It may be urged that a larger district would make a better showing. In this connection it may be noted that the line from Bakersfield to Summit is almost identical with half of the line assumed in Mr. Hobart's paper on 2400-*Volt Railway Electrification*.* On each side of the summit Mr. Hobart's assumed line is 3800 ft. rise in 48 miles with the ruling grade of 2.2 per cent, while the west slope of the Tehachapi is $49\frac{1}{2}$ miles, rise of 3764 ft. and a ruling grade of 2.4 per cent. Also Mr. Hobart assumes freight train weight on heavy days of 1800 tons as against 2000 tons on the Tehachapi. Furthermore, the Sierra study covered a district more than double the length of the Tehachapi, and the result was the same.

In the various appendices will be found complete details of all the elements of the investigation, as noted by the cross references given after the various items of the tabulations herein.

Acknowledgments are hereby made to Mr. G. W. Welsh and Mr. F. E. Geibel, both assistant engineers in the electrical engineer's office, Southern Pacific Company, for assistance in the preparation of this paper. The former made a thoroughly painstaking study of the problem as a whole, and to the latter is due the novel method of determination of substation spacing and capacity as detailed in Appendix A.

## APPENDIX A

### Substations

*Substation Spacing and Heating Loads.* It is not the purpose here to go into a theoretical discussion of the economical spacing

*See A. I. E. E. Proceedings, May, 1913, p. 1012.



of substations, balancing off the losses and fixed charges of the distributing system against the losses and fixed and operating charges of the substations. Any such discussion requires the lengthy consideration of various operating conditions which seldom, if ever, are obtained in practise; hence the determination leads nowhere.

The following is simply a brief description of a very convenient and quick method of determining the feeder and substation layout in preliminary studies of the electrification of mounting divisions of steam railroads. The method was developed by Mr. F. E. Geibel, assistant engineer, Southern Pacific Company, in the original study of the problem.

The conditions, as set forth in the general study, require an average train speed over the electrified section. It is therefore necessary to maintain an average voltage over the sections between substations. Formulas for the average volts drop over the section were deduced as follows:

Let $L$ = distance in miles between substations.
$I$ = current per train in amperes.
$R$ = resistance of distributing system in ohms per mile of circuit.
$A$ = distance in miles between first and second trains.
$B$ = distance in miles between second and third trains.
$V$ = volts at substation.
$E$ = instantaneous volt drop on line.
$D$ = average volts drop over section between substations.
$X$ = distance in miles between first train and a substation.

Considering first only one train between substations:

$$\left(\frac{L-X}{L}\right) I = \text{current drawn from one substation.}$$

$$XR = \text{total resistance to same substation.}$$

$$\text{Therefore } E = \frac{RI}{L}(XL - X^2)$$

$$\text{but } D = \frac{\sum_0^L E}{L} = \frac{RI}{L^2}\int_0^L (XL - X^2)\,dX$$

$$= \frac{1}{6} R I L = \text{average volts drop.}$$

Similarly, formulas for two and three trains in a section were deduced, for average drop as follows:

One train between substations, $D = \frac{1}{6} R I L$

Two trains " " $D = \frac{1}{6} R I \left( 2 L - \frac{3 A^2}{L} \right)$

Three " " " $D = \frac{1}{6} R I \left[ 3 L - \frac{2 (2 A + B)^2}{L} \right]$

If the trains are following at equal distances then $A = B$ and the last formula becomes

$$D = \frac{1}{6} R I \left[ 3 L - \frac{2 (3 A)^2}{L} \right]$$

The loads on the substations were plotted graphically for several substation spacings up to twenty-five miles, and the heating loads were computed for each spacing. It was found, however, that the heating load varied approximately as follows:

Total heating $= 2 \left( \frac{L}{A + B} \right) V I$ for trains alternately $A$ and $B$ miles apart, when the distance between substations is equal to or greater than the greater spacing between the trains. For trains of equal distance apart, total heating $= 2 \left( \frac{L}{2 A} \right) V I$. $V I$ is the amperes per train multiplied by the substation voltage.

