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RURAL POWER SUPPLY, ESPECIALLY IN BACK COUNTRY AREAS.

By Lloyd Mandeno, B.E., M.I.E.E.
(Member)

Summary.

It is now widely recognised that the interests of the whole community will be served if, so far as is economically possible, the amenities of the town are extended into country areas.

Rural Power Supply practice has evolved from what originally was standardised for urban distribution. But it is contended that further evolution of method is still required before the maximum extension of the service into back areas is possible.

Some statistics are given for the extent of the rural supply in overseas countries, and reference to developments in U.S.A. under stimulus of the R.E.A. is made. Corresponding figures for N.Z. Power Boards operating in sparsely settled areas are given and an enquiry made as to the extent of the load remaining to be picked up. A full and suitable survey of unreticulated areas is advocated, so that the problem can be tackled comprehensively.

Modification of standard methods to suit back country work are discussed and a description is given of the system of distribution in the Tauranga and Bay of Islands Power Districts.

The operating advantages of the single wire H.T. Earth Return system are set out and also the terms of the dispensation from the provisions of the 1935 Supply Regulations permitting its use.

Various technical considerations are discussed, including: operating voltage, earth connection, location and construction of lines, also mechanical pole erecting plant.

The use of condensers connected in series on the earthed side of H.T. Spur circuits is explained and interesting benefit in the form of high speed pressure regulation power factor correction is shown.

A basis for estimation of rural loadings is given and some comparative construction costs of single and three phase.

The paper is subdivided as follows:—

Introduction.

Although the earliest public electricity supplies in New Zealand operated with alternating currents, most of them thirty years ago were D.C., the distribution range of which was very limited. It was the same, of course, in most other countries overseas, and so during the first forty years of the power supply industry the electric service was generally regarded as economically possible only to urban or industrial communities.

Furthermore, in contrast with laymen, power supply engineers had, by long contact with the problems of extension, developed a more or less subconscious, and in some cases exaggerated appreciation of the difficulties of extending their service outside town limits. So it is of interest now for engineers to recall the re-adjustment in ideas which had to take place in the months or years following the passing of the Electric Power Boards Act. By that time the wide variety of purposes for which electricity could be applied in the home had been demonstrated in some towns where A.C. hydro supply was available as in Dunedin, Christchurch, New Plymouth and Whangarei and at Tauranga, in which town, electric water heating besides electric cooking became established in general popularity.

This development tended to accentuate the advantages held by the town dweller over the country resident. But in this Dominion it can hardly be seriously disputed that our economy depends in a unique degree on the prosperity of its rural industries. Correspondingly it had been recognised that the provision of attractive conditions of life in rural areas is desirable so as to slow down the townward drift. Good roads, motor transport, extending educational facilities, rural telephones and battery operated radios have helped towards this end, but given all these things there is yet a disinclination for most New Zealand households to remain, much less to settle, in districts where power supply is not available.

The first attempts at the reticulation of purely rural districts were, so far as the writer is aware, made as follows:—

Table I.—Early Rural Extensions.

Name of Authority	Locality Reticulated	System of Supply	Distribution Primary	Pressure Secondary	Approx. year of Initiation
Dunedin Corp.	Taieri Plain	3ph. 50cy.	3,000	230/400	1914
Taitapu Dairy Co.	Halswell County	3ph. 50cy.	3,000	230/400	1917
Tauranga Bor.	Otumoetai, Gate Pa, Papamoa	3ph. 50cy.	11,000	230/400	1919

General extension of these pioneering efforts in rural electrification presented difficulties. The relatively large amounts of capital required to cover their adjacent rural areas were an obstacle to the municipalities, most of which were by this time operating their own schemes. So a great impetus to rural electrification was given by the passing in 1918 of the Electric Power Boards Act, which provided machinery for the merging of the electrical interests and financial responsibility of adjoining urban and rural districts.

By July, 1920, six Power Districts in the North Island and four in the South had been constituted and by March, 1922, four Power Boards had commenced power supply in a small way. By March, 1944, the proportion of the electric supply industry conducted by Power Boards in the Dominion is indicated by the following figures:—

Table II.—Proportion of Distribution controlled by Power Boards.

	Power Boards	Total for N.Z.
Number of Consumers	262,269	165,303
Route Miles of Line	21,079	29,595
Energy handled by Distribution Authorities (Millions of Units)	1,282	1,959
Capital Outlay (Millions of £'s) (Excluding 23 million £'s by the State)	15½	23

Whilst Power Boards were constituted primarily to secure reticulation of rural areas, their consumers of course comprise both rural and urban residents. Thus the above figures give no indication of the extent of rural electrification in New Zealand, nor does it help to say that, of the total population of the Dominion, 97.1% is included in licensed areas of supply. So far as the writer is aware no attempt has yet been made to estimate the total number of farms supplied with electricity and the total which are not so supplied. In the writer's opinion it is high time that such a survey should be made.

Rural Electric Supply Overseas.

The extent of the penetration of power lines into rural areas in many overseas countries is possibly not sufficiently realised. Ten years ago it was reported that approximately 100% of the farms in Holland and 90% in Germany, France and Denmark were supplied, and 75% in Sweden. In Canada the Ontario Power Commission claims to have connected up 55% of the farms within the populated portions of the province and has just announced a programme to raise this percentage to 85%. In U.S.A. the most spectacular developments are occurring under the stimulus of President Roosevelt's Rural Electrification Act of 1936. Under this Act an Administration was set up to control the issue of Loans from the American Treasury to Co-operative Associations of farmers and others at an interest rate originally of 3% (and now about 2%) "for the purpose of financing the construction and operation of generating plants, electric transmission and distribution lines for the purpose of furnishing electric supply to persons in rural areas, who are not receiving central station service." By the middle of 1942, the Administration had:—

(a) Advanced 460 million dollars (9% of which was for the construction of small generating plants.)
(b) Had financed the construction of 383,000 miles of overhead line, divided amongst 789 undertakings.
(c) These were supplying a total of 981,000 consumers.
(d) Under its encouragements the number of electrified farms in U.S.A. has grown from 743,954 in 1934 to 2,126,150 in 1941.

In 1942 approximately 4,000,000 farms remained unelectrified, but a programme has recently been announced involving the expenditure of astronomical sums for the purpose of substantially cancelling out this unelectrified four million. Power supply reticulation of the more sparsely settled areas of the U.S.A., appears in the main, to be controlled by regularly constituted Co-operative Associations of farmers. These Associations purchase their power in bulk from Power Companies, Municipalities or Government owned plants, whilst in many cases they generate their own power.

Rural Costs in U.S.A.

Striking advances have been made in reduction of reticulation costs and it is claimed that the overall cost of reticulation has been reduced from approximately 1600 dollars per mile in 1935 to less than 800 dollars in 1940. This figure includes cost of transformers, services and meters and all overhead costs. The average cost of single phase work, on the same basis, is given as 620 dollars per mile in 1941. The average price of bulk power purchased by R.E.A. Systems was 1.05 cents per unit and the average price per unit to con-

sumers in 1941 was 4.2 cents per unit whilst the average revenue per annum per mile of line was only 108 dollars. Having regard to New Zealand statistics the remarkable feature of these American figures is the low density of consumers per mile of line which, on all the R.E.A. financed systems, averaged under 2¼ consumers per mile in 1942.

Comparison with New Zealand Rural Costs.

We shall do well to contrast these statistics with our performances up to date. In New Zealand amongst the 41 operating power boards the average is 12½ consumers per mile, only six are below 5 and the lowest is 3¼ per mile. The average outlay per mile is approximately £700 per mile overall. Even those Boards which show lowest cost per mile still show costs in excess of the abovementioned figures from America. Further it will be seen from the foregoing figures that the rate of usage in individual rural homes is much greater in New Zealand than in U.S.A. and in this respect we are fortunate.

The details of those boards showing lowest costs of construction taken from the 1944 Public Works Statements, are shown in Table III.

The figures for "overall cost per mile," are of course not strictly comparable with each other, being largely influenced by variations in the rates of labour and materials prevailing at the time of construction, also on the relative amounts of capital expended in depots and buildings, etc. Also for undertakings below a certain optimum size "annual costs per unit sold," are to some extent dependent on the annual turnover and on the compactness or otherwise of the Power District concerned. But these figures show that New Zealanders have no justification for the degree of complacency frequently met with as to the completeness of electrification of our country districts, instanced for example by the oft-repeated statement that "New Zealand Supply Authorities have made electricity available to 97% of our population, a figure which cannot be bettered anywhere in the world."

Work Remaining to be Done in New Zealand.

From such a statement as that just quoted, it may be concluded that only 3% of our people remain without electric supply in their homes, but of course, there is no justification for this statement. It seems that the time is overdue when a survey should be undertaken to ascertain just what the true figures are. Most of those remaining unconnected will be

Table III.—Particulars of Power Boards showing lowest overall capital outlay per mile of Distribution.

	Total Capital Outlay.	Miles of Line.	Overall Cost per Mile £s.	Consumers per Mile.	Revenue per mile, £'s.	Units Sold, Millions.	Total Cost per Unit Sold.	Date Supply Commenced.
Ashburton	412,923	1,030	402	4.9	76	20.0	.9	1923
Bay of Islands	195,449	470	416	5.6	94	9.0	1.08	1940
Malvern	70,791	194	365	4.1	52	1.4	2.08	1925
North Auckland....	389,672	899	433	5.7	102	23.3	.83	1936
North Canterbury	291,219	870	335	4.6	67	10.5	1.00	1928
Tauranga	210,871	620	340	4.1	87	14.5	.85	1926
Waitaki	237,206	559	424	9.2	108	17.0	.83	1926

farmers. Although as stated, it is not known what number of farmers' homes are connected, it is of interest to consider the total number which are available for connection. The New Zealand Year Book of 1939, sets out the total number of holdings in the Dominion as follows:—

Table IV.—Total Land Holdings in New Zealand.

Class of Holding.	*Number of Holdings, 1935-36.*
Dairyfarming	40,067
Mixed dairying and sheep farming....	7,017
Sheepfarming	15,589
Mixed Agricultural and sheepfarming	5,479
General Mixed farming	4,274
Fruit-growing	1,375
Market-gardening	957
Poultry-farming	287
Nurseries and Seed gardens	80
Timber-growing	131
Flax-growing	25
Idle and Unused	2,950
Other and unspecified	6,316
Total	84,547

In 1944 the total number of holdings had increased only to 86,137 and the above table therefore represents present conditions with reasonable accuracy. Of the above categories, it may be taken for granted that the degree of saturation will be highest among dairy-farming districts. This is evidenced by the following figures. In 1944 there were 66,082 holdings having on them cows in milk, and of these 33,832 had herds of 10 or more cows. In 1936 the number of milking machines in use was shown as 18,458, whilst in 1944 the figures had increased to 31,088.

But we must be further off 100% saturation in the other categories of farming. This is suggested by the following statistics of machinery on New Zealand farms taken from the 1944 report of Agricultural and Pastoral Production.

Table IVa.—Motive Power Plant on N.Z. Farms:

	No.	H.P.
Agricultural Tractors	13,967	271,983
Other internal Combustion Engines	23,882	72,252
Rotary Hoes, etc.	813	4,754
Total Milking Plants	31,487	—
Machine Shearing Plants	11,555	—
Threshing Machines	1,129	—
Electric Motors	65,699	66,435
Cream Separators	54,107	—

Thus the returns still show a greater aggregate H.P. of stationary oil engines than electric motors on our farms. Apparently nearly one-half of the 24,000 engines may be driving shearing machines. As there are in the Dominion 32,259 flocks of sheep over 200 in size, it is apparent that as yet electric power supply has not penetrated very far into those pastoral areas, whence still comes say, one-third of New Zealand's export production. So without detracting from achievements of the Power Boards in the past, it would appear desirable and necessary that the problem of Rural Reticulation be analysed and if possible looked upon from a new standpoint, if New Zealanders do not want to be out-distanced in the matter of carrying the benefits of power supply to their out-back settlers.

