NIGEL HARRISON TST

A REVIEW

OF

SOME ASPECTS

OF

ELECTRICITY DISTRIBUTION

BY

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INSTITUTION OF ELECTRICAL ENGINEERS

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A REVIEW OF SOME ASPECTS OF ELECTRICITY DISTRIBUTION

Address given in Liverpool on October 1, 1956, by Mr. P.d'E. Stowell

as Chairman of the Mersey and North Wales Centre of the

Institution of Electrical Engineers

When I realised that it would be necessary for me to choose a subject for an address which would be of general interest I found that I was presented with something of a problem. I looked back through the records and discovered two things. First, that with few exceptions Chairmen of Local Centres choose for their address a subject associated directly with their work. Second, that over the years many addresses have already dealt fairly exhaustively with the distribution of electricity. I pondered on the idea of being one of the exceptions, for the reason that I am concerned with the distribution of electricity; it is a subject which has become so commonplace as to be taken more or less for granted, and however interesting it may be to those engaged in it, it is not easy to make attractive to those who are not. However, I decided in the end that I should fall into line with the majority of my predecessors and deal with my own subject. I thought that the integration of the industry which has occurred in the last few years, might enable me to take a broader view of electricity distribution than most of my predecessors could, and I hope to be able to approach the subject from a somewhat new angle.

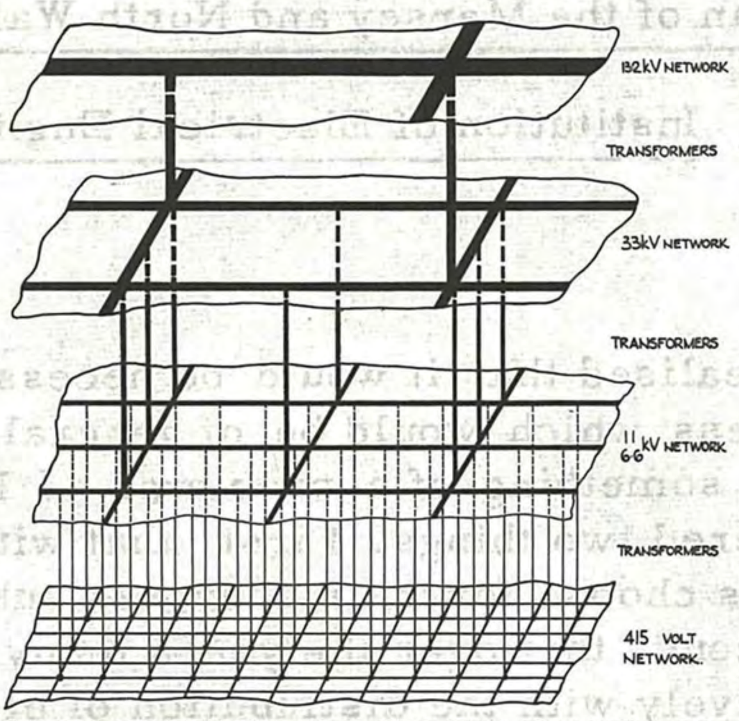
There is of course a vast amount which could be told about the manner in which distribution practice has been unified and improved, but it is impossible to do this comprehensively in the time at my disposal. So I propose to deal with certain selected aspects and particularly those which differ most from previous practice or from practice elsewhere.

One of the important things that must be emphasised about public electricity distribution networks is that they have evolved over an extended period of time, and therefore many features of past practice continue to exist for a very long time. These features have a bearing on future design because one has always to make the best use of what one has, and it also means that some knowledge of the background is necessary to a full appreciation of distribution practice; and it makes it somewhat difficult to make categorical statements about a distribution network for it is not, nor will it ever be, a coherent entity exhibiting characteristic features uniformly throughout it.

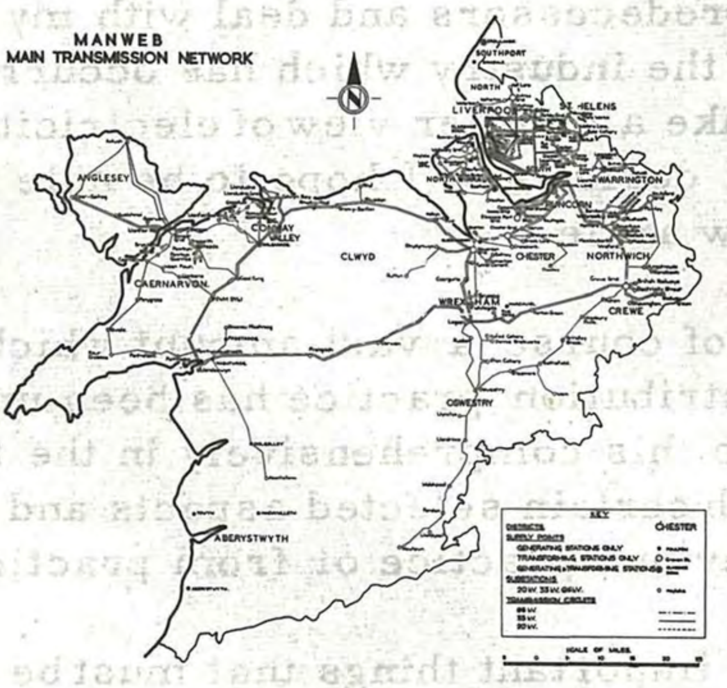
Quite apart from progressive changes in distribution practice as techniques have improved over its 60 to 70 years existence, the electricity supply industry has passed through a number of phases which have had such a considerable effect on development that they are worth mentioning briefly.

First there was the direct current era when each power station served its neighbourhood within a very small radius, strictly limited by the use throughout of the voltage at which the consumers were supplied.

ON THIS AND THE FOLLOWING PAGES
ARE REPRODUCTIONS OF THE SLIDES
WHICH ILLUSTRATED THE ADDRESS



SYSTEM OF NETWORKS FOR DISTRIBUTION OF ELECTRICITY.



New points of supply to the Area Boards agreed in the eight years 1948 - 1956	128
Estimated capital saving compared to development from existing points of supply	£12,300,000

Next came alternating current with generation usually at 6.6 kV. This enabled the distribution distance to be greatly increased, but still it was characteristic for most localities to be supplied by distributors at that voltage, radiating entirely from the local power station, and as the load grew more and more generating plant was installed there.

The third era began with the introduction of the 132-kV grid under the 1926 Electricity Act. Even this did not alter the basic feature of a distribution system being centred on a single supply point, because, although the grid did interconnect generating stations, certain provisions of the Act made it uneconomic for most undertakings to take a supply at more than one point.

So we see that from the beginning distribution systems continued to be developed, each around a single point of supply. This method of development had the apparently inevitable result that many distribution centres became much too large for the voltage in use. Short-circuit levels became excessive at these centres and the amount of copper buried in cables in the immediate vicinity of some of them needs to be seen to be believed.

The fourth era, that of complete integration is the one we are now in. It started in 1948, roughly a quarter of a century after the previous era commenced, and it resulted from the 1947 Electricity Act. For the first time it then became possible to depart from the idea of distribution networks emanating from a single point of supply. Instead it became possible to adopt an integrated method of distribution, and to make full use of a system of networks at different voltages, fed in succession one from another. This forms the main theme of my address, but there will be some digressions from this theme.

The integration of distribution was, of course, the main purpose of the 1947 Act, but a future Chairman of this Centre in an era yet to be realised - probably the nuclear power era - will perhaps also record among the characteristic features of the era we are now in, the divorce of generation and distribution, the development of the 275-kV super grid and the relegation of the 132-kV grid to distribution purposes. By the divorce of generation from distribution I do not mean only the separation laid down by the Act into a generating authority - the British Electricity Authority as it was, now the Central Electricity Authority - and a number of autonomous distribution Boards, of which MANWEB is one; I refer more particularly to the physical fact that the power stations of the present are no longer being built to supply local distribution systems, but instead are being connected solely to the 132-kV grid. This is a feature that was ripe for development, and indeed began in a small way in the previous era. But now in this era, it is the rule rather than the exception. For instance, it applied to three out of the four new power stations put into service in the Merseyside and North Wales area since 1948. That it did not apply to the fourth was only because the scales of balance just failed to be tipped over in time.