It is to be noted here that all of the above expressions apply only to direct-current systems and cannot be used on single-phase systems without complication. It is, also, to be noted that the formulas are deduced assuming trains running in one direction only, as, on the grades considered, the trains coming down grade do not draw a running current but only a small current for control purposes.

In applying the formulas to the problem in hand the following assumptions were made:

2000-ton trains with four 100-ton locomotives per train.

Trains 15 miles per hour, spaced alternately 5 and 10 miles apart.

Locomotive efficiency 90 per cent. Train resistance 6 lb. per ton.

Substation voltage 2400. Train voltage 2100 average.



In Fig. 2 will be found curves showing the total conductivity, in terms of total million circular mils of copper equally divided between positive and negative circuits, required to give the average voltage over the section for various grades. These curves were plotted from the formulas given above. With substation spacings up to 8.65 miles, the average drop is greater with one

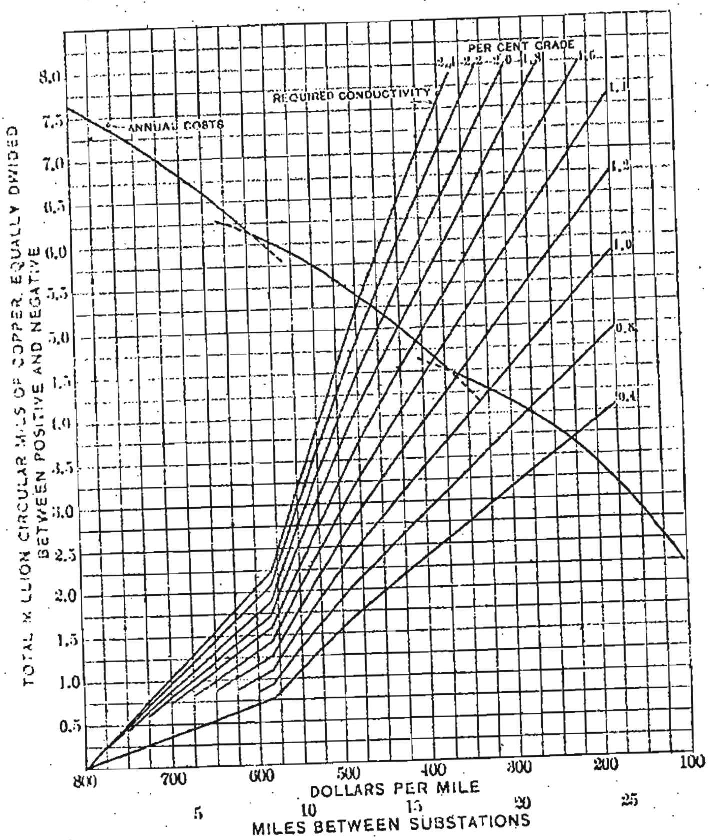



Fig. 2—Contact System

train in the section, and between 8.65 miles and 26.9 miles the average drop is greater with two trains in the section. Hence the break in the curves at 8.65 miles.

There is also plotted in Fig. 2 a curve giving the annual costs per mile on a contact system of the required conductivity. A contact rail system was considered with no positive feeders but 75-lb. old rail as negative feeder. The annual cost curve shows three distinct sections, namely: the lower section, no negative feeder; the middle section, one 75-lb. rail negative feeder; and the upper section, two 75-lb. rail negative feeders. As worked out, however, the system required no negative feeder. From Fig. 2, it is seen that the annual cost per mile on the con-