Coping with the Problem:

It is necessary to point out that the problem is not a simple one but rather that many considerations enter into it. The answers will include:—

(a) The organising of a full survey of the remaining unreticulated areas.
(b) Provision of adequate Capital and sufficiently low Interest Rates.
(c) Reduced Costs of Bulk Power.
(d) The devising of supply and methods of construction whereby to secure minimum capital outlay per consumer supplied.
(e) By similar methods to develop durable and reliable methods of design and construction whereby operating and maintenance costs are minimised.
(f) The removal of impediments against attainment of the above objectives such as, for instance, modification of Supply Regulations, removal of Sales Tax, etc.

(a) *Survey of Unreticulated Areas:*

Before the problem can be comprehensively dealt with, the need for a proper survey is apparent. This should include the number, location and load requirements for each of the unconnected homesteads together with the mileage of line required for connection to existing reticulation systems or possibly to small local hydro stations.

(b) *Finance of Back Country Reticulation:*

This subject is now receiving the active consideration of Power Boards and a scheme is mooted whereby a Fund, to be administered by a specially constituted Board, will receive contributions from Supply Authorities, and from the Hydro Electric Branch of the Public Works Department, calculated at the rate of ½% of their gross revenue. These contributions may be utilised to pay annual charges on a central loan fund from which disbursements will be made wherewith to assist rural boards to penetrate into areas which, on their own, will for 10 or 15 years ahead, remain uneconomic to reticulate. The scheme has been criticised as inadequate for a proper solution of the problem, and it may be that some such idea as that which is the basis of R.E.A. operations in the States might with advantage be adopted here. The proposals of the supply authorities are, however, evidence of commendable desire by the representatives of urban consumers to assist in carrying power to those at present without it, and if further developed, along with the adoption of modified engineering methods, the scheme should meet the need for which it has been formulated.

(c) *Cost of Bulk Power:*

The cost of bulk power to Power Boards amounted in 1944, to approximately 46% of their revenue from sale of power. Almost the whole supply is purchased from the State. In 1936 the percentage was 32%, from which it is apparent Bulk Power costs are rapidly assuming a marked prominence in the revenue accounts of the Boards. We are, however, primarily interested at the moment in back country work, and in this case capital charges on reticulation enter more prominently into the cost of delivering energy to the consumer. Nevertheless the beneficial effect of low bulk power cost is apparent from consideration of the fact that Wairere, which of all shows the lowest density of consumers per mile of line, yet shows "total costs per unit sold" which are appreciably less than the average of all the Boards (after excluding those two which are operating in the main centres.) The compensating factor in this case is that Wairere Board generates its own supply. This example is confirmation of the soundness of the policy of the Federal Government of U.S.A. when, where circumstances warrant, it finances the rural supply authorities not only to construct their reticulation systems but also to develop local power sources.

(d) *Design and Operation of Back Country Reticulation Systems*:

Whilst the considerations just mentioned have their importance, it is proposed in what follows to discuss in some detail practical points which have come under the writer's notice during 30 years' contact with this problem. As pointed out earlier rural supply has developed from experiences gained in the supply of power in urban areas. Various modifications from customary practice in town supply systems have already been developed for rural work, but it is the writer's view that considerably further modification to these earlier methods must be introduced before the back country problem will be adequately solved. For instance, the supply regulations require that, inside town limits, spans must not exceed 2½ chains and the sag tables in the Supply Regulations apparently do not contemplate spans in country districts exceeding 8 chains. Having regard to the present heavy cost of poles, it is becoming more than ever essential that we must think in terms of spans much in excess of these figures if the back country is to be reached. Increase in span length introduces new problems, but there is experience to show it can be solved. It should perhaps be here pointed out that the territory remaining to be reticulated is for the most part much more rugged than most of the present reticulated areas. Hence new methods of construction are definitely called for.

(d-1) *System of Supply*:

Three phase supply is now universal for urban use and in New Zealand (except for some of the early work of the Dunedin Corporation) was almost universally carried over to rural supply systems. It is not questioned that in districts such as the densely settled dairying districts this decision was right. I agree also, that three phase should still be used for main lines into the back country, but all spur lines must be single phase. Just at what density of load it is economic to change from three phase to single phase distribution, is a question to which no simple answer can be given. Different and varying factors enter into the solution of the problem. For instance the number of consumers and the number of motors exceeding 1 h.p., per mile of reticulation; also the relative cost of single phase and three phase motors, and their efficiency and the same regarding costs of the various categories of reticulating material. Lines on which the load may be expected ultimately to develop beyond the capacity of a single wire, should be constructed so that the change-over may readily be made when this becomes necessary.

(d-2) *The Tauranga System*:

In the writer's opinion the extension of three phase has already gone beyond the economic limit and most boards are now making high tension spur line extensions in two-wire single phase. This tends to produce a mixture of single and three phase motors on consumers' premises which from some aspects is undesirable. Except for one or two pioneering extensions in the vicinity of Tauranga all rural distribution carried out by the writer in the past 25 years has been by single phase spur lines served from three phase trunk lines. The Tauranga Power Board's System built about 1925 included an 11,000 volt 3 phase 4-wire primary distribution with service transformers connected between phase and neutral, or, when over 6 miles from the telephone exchanges, connected between phase and ground. The neutral wire was erected to meet the regulations of that time. Low tension distribution was mainly 230/460 volt 3-wire single phase, this being no doubt the first rural undertaking to use the 3-wire system with 230 volts to midwire. No special difficulty has, I understand, been experienced in the operation of this system which has now had experience with over 2,000 earth years, that is, the number of h.t. earth returns multiplied by years of operation. The disadvantage of this system, of course, is that earth leakage relays of the usual type are not applicable to it. It is of interest to note the close similarity of the Tauranga system with what has been recently standardised by the R.E.A.

(d-3) *The Bay of Islands System*:

In the Bay of Islands distribution system, main load centres are served by means of three phase lines, comprising conductors up to 19/064 copper, or 7/144 SCA, from which spur lines are fed through insulating transformers, for the most part of 50 KVA capacity. The primary of the insulating transformer is connected between phases of these three phase lines and the secondary between earth and the single wire outgoing spur line. These lines at present operate at 6,350 volts to earth. Transformers supplying rural consumers on the main line are of course single phase 11,000 volt with 230/460 secondaries. By this arrangement it is feasible to protect the three phase lines with earth leakage relays, whilst earth faults on the spur lines are taken care of by the 12½ amp fuse on the transformer secondary. Such faults are, of course, limited in magnitude by the impedance of the insulating transformer, the reactance of which, as shown later, can be made quite considerable without introducing poor voltage regulation.

Advantages of the Bay of Islands System:

Experience of the past few years has proved quite a large number of operating advantages for this system of isolated earth circuits. They may be partially enumerated as follows:—

(a) The single conductor line is remarkably trouble free. Contacts between adjacent conductors cannot occur, whereas on two or three conductor lines clashes of conductors may be frequent in localities frequented by sea birds or wild fowl or where conductor spacing is insufficient, or where high winds may carry pieces of bark or tree branches against the conductors.

(b) The location of faults is greatly simplified and many widespread outages due to earth faults are avoided by reason of the fact that the earth leakage relays respond only to earth faults on the three phase system and are not affected by earth faults on the spur line.

(c) Sectionalising circuit breakers operated by Earth Leakage relays are thus largely unnecessary.

(d) The insulation of the earth working circuit from the three phase circuit sometimes assists in the minimising of induced voltages which occur in parallel communication circuits on the occurrence of earth faults on the power line. That is to say, the only length of parallel with a communication line which has to be taken into account is that between the main feeding point of the 11 KV 3 phase line and the insulating transformer. The parallels beyond that do not influence the calculation.

(e) The fact that one side of the secondary of the insulating transformer goes to earth makes it possible to connect in low voltage equipment whereby to record conditions in the high voltage circuit. Our practice is to instal permanently in each earth connection a thermal current maximum demand indicator and from time to time, load curves from graphic instruments can easily be taken. Useful statistics on load growth and diversity in the various localities are thus easily available.

(f) In the same way condensers can be connected in series in the high voltage circuit whereby to—
  i. automatically control power factor, and
  ii. compensate for line drop.
This development is discussed later.

(g) Better voltage regulation at consumers' premises is obtained. This follows from the fact that the system lends itself to the placing of an individual transformer at each homestead (that is in all average cases where separation between homesteads exceeds 50 chains under present conditions or about 25 chains under normal price conditions.) The use of the series condenser has not yet been generally applied, but as shown later it also has most valuable possibilities in this direction.

(h) Single wire lines effect a great reduction in the amount of equipment required. Fewer and lighter poles suffice and 60 to 80 per cent. less insulators. As compared with three phase work, two-thirds of the cutouts can be omitted and sectionalising switches are single instead of three pole. Three shot sectionalising cutouts become an economic possibility.

(i) Each item of material saved in the manner just indicated eliminates a possible source of breakdown (especially as regards fuse links). Increased freedom from interruption is the result.

(j) A great saving of time in wire stringing results from the fact that no time is lost in regulating, in all spans, the tension of the second and third conductors to equal that of the first.

The fact that all rural motors are single phase, completely eliminates the troubles following the blowing, anywhere on a 3 phase system carrying three phase motors, of a single fuse.

Authority for the Use of the System:

The system above described is operated by dispensation under Regulation 12-13. The requirements of Regulation 31-04 of the 1935 Regulations are varied subject to the following conditions, as adopted by the Advisory Committee of the Chief Electrical Engineer:

1. That the fuse links for all lines with an earth return, shall be set to operate at not more than 1½ times full load with a minimum rating of 2 amperes.
2. That the low pressure side of each distribution transformer be connected to earth.
3. That the earth connection of every 11,000 volt to 6,350 volt transformer and of every transformer stepping down from 6,350 volts shall have a resistance to earth not exceeding 5 ohms.
4. That before commencing any additional installations of 6,350 volt earth return power lines, seven days' notice shall be given to the Telegraph Engineer as is required by Regulation 22-21 (2) (b) in the case of all extra high pressure lines.
5. That the normal maximum return current in any earth return 6,350 volt spur line shall not exceed 8 amperes.
6. That the average separating distance between any 6,350 volt spur line and any communication lines not involving Morse telegraph circuits shall not be less than four chains.
7. That no 6,350 volt earth return electric power line shall be erected parallel to any trunk or toll communication line carrying Morse telegraph wires, with a separation such that the electromagnetically induced voltage in any Morse telegraph circuit is estimated to exceed 2 volts A.C.
8. That the earth connections on the earth working transformers shall with the exception of the 5 ohm requirement, comply strictly with the Electrical Supply Regulations, and are installed at such a distance from earth connections of communication circuits as not to interfere with such communication circuits. If any interference with communication circuits results due to proximity of the earth connections, then the licensee shall remove the transformer earth to such distance as to not interfere with communication circuits, or take such other steps as may be convenient.