With the power stations connected direct to the 132-kV network it is inevitable that the 132-kV network is becoming a part of the distribution system. It will become more and more so as time goes on, aided by the introduction of the 275-kV network. Indeed the connection of power stations direct to the 275-kV network will soon be a fact, and in a decade or so, if large central power stations continue and I think they will, all the important power stations will take very little note, if any, of the existence of the 132-kV network. I put in the reservation about large central power stations, because there is a faint chance that a relatively small and completely automatic generator working from nuclear power might again make local

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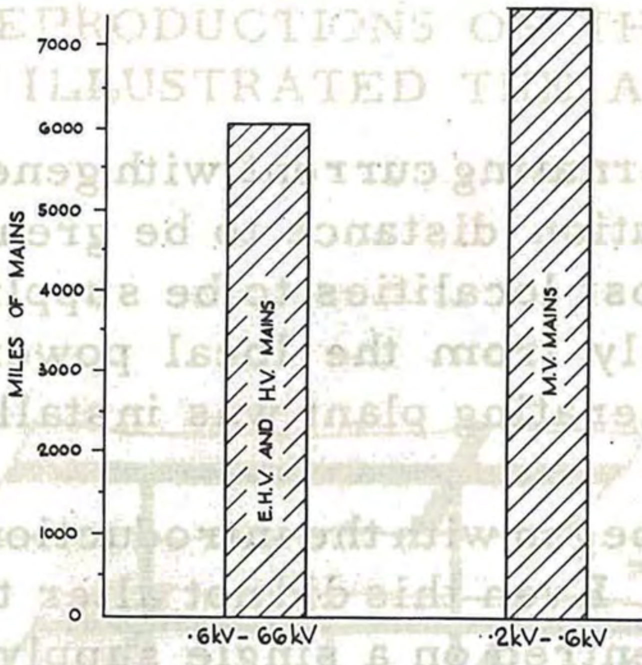
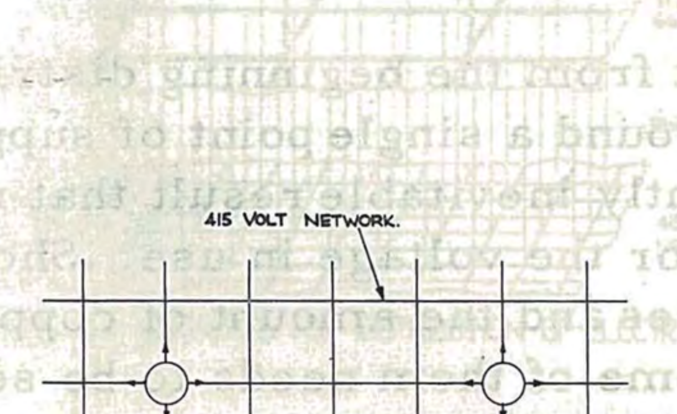
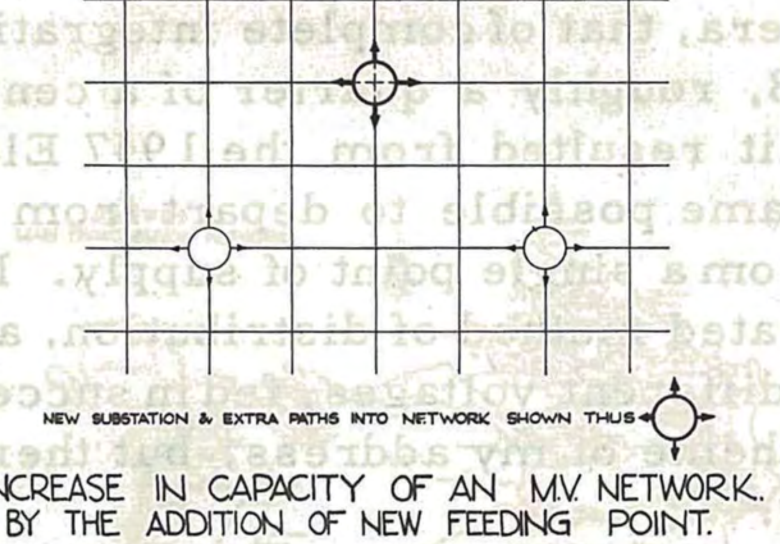


TOTAL MILEAGE OF MAINS IN MANWEB
AT 31/3/1956.



INCREASE IN CAPACITY OF AN M.V. NETWORK.
BY THE ADDITION OF NEW FEEDING POINT.



COMPARISON OF OLD & NEW METHODS OF PROVIDING MEDIUM VOLTAGE SUPPLIES TO AN URBAN AREA.

generation economic, and as a result take us back almost to where we came in.

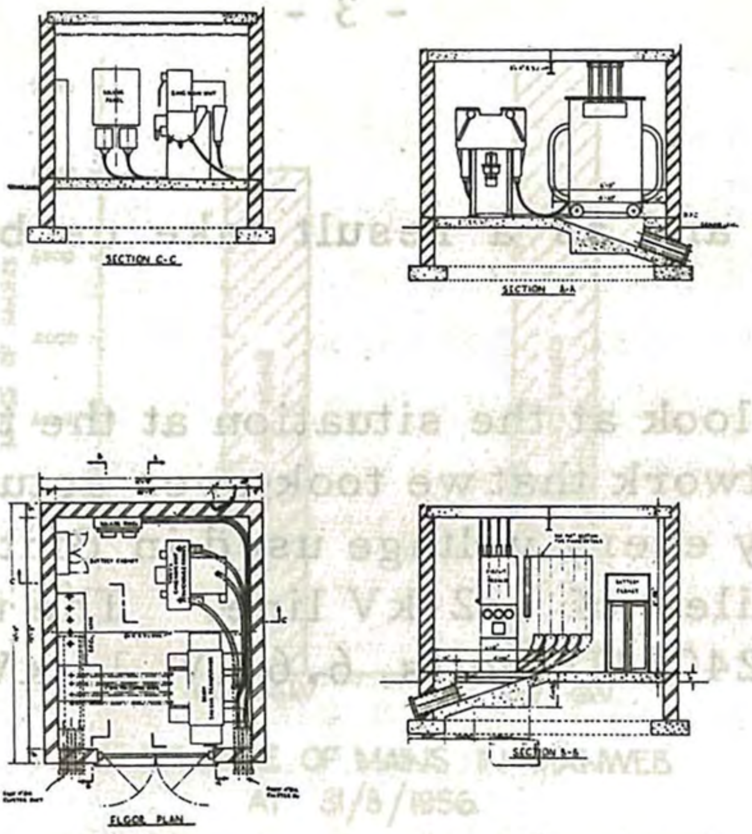
Let us now look at the situation at the time MANWEB came into being in 1948. The network that we took over actually consisted of sections operating at practically every voltage used in Britain, from 110 volts up to and including a few miles of 132-kV line. The networks that were most common were those at 240/415 volts, 6.6 kV, 11 kV and 33 kV and of course the 132-kV network.

First, let us start with the lowest voltages. Although the nominal 415-volt distribution network is the one that has perhaps the least notice taken of it, in fact any distribution system invariably has a considerably greater mileage of medium and low-voltage mains than of all the other voltages put together. In the case of MANWEB, the figures are 7500 miles of 415-volt mains out of a total of 13500 miles of mains; and it is in the medium and low-voltage networks that about half of our invested expenditure lies. Moreover, this expenditure consists not only of the cost of the cables - I am referring at the moment to the urban underground systems - but of the cost of burying them in the ground, and this is at least as costly as the cables themselves. It follows that it is seldom economical to lay down small mains in the first place, and to add additional copper later as the load grows, because of the cost of digging up the ground twice.

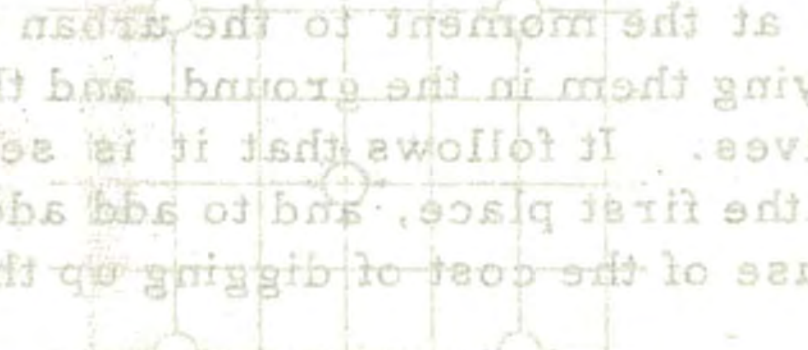
But at the same time one obviously cannot afford at the outset to put down a network of mains and substations, which will cater for all future needs, even if one knew for certain what the future had in store. However, the load with which a network can deal can be increased very considerably, without increasing the size of the mains, by increasing the number of feeding points and so increasing the number of paths over which the power can be distributed; and at the same time reducing the distances over which it has to be distributed. That provides the solution which it is now generally agreed is the right one. It is, of course, well known that voltage drop is one of the most important limits to the capacity of a distribution network, particularly at the lower voltages and everyone knows that if the distribution distance is halved the power that can be distributed is doubled.

Therefore, it is sound practice to aim at a network of medium-voltage mains which, once provided, will not be expected to require any material additions for all time, and of course it is desirable to use the minimum size of cables which it is judged will serve this purpose. The network is fed by transforming stations, and the distance to be distributed, and hence the capacity of the network, is determined by the spacing between the substations, and hence by their number. So at the beginning, when the demands on the network are relatively small, the minimum number of substations are provided, and others are added progressively as the load grows.

To make this arrangement work out in practice, it is necessary that the mains should be of reasonably uniform size throughout, as otherwise it is impossible to add a new substation, without expensive additions to the medium-voltage mains to connect it into the network. Unfortunately, in some of the networks put down in the past, the principle was adopted of using a large variety of sizes of mains to suit the expected load on them. Thus very large mains were used near the initial substations, where the current is high, tapering to small mains on the fringes between substations, where it is low. As a consequence there was a tendency to increase the size of substations without increasing their number, instead of increasing the number and retaining a uniform size of substation. In particular, transformer sizes were tending to increase, and substations having 2000



500 kVA SUBSTATION



SOME TYPICAL METHODS OF GIVING SUPPLY TO INDUSTRIAL CONSUMERS.

kVA of transforming plant were becoming common, and even 4000 kVA was not unknown.