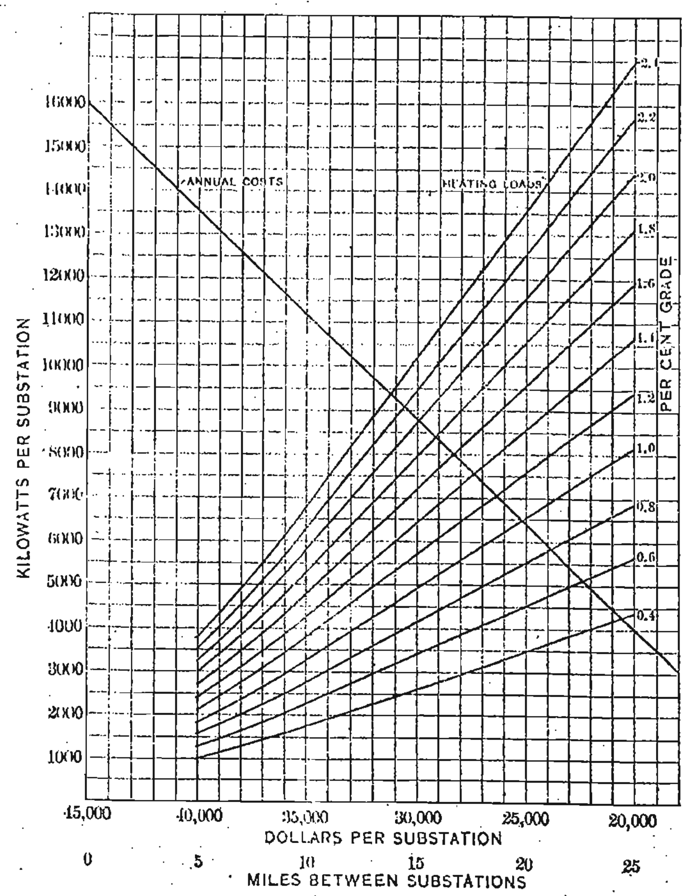



FIG. 3—SUBSTATIONS

tact system for any given substation spacing and grade can be read directly.

Similarly from Fig. 3 the heating loads on substations for any given spacing and grade may be read off, or, if referred to the annual cost curve, the annual cost per substation is given. This



latter value divided by the spacing gives the substation annual costs per mile.

The above annual costs were taken at various substation spacings on several given grades and the results, the total annual costs per mile, were plotted in Fig. 4. This gives a series of

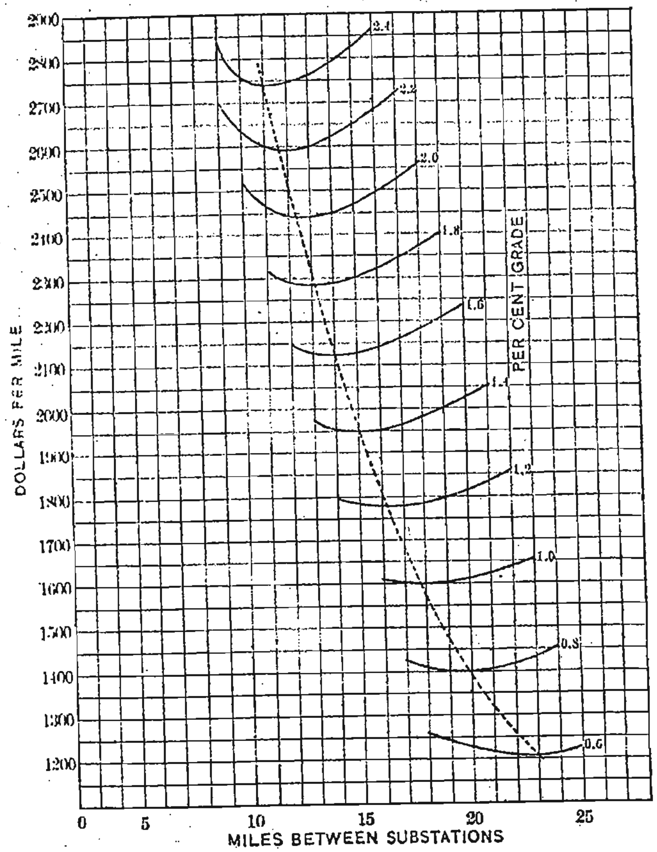



FIG. 4—TOTAL ANNUAL COSTS

curves, the minimum of each being the economical substation spacing on the given grade. These results were transferred to Fig. 5 which shows, for any given grade, the economical spacing, the heating load on substation and the size of contact rail required.