9. That if the operation of any earth return electric power line interferes with the operation of the Post and Telegraph Department's metallic telephone circuits or any telegraph circuits which are paralleled by the earth return electric power line, then the licensee shall convert the electric power line to two (or more) wire operation.
10. That all alterations carried out as required by the preceding conditions shall be at the licensee's expense.
11. That in all cases the Chief Engineer of the Post and Telegraph Department shall be the sole judge as to whether interference takes place.
12. That connections with earth shall be placed as far as practicable, in such a position as will be inaccessible to persons or stock.
13. The 230 volt secondary of the transformer shall be earthed in such a manner as to ensure that the voltage measured at the transformer between the phase wire and earth shall not under any circumstances exceed the voltage between such phase wire and the neutral wire.
14. Earthing terminal on 6,350 volt side of transformer to be brought out through an insulating bushing and not attached internally to transformer casing.

Under the above dispensation, it will be noted that the loading of spur lines is at present limited to approximately 50 kw normal full load whilst parallels with communication circuits must observe an average separation of 4 chains.

Experience in Bay of Islands:

After six years' experience in the operation of the Bay of Islands system, during which time over 250 miles of single wire 6,350 volt line has been put into commission, excellent results have been obtained. It is understood that the Telegraph Department know of no occasion on which any trouble on their system could be attributed to the operation of these earth working single wire lines. Even although for example the earth return of one 30 KVA transformer is located within about 6 chains of a telephone exchange, the Telegraph Engineers have had no occasion as yet to call for any alteration to the Board's system in terms of the clause 9 in the above dispensation.

Operating Voltage on Spur Lines:

As stated the earthworking lines so far commissioned operate at 6,350 volts to earth. This involves the stocking of two ranges of single phase transformers—those which are connected to the three phase lines and so are wound for 11000/480,240 volts, and those for the spur lines which are 6350/480,240 volt ratio. The distribution transformers are thus not interchangeable between the main and the spur lines, but they would be if the spur line operated at 11 KV to earth. Transformer makers offer to construct their windings, so that without additional cost, one side of the KV winding can be earthed.

The raising of voltage on the spur lines will have various advantages:—

(a) On the occurrence of a high resistance earth fault on a spur line the blowing of fuses protecting such spur line, will become more certain. Because of this fact, experience has shown that 11 KV lines are safer in rural service than are 3 KV lines. It is submitted, therefore, that the raising of pressure to the extent mentioned, will not, when the factors are balanced up, introduce increased hazard.

(b) It will as abovementioned make distribution transformers interchangeable between the main and the spur line.

(c) For a given load transmitted it will reduce the electromagnetically induced voltage in parallel communication circuits.

(d) It will increase the number of back country homesteads which can be reached economically by means of high strength galvanised steel conductors. The introduction of higher pressure on these lines will, of course, make advisable the use of a better class of line insulator, but as so few insulators are required on the type of line we have under consideration, this fact will have very little influence on construction costs.

(e) When considering the sparsely populated type of country for which the single wire system is suited, it seems appropriate that an operating voltage which is somewhat higher than is usual in closely settled areas, should be adopted.

Earth Connections:

Provided that earth connections are properly installed in the first instance, their maintenance is a simple matter and

there is no evidence as yet to show that the life of these earth connections, which actually carry power current, will be any shorter than that of the customary earths which normally do not carry current. Earths are made in the usual way by means of wires laid in trenches and also by means of solid steel rods driven to depths of up to 22 ft. These rods are brazed to the earth wires and these joints are enclosed in a tin filled with joint compound as a guarantee against corrosion. Copperclad rods will no doubt be used in the future. The use of salt or other chemical for reduction of soil resistivity, is not practised.

The use of earth rods of considerably greater length than has been customary, has been found to show appreciable economy and to provide an ohmic resistance which, as might be expected, is little affected by seasonal changes.

Two early tests which illustrate the effectiveness of longer rods, may be quoted, these being in soil of higher resistivity than is general in the North.

Table V.—Test Results Illustrating the Effect of Deep Earth Rods.

Earth Number		
Original Earth included ¾″ rods— Number and Length	11—6¾′	8—6′
And also the length shown of No. 8 Copper Wire in 15″ trench	50′	240′
Original Earth resistance (ohms)	14	30
Deep rods added—number and length	2—20′	5—20′
Earth Resistance after adding deep rods (ohms)	6.5	7

Provision is being made for the use of much deeper earth rods.

Distribution Transformers and their Protection:

Distribution Transformers are provided with 6.35 KV primaries having the usual 4 taps, their ratings and secondary voltages being as follows:—

Table VI.—Particulars of Distribution Transformers.

Rating.	Secondary Volts.	Price in 1939.	Efficiency.	Approximate Price of 3 phase 11,000/400 volt in 1940.
		£ s. d.		
2½ KVA	240	16 17 9	94.4	Not used.
5 „	240/480	26 17 6	95.4	Not used.
10 „	„	30 11 0	96.3	£52 0 0
20 „	„	39 9 0	97.2	£62 0 0
30 „	„	43 11 0	97.4	£70 0 0

Tanks are provided with a pocket for the reception of a maximum reading mercury thermometer and the usual accessories. Protection consists of one drop-out and, when available, one lightning arrestor. On the Low Tension side each outgoing line (if more than one) is protected by tramway type cutouts. The 2½ KVA transformers are, of course, used for supply to single homesteads where no range is installed.

In the writer's view distribution transformers are to be regarded as portable appliances to be applied in situations suited to their capacity. When the load grows beyond their capacity, as shown by the maximum reading thermometer, or by office records of connected load, they will be shifted to new locations and their place taken by larger ones. The single phase transformer especially in the smaller sizes, is best adapted for use this way.

Lightning Protection:

Statistics show that the frequency of lightning storms is greater in the Bay of Islands districts than in other parts of New Zealand. The two stations in this area, where observations have been taken over a considerable number of years, shows 20.7 and 18.4 storms per annum on the average compared with:—

5.1 at Wellington.
3.6 at Christchurch.
4.8 at Dunedin.
15.2 at Invercargill.

Their severity is correspondingly heavier in the North also. Originally the Southern county was fairly completely equipped with arrestors but none have been available for the Northern one. Our experience confirms our earlier opinion that arrestors are certainly justified in back country work, not so much from the aspect of transformer protection as from the reduction in maintenance costs through the lesser number of high tension transformer fuses blown. Our experience suggests that if the makers' voltage rating limits are observed that the life of arrestors of the better known makes are satisfactory and that radio interference emanating from the arrestors is not troublesome.

Rural practice in U.S.A. after much wider experience with severe lightning storms than we have in New Zealand, is to connect in the lead from the lightning arrestor with the low tension neutral earth so as to minimise lightning surge pressures between primary and secondary. It appears that this is one feature in which our supply regulations should be amended so as to authorise that practice.

Motors:

Practically all motors on rural lines are of the repulsion-induction type and the use of the ordinary split phase motor is discouraged. Recent prices and leading electrical characteristics of common sizes are as follows:—

Table VII.—Particulars of Farm Motors.

Type.	H.P.	Volts.	Efficiency at F.L. %	Power Factor F.L.	Price of Bare Motor	
					Single Phase	3 Phase
					£ s. d.	£ s. d.
R.I.	½	230	63 to 71	63 to 67	11 12 6	Not used
R.I.	1	230/460	69—72	65—88	16 17 6	11 2 0
R.I.	1½	,,	72—78	73—88	21 17 6	12 16 0
R.I.	3	,,				
Capacitor	1	230 or 460	78	·95	18 12 6	11 2 0
Capacitor	3	230 or 460	79	.97	30 10 0	17 12 0

Whilst experience with the better types of repulsion-induction motors has been very satisfactory (the first milking machine motor connected up by the writer nearly 30 years ago was of this type and is believed to be still in regular use), yet it is the writer's belief that the capacitor motors will come extensively into favour as soon as makers have realised the need for better condensers than have, up to the present, been supplied by most of them.

Points in Location and Construction of Distribution Lines:

There has been a tendency in some quarters to regard as sound practice and good engineering, the use of many poles separated by short spans. In the writer's opinion, this is not usually good economics and the design and construction of such lines certainly does not call for engineering skill. Where wooden poles are used it is the writer's view that the larger the number of poles, the greater the number of points of attack for wood fungus, with consequent increased maintenance costs as well as capital charges. If wooden poles are to be used, substantial ones placed at a minimum number to the mile will give the most economical job, and for back country work as previously noted it is essential that all sound economies be availed of. The adoption of long spans without introduction of changes in the details of construction will, however, lead to trouble. But if the need for these changes is faced up to, trouble free lines can be built.

In the use of long spans, the first difficulty that will be met with, will be fatigue in the material of the conductor at the point of attachment to the insulator. Fatigue may be introduced by two principal causes; the first being from high frequency vibrations resulting from light winds, the second from side sway caused by successive transverse winds in alternate directions. Vibration of the first sort may make itself apparent when steel conductors are found to be cutting into the porcelain in the grooves of straight stem insulators. An effective type of binder is thus clearly called for. Our practice also is to bind tightly to the conductor, a length of the conductor material for five feet on each side of the insulators. Augmenting the total weight per foot of the conductor this way will help to detune the vibrations and the slight frictional loss within the damper appears to absorb sufficiently some of the energy of the travelling waves. Then to avoid fatigue of the conductor caused, as mentioned, by side sway, the support should be arranged so as to allow freedom of movement to the conductor without the necessity for bending. Consequently we use disc suspension insulators for all spans over a certain limit. On single wire lines this disc suspension insulator is carried on a short length of 4 x 4 cross-arm. In the use of S.C.A. Cable, armour rods have consistently been used and our experience to date with them has been satisfactory. The use of three strand conductors as a precaution against vibration is referred to later.

In the location of power lines considerable expense has on occasion been incurred in a desire to avoid angles and to get the maximum length of straights into the route of the line. On the contrary in our view, advantage should be taken of the topography whereby to introduce angles into the route for the double purpose of obtaining long spans and of ensuring that poles need be guyed from only one direction and not two. It takes a little time for each line surveyor to acquire the necessary eye for topography, whereby to secure the most favourable route.

Poles:

New Zealand has in the past been fortunate through its comparative proximity to the land of the Australian hardwoods and the writer has experienced lines now 30 years old where most of the original bark poles are still in service. For traversing rough country wood poles have the additional merit of greater protection for linesmen against shock.

Nevertheless shortage of supplies and their soaring costs

direct our attention more definitely towards reinforced concrete. Here, however, the present high cost of reinforcing steel presents a problem. The amount of steel in a pole for any given modulus of resistance is of course reduced by increase of lever arm between tension and compression sides. With this in view the writer has recently developed poles of "T" and "L" shaped cross section. Such a shape readily provides considerable resistance in both transverse and longitudinal directions. Each flange, though only three inches thick, is yet sufficient to give at least one inch cover to the three reinforcing rods. A recent test on a 30 inch pole of the above description, 28 days old, made with slow hardening cement and reinforced with two one inch rods and one three-quarter inch rod, not work-hardened, carried a test load of 1300 lbs. transversely and 900 lbs. longitudinally without measurable permanent set.

The strength in the reverse longitudinal direction was not tested and would be less, being designed for one-third of the transverse strength. In this connection it is considered that the requirement of the Supply Regulations that the longitudinal strength be not less than .25 of the transverse is insufficient. Observation shows that poles are often damaged in handling, the steel thus is overstressed and the resulting cracks invite attack on the steel.