Large transformers for low or medium-voltage distribution, say, of 1000 kVA and above are undesirable, because the loss of one of them due to any cause is a serious embarrassment. With large transformers, and particularly with a tapered network, it is usually quite impossible to transfer the load to neighbouring substations. The consequence is that each substation has to be self-supporting, and duplicate transformers in each substation become the rule rather than the exception. This, obviously, means a poor utilisation factor, and adds considerably to the cost. If, on the other hand, transformer sizes are limited, and the network is not tapered, the load of any one transformer can be redistributed among its neighbours, and high utilisation factors are possible. This is the principle of what I call the network system, and which I wholeheartedly believe to be the best arrangement: and it applies not only to the 415-volt network, but equally to the higher-voltage networks to which I shall refer later.

We limit our transformers feeding medium-voltage networks to 500 kVA and the network itself is composed mostly of 0.1-in^2 cables reasonably uniformly throughout, except for spurs for which smaller sizes are satisfactory and for the very short connections into the substations where 0.2-in^2 cables are occasionally necessary.

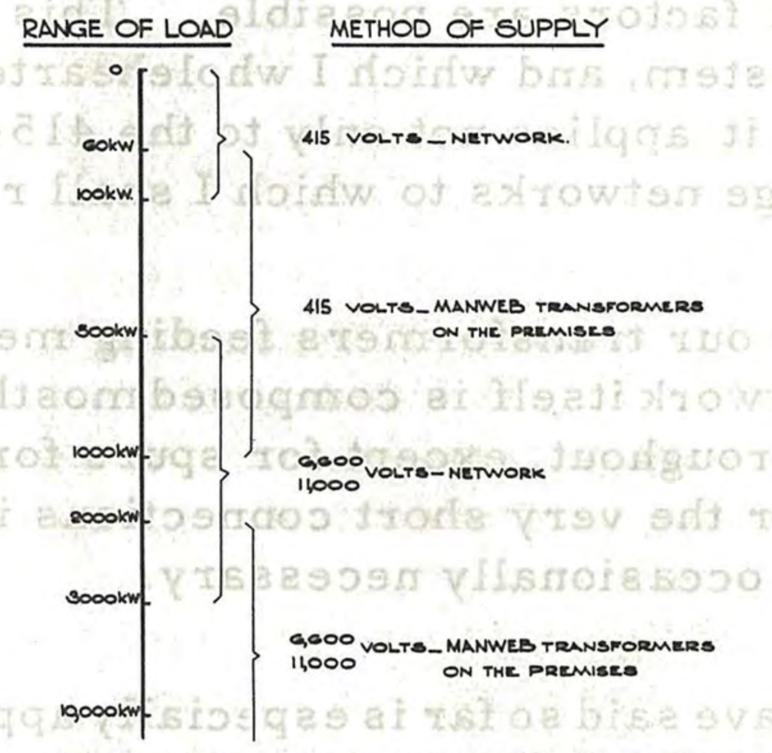
What I have said so far is especially appropriate to those medium-voltage networks where the load of each and every consumer does not deviate too widely from an average value, and potentially at least this is absolutely true of networks serving purely residential loads, that is housing estates. But of course many networks exist, for example in those parts of towns which have commercial and small industrial premises, where this does not entirely apply. In the course of time it is by no means uncommon for the character of the load on a network to change materially due to change in the use of the premises, and here and there individual loads, which are greatly in excess of the average, appear. It then becomes a problem of how to deal with these larger loads for there is an obvious limit to the size of an individual load which can be tapped off the network without sooner or later running into serious trouble.

For long enough now such a limit has been abundantly recognised, although opinions have differed fairly widely on the appropriate value, and on the method of solving the problem. The solution in general is that the larger individual loads must be carried on the high-voltage network direct - there is no doubt about that - and for really large loads the solution is simply to give the consumer a supply at high voltage, that is, 6.6 or 11 kV. By giving the supply at high voltage I mean that it is metered at high voltage and the consumer then takes over the supply at that voltage and transforms it to meet his requirements. As a quid pro quo for taking the supply in bulk in this way, such consumers have always been offered a reduced tariff, which takes into account the reduced cost of supplying them.

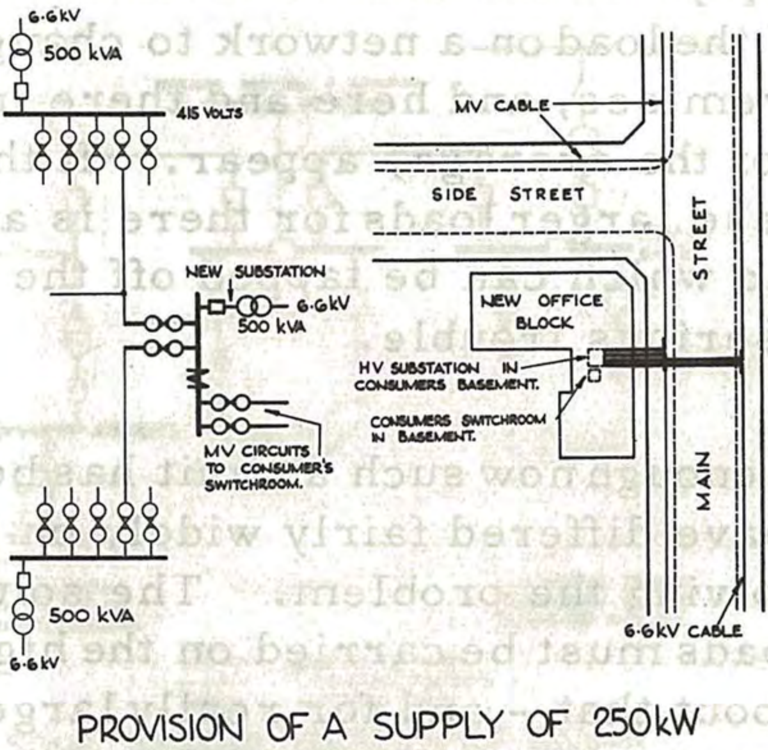
To give a supply at high voltage, however, entails considerable costs represented by the switchgear and expensive metering equipment needed, and these costs are substantially independent of the size of the supply. So there is a lower limit to the size of supply for which high voltage is a really economic proposition for the supply authority. Nor, except for large loads, can it be attractive to the consumer, as he may have to duplicate his transforming plant to give him satisfactory security and again costs which are independent of load make this expensive for small loads.

The C.E.A. and Area Boards standard protective current transformer for 6.6-kV and 11-kV 150-MVA switchgear controlling step down transformers has a ratio of 80/40/5.

0.5 seconds is the limit of time for which this transformer can be designed to carry 13.1 kA.



METHODS OF SUPPLY TO INDUSTRIAL CONSUMERS NORMALLY USED



PROVISION OF A SUPPLY OF 250kW TO A COMMERCIAL CONSUMER.

By whatever standard one adopts, there is in fact a considerable gap between the load which can be supplied economically from the 415-volt network, and that which can be supplied economically at high voltage. Although the upper limit of supplies from the 415-volt network has usually been recognised, the lower limit of supplies from the high-voltage network has often escaped notice, and apparently still does in some areas. The lower limit of supplies from the high-voltage network is about 500 kVA, first on the score of economics and second, because it is virtually impossible to design a satisfactory current transformer for a primary current less than 40 A. This represents about 500 kVA at 6.6 kV or 800 kVA at 11 kV. By satisfactory is meant, among other things, a current trnasformer capable of withstanding a normal short-circuit level for a reasonable time. For the usual level of 150 MVA at 6.6 kV, that is a short-circuit current of 13.1 kA, even a primary current of 40 A means accepting a time of only 0.5 sec, if the current transformer is to be accommodated in any customary form of switchgear. So I am convinced that it is necessary to avoid giving small supplies in the 100 to 200-kVA region at high voltage, as this entails accurate measurement with a current of 5, 10 or 20 A.

Of course one way of getting round, rather than over, this problem which has also been used, is to give the supply on paper at high voltage, but to meter it at the 415-volt terminals of the transformers, and to use some calculated adjustment for transformer losses. I advisedly used the words 'get round the problem' as it cannot but seem a somewhat round about solution and it has little influence on the economics of the case.

In this area every endeavour is made to work to a limit for supplies direct from the 415-volt network in the region of a demand of 60 kW, or 100 kW of installed load. Above that, however, supplies are still given in the true sense of the word at medium voltage not direct from the network but from a transformer, which the Electricity Board provides, on the consumer's premises. In addition to publishing a tariff for 415-volt network supplies, and one for high-voltage supplies, there is a separate tariff for the case in question, that of a medium-voltage supply from a substation on the consumer's premises. As the high costs associated with the 415-volt network are not incurred for this type of supply, the tariff properly takes account of this. It is thus arranged to be much more attractive than the tariff for 415-volt network supplies, and equally the high-voltage tariff is arranged to become still more attractive only above the limit at which high-voltage supplies are more economic. For a supply at 415 volts from a substation, the consumer has to provide on his premises space and a housing for the high-voltage equipment and transformer, but no more than he would if in fact he were given a high-voltage supply; and he has the advantage that he does not become involved in the ownership of high-voltage equipment, which he does not have the staff capable of operating, nor has he to worry about what will happen in the event of a breakdown. The standby supply is in fact provided by the Electricity Board from neighbouring transformers over the 415-volt network and this arrangement also enables economic use to be made of any transformer capacity, which at any time the consumer does not require.