As stated in the report, the track district under study was divided into several sections of average grades. By applying the latter curve, therefore, to these sections the spacing and heating loads of the substations are easily determined.

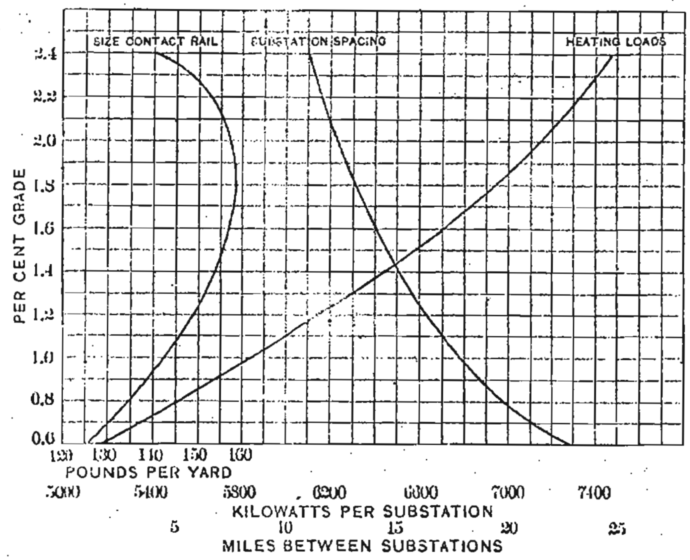



FIG. 5—ECONOMICAL SUBSTATION SPACING

After making the proper allowance for yard switching and stub ends, the following substations were located:

| No. substation | Spacing | Heating load | Installed capacity |
|---|---|---|---|
| 1 | 5 miles from Bakersfield | 4900 kw. | three 2000-kw. units |
| 2 | 13.5 mi. | 6500 " | four 2000 " " |
| 3 | 11.6 " | 7200 " | four 2000 " " |
| 4 | 10.5 " | 7000 " | four 2000 " " |
| 5 | 10.5 " | 6600 " | four 2000 " " |
| 6 | 13 " | 6900 " | four 2000 " " |
| | 3.7 mi. to Mojave | | |

The larger part of the grade being either 2.4 per cent or under 1 per cent, a 140-lb. contact rail was required for the main line and 75-lb. for sidings.

The unit first costs used are as follows:

SUBSTATION

$35 per installed kw.

The above is based on a recent west coast installation corrected for 2400-volt apparatus.



MAIN LINE CONTACT RAIL, 2400 VOLTS

| | | |
|---|---|---|
| *Material:* | | |
| 110 tons special 140-lb. contact rail at $33.00 per ton.. | | $3630.00 |
| Freight thereon at $13.50 per ton.................. | | 1485.00 |
| 176 pairs splice plates delivered.......... | $88.00 | |
| Bolts and nuts......................... | 12.00 | |
| 704 bonds at 74c......................... | 521.00 | |
| 480 insulators, brackets and felt delivered.... | 480.00 | |
| Paint................................. | 20.00 | |
| 10 inclines at $7.50...................... | 75.00 | |
| 5 jumpers at $100.00..................... | 500.00 | |
| Anchoring, modified ins. caps, extra 10c x 176. | 17.60 | |
| Substation connections................... | 35.00 | |
| 960 long ties excess cost at 50c........... | 480.00 | |
| 960 brackets for protection at 50c.......... | 480.00 | |
| Lumber for protection.................... | 500.00 | |
| Bolts, screws and fittings................ | 80.00 | |
| | $3288.60 | |
| Extras 5 per cent....................... | 164.40 | |
| | $3453.00 | |
| Store charges 6 per cent................. | 207.00 | $3660.00 |
| *Labor:* | | |
| Delivering rail 110 tons at $1.50........... | $165.00 | |
| Installing insulators 480 at $.10........... | 48.00 | |
| " protection brackets at $.10....... | 96.00 | |
| " rail............................ | 200.00 | |
| " bonds at $.30 ea................ | 211.20 | |
| " protection...................... | 400.00 | |
| Painting................................ | 100.00 | |
| Work train.............................. | 100.00 | |
| | $1320.20 | |
| Extras 10 per cent....................... | 132.00 | $1452.20 |
| | | $10,227.20 |