For back country work, a design which gives an adequate resistance modulus in all directions but which is as light as possible is required. The "T" section pole gives excellent appearance but is not so economical of steel as the "L" section. A 30 foot "L" section pole rated at 18 foot-tons of ultimate transverse strength weighs approximately 1600 lbs. and its cost may be put down as follows:—

	£	s.	d.
160 lbs. of steel at £23 + S.T.	£1	19	6
260 lbs. of slow hardening cement at £7	0	16	0
11 cubic feet of set aggregate including for mixing and moulding and for depreciation on plant, at £5 per yard	2	0	8
	£4	16	2

The above pole is adequate for carrying one three phase H.T. circuit and one four wire circuit in spans where topography suits, up to 6 chains. Obviously for the support of a single wire line, a much lighter pole is adequate. A pole having only half the resistance movement of the abovementioned one will, without a guy be adequate to carry a 7/074 S.C.A. conductor in spans of 12 chains.

Pole Handling Equipment:

The high level of labour costs ruling in recent years underlines the need for mechanical equipment in all operations where labour savings can be made. In the erection of the Bay of Islands Board's system, appreciable savings have been made by the purchase of a pole erecting machine. This is of American origin and comprises a caterpillar type tractor on which is mounted an earth borer for hole digging and a mast and winch for pole erection. It is fitted with augers for 16 or 20 inch diameter holes and in heavy clay country puts down a hole 6 ft. deep in about 80 seconds. If required it can bore to 11 feet deep, and during 1942 put down large quantities of holes this depth for the Army. The tractor operates on diesel fuel and is used for snigging poles from the spot where dropped from the pole lorry (and fitted by the pole fitters) to the site. It then digs the hole and lifts the pole into position, proceeding thence under its own power to the next site. Its crew comprises two men. The pole tramping squad follows some distance after it.

In usual cross country going where the average number of fences have to be dealt with, it is not unusual for the machine to erect between 40 and 50 poles per working day. The same machine erected a line of 45 foot hardwood poles and it was noted that its customary performance was to spend 11 minutes at the pole site from the time of arrival till it was packed again and ready for the next site, the hole meantime being dug and the pole lifted into it. Owing to the nature of the country on that particular route transit time between pole sites averaged 40 minutes. Although the machine can navigate fairly mountainous country, the system of the Bay of Islands Board traverses many areas of country where manual methods of pole erection were necessary. For transport of this machine over distances, it loads itself on to the trailer of the pole lorry by means of steel ramps designed for lightness of weight.

In rough country poles are snigged up to their sites sometimes by bullock teams, and on other occasions hauled by the lorries by a long lead of flexible steel rope which passes round a snatch block anchored to a dead man above the pole site.

Use of Series Connected Condensers:

Reference has been made earlier to the insertion of a series condenser in the secondary of the insulating transformer. The adoption of this method of connection was first suggested by recognition of the fact that condensers connected in the ordinary way across our distribution lines will prove an embarrassment in the application of ripple frequency to the control of off-peak loads, etc. But the placing of the condenser in series with the line will on the other hand not attenuate the ripple frequencies as do shunt condensers. Apart from this advantage a series condenser will produce two additional most beneficial effects. Firstly, they will inject leading reactive KVA into the system in proportion to the square of the load on the circuit into which they are introduced. Secondly, if suitably proportioned to the reactive values of the three phase 11 KV supply line and of the insulating transformer, they introduce instantaneous voltage regulation into the circuit. This regulating action operates so quickly as to wholly or partially eliminate flicker on lamps which otherwise would result from the starting current of motors connected off the same line. No voltage regulator which depends on any sort of mechanical motion for its functioning can possibly act so quickly.

Normally in order that good voltage regulation can be assured it is necessary to minimise as far as possible the inductive reactance of overhead lines and of transformers. But when a series condenser is introduced into the circuit the presence of inductive reactance in the lines, transformers or in the connected load, becomes almost beneficial as it gives greater scope for control of pressure. It thus becomes unnecessary to specify that insulating transformers shall have minimum reactance volts. Release from this limitation facilitates more robust design of the transformer. The somewhat higher reactive impedance of single conductor earth return lines as compared with two or three phase lines is also now an advantage.

The explanation of their operation will be understood by reference to Figure 1 which shows the vector relations in the secondary circuit of the insulating transformer.

O.P. represents the load current I passing to earth and to the single wire line. This lags behind the voltage OA by the power factor angle ø. AB is the resistance drop in the transformer secondary, BC the reactance drop in the secondary, and CD is the voltage impressed across the condenser.

Without the condenser in circuit the pressure which must be induced in the secondary to obtain a line voltage of OA

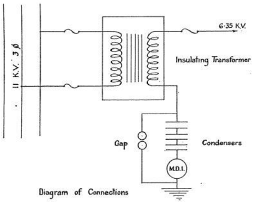


Fig 1. Arrangement of Insulating Transformer and Series Condenser

is OC, but with the condenser in it is OD. OD is numerically less than OC by CD x Sine ø (approximately).

But CD = Rc I

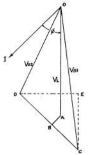
Where Rc = reactance of the condenser (in ohms)

So that the pressure variation produced by the condenser is:— Rc I Sine ø

And the per cent. regulation so produced is:

$$\frac{I \times Rc \times \text{Sine } \phi \times 100}{V} = \frac{KVA \times Rc \times \text{Sine } \phi}{(KV)^2 \times 10}$$

In practice 2 or 3 standard 4 KVA 400 volt condensers connected into the earth lead and of course shunted, as



Vector Diagram

shown, by a gap produce a rising instead of a falling volt chart as load comes on the secondaries of 50 KVA insulating transformers connected off heavily loaded lines 25 miles from the main substation. Voltage charts taken at such an insulating transformer are reproduced in Fig. 2 (p. 263).

Example of Reticulation Costs using Earth Return:

Whilst it is held that the economy of the single wire system for back country work comes largely from reduced maintenance costs, yet reduced capital outlay also contributes to lowering the total annual costs.

Costs of construction have been so distributed, not only during the war but also immediately prior to it, that examples of costs quoted from Bay of Islands (the whole of which system has been constructed since the beginning of 1939) are not readily comparable. It may be of interest, however, to quote as an example the cost of reticulation of a self-contained circuit. This is Northern Ruapekapeka, one of the smallest of the isolated circuits. It is fed from the Kawa Kawa–Opua 11 KV line through a 30 KVA insulating transformer and the work was done in December, 1944, with materials, much of which had not been long in stock. The circuit includes a total of 7 miles 74 chains of route mileage made up as follows:—

Northern Ruapekapeka Mileage:

1-wire 6.35 KV	7/061	HDBC	4m. 03ch.	
1-wire 6.35 KV	No. 6	PG	67ch.	
1-wire 6.35 KV	7/080	Galv.	48ch.	
1-wire 6.35 KV	No. 8	PG	1m. 75ch.	
				7m. 33ch.
2 wire separate LT No. 8 HDBC				41ch.
2 wire common LT No. 8 HDBC				8ch.
Total Route Mileage				7m. 74ch.

Transformers included were:—

1—30 KVA insulating
6—2½ and 2—5 KVA distribution.

The costs as shown in the Board's books and as supplied by the Secretary, are as follow:—

	High Tension.	Low Tension.	Sub-stations.	Services.	Total.
	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Stores	376 2 9	10 14 4	450 1 4	70 17 5	907 15 0
Wages	262 13 11	5 0 6	39 1 10	20 10 6	327 6 9
Transport ..	81 11 11	10 17 6	9 1 1	21 15 7	123 6 1
General	57 0 0	—	10 0 0	20 0 0	87 0 0
Totals	£777 7 9	£26 12 4	£508 4 3	£133 3 6	£1445 7 10

The above costs do not include service meters. After allowing 5% on the costs shown, the cost per route mile works out at £190 overall (cost of, but not chainage of, service lines included).

Rural District Power Demands:

As stated previously records are kept of the maximum demand in amperes in the earth lead of each of the 24 insulating transformers in service. Some of them serve small townships and others purely rural districts, but in practically all cases the recorded demand closely agrees with a demand calculated as follows:—

Demand in KVA = Consumers .... × .2
\+ Ranges .... × 1.5
\+ Domestic Waterheaters ... × .4
\+ Dairy Waterheaters ...... × .2
\+ Milking Motors .... × 1.0
\+ Separators and Pumps ...... × .1

Rural Line Conductors and Earth Return Circuits:

The various classes of conductor available for high tension rural lines include:—

Hard Drawn Stranded Copper ("HDBC").
Steel Cored Aluminium ("SCA" or "ACSR").
Copper-clad Steel or "Copperweld."
Galvanised Steel, solid or stranded.
Bronze Wires.
Cadmium Copper.

Bronze and Cadmium-copper although about 25% stronger in tension than hard drawn copper, yet both of these materials have correspondingly higher electrical resistance and cost, so are not of much interest as power conductors.

Although *Copper-clad steel* seems to be ideal as a conductor for rural work on account of its strength, fair conductivity, ease of jointing and high durability, and it is at present being extensively used for rural work in the U.S.A., yet price has been against its extensive use in the Dominion.

Copper is generally preferred to SCA on the score of its smaller bulk for the same conductivity and because of its durability and ease of jointing, but price conditions at the moment are heavily against it.

Satisfaction in the use of *SCA* is contingent on scrupulous care in jointing and on taking adequate precautions against fatigue near points of attachment. A fair amount of seven strand SCA having three aluminium strands has been used in New Zealand, but this construction involves exposing three of the four steel strands to direct atmospheric attack, whereas all exposed strands should, it is believed, be of aluminium with the steel entirely enclosed.

With this latter construction the steel will be protected and its life probably indefinitely prolonged by the coating of aluminium oxide which forms over the galvanised surface.

The effective resistance of SCA cables is not always the same as the DC resistance. Particularly in cables comprising 6 aluminium strands spiralling a steel core, the longitudinal magnetic flux which is set up in the steel core can in some cases produce hysteresis and eddy current losses such as to constitute an increase of 20% on the DC resistance.

Galvanised Steel:

Has sufficient conductivity to make it suitable as a high tension conductor over many miles of back country spur lines. If used in inland districts, suitably manufactured wire may be expected to give good life and even near the sea coast, lines using standard fencing quality wire have given a life of 20 years in the Tauranga district. Methods of galvanising have been developed in the meantime which should further prolong the dependable life of steel conductors.

The writer has previously favoured the use of solid conductors because of the greater distance that corrosion must penetrate before the strength of the conductor depreciates by a given percentage in solid wires as compared with stranded ones. As against this consideration, the higher ohmic impedance of solid conductors on ripple frequencies would constitute an objection against their use if future developments prove that it is economic and desirable to use ripple frequency for control of back country loads. But this same feature of increase of effective resistance (and of internal reactance) with the frequency is valuable from the aspect of lightning protection. Owing to the internal eddy current and hysteresis losses on high frequency steel conductors constitute effective surge absorbers so that steep wave front transients undergo comparatively rapid attenuation. For this reason lengths of steel conductor have on occasion been introduced into transmission lines which for the most part were of copper.

A further important consideration from the aspect of back country reticulation is that of conductor vibration. Twelve years ago as the result of tests the Ontario Power Commission established that angular, rather than round conductors, are much less prone to damage by vibration than are round ones. For this reason three strand conductors are being extensively used for rural work in America and also in Victoria. In Bay of Islands as a compromise amongst these conflicting factors, we are now using three strand high tensile steel.