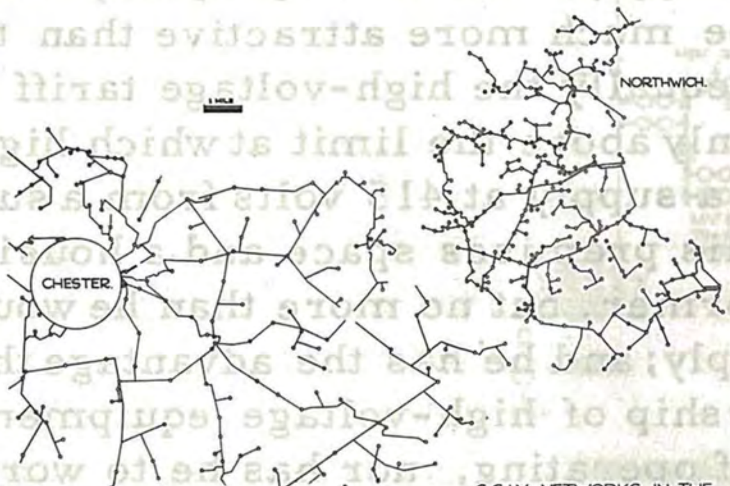
Normally these arrangements provide for one 500-kVA transformer on a consumer's premises above which a high-voltage supply is a reasonable proposition, but in some cases two such transformers may be the best solution. The tariffs are therefore designed so that, if account is taken of all factors, the economic situation is equally favourable in normal cases up to 1000 kVA, either to 415-volt supplies from a transformer, or to high-voltage supplies.

415 VOLT LINE - NEAR CHESTER

200 kVA SUBSTATION - NEAR CHESTER

SINGLE PHASE 6.6kV LINE NEAR NORTHWICH

10 kVA TRANSFORMER - NEAR NORTHWICH



THE FOLLOWING PARTICULARS APPLY TO A RURAL DEVELOPMENT SCHEME WHICH IS IN PROGRESS AT PRESENT:

NO. OF PREMISES TO BE GIVEN SUPPLY	= 521
NO. OF 5-kVA 11/.25-kV TRANSFORMERS (1 PHASE)	= 181
NO. OF 15-kVA 11/.25-kV TRANSFORMERS (1 PHASE)	= 31
NO. OF 25-kVA 11/.25-kV TRANSFORMERS (1 PHASE)	= 3
NO. OF 50-kVA 11/.415-kV TRANSFORMERS (3 PHASE)	= 2
TOTAL NO. OF 11/.415-kV TRANSFORMERS	= 217
TOTAL LENGTH OF 3-PHASE 11-kV LINE	= 25 MILES
TOTAL LENGTH OF SINGLE-PHASE 11-kV LINE	= 52 MILES
TOTAL LENGTH OF MEDIUM-VOLTAGE LINE	= 20 MILES

500 kVA SUBSTATION

DETAILS OF A RURAL DEVELOPMENT SCHEME

So far I have dealt only with some aspects of urban underground networks. In rural areas, somewhat different consideration should apply, though this has not always been properly recognised.

For instance, the rural area around the city of Chester had been pretty comprehensively developed when MANWEB took over in 1948. That development had in fact taken a form not dissimilar from an urban network, in the sense that a comprehensive network of medium-voltage 3-phase overhead mains had been provided alongside almost all the roads, with substations, having 3-phase transformers of capacity mostly in the range 100-200 kVA suitably disposed to supply it.

Oddly enough, the immediately adjoining area around Northwich, which is similar in character, and had been developed to about the same extent, had been done on a very different and much superior pattern. There, no medium-voltage network had been provided at all, in the proper sense of the word 'network'. Instead high-voltage mains, most of them single phase, had been taken along many of the roads, to each small group of premises and even to individual premises. This limited 415 and 240 volts to very short connections, little more than services in fact, direct from each transformer. In this case the majority of the transformers are in the range 5 to 25 kVA and are nearly all single phase. The result is that around Northwich the bulk of the copper has been put into the high-voltage network whereas around Chester most of it is in the medium-voltage network and if one looks at a map of the high-voltage networks in the two areas, the difference is quite remarkable.

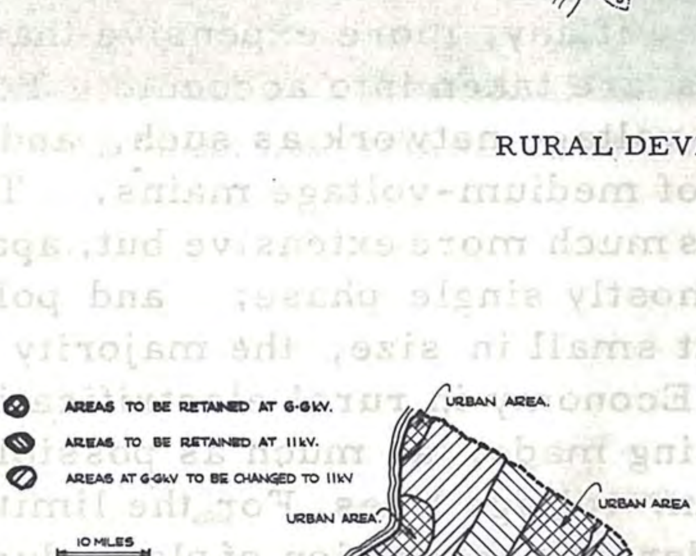
Where overhead lines can be used high-voltage mains are as cheap, if not cheaper, than medium-voltage mains. Moreover numerous small single-phase transformers are little, if any, more expensive than a few large ones even when switching costs are taken into account. So it pays in rural areas not to have a medium-voltage network as such, and in fact to use the minimum possible amount of medium-voltage mains. The high-voltage network consequently becomes much more extensive but, apart from a proportion of 3-phase lines, is mostly single phase; and pole-mounted transformers are numerous, but small in size, the majority in fact have a nominal rating of only 5 kVA. Economy in rural electrification is an absolute necessity, and so use is being made, as much as possible, of the same poles to carry high and medium-voltage lines. For the limited amount of medium-voltage mains, a considerable proportion of plain aluminium conductor is being used in place of copper, and the use of steel conductor for some of the single-phase high-voltage spurs is being introduced again. In many cases electricity supplies have to be taken along routes where telephone lines exist, and vice versa. Two or three years ago a reciprocal agreement was negotiated between the Electricity Boards and the General Post Office whereby, in suitable circumstances, a single set of poles owned by one of the two parties is used to carry both medium-voltage mains and telephone lines.

Whilst speaking of rural electrification it is worth mentioning another aspect of the very extensive developments which MANWEB have undertaken. One of the problems that had to be settled before embarking upon large-scale rural electrification was in deciding where to start. It would have been possible to have selected the more remunerative bits here and there and to have developed them piecemeal. But it was apparent that if that were done, even if it were economically attractive, taking the short-term view, it would entail moving construction staff about the Area at frequent intervals. This would obviously make the complete electrification of the entire Area more expensive, and thus less economical taking a long

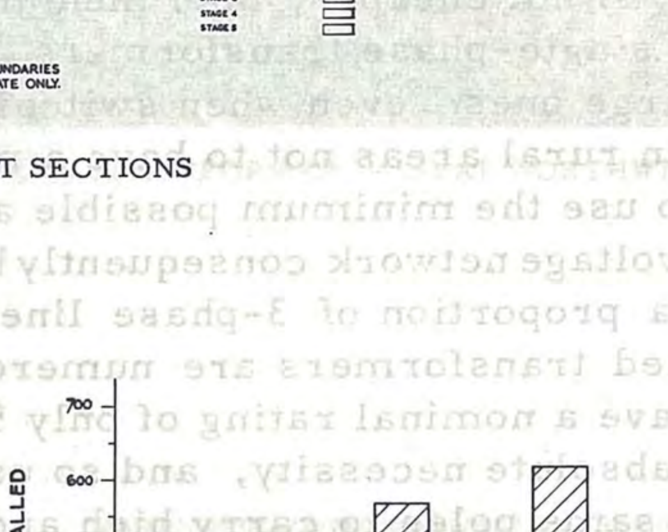
COMBINED 11kV and 415 VOLT LINE

COMBINED 415 VOLT AND TELEPHONE LINE

RURAL DEVELOPMENT SECTIONS



REDUCTION OF AREA
SERVED FROM 6.6kV HV NETWORK.



SWITCHING VOLTAGES OF GENERATING
PLANT IN THE MANWEB AREA.