Say $10,225.00 per mile

SIDING CONTACT RAIL COSTS, 2400 VOLTS

| | | |
|---|---|---|
| *Material:* | | |
| 59 tons special 75-lb. contact rail at $46.50 del........ | | $2740.00 |
| 352 bonds at 60c......................... | $211.20 | |
| Other material........................... | 2560.80 | |
| | $2772.00 | |
| Extras 5 per cent....................... | 138.60 | |
| | $2910.60 | |
| Store charges 6 per cent................. | 174.60 | $3085.20 |

*Labor:*

| | | |
|---|---|---|
| Delivery of rail 59 tons at $1.50 | $93.50 | |
| Installing bonds at 30c | 105.60 | |
| " insulators | 48.00 | |
| " protection brackets | 96.00 | |
| " rail | 100.00 | |
| " protection | 400.00 | |
| Painting | 100.00 | |
| Work train | 100.00 | |
| | $1043.10 | |
| Extras 10 per cent | 104.30 | $1147.40 |
| | | $6972.60 |
| Say | | $7000.00 |

The above is based on Pennsylvania R.R. type of third rail with protection installed on both sides. Cost of rail is based on New York Central cost of special rail plus freight charges. Cost of specialties is taken from quotations. Labor is according to west coast practise.

### Main Line Bonding

Two 10-in., 450,000-cir. mil bonds per joint.

| | | |
|---|---|---|
| Bonds | $570.00 | |
| Cross bonds | 75.00 | |
| Labor | 375.00 | |
| | $1020.00 | |
| Extras | 102.00 | $1122.00 |

### Sidings and Yard Track Bonding

Two 4/0 bonds per joint.

| | | |
|---|---|---|
| Bonds | $320.00 | |
| Cross bonds | 100.00 | |
| Labor | 400.00 | |
| | $820.00 | |
| Extras 10 per cent | 80.00 | $900.00 |

The above is based on the actual cost of bonding in an installation recently made in the vicinity of San Francisco. The fact that the track would be bonded under heavy traffic should not be overlooked.



### TOTAL FIRST COSTS

#### Substation and Distribution

| | | |
|---|---|---|
| *Substation* | | |
| 46,000 kw. at $35 | | $1,610,000 |
| *Contact rail* | | |
| 65.84 mi. main line at $10,225 | $673,000 | |
| 21.60 mi. sidings at $7000 | 152,000 | |
| | | 825,000 |
| *Bonding* | | |
| 65.84 mi. main line at $1120 | $73,800 | |
| 21.60 mi. sidings at $900 | 19,440 | |
| 32.29 mi. yard tracks at $900 | 29,060 | 122,300 |
| | | $2,557,300 |

### Annual Costs

For the reason that one organization should maintain all transmission and distribution system, the annual costs of maintenance and repair for contact system are to be found under Transmission Line Costs, Appendix C.

## APPENDIX B

### Generating Station

Two principal considerations fixed the generating station at a distance from the track: fuel and water.

Twenty miles off the right-of-way from a point 6 miles east of Bakersfield is located a large oil field from which the company obtains much of the fuel oil used in its locomotives. Plenty of water for condensing purposes is obtainable near by. The annual charges on a transmission line under these conditions do not impose so heavy a burden on the operating costs as would the delivery of oil at the right-of-way; besides, to develop sufficient water along the track would cost a great deal. For these reasons the generating station was located in the oil fields on fairly level land where excavating costs were reasonable and on soil sufficiently firm for ordinary foundations.

The load curve, Fig. 6, indicates that a three-unit station is desirable, two units of which would carry the load ordinarily, with one as a spare. A study of the load curve and train diagram fixed the maximum capacity of the units at 18,000 kw. at the two-hour overload rating—an economical size in first cost and in annual operating costs. The point of maximum economy without auxiliary nozzles is in the neighborhood of 10,000 kw., and the hand-operated nozzle will enable the machine to carry