Impedance of Steel Conductors:

Both the ohmic impedance and the internal reactance of steel conductors are far from constant when alternating current is being transmitted. Variations in the magnetic permeability of iron of course accounts for this. But as permeability varies with flux density, so impedance of the conductor varies to some extent with the amount of current transmitted. These variations in the "skin effect" are more pronounced in soft rather than in high tensile steels. Much of the published data on the subject is unsatisfactory and apparently contradictory, due no doubt to the numerous and variable factors involved. Stranding of the conductors largely

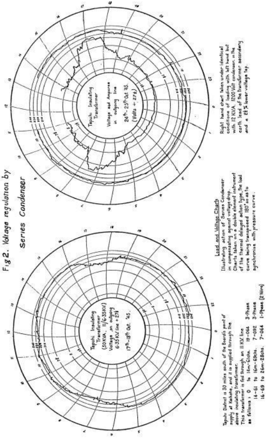


Fig 2. Voltage regulation by Series Condenser

reduces, but cannot altogether eliminate "skin effect." It is interesting to note that at low current densities, the effective AC resistance is influenced to a measurable extent by orientation of the conductor, that is whether it is in line with or transverse to the terrestrial magnetic field.

It is useful to memorise the resistivity of conductors by a constant which is the product of the resistance per mile (DC) by weight per mile in pounds. Expressed in this way there appears to be reasonable agreement that the DC resistivity of iron and steel wires is approximately as under:—

	Ohms per mile pound.	Micro-ohms per cubic cm.
Steel—45 ton quality	7200	14.4
Steel—30 ton quality	6700	13.4
Iron—B B quality	5700	11.4
Iron—E B B quality	4800	9.6

It must be remembered, however, that the above figures do not by any means indicate the relative effectiveness of these materials for AC transmission. In point of fact, in solid conductors for AC current, 45 ton steel has usually a better effective conductivity than has soft iron.

In each of the formulae for calculating AC resistance of steel from the DC figure, that have come under notice, there are various defects, and it is in fact impossible to devise a formula which will, in the present state of knowledge, reliably forecast the effective AC resistance of any given sample. But for the better understanding of the factors involved it is useful to attempt to construct a formula which fits the known facts.

Solid Conductors:

From a scrutiny of various published results of tests on solid iron and MS wires there is a general agreement that the AC resistance increases uniformly with the current up to about 10 amps, when it then reaches an approximately steady value, sometimes dropping and in other cases rising with currents over 10 amps.

At one amp the effective resistance is usually only little in excess of the DC figure, but the rate of rise from that is approximately proportional to:—

(a) The diameter of the conductor.
(b) The amperes transmitted.
(c) The frequency (at over 100 cycles the rate of rise will be nearer proportional to the square root of frequency).
(d) The square root of the conductivity and of the permeability.

For thirty ton iron and mild steel, the following formula appears to fit the test figures rather approximately:

$$Ra = Rd \left(\frac{1 + Af}{500} (1.2d - 1) \right)$$

where Ra = effective resistance on AC
Rd = DC resistance
A = Amps (but disregard excess over 10 amps.)
d = diameter of conductor (in tenths of an inch)
f = frequency (cycles per second).

In hard drawn 45 ton solid conductors the rate of increase is usually less than half that indicated by the above formula.

Stranded Conductors:

By stranding a conductor air gaps are introduced which limit the internal circular magnetic flux and thus greatly reduce the skin effect. If the strands do not exceed one-tenth of an inch or 12 gauge, the AC resistance at 50 cycles rises slowly by an increment which, up to 30 amps is in direct proportion to the current. For 45 ton quality steel the following seems to fit the facts for hard drawn stranded cables up to ½ inch diameter, for frequencies to 60 cycles and currents to 30 amps.

$$Ra = Rd \frac{(1 + A\ 3/2 \times d \times f \times D)}{30{,}000}$$

The symbols have the same significance as before
but d = diameter of each strand in tenths of an inch and,
D = diameter overall in inches.

Inductive Reactance of Steel Conductors:

The reactance of the usual overhead circuit when composed of non-ferrous metals is, for a given frequency a fairly constant quantity for normal sized conductors and spacing, being of the order of 1.2 ohms per route mile at 50 cycles. It varies of course directly as the frequency and the internal reactance of the conductor is in ordinary circumstances negligible.

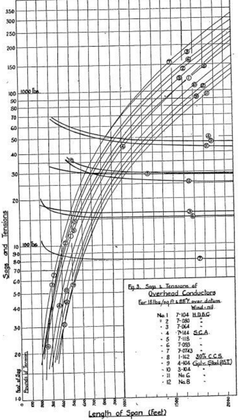


Fig. 3. Sags & Tensions of Overhead Conductors
For 18 lbs/sq. ft. & 88°F. over datum. Wind–nil.

With conductors of iron, however, if the conductor is regarded as a bundle of parallel filaments, the internal filaments are surrounded by a sheath of comparatively high magnetic permeability and so their reactance is high. So the effective reactance in such a circuit comprises:—

(a) That due to external reactance as in the non-ferrous circuit abovementioned, plus
(b) the internal reactance.

Due to the great variations in permeability (b) is highly variable.

For 45 ton hard drawn unannealed conductors average figures for internal reactance at 50 cycles and 10 amps are:—

No. 6	5.5 ohms per mile of conductor in circuit.	
No. 8	7.5 ohms	ditto
4/12	1.0 ohms	ditto
3/12	1.25 ohms	ditto

Impedance of an Earth Return Circuit:

The exact route whereby the return current traverses the earth between the two earth connections of a single wire circuit depends on the resistivity of the earth's crust in the locality. The higher the resistivity the deeper the penetration of the filaments of return current. Nevertheless mathematical investigation shows that for alternating current the return path will adhere roughly to the path of the overhead conductor and practically the whole of the current will be concentrated in the soil within a few hundred yards of the overhead line. For soil resistivities as high as are usually experienced the mean return path of the current works out at about 1500 feet below the earth's surface and the impedances are worked out accordingly.

The impedance of such a circuit thus comprises:—

(a) Those of sending and receiving transformers and connected loads.
(b) Resistance of sending and receiving earth connections.
(c) Effective AC resistance of overhead conductor.
(d) Internal reactance of overhead conductor.
(e) Resistance of earth path.
(f) Reactance of the circuit comprising the conductor and earth path in series.

It is of interest to set down usual values of these quantities:—

(a) Typical transformer impedance characteristics are well known and need no further comment. The influence of a series condenser in the earth connection of an insulating transformer is referred to elsewhere and it is shown that the introduction of reactance into the circuit as at (d) and (f) gives greater scope for voltage regulation by series condenser.

(b) The ohmic resistance limits of the earth connections have been set out in the dispensation terms.

(c) The ohmic resistance of the commoner classes of conductors are shown on Table VIII.

(d) As shown in a later paragraph the internal reactance of solid steel conductors is appreciable, though for stranded it is only of the order of one ohm per mile at 50 cycles.

(e) At 50 cycles the ohmic resistance of the return path is of the order of .1 ohm per mile and is usually less than that figure.

(f) The inductive reactance of the earth return path and of the overhead conductor in series with each other is of the order of 1.2 ohms per route mile.

Particulars of Conductors for Rural Work:

In the following Table VIII various particulars of the commoner conductors are set out as a means of demonstrating some crucial features in their application to back country distribution.

In column A—

H.D.B.C. = Hard Drawn Bare Copper.

S.C.A. = Steel Core Aluminium.

30% CCS = Copper clad steel having 30% of the conductivity of the same section of copper.

P.G. (45T) = Galvanised steel 45 ton, quality unannealed.

Column B—

Shows the number of strands and their diameter.

Column C—

Shows breaking strength as set out in the E.S.R., B.S.S. or eminent makers' lists.

Column D—

Is the maximum working tension permitted by E.S.R.

Column E—

Side pull for each degree variation of bearing at the pole with tension D in the conductor.

Column F—

Wind pressure per lineal foot at 18 lbs. per square foot of diametral plane. The summation of E. and F. provide for ready calculation of side pull on insular pins and poles.

Columns G, H, I—

Show the necessary sag in feet at maximum summer temperature for spans of 660 feet, 1,000 feet and 2,000 feet, so that the working tension will not be exceeded at stated wind pressure and at a temperature 88 degrees F. below summer temperature.

Column J—

Shows the allowable tension in calm weather at summer temperature for spans of 2,000 feet. It may be noted that the correct tension for other spans from 2,000 down to 660 feet is sensibly the same as that shown in column J for conductors of H.D.B.C. and S.C.A., but for steel the permitted tension at 660 feet is about 20% greater.

Column K—

Gives the effective AC resistance in ohms per mile at 60 degrees F. and 10 amps. The AC resistance of S.C.A. conductors is taken as the D.C. resistance plus 10%.

Columns L, M—

Show the transmission capacity of the various conductors when used in single wire circuits having 6.35 and 11 KV to earth respectively, assuming 5% of the KVA transmitted is energy lost in conductor and earth return.

Column N—

Is weight per mile in pounds.

Column O—

Shows the present day cost per mile so far as the figures are known—they are based on recent quotations from England for H.D.B.C. and solid P.G., and from Canada for S.C.A. and C.C.S. whilst stranded galvanised is estimated at £60 per ton.

Column P—

The cost per mile of conductor for transmitting 100 KVA miles at 6.35 KV.

Column Q—

See paragraph below.

Survey of Rural Lines:

A method of survey whereby it can quickly be determined whether there is clearance for any given conductor in a contemplated span was developed for Bay of Islands and although simple the writer has not previously seen it suggested and may be worth recording.

Instead of the usual surveyor's drum and band, a special drum was designed whereon to wind a 20 chain length of No. 20 S.W.G. piano steel wire on which chains are marked in the usual way. For longer spans two such lengths can be joined. If the piano wire is supported at the proposed pole sites at the height equal to that by which the lower insulator exceeds in height the minimum permitted conductor clearance and if the piano wire is drawn up to the correct tension as shown by a surveyor's dynamometer then the wire assumes the same catenary curve as will the conductor and thus immediately shows if the required dip in round contour exists. The utility of the method follows from the fact abovementioned regarding column J of the table, where it is remarked that for most conductors the correct stringing tension is practically constant for all spans exceeding 10 chains (and for shorter spans the method errs on the safe side).

The correct tension at which the piano wire is to be held follows easily from the fact that if the tensions in any two wires in a given span are proportioned to the respective weights per foot of conductor then the wires will form themselves into identical catenarys.

On this basis column Q of the table has been worked out from columns J and N on the basis that No. 20 S.W.G. steel wire weighs 18 lbs. per mile.

Conclusion:

In concluding this paper the author is conscious of having dealt inadequately with many aspects of the subject which he set out to survey. He would, for instance, like to have had time and space to put forward concrete suggestions as a basis of discussion for such modifications of the Supply Regulations as the back country calls for. Nevertheless it is hoped that the paper may be found to contain material which will assist in the recognition of Rural Power Supply as a separate and distinct field wherein is justified a complete review of past methods and development of new ones. Such review should be untrammelled by preconceptions other than devotion to sound engineering and to the extension of the benefits of power supply to a deserving section of our people.

Assistance in the assembly of test data, etc., by my assistant, Mr. R. R. Clarkson, and by the technical staff of the Bay of Islands Power Board, is hereby acknowledged.

Table VIII.—Particulars of Bare Overhead Conductors.