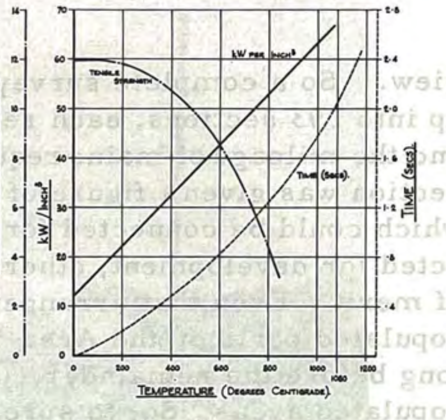
view. So a complete survey was made of the whole Area. It was divided up into 193 sections, each representing 9 to 12 months' work for one gang, and the mileage of mains required in each section was then assessed. Each section was given a figure of merit represented by the number of premises which could be connected for each mile of mains. Sections were then selected for development, other things being equal, in the order of this figure of merit. Even that arrangement would have resulted in the more densely populated parts of the Area in Cheshire and Shropshire being completed long before the remainder, and this would have been hard on the sparsely populated areas. So, to spread the benefits more widely, each county area was treated separately and sections were selected pro rata so that all counties will be fully developed by about the same time. A stage has now been reached which is about half-way through the complete development, and these arrangements have worked out exceedingly well. It has been possible to contain all the requests for electricity supplies that come from individual property owners and committees, which otherwise would have caused construction teams to go hither and thither all over the Area. Indeed, it is interesting to find that the consumers' Consultative Council, who are advised of the sections selected in each stage of the programme, often show a greater determination to avoid deviations from our set plan than we do ourselves.

Now I want to return to the more general problems of high-voltage distribution. I have already said that we were faced with a great variety of different voltages to contend with. Ignoring some 250 miles of high-voltage mains at half a dozen different voltages below 6 kV the local high-voltage distribution is at a nominal 6.6 kV or a nominal 11 kV.

Practically all the densely loaded urban areas used 6.6 kV, and the greater part of the less heavily loaded rural areas have 11 kV. This is a legacy of the past and opinions differ on what should be done about it. Some undertakings were in process of modifying their 6.6-kV networks so as to operate them at 11 kV, and aimed to effect this completely in due course. Others were quite satisfied with 6.6 kV. Such modifications are expensive, particularly in urban areas, and I consider that the increased capacity is better obtained by spending the money on the development of the next higher-voltage network at 33 kV. But the boundaries between the 6.6-kV and 11-kV networks are a considerable handicap to proper development of the network. So we are reducing the length of these as far as possible by eliminating 6.6 kV from rural areas, and also from all the smaller urban areas where it exists surrounded by 11 kV. The larger areas of 6.6 kV are being retracted somewhat to the most satisfactory boundaries that can be found and will then remain, at least for the time being. Nevertheless, apart from transformers, all the equipment which is being used on these networks is suitable for 11 kV.

I have already said that at one time almost 100% of the generating plant fed direct into the 6.6-kV and 11-kV networks. The present position is vastly different from that, and in this Area, where the percentage is perhaps higher than elsewhere, the generators connected to 6.6-kV and 11-kV networks represent only 15% of the total capacity. Generators connected to the 33-kV network and the 132-kV network make up the remainder of the total about equally. I have mentioned earlier that the era of generation at 6.6 kV or 11 kV led to somewhat excessive concentrations of power at the supply points, and of distribution mains in the vicinity. Also high values of short-circuit power were an inevitable consequence. Even when generation ceased at one of these points it was somewhat natural to substitute an equivalent capacity of transformers as the copper was there to distribute a large supply from that point. So short-circuit levels in the vicinity of 500

TYPICAL OPERATING TIMES WITH TIME GRADED PROTECTION.



EFFECT OF 13·1 kA IN 0·1 INCH² COPPER.

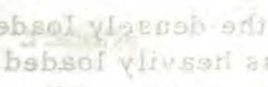
VOLTAGE kV	CURRENT kA	FAULT POWER MVA
6.6	13.1	150
11	7.8	150
11	13.1	250
33	13.1	750
132	10.9	2500
132	15.3	3500
275	15.7	7500

FAULT CURRENTS AND FAULT MVA

FAULT CURRENTS AND FAULT MVA

NETWORK VOLTAGE kV	TOTAL TRANSFORMER CAPACITY TO NETWORK MVA	NETWORK FAULT POWER MVA
6.6	22.5	150
11	22.5	150
33	135	750

TRANSFORMER CAPACITY TO NETWORK RELATED TO FAULT MVA



PREFERRED GROUPING OF TRANSFORMERS.

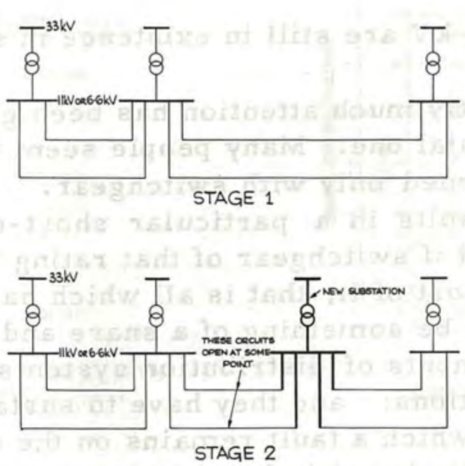
MVA at 6.6 kV and 11 kV are still in existence in some places.

More recently much attention has been given to this problem but it is still a controversial one. Many people seem to think of short-circuit levels as being concerned only with switchgear. The attitude is rather that if a proposal results in a particular short-circuit level at a predetermined voltage and if switchgear of that rating is obtainable, and if the scheme can bear the cost of it, that is all which has to be considered. I believe that attitude to be something of a snare and delusion. The truth is that almost all components of distribution systems are, sooner or later, affected by fault conditions; and they have to sustain these conditions for the short time during which a fault remains on the system. Last session I discussed this subject at length before two district meetings of this Centre, so I will not do so on this occasion. Suffice it to say that distribution networks often have to allow for faults remaining for two seconds, and that cables which carry more than 50 kA/in^2 for this time cannot be guaranteed not to have been permanently damaged throughout their length. So on this hypothesis it follows that even if the network contains no mains of less than 0.3 in^2, the fault current should not exceed 15 kA, no matter what switchgear can be designed for.

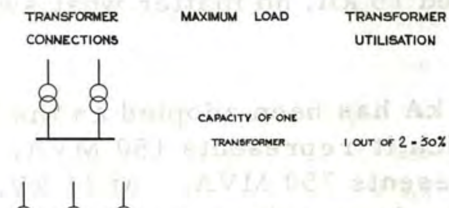
To cut a long story short, 13.1 kA has been adopted as the limit in this area for 6.6-kV networks, at which it represents 150 MVA; and also for 33-kV networks, at which it represents 750 MVA. At 11 kV, 150 MVA is also used as the usual limit because, for one thing, 11-kV networks, as I have said before, happen to be less densely loaded than at 6.6 kV; so there is no general need to make much use of the higher short-circuit level of 250 MVA which corresponds to 13.1 kA at 11 kV. But the 11-kV equipment, including the switchgear that we use, is such that it would be possible, without excessive expense, to increase the 11-kV short-circuit level to 250 MVA if this becomes necessary in future.

To keep short-circuit levels down to the figures which I have quoted is not easy. It entails in particular avoiding the concentration of too much transforming capacity at any one place. This is a good thing to avoid for several other reasons. Just as I have expressed the opinion that, in feeding a medium-voltage network from a high-voltage network, it is preferable to have a larger number of smaller substations rather than the reverse, so also do I firmly believe that it is true of the methods of feeding a high-voltage network from a yet higher-voltage network.

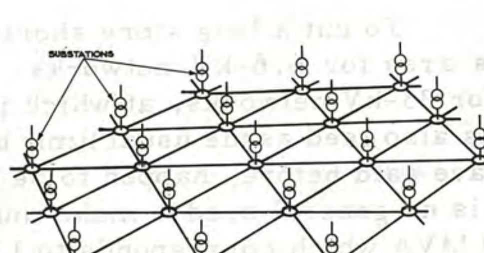
There exists, however, the contrary opinion which runs on the lines that because of the difficulty in obtaining substation sites large substations must be used, and it is true that, for instance, 33/11-kV transformers as large as 20 MVA can be used without exceeding a limit of 150 MVA at 11 kV. But this is only possible by arranging that each such transformer feeds a separate section of network, and full duplication is then invariably necessary. Such an arrangement has the disadvantage that it is virtually impossible to contrive that the circuits have alternative means of supply, so that each fault causes an interruption of supply, and restoration has to be effected by switching. On the other hand, if it is arranged that two or three transformers operate in parallel, then it can be contrived that supplies will not be interrupted at all on the occurrence of a fault. This is a decided advantage and forms the basis of MANWEB policy. Then again, there is a choice between installing several transformers at one point, at least one acting as spare for the others and doing no more than that. Or each transformer can be put at a different point. This has the merit that the distances over which the power has to be distributed at the lower voltage is considerably reduced, and so there is less voltage drop and the distribu-



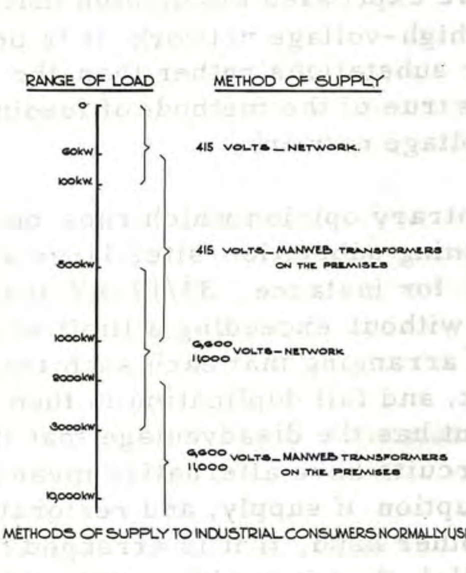
INCREASE IN 33/11 or 6.6kV. TRANSFORMER CAPACITY



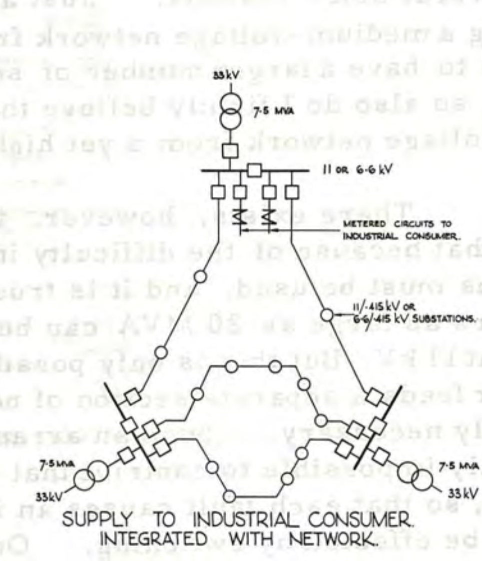
TRANSFORMER UTILISATION.



DISTRIBUTED INFEEDS TO A NETWORK.



METHODS OF SUPPLY TO INDUSTRIAL CONSUMERS NORMALLY USED



SUPPLY TO INDUSTRIAL CONSUMER INTEGRATED WITH NETWORK.

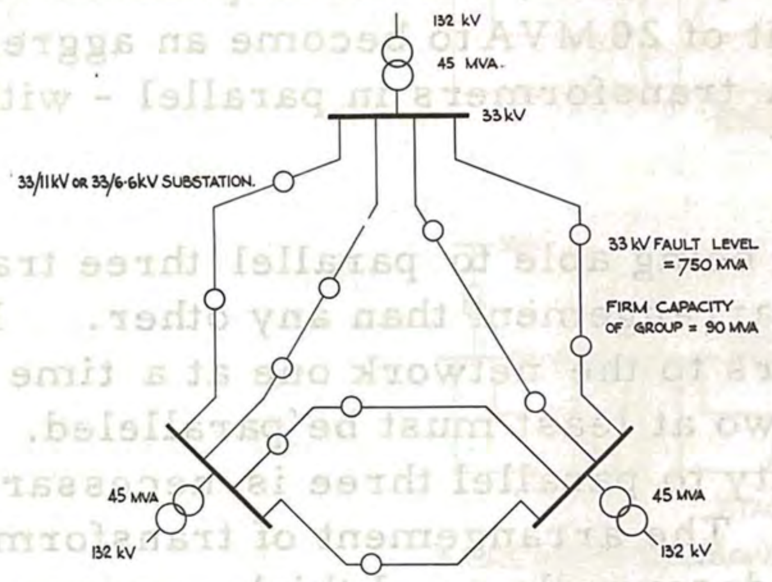
tion losses are lower. These again are considerable advantages. So MANWEB policy is based on using groups of two or three transformers, each one at a separate substation where possible, and the impedance of the network between them permits the limit of 20 MVA to become an aggregate of 22.5 MVA - that is, three 7.5-MVA transformers in parallel - without exceeding 150 MVA at 6.6. or 11 kV.

In my opinion the facility of being able to parallel three transformers is a much more satisfactory arrangement than any other. It is desirable to be able to add transformers to the network one at a time and to maintain full continuity of supply, two at least must be paralleled. A little consideration shows that the ability to parallel three is necessary to avoid one having to be the odd man out. The arrangement of transformers in pairs - a popular arrangement but undeservedly so, I think - means that under normal conditions transformer loadings should not exceed half of their capabilities. With three transformers the corresponding figure is two-thirds, which is 33% better. This applies when three transformers are located together. When they are installed singly on a network the conditions can be even better because each one is geometrically surrounded by about six others, and, if the size is not excessive compared with the transfer capacity of the network, there will be sufficient spare capacity even if each transformer is normally loaded up to six-sevenths of its capability. This would be 70% better than for paired transformers.

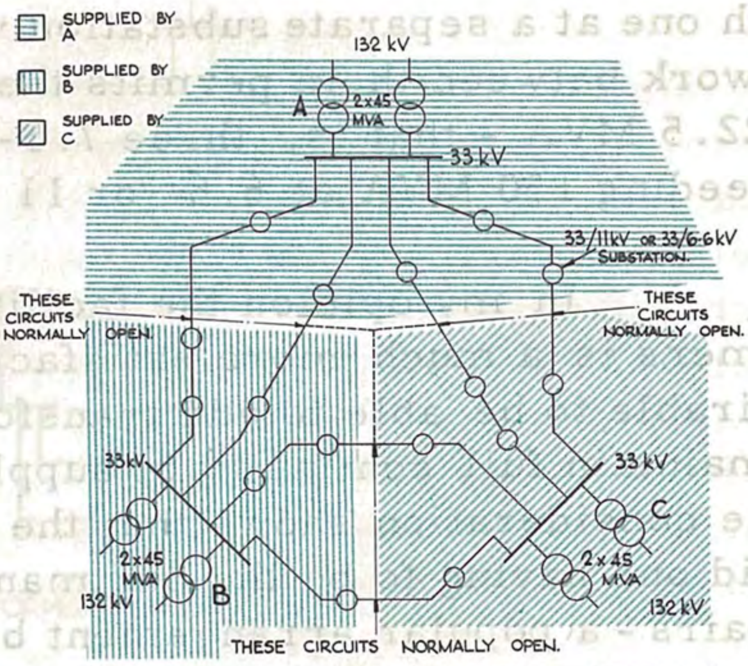
So as I said before in referring to medium and low-voltage networks I am convinced that the most economic method of feeding a high-voltage network will be achieved by using, as far as possible, a uniform size of in-feed distributed throughout the network.

Of course the networks that we have now cover very wide areas and as a result vary very considerably in load density. In built-up areas the optimum size of in-feed is determined by the factors that I have mentioned, and it is seldom necessary, or desirable, to depart from this size. But, of course, outside built-up areas load density may be so low that the distance between feed points would be excessive on this basis. The size of in-feed points must then be reduced but, in my opinion, it is still desirable to retain a uniform size of in-feed over reasonably large areas, for if a variety of sizes are used for neighbouring feed points, the facility is lost of being able to transfer load between them under abnormal conditions.

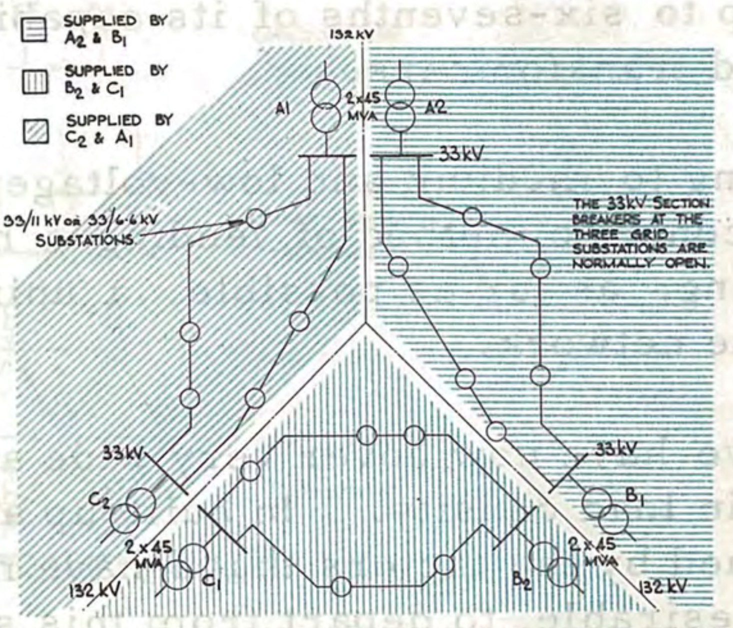
Just as there is a limit to the size of individual load which economically can be tapped off the 415-volt network - 100 kW was stated as the limit in that case - so is there a limit to the size of individual load which economically can be tapped off a 6.6-kV or 11-kV network. The limit is obviously related to voltage and 1500 kW for 6.6 kV corresponds in round figures to 100 kW at 415 volts on a pure voltage basis. Actually some other factors come in to the problem, and in fact it is usually economic for an individual consumer's load up to 3000 kW to be tapped off a 6.6-kV network. The limit of 100 kW at 415 volts is fairly widely acknowledged, but it does not appear that it is so generally recognised that loads in excess of 3000 kW should be taken direct on a higher-voltage network than 6.6 kV. Again, however, supplies given and metered at 33 kV leaving the consumer to transform to his utilisation voltage has economic disadvantages for a load below about 10000 kW. Therefore, the practice in this area for a load above 3000 kW is for the Electricity Board to provide a transforming station on the consumer's premises. The consumer provides the site and building and takes over the supply at 6.6 or 11 kV according to the network voltage in the vicinity of his works, and that network is used to provide the consumer's supply in emergency and to absorb surplus transforming capacity.