	Size of Cable.	Breaking Strength.	Max. Working Tension.	Side Pull for 1°	Wind Pres. Lbs. Feet.	Sag at 88° F. over datum. 660 ft. Span.	1000 Span.	2000 Span.	Tension at 88° F. 2000 ft. Span.	Resis. per Mile 10 amp. AC.	Transmission Capacity KVA × Miles. 6.35 KV.	11 KV.	Weight per Mile Lbs.	Conductor Cost per Mile. £	Cost per 100 KVA Mile 6.35 KV £	Tension in 20 SWG Survey Wire.
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
H.D.B.C.	7/104	3657	1487	25.8	.468	19.4	44.3	176	660	.744	2160	6800	1231	76	3.50	9.6
"	7/080	2194	880	15.3	.360	23.7	55	220	313	1.257	1340	4250	728	45	3.35	7.7
"	7/064	1416	562	9.8	.288	29.0	67	270	164	1.965	880	2780	466	29	3.30	6.3
S.C.A.	7/144	4885	1954	34.0	.650	18.2	44.0	172	500	.800	2000	6250	905	57	2.85	10.0
"	7/118	3410	1363	23.8	.532	21.1	49.5	200	290	1.20	1400	4400	607	38.3	2.75	8.6
"	7/093	2160	872	15.2	.418	25.4	59.6	242	151	1.90	910	2970	377	23.8	2.63	7.2
"	7/0743	1464	585	10.2	.333	29.2	70.5	284	80	3.00	585	1860	239	14.7	2.52	6.0
30% CCS	1/162	1800	720	12.6	.243	16.7	41.5	175	208	7.05	255	800	385	27.2	9.4	9.7
PG (45 T)	4/104	3100	1530	26.7	.376	11.1	29.0	125	460	12.5	145	457	622	16.7	11.5	13.3
PG (45 T)	3/104	2310	1140	20.0	.335	13.8	35.2	150	286	16.5	110	316	463	12.4	11.2	11.1
"	No. 6	2650	1306	22.8	.288	10.0	26.5	114	432	22	82.5	240	530	10.6	12.8	14.7
"	No. 8	1830	905	15.8	.240	12.1	31.4	135	253	27	67	212	367	7.3	10.9	12.5

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BIBLIOGRAPHY.

1. WORCESTER—"Iron and Steel Conductors," G. E. Review, June, 1916, p. 494.
2. TAYLOR AND BRAYNOR—"American Hydro Electric Practice" (Mc-Graw-Hill, 1917), p. 311.
3. TOOGOOD, H. F.—"Use of Galvanised Conductors," *Trans. E.S.A.E.A. of N.Z.*, Vol. III, 1929, p. 74.
4. JAMIESON—"Vibration in Overhead Conductors," *Trans. E.S.A.E.A. of N.Z.*, Vol. 7, 1934, p. 72.
5. "Deep Grounds," *Electrical World*, Sept. 5th, 1942.
6. WALTON—"Electrical Properties of Galvanised Steel Conductors for Overhead Lines," *Jl. I.E.E.*, Vol. 66, Oct., 1928, p. 1065.
7. BAYLISS (in discussion)—"Properties of Galvanised Steel Conductors," *Jl. I.E.E.*, Vol. 67, Jan., 1929, p. 206.
8. WOODHOUSE—"Overhead Electric Lines," *Jl. I.E.E.*, Vol. 67, Feb., 1929, p. 217.
9. MORGAN AND WHITEHEAD—"Impedance and Power Losses of Three Phase Overhead Lines," *Jl. I.E.E.*, Vol. 68, March, 1930, p. 367.
10. VARNEY—"Vibration of Overhead-line Conductors," *Jl. I.E.E.*, Vol. 77, 1935, p. 407.
11. DEAN—"Design Data in Rural Distribution Lines," *Jl. I.E.E.*, Vol. 77, Dec., 1935, p. 749.
12. MAY—"High Voltage Distribution in Rural Areas," *Jl. I.E.E.*, Vol. 87, July, 1940, p. 33.
13. DOUBLE AND TUCK—"Vibration of Overhead Line Conductors," *Jl. I.E.E.*, Vol. 86, Feb., 1940, p. 129.
14. "Annual Statistics in relation to Hydro-electric Development and Operation," Govt. Printer (*Annual*).
15. "Statistical Report on Agricultural and Pastoral Production of N.Z.," Govt. Printer, 1945.
16. DAVIS—"Lightning Protection of Meters," *Electric Light and Power* 1941, March, p. 38.

DISCUSSION

MR. J. G. LANCASTER said that, in his opinion, Mr. Mandeno had presented a paper which was most valuable to supply engineers concerned with the design of rural electrical lines, for which, as the author had stated, special methods were essential. In electrical reticulation work generally, and especially in rural work, there was much scope for economics in the selection of conductors and in the fixing of spans and selection of poles. Such work could be done by rule-of-thumb methods, and public money wasted, or it could be carried out as an engineering job.

His difficulty in considering Mr. Mandeno's proposal was how to determine whether a 3-phase load might be expected ultimately. He had in mind a number of cases where light lines were installed in sparsely settled country areas and in a relatively short time the supply authority was asked to extend the line to the bush and a 100 H.P. sawmill. He presumed that, in such a case Mr. Mandeno would pull down the original line and replace with a 3-phase construction.

He asked Mr. Mandeno to indicate the maximum horsepower of single-phase motors he would use on this rural work, also the cost of the earth-boring and pole-erecting machine. He asked, further, that more details be given for the example quoted in the paper, the number of poles per mile, and details of the poles so that a comparison could be made between Mr. Mandeno's very low costs and the cost of more or less standard construction with, say, eight-chain spans.

Mr. Mandeno was a pioneer. He was the first in this Dominion to apply electricity for general domestic water-heating, and, again as a pioneer, he had shown members of the Institution how to build low-cost country lines.

MR. A. E. DAVENPORT, after congratulating Mr. Mandeno on putting on paper this, hitherto, very controversial subject, said Mr. Mandeno, during the course of the last 20 years, had developed the described system of electrical supply, which the speaker had had the opportunity of studying.

The ordinary electrical engineer, when he first heard about this earth-return system for high tension, and when he first saw it, wondered why he was worrying so much about it. The whole question was one of economics. Technically it worked. It gave supply to the consumer and in the territory in which it operated it was doubtful whether any other form of supply would have done it so economically with the loading available. The question was to determine just when to revert to the normal 3-phase system. There were load limitations. Some of them applied by Regulation, of course, to the single-phase system and one then had to determine whether to build light lines of single wire and to put in poles which would hardly be able to carry 3-phases or build 3-phase in the first place. That was the problem that faced one right at the outset. It depended on the access and on the load growth. It required an access and load survey in the first place. Mr. Mandeno had done all these things and in the area of supply he had tackled, economics had played a major part.

Mr. Mandeno's object was to bring power amenities alike to city and country; and with that object, all must be in sympathy. In the section of the paper dealing with "methods of coping with the problem", the first thing necessary was to carry out a load survey. In 1945, the Electricity Act formed the Rural Reticulation Council and out of the activities of the council the

necessary load survey would be taken. Some of it was also included in the Census and Statistics Return forming part of the last census. A little time would elapse before some of it was available.

Mr. Mandeno, said Mr. Davenport, mentioned the question of reduction of bulk charge to supply authorities, pointing out that from 1936 to 1944 the cost of bulk power to power boards in purchases from the State rose from 32 per cent. to 46 per cent. of their revenue from the retail sale of power. There was another side to that story. The facts were correct. During those years the consumption of units went up by something like 150 per cent. and the State Hydro capital outlay likewise increased. They had to double their capital; it went up from £13,000,000 to £26,000,000. But the charges to the supply authorities went up only 34 per cent. In other words, they were able to make more effective use of their existing installations without excessive capital expenditure; but the rub would come in the future when existing reticulation had reached its limit and would have to be extended.

The net effect of the present cost of materials and labour was that the cost per unit had not varied; it had even dropped slightly, because, along with the increased capital costs, the number of units had doubled. The present day costs were more than twice those before the war. They were facing in the next five years the doubling of State outlay on State hydro but not the doubling of kW capacity. The effect over all was that the prices per kW would go up; and they would be very fortunate if the cost of bulk power did not have to follow suit.

Another factor mentioned was that of small power schemes. The subject was ventilated frequently in the North Island and Mr. Mandeno probably gave the answer. In remote localities, Mr. Davenport could see no objection to the installation of small schemes. But where the scheme was large enough and accessible to the major power supply, and where the small scheme had to work in parallel with the Department's system and was dependent on selling power to the Department, then it was considered that, where such a scheme was installed, it should be developed with, generally, more kW capacity than the local authority would put in, so as to take advantage of the availability of the water to pump units into the system. There was a point, also, that the local supply authority established in a rural area would be hampered, in fact dominated, by a lack of capital so that the development of the station itself would, generally, be cut down and could only be of benefit to the local community, so losing the opportunity of its being of benefit to the power supply at large. At the present time, this problem was complicated by the shortage of manpower and of materials. It was clear that if any licences were given for the development of these plants they could, in their total effect, seriously divert manpower and materials needed for the accomplishment of major schemes. Approval of licences was being withheld in the meantime. That was not to say that the plants were not going to be developed ultimately. There was a proper place for them but owing to present day conditions the proper place was not now.

Single wire distribution, said Mr. Davenport, was not generally applicable where the load was sufficiently heavy to warrant the ordinary system. One of the dominating features was the securing of low earth resistance and the maintenance of that low value. Mr. Mandeno had exercised a great deal of ingenuity, particularly by voltage control by condensers and earth resistance with a system probably no others had begun to apply.

MR. A. BUCKINGHAM congratulated Mr. Mandeno both on his originality and on having the courage of his convictions, in maintaining his right to think and act differently from the majority. It was something to be proud of that in New Zealand he was allowed to stick to his guns by the controlling authorities; that would not be possible in all countries. For most engineers, Mr. Mandeno's system was impracticable today because it was necessary to start such a system with an absolutely clean sheet. In pre-war days most engineers considered, with the level of costs then existing that using the more orthodox systems was justified, technically and economically, and Mr. Mandeno's system was not justified, the main reason being, of course, that it was possible fairly easy to change over to the normal 3-phase supply system. Under the present higher costs level, the savings under Mr. Mandeno's system were much greater but it was doubtful whether they did justify such a drastic alteration. Mr. Buckingham was satisfied that in Canterbury, under 1946 costs, a single-phase spur line could be built for £250-£350 per mile, depending on the number of consumers to be supplied, and any reductions Mr. Mandeno could make on those figures did not seem to be sufficient to warrant the disadvantages his system introduced. It was cheaper for maintenance to have one conductor instead of two, but some of the advantages claimed by Mr. Mandeno were also advantages under the orthodox single-phase system.

All agreed with running lines in difficult country as the topography of the country, not the roading system, dictated.

Mr. Mandeno's system required quite a comprehensive two-pole structure, with insulating transformer, at the commencement of each single-phase line, and the capital cost of this had to be split up over the consumers supplied by that line. The value of the paper, said Mr. Buckingham, would have been enhanced a good deal if it showed the extent of single-phase spur lines, the number of transformers and the number of consumers; that would have given a more balanced view of how the system worked out. Of course, the main general disadvantage of the system was the difficulty in catering for increased load. Mr. Mandeno's system would grow and the time would come when his single-phase lines would not be satisfied with 30 or 50 kVA insulating transformers or a supply at 6350 volts. And Mr. Mandeno would then have his difficulties, both in Wellington and in the Bay of Islands.

Mr. Buckingham then referred to a recent paper read by Pickles and Wills before the I.E.E. on single-phase supply in Great Britain. It advocated two conductors, as was common in New Zealand and the great merits, both technically and economically, over the three-phase system were strongly stressed and agreed upon by members when the paper was discussed. In the case illustrated in the paper, the single-phase lines supplied transformers up to 50 kVA capacity and farm motors were supplied up to 25 h.p. single-phase. In that respect, the system carried heavier single-phase loads than did any similar system in New Zealand.