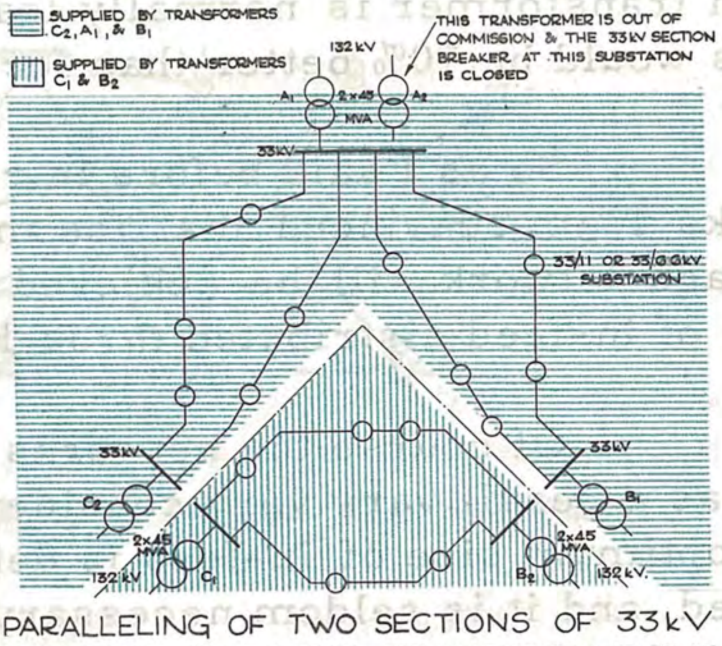
GROUP OF THREE 45 MVA GRID TRANSFORMERS SUPPLYING 33kV NETWORK.



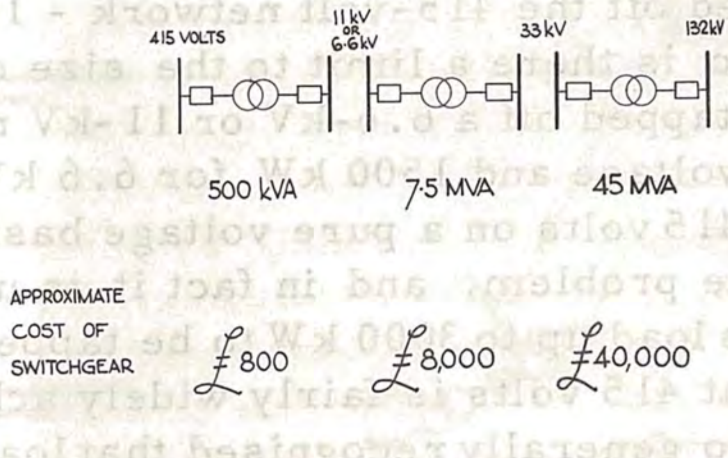
ORTHODOX METHOD OF OPERATING SECTIONS OF 33kV NETWORK FROM INDIVIDUAL GRID POINTS.



PROPOSED METHOD OF OPERATING SECTIONS OF 33kV NETWORK FROM PARALLELED GRID POINTS.



PARALLELING OF TWO SECTIONS OF 33kV NETWORK WITH A GRID TRANSFORMER OUT OF COMMISSION.



APPROXIMATE COST OF TRANSFORMERS AND CONTROLLING SWITCHGEAR.

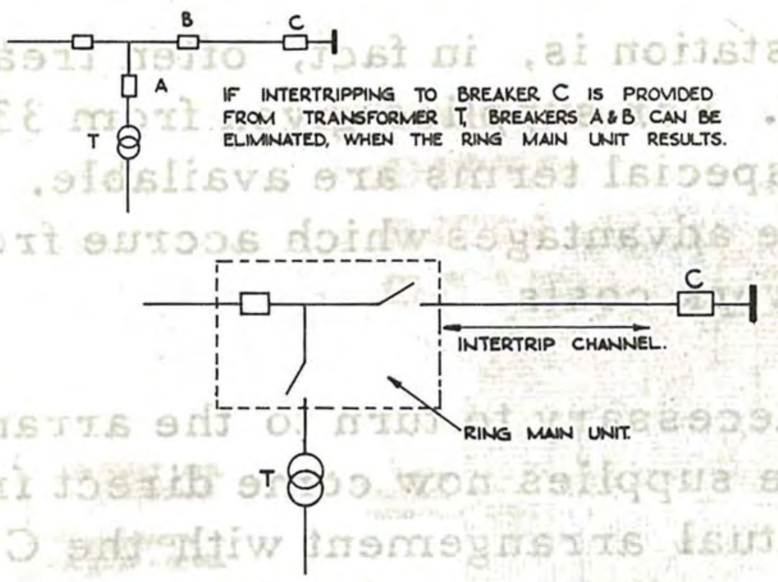
Such a transforming station is, in fact, often treated as one of a group as previously mentioned. For supplies given from 33-kV substations on consumers' premises, special terms are available, so that the consumer is given the benefit of the advantages which accrue from his load not normally involving 6.6-kV network costs.

Now it is necessary to turn to the arrangements for feeding the 33-kV network. These supplies now come direct from the 132-kV grid and are the subject of mutual arrangement with the C.E.A. The conditions are basically no different, however, from those obtaining at lower voltages. The points of supply to the 33-kV network must again be limited in size otherwise short-circuit levels higher than 750 MVA result, which for the same reasons as previously, are undesirable. A grid transformer size of 45 MVA is the preferred one in this area. It permits three such units to be run in parallel within the 750-MVA limit at 33 kV. In a number of cases in this area points of supply having a single 45-MVA transformer are being used. Two or three such points will be run in parallel so that no transformer is merely a standby for another, but instead is effective all the time to assist in reducing losses, and in maintaining a uniform voltage throughout the 33-kV network.

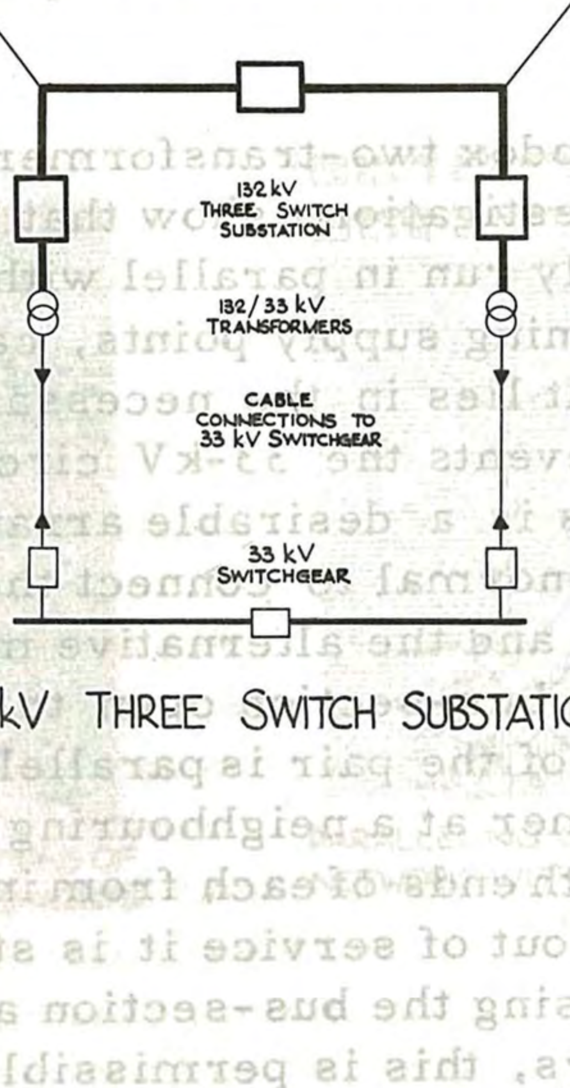
The more orthodox two-transformer arrangement is also being continued, but recent investigations show that the custom whereby the two transformers are normally run in parallel with each other, with a split in the network between adjoining supply points, can be improved upon. The defect in this arrangement lies in the necessary splits between adjoining supply points, as this prevents the 33-kV circuits being fed at both ends. To feed them at both ends is a desirable arrangement in the interests of supply continuity. It is normal to connect the two transformers to separate sections of busbar, and the alternative method makes use of this by normally running with the bus-section open to separate the pair of transformers, and instead each of the pair is paralleled through the network with a corresponding transformer at a neighbouring supply point. The 33-kV circuits are then fed at both ends of each from independent points of supply. When one transformer is out of service it is still possible to maintain the double-ended feeds by closing the bus-section at the supply point affected. With 45-MVA transformers, this is permissible within the 750-MVA limit for the short-circuit level, and the arrangement allows each pair of supply points to be loaded to the capacity of three, instead of two, out of the four transformers.

One of the aspects of electricity distribution engineering on which opinion differs most is associated with switchgear, and I think I would be expected to say something about it. The reason for the varied opinion on switchgear is undoubtedly because switchgear in general is the least useful feature of a distribution network. Everyone accepts that cables and overhead lines perform the necessary function of distributing the electricity from place to place, and that transformers perform the useful function of changing from one voltage to another. Switchgear, using the term in the broad sense fulfils only two rather negative functions. They are, first, removing from the network faults which would be better if they never occurred and, second, facilitating maintenance of the other components of the network which would be better if they needed no maintenance. The result is that a great deal of time is nowadays properly spent in trying to eliminate switchgear - the passenger on the network - as far as possible. It is an expensive item, particularly at higher voltages, to the extent that it not infrequently costs as much as the component of the network that it controls and protects.