Concerning "Rural Electrical Supply Overseas" (see Page 237), Mr. Buckingham thought it could be claimed that the coverage in New Zealand was more complete than in Australia, Canada, America, or Great Britain. Coverage was the most important factor. As to the R.E.A. activities in America, by the end of 1941 when construction more or less ceased, capital costs were reasonably low and ran from £200-£250 per mile, interest and sinking fund charges were reasonably low, and power charges were just over one cent per unit, which some would say was rather high. The test the R.E.A. systems had to face was the maintenance cost after the first ten years' operation. There had been much criticism of R.E.A. lines in America.

One factor in keeping up capital costs in New Zealand was sales tax and import control. Many of the stationary oil engines to which Mr. Mandeno referred were probably very little used. They had been superseded by electric motors but had not been removed. He mentioned supply to electric shearing plants but no one aspired to get much revenue from that. The main difficulty today with such a demand from consumers for shearing equipment was to give supply, because the return could be greater in other ways.

As to assistance to back-country areas, Mr. Buckingham agreed that the subsidy to be given by the Rural Reticulation Council might not, in many cases, be adequate, but it was greater than under the R.E.A. in the United States and greater than the assistance given for rural line construction in Canada. He agreed with Mr. Mandeno that better assistance would have been given by modification of bulk supply tariffs.

He hoped the agitation for local hydro plants would be continued, notwithstanding that the reasons given by Mr. Davenport might be sustained at the moment.

Mr. Mandeno's remarks regarding span lengths showed it was dangerous to be dogmatic. Canterbury engineers' experience was that customary span lengths were too long to withstand snow conditions and the spans were being shortened in new construction. Mr. Buckingham asked Mr. Mandeno how he dealt on his single-phase spur lines with high resistance earth faults without leakage relays. Maintenance of 5 ohm earths under Canterbury conditions would be almost impossible and so also would the use of long earth pipes.

MR. N. A. DAVIDSON suggested that attention should be directed to the question of transformers as a substantial item of cost in rural lines. On many lines the transformer amounted to one-third of the total costs and to more than the cost of the poles. Standardisation should be taken up by the interested parties. The question of meters was considered in an earlier paper and in rural areas opinion was very strongly for one meter for one farm. There was a strong case for modification of tariffs.

Mr. Mandeno discussed impedance in an earth return circuit. In designing a new line, what practical test did he make to determine this for the particular line and locality? He mentioned rural costs in the U.S.A. and how low they were compared with New Zealand figures. That was largely due to the use of standardised transformers. Bulk power charges were absorbing an increasing amount of power boards' revenue and that would have a big effect on rural reticulation.

Mr. Davidson pointed out that if changing over to a two- or three-phase line later, Mr. Mandeno must shorten his spans. One criticism of his system was: how was he going to make the change-over to two or three wire.

MR. J. LYTHGOE thought Mr. Mandeno had done something worthy of comment. In connection with losses on his lines, had he gone into the matter of losses single-phase against 3-phase lines? When one looked at the statistics of the supply authorities the amount of total units lost was noticeable. If there were going to be an increase in the cost for power, the supply authority engineers would have to find some means of balancing it and if they could utilise half the quantity of units lost at the present time some thought they might nearly balance the ledger. All knew that as the demand increased the losses became greater. It was shown in Pickles's paper that losses in Ayrshire were considerably less than any supply authority in this country, because they had to pay for every unit. Here electricity was bought on a kVA. demand basis—and blow the losses, so long as one obtained one's revenue. The losses in some cases were so great that they would stagger engineers brought up on steam generation.

In country districts, the industrial or motor load was very small in comparison with the house load and with the single-phase line the economic factor entered; but where, as Mr. Lancaster mentioned, a 100 h.p. motor came on, one had to have a 3-phase line to supply it and the revenue from that extra 100 h.p. had to pay for the extra line. No one had mentioned the class of pole Mr. Mandeno was using in his locality. Poles were practically unprocurable from Australia and they were relying on the home-made reinforced concrete pole. He would like the cost of the T and L poles and the composite pole.

MR. F. T. M. KISSEL did not wish to discuss any of the technical aspects but had one or two comments in connection with the section "Rural Supply Overseas", and rural costs in the U.S.A. The R.E.A. was to a very considerable extent comparable with the R.E.R.C. subsidy scheme in New Zealand and when Mr. Mandeno compared the average New Zealand consumers per mile as being comparatively high as compared with the American figures he must remember that the averages he had taken in New Zealand were on systems developed without assistance from anyone but with the ingenuity of the engineers of the power boards and the support of the consumers in the same area. If he were to make a year or so hence a comparison of consumers per mile and cost per mile under the New Zealand rural reticulation scheme, he would find it compare more than favourably with the U.S.A. figures he had used.

A meeting of the R.E.R.C. was held just before Mr. Kissel left Wellington and quite a number of subsidies were granted to power boards throughout New Zealand. Generally the requests for subsidies were rather less than anticipated. There might be reasons for that. First and most likely was the difficulty of doing reticulation work of any kind at the present time, boards therefore delaying making application until conditions were more favourable. It might also be due to the explanation given to the power boards at their conference in September—that the assistance was for rural reticulation, and not for power boards to carry out ordinary reticulation. R.E.R.C. schemes were to enable power to be carried to areas which otherwise would not be reticulated. Among the applications dealt with by the board, 75 to 80 per cent. were granted, perhaps not to the full $7\frac{1}{2}$ per cent.; they might have been modified to some extent. Lines costing £700 to £1,100 per mile were not rural lines but lines travelling through areas quite capable of reticulating themselves. The council was concerned with the areas which otherwise would not be reticulated and were not likely to grow. He was pleased to note that most supply authorities recognised that fact and had been abstemious in their applications.

Mr. Kissel thought it would be found when the lines were summarised that they would probably average under two consumers to the mile. The figures quoted by Mr. Mandeno were of $2\frac{1}{2}$ under the R.E.A.; they also gave the cost as about 4.2 cents per unit. It was hoped the supply on these N.Z. rural lines was going to cost the average consumer less than 4.2 cents per unit, and also that the capital costs were not going to be very much more than the figure of 1,600 dollars coming down to 800 dollars. That was in New Zealand just about the upper limit for a 3-phase line running into a rural area. The American costs were not very much lower than the costs in New Zealand. Mr. Mandeno had a scheme to build lines at £180 and Mr. Buckingham nearly the same. New Zealand compared more than favourably and was to be congratulated on getting the existing coverage without any subsidy and on the fact that the subsidy now came from the electrical system and not from any Government funds or outside funds of any other kind.

MR. F. W. FURKERT asked had there been any investigation into losses on these lines as against losses on the normal two-wire line. It seemed that the system set out in Mr. Mandeno's paper was one which might well be adopted in places where it was reasonably certain that there would be no large increase in load. In the far North there were places quite unlikely to develop so much as to need a 3-phase line. It turned very largely on future growth. If there was not going to be any, Mr. Mandeno had probably brought forward something which would be of considerable advantage.

Mr. Mandeno in reply said that his paper had set out to discuss the broad problem of back-country reticulation, a subject of which the engineering and economic aspects had not been discussed as such up to the time the paper was originally presented in 1945. In thus attempting to treat the matter somewhat broadly it had not been possible to go much into detail. Those who took part in the discussion had indicated an interest in the single wire 11 kV. system of distribution and had asked numerous questions regarding it. It would be understood however, for the reasons given, that no attempt was made in the paper to fully argue the case for that system.

Mr. Lancaster, in common with other contributors to the discussion, had expressed a doubt as to the feasibility when planning the reticulation of a new area of determining which lines should be designed for 3-phase and which for single wire.

In practice it was found that if reasonable judgment were exercised in the early design of the scheme remarkably few changes from single to three conductors were found to be necessary. The earth return system obviously had its special application in the back country. In these areas it was often economically impossible to reach communities and homesteads by 3-phase lines, whereas it could be done with 11 kV. single wire. Were such communities, asked Mr. Mandeno, to be denied the electric service until, with the aid of such subsidy as might be available, they could finance the cost of a 3-phase extension?

In any case why should they wait for the 3-phase line seeing that, if not in the majority of New Zealand communities at present unreticulated at any rate in many of them, the single wire system would give the better service, both in the matter of voltage regulation and in dependability of the supply. It was admitted that as at present developed and authorised the limit of load which might be carried by a single wire circuit was approximately 100 kVA., but in the majority of the districts now lying round the fringes of reticulated areas of the Dominion a distributing centre could be chosen from which to radiate single wire lines, the demand on which was unlikely to exceed 100 kVA. for a considerable period of time and, with increasing experience of the single wire system, it would appear likely that it might be found practicable to raise the present somewhat arbitrary limit of 100 kVA. on such lines.

In reality it was not nearly so pressing to provide for introduction of 3-phase supply as some of those who contributed to the discussion appeared to contemplate. So far as carrying capacity of the lines was concerned, Mr. Mandeno continued, it should not be overlooked that the single wire line operating at 11 kV. would carry as much power with the same percentage line loss as a 3-phase 3-conductor 11 kV. line having three times the weight of conductor per mile of line, and on the secondary side of the transformer the 230/460 volt 3-wire line was more satisfactory for reaching homesteads at some distance from the transformer than was the 230/400 volt 4-wire 3-phase line. And as a source of motive power the single-phase system was not at such a disadvantage as some appeared to think.

An increasing number of industrial plants using power for numerous motors, in some cases aggregating many hundreds of h.p., was being run from single-phase systems. However, Mr. Lancaster asked what would be done to provide for the possibility of a demand for supply of 100 h.p. to a saw-mill which might be established alongside a single-wire line. The reply was that the economies which the latter system might be expected to have already effected would, in all probability, enable the single-wire line to be written off and, if the business warranted it, a new and undepreciated 3-phase line would either replace or supplement it. For instance, suppose a single-wire line could be constructed, under present conditions, at £190 per mile, then in the class of country in mind a 3-phase line of corresponding capacity would cost at least £350. Assume 10 miles of line were involved and that (also a fair assumption) line maintenance costs were proportionate to the capital cost and assume capital charges, depreciation and maintenance at 10% of first cost per annum. Then if the application from the saw-mill owner were received half-way through the life of the asset, say 10 years from commencement of supply, it was apparent that the total annual savings which the lower cost line had effected was practically equal to its first cost.

In his experience over a fair number of years Mr. Mandeno had found that the chances of any given line in back country being called upon to carry such a motive power load was a small fraction of the once in 10 years assumed. His experience also indicated that additional capacity had to be built into 3-phase lines at least as often as into single-wire lines.

A passage in the introduction to Messrs. Pickles and Wills' recent paper before the Institution of Electrical Engineers on the reticulation of the County of Dumfries, Scotland, was relevant:—

> "Sound engineering development consists in supplying the immediate and foreseeable needs at the minimum of cost, consistent with technical suitability and reliability. There is no virtue in making excessive provision for future development or in providing plant which is unduly heavy or costly for the work. Risks must be balanced, and the best solution of any engineering problem is usually one which combines immediate suitability with flexibility to meet increasing demands. In this particular problem the authors claim that the single-phase system satisfied all immediate and foreseeable needs at the minimum cost, and is sufficiently flexible to meet growing demands. Moreover, for this particular purpose the system has technical advantages over the 3-phase system, such as simplicity, reduced maintenance, absence of the balancing difficulties inherent with small 3-phase supplies, and better use of the mains and transformers provided. One technical disadvantage only is admitted, and that a comparatively minor one arising with certain motive power loads."

As to the maximum size of motors which should be carried on single-phase lines 7½ h.p. motors were operating satisfactorily and driving refrigerators under automatic control about 27 miles from the Board's point of supply. Before long much larger motors operated from these lines were anticipated.