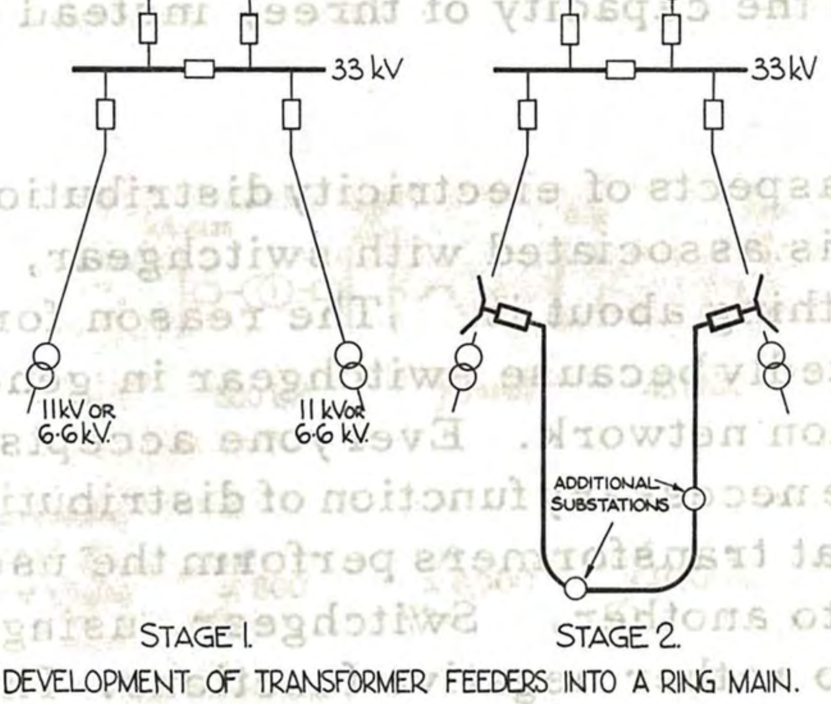
With switchgear goes protective-gear as part and parcel of it.



REDUCTION IN SWITCHGEAR REQUIREMENTS BY THE PROVISION OF ADDITIONAL PROTECTIVE GEAR.



132 kV THREE SWITCH SUBSTATION.



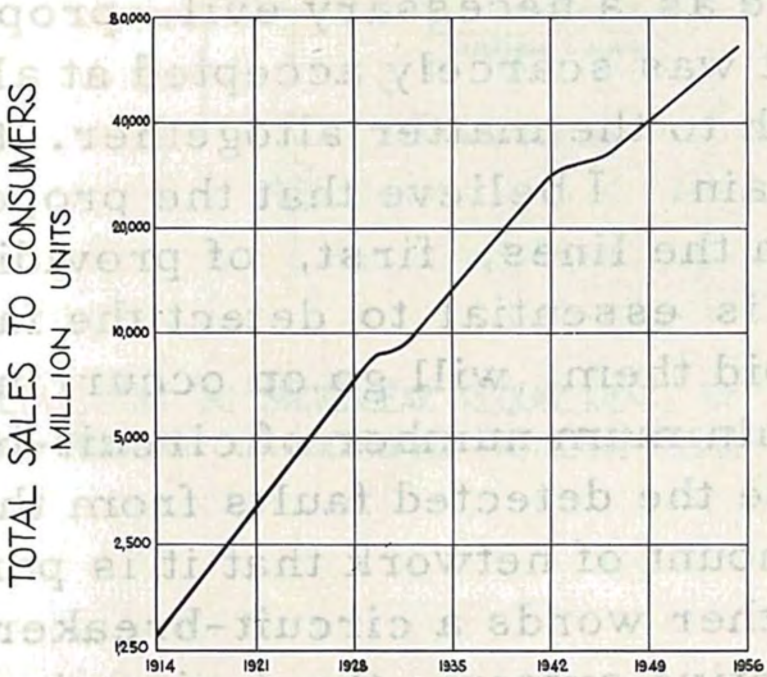
DEVELOPMENT OF TRANSFORMER FEEDERS INTO A RING MAIN.

In a desire for economy it is possible to take an attitude, for instance that, if a circuit-breaker equipment cannot be eliminated altogether, it can at least be made less expensive by reducing the protective-gear associated with it. Indeed, there is evidence that in some places, although circuit-breakers were accepted as a necessary evil, proper protective-gear was an even worse evil that was scarcely accepted at all. This, in my view, was the wrong approach to the matter altogether. It is something like having a body without a brain. I believe that the proper outlook is almost the reverse. It works on the lines, first, of providing without question the protective-gear which is essential to detect the faults that, with the best will in the world to avoid them, will go on occurring on the network. Second, of providing the minimum number of circuit-breakers - the expensive components - to remove the detected faults from the network. This entails deciding the largest amount of network that it is permissible to disconnect for each fault. Put in other words a circuit-breaker should be regarded as a final relay in a protective system - the device, in fact, that merely opens the main circuit when the protective equipment decides that it should be opened. This is quite distinct from considering a circuit-breaker as an end unto itself and protective-gear on the basis of the less said about it the better.

One of the early applications of the full-protection-minimum-number-of-circuit-breakers technique is the so-called three-switch 132-kV substation, with two lines and two transformers, in which three circuit-breakers are made to do all that by the other technique would require five. This at 132 kV represents a considerable saving. The principle on which this arrangement is based, is that a network must be designed to be able to carry on if a transformer breaks down, and it must also be able to carry on if a feeder becomes faulty. As transformers and feeders perform quite different functions, it can be quite satisfactory for one transformer and one feeder at a point to be disconnected simultaneously.

In addition to being the basis of the three-circuit-breaker 132-kV substation, this principle is also the basis of other means of achieving economy in switchgear. The extreme is arrived at when the same rating is used for feeder and transformer, a circuit-breaker between them then serves no essential purpose and can well be omitted, even though its omission generally adds to the protective-gear that is needed. In some areas very extensive use is made of feeder-transformers as this arrangement is called. The tie of equality between the size of feeder and the size of transformer is a handicap, however, as the economic conditions governing the optimum size of the two are materially different. This arrangement also appears to have the disadvantage that a real network does not result. The wholesale use of transformer-feeders leads, in fact, to each supply point being surrounded by circuits emerging from it radially, and it would appear inevitable that future development will tend in the direction of increasing the capacity of existing supply points, instead of increasing their number. That, in turn, could lead back to a situation which to all intents and purposes was characteristic of a past era, namely excessive concentrations of power and excessive short-circuit levels.

In this area transformers are connected direct to feeders, but only in special cases, and the sizes are not equalised as they are used simply as a stage in development of a network and not as a permanent feature. Economy in switchgear is, however, achieved by means of ring-main-units, which could be regarded merely as a means of making feeders connected direct to transformers extensible, but in fact they are used as a complete arrangement of rings. This practice has been followed elsewhere but to a much more limited extent than is deserved by the flexibility coupled with



GROWTH OF ELECTRICITY CONSUMPTION IN GREAT BRITAIN SHOWING THE DOUBLING OF CONSUMPTION APPROXIMATELY EVERY SEVEN YEARS.

MNWO/2478/X

economy which it provides.

Finally in a review of this nature an attempt is usually made to forecast what the future has in store. Perhaps the most remarkable thing about the electricity supply industry is the way in which the load has doubled itself over and over again, in periods of time which have seldom been longer than seven years. Every now and then there have been indications of slowing down in this rate of increase, but they have invariably turned out to be temporary variations from the mean rate and no more than that. The question is for how long will this increase be maintained? It seems difficult to expect it to continue indefinitely as saturation must eventually occur. There is, however, no definite sign that saturation is yet in sight and my opinion is that it is still a long way off. The rate of load doubling every seven years could mean a doubling of the network every seven years which would also mean facing the problem that in the next seven years we have to build as much as has been built over all the years to date. But as indicated earlier the lower-voltage networks remain substantially unchanged and are made to carry more and more load by introducing injection points at ever-decreasing distances. Most of the development that takes place, therefore, is primarily the development of the higher-voltage networks. The 132-kV grid was once regarded as a pure transmission system and it was, for instance, quite an event in the country as a whole, when an additional transforming station was put into service. Now it is necessary in this area alone to commission two or three new 132-kV stations every year and seven years from now we shall need twice as many annually. The 132-kV grid must, therefore, come to be regarded as much more a distribution network than anything else, and the same fate will no doubt in due course overtake the 275-kV super grid as well.

It is difficult at this time to foresee anything that could vastly affect the course of progress in distribution of electricity. Nuclear energy may do so but at present it seems unlikely to be distributed other than in the form of electricity. So I conclude with the thought that distribution networks will continue to grow and grow and that the growth will depart from established practice only to the extent that existing methods and materials will continue to be progressively improved, perhaps especially in the field of insulation. Those people, who are engaged in the distribution of electricity in particular, can rest assured that the future holds much in store to keep them interested, and there are many problems yet to be solved. There will be no shortage of work to be done, from which they will be able to derive pleasure and pride in rendering an ever more important service to the community as a whole.