The cost of the earthborer referred to in the paper was approximately £2,200 in 1938, and the present cost of a somewhat improved machine was £3,300.

As to details of the poles used on the particular extension for which costs were given in the paper, these were desapped M.A.H.; those carrying the single wire were about equally 26 ft. and 30 ft., the minimum mean butt diameters being 10 in. and 11 in. respectively. On this extension the poles averaged 6.7 per mile.

Mr. Mandeno appreciated Mr. Lancaster's kindly references to his earlier work, also Mr. Davenport's. Mr. Davenport remarked that the whole question in back-country supply was one of economics, and subject to the proviso that sound engineering rather than rule of thumb was also essential, Mr. Mandeno agreed. Even though subsidy schemes might in some measure tend to obscure the economics of rural power supply the fact would remain that the prosperity and wealth of the Dominion might not be such as to warrant the adoption of other than the best thought out and most economical system for carrying the benefits of power supply to its isolated primary producers.

Mr. Davenport's insistence on the prospect of increasing rather than of decreasing costs of bulk supply was well understood but did not this reinforce the point made that those distribution authorities who were primarily interested in carrying power into remote areas should receive power at the most reasonable costs possible? Most of those authorities at present passed on, in payment for bulk power, from 35 to 55 per cent. (and even more in some cases) of the total revenue received. If they received power at the same cost per kilowatt as the metropolitan authorities, their power costs would be reduced by about one-third. From this it appeared that the introduction of a flat rate of charge in lieu of the present heavily stepped tariff of the State Hydro-electric Department should enable rural boards to effect a saving of something like 15% in their total costs.

It was recognised, of course, that this matter was largely political and it might be that metropolitan authorities might prefer to render assistance to rural authorities by some other method such as the subsidy scheme. But enlightened self interest should ensure that the metropolitan authorities by some means or other made possible the extension of the power service into all but the most remote of those localities from which the Dominion's primary production is drawn.

As to the development of small hydro electric schemes by local authorities it was pleasing to have Mr. Davenport's endorsement of the idea, limited though that endorsement was. The policy of the Department in the past had very definitely discouraged such developments. Yet there were numerous sites available where automatic and therefore unattended plants could be put in for a total capital cost per kilowatt appreciably less than the major stations were costing. Further, such small stations delivered their output adjacent to where it was consumed, so saving transmission losses.

Mr. Mandeno did not think that local authorities, if given the opportunity, would be deterred from such enterprises by reason of lack of capital. Witness the Tauranga Borough Council which in 1926 had spent £64 per head of

population on its hydro electric scheme and, in recent years, would have considerably extended its generating capacity had State policy so approved. This figure for Tauranga compared with a total investment by the State, 20 years later, in hydro-electric development of £17 per head. Mr. Mandeno could not agree with Mr. Davenport that these local schemes would benefit the local community only. There was now a more general awareness of the prospect of continuing power shortages. Each kilowatt produced in the local plants would be at least as effective in assisting to relieve the general shortage as a kilowatt from the major schemes and if, as was maintained, there were local plants which could be installed more cheaply and expeditiously, than the major schemes, what argument remained against their development.

Mr. Davenport contended that it would be more effective to concentrate all available resources on the major schemes but this was surely an example of a general statement which might be misleading when applied to particular cases. For instance, labour was not 100% mobile and there were local schemes for which the necessary labour would be forthcoming at the present time even though the major schemes were, no doubt, being prosecuted with all the expedition that the resources of the State would permit.

Mr. Buckingham had remarked that, for most engineers, the adoption of the system described was not practicable because it was necessary to start such a system with an absolutely clean slate. But it was difficult to understand just why Mr. Buckingham should think so. What was there to prevent any engineer from connecting in a standard insulating transformer at any point along his existing 3-phase 11 kV. lines and running 10, 20 or 30 miles into back country to pick up isolated homesteads on runs or farms. The distribution transformers he would use on this extension would serve also for use if so desired on his existing 11 kV. lines and whether he connected their secondaries for either 2-wire or 3-wire it was hard to see how any complication could ensue to him or his consumers. Mr. Buckingham admitted that under present conditions of high costs the savings of the described system demanded for it serious consideration but he thought they were hardly such as to justify the drastic changes which would become necessary. That remark possibly suggested that changing over 3-phase lines to single-wire lines had been suggested but that was not so. There might, however, be numerous cases where existing 2-wire single-phase lines had reached the limit of their capacity and so should be changed over to single-wire operation. Such a change would increase their capacity up to four times.

Mr. Buckingham had remarked that all agreed with running lines according to topography rather than along roads and it was true that it was now fairly general practise to do so. At the time that the Tauranga rural system was installed however, Mr. Mandeno could not remember any previously erected system where that principle had been to any extent generally followed.

The additional cost of the insulating transformer was quite admittedly a disadvantage even though as shown in the paper there were numerous compensating advantages. When however the cost of the insulating transformer was spread over the 10 or more miles of line fed from it the cost was relatively light.

Mr. Buckingham referred to the recent paper by Messrs. Pickles and Wills describing the rural electrical development of the County of Dumfries. That paper had, according to reports, made a profound impression in Britain and it confirmed in a striking manner several of the principles for which Mr. Mandeno stood, as for example the use of the single-phase 3-wire 230/460 volt secondary distribution system. So far as he was aware the Tauranga scheme was the first rural supply in any country in which the system had been adopted. Information indicated that other considerable rural areas in Britain were likely to be reticulated similarly.

If single-phase supply was now recognised to be best in Britain could there be much more lingering doubt as to its suitability for New Zealand back-blocks? By comparison the county of Dumfries was thickly populated as would be apparent from the relative figures for Dumfries and Bay of Islands Power District. In the latter district the reticulation was in course of construction, somewhat over half the area having been covered.

	Dumfries.	*Bay of Islands.*
Area of Supply (square miles)	1,175	2,637
Population	60,000	30,570 (51% being Maori)
Number of Consumers	11,126	3,702
Total Route Length of Lines (miles)	810	671
Route Length of HT Single-phase Lines	235	429
Number of Distribution Transformers	993	742

These figures suggested that in order to adequately meet the problem of electrifying the back-blocks of New Zealand engineers might well consider further departures from 3-phase practice than British engineers had come to recognise as desirable and necessary.

Mr. Buckingham had remarked that the authors of the Dumfries scheme advocated for primary distribution the 2-wire single-phase system as commonly used in New Zealand rather than his scheme. But so far as Mr. Mandeno knew it had not occurred to anyone in Britain to attempt the use of single-wire distribution and, in any case, as shown by the comparative statistics just quoted the problem in Britain was very different from that of carrying power into the back-blocks of New Zealand. Furthermore it might not be irrelevant to enquire whether there was any rural system established anywhere prior to the Tauranga rural system which had adopted direct transformation from 11 kV. distribution lines or had adopted single-phase as the standard for supply to motors, especially in a district which was predominantly a dairying one.

Mr. Buckingham had questioned the advocacy of the use of long spans having regard to the occurrence of snow storms in certain areas. He must agree, however, that long spans were desirable so far as conditions permitted and with single-wire construction there were several factors that made possible the use of longer spans, as for instance, stronger conductors might be used, loads on supports were reduced and danger of clashing of conductors due to sudden release of adhering snow was eliminated.

No difficulty whatever had been experienced up to the present time in clearing high resistance faults on single-wire lines and it was doubted whether there was any populated district in New Zealand where such a line falling to the ground would not be promptly isolated. In this connection Mr. Buckingham would perhaps have noted that all lines in the Dumfriesshire scheme were protected with arc suppression coils, the implication of which might well be pondered by New Zealand power supply engineers.

Mr. Davidson's query regarding the scheme was how would one provide for changeover to 3-phase? Occasionally on short routes which had been expected to develop into extensions of the main 3-phase system they had erected 4-hole arms on which only one conductor was run, having in view the addition of the 3-phase circuit later, but in general they agreed with the contributor to the discussion on the Dumfriesshire scheme who stated: "In laying out lines of this description it is essential to design them for single-phase work so as to obtain the full economy possible. Lines should not be designed so that they can be converted later to a 3-phase system."

As to Mr. Davidson's question regarding tests for impedance there had not been occasion to make tests for any proposed new line. In practise the impedance of the earth return had been found negligible in the type of circuits under consideration, provided the normal attention was given to the transformer earths.

Mr. Lythgoe had enquired regarding the relative losses in 3-phase as against single-wire working. The reply was that no comparative statistics were available for such losses on typical examples of the respective systems which were truly comparable in all such matters as mean radius of distribution, loading per mile of line or the ruling level of costs at time of construction or costs per mile of reticulation. But on general principles it appeared that the single-wire should, other things being comparable, be the more efficient.

Pickles and Wills' comparative figures for transformers of equal output were not disputed. They said that as compared with 3-phase transformers single-phase were:—

20% cheaper
10% lower in iron and copper losses
15–25% lighter
have better regulation
have fewer bushings and other points of weakness.

Admittedly the single-wire system introduced an extra transformer but as against this the high-tension line losses were in general much less. Also because the single-phase earth working transformer substation was cheaper more of them could be used with consequential savings in low-tension line losses.

Mr. Lythgoe enquired for the cost of the concrete poles of L and T section developed. The cost depended in quite appreciable measure on the number of poles over which the cost of the pole making plant might be spread and anyway a bare figure for cost did not signify much nowadays.

The following table gave basic data on some of the standard sizes of L pole. On account of current conditions these designs were worked out to give reasonable strength with minimum reinforcing steel:—

PARTICULARS OF L SECTION POLES.

Length.	Total Weight of Steel. (lbs.)	Volume of Concrete. (cu. ft.)	Weight of Pole. (lbs.)	Ultimate Transverse Strength. (tons/ft.)	Present Contract Price. £
33 ft.	176	12.3	1970	30	7/4/9
30 ft.	160	11.0	1760	28	6/14/9
30 ft.	117	11.0	1720	21	6/3/9
26 ft.	102	9.5	1480	17	5/13/3
23 ft.	89	8.0	1250	17	5/3/0

Mr. Kissel had pointed out that the Rural Electrical Reticulation Council Scheme might be expected to show results in New Zealand comparable with what the paper showed the R.E.A. had achieved in America. In this connection it should be explained that the paper was presented to Auckland Branch over 18 months before the Christchurch Conference and at that time no decision had been taken to establish the Rural Subsidy Scheme. But even though the R.E.R. Fund was now an established reality the Dominion could not afford to regard the problem of rural reticulation as fully solved.

As shown in the paper the R.E.A. undertakings, which by statute were required to be self-supporting concerns, were succeeding in balancing their accounts with average total revenue of 108 dollars, or say, £34 per mile.

This was an average figure over their complete undertakings involving many hundreds of thousands of miles of reticulation. The comparable figure for all New Zealand Power Boards was an average revenue of £190 per mile (which also was approximately the average cost per mile) Mr. Mandeno did not wish to decry the New Zealand achievement but in the light of the figures quoted in the paper he felt they could not afford to become complacent about it.

Mr. Furkert had enquired about the relative losses as between single-wire and 2-wire lines and he would note that this had been covered in replying to Mr. Lythgoe.

In conclusion Mr. Mandeno had to reiterate what he had mentioned in introductory comments at the Conference, his acknowledgment of the co-operation of Mr. Kissel and Mr. Green and of the officers of their respective departments in authorising the practical application of the system which had been developed. Perhaps he might particularly refer to the co-operation of the following District Engineers of the Telegraph Department, namely, Mr. G. W. Gilchrist, and the late Mr. P. H. Mason.