1961

35th Convention

ASSOCIATION OF MUNICIPAL ELECTRICITY UNDERTAKINGS OF SOUTHERN AFRICA

VERENIGING VAN MUNISIPALE ELEKTRISITEITS-ONDERNEMINGS VAN SUIDELIKE AFRIKA

35ste Konvensie

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The Kariba Project

by

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A. THE POWER SUPPLY SITUATION IN THE RHODESIAS BEFORE THE KARIBA PROJECT WAS UNDERTAKEN.

The power supply situation in the Rhodesias in the mid-1950's was comparable in many ways with that existing in Europe at about the time of the first World War. Power production was still concentrated mainly in comparatively small thermal power stations supplying individual communities although some degree of interconnection between power stations had already evolved and several areas were served by local transmission systems or "grids." The largest of these was that of the Southern Rhodesia Electricity Supply Commission which by the 1950's had established an extensive 88kV and lower voltage transmission system serving a limited degree of interconnection with the major cities of Salisbury and Bulawayo. A smaller but more heavily loaded grid had also been provided in the Northern Rhodesia Copperbelt by the Rhodesia Congo Border Power Corporation whose 66kV system linked the principal mine generating plants. These grids were, however, local in character and no general interconnection between the power stations and consuming centres of the Rhodesias existed.

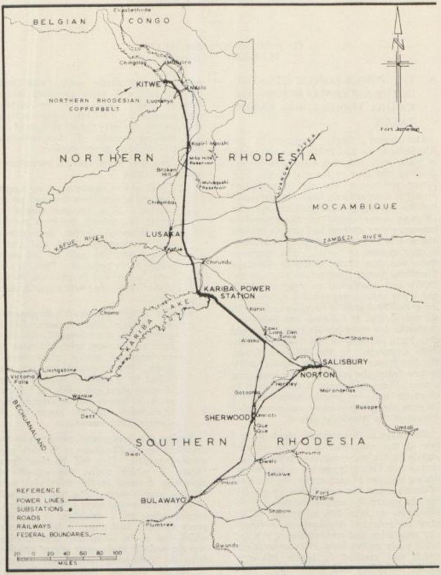
This stage in development was a natural one at the time and had been dictated mainly by the great distances between load centres (see Figure 1) and the comparatively limited demand at each centre. In this state of development, however, it was not possible for the electricity supply industry of the Rhodesias to take full advantage of the great technological developments in electricity generation and transmission which had taken place mainly from 1930 onwards and which had resulted in higher efficiency, greater reliability and lower costs. These advances were associated with the use of very large generating units, with high voltages and with other advanced design features which could not be utilised economically by relatively small isolated undertakings and with the advantages of the now familiar concept of interconnection between individual power stations.

The principal advantages of interconnection are of course:—

(i) Local power reguirements no longer need to be met from the local power stations. If a cheaper source of power is available elsewhere on the interconnected system then power can be generated there and transmitted over the grid to the point where it is required. Thus, at all times, power can be produced in the plants with the lowest production costs.

(ii) The costly provision of spare generating plant is much reduced. When power stations are isolated each must have at least one spare generator as an insurance against plant breakdown. When power stations are linked by a grid the total provision of spare plant can safely be reduced as it is reasonable to assume that breakdown will not occur in all stations simultaneously.

Against this background, the demand for electricity in the Rhodesias at the time was growing rapidly. This will be clear from Figure 2, which shews the growth of electricity demand in the Rhodesias over the last twenty years. The rate of growth of load has averaged some 11% per annum, corresponding to a doubling of demand every six and a half years. A further factor which had to be taken into consideration was the periodic inadequacy of coal supplies from the Federation's only major colliery at Wankie and the difficulty which was experienced at times by the Rhodesia Rail-



BELGIAN
CONGO
Elisabethville
Chingola
Mufulira
KITWE
Ndola
NORTHERN RHODESIAN
COPPERBELT
Luanshya
Kapiri Mposhi
NORTHERN
RHODESIA
Broken Hill
Fort Jameson
LUANGWA RIVER
MOCAMBIQUE
LUSAKA
KAFUE RIVER
Kafue
ZAMBEZI RIVER
Chirundu
KARIBA POWER
STATION
Karoi
Choma
KARIBA LAKE
Lions Den
Sinoia
Alaska
Shamva
SALISBURY
NORTON
Livingstone
Victoria Falls
Hartley
Marandellas
Gatooma
Rusape
Wankie
Dett
SHERWOOD
Umniati
Que Que
Umtali
BECHUANALAND
SOUTHERN
RHODESIA
Gwai
Umvuma
Gwelo
Selukwe
Insiza
REFERENCE
POWER LINES
SUBSTATIONS
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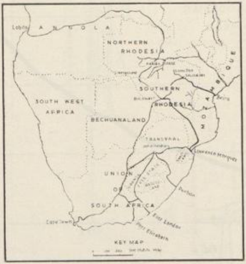


LOCATION MAP

FIG. 1

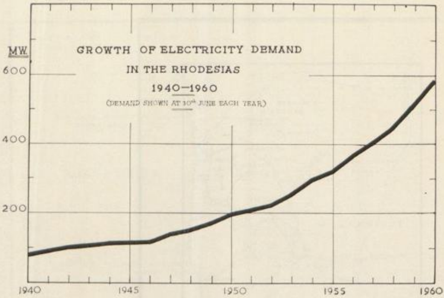


Fig. 2.

ways in transporting coal from Wankie to thermal power stations in other parts of the Federation. The location of Wankie Colliery and of the main railway lines is shewn on Figure 1 and it will be seen that Wankie is in the North Western corner of Southern Rhodesia, remote from the main centres of population at Salisbury, Bulawayo and in the Northern Rhodesia Copperbelt. The railway haul from Wankie to the Copperbelt, for example, is some 550 miles and to Salisbury some 470 miles.

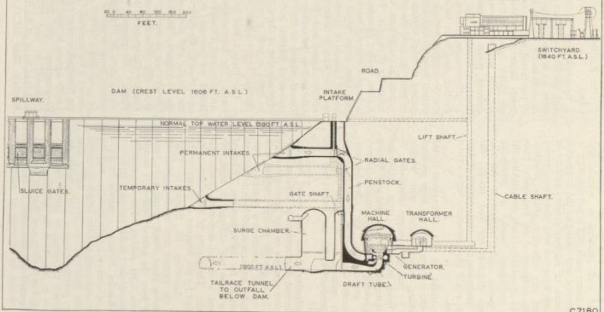
In this situation the advantages to the Rhodesias which would follow from interconnection of the generation stations and the development of hydro-electric rather than coal-fired generating stations as the means of meeting increased power requirements were obvious. Before any decision was reached, however, a careful study was made of the alternative methods of development of the power supply system which were possible.

These included:—

1. Continued development of isolated coal-fired power stations serving local load centres.
2. The development of a large pit-head power station at Wankie colliery associated with high voltage transmission lines to transmit the power to the load centres.
3. The development of a large water-power station on the Zambesi or Kafue rivers with similar high voltage transmission.
4. Nuclear energy.

The last of these alternatives — the possibility of employing nuclear power — was soon concluded to be both impractical and uneconomic. At that date the best estimate that could be made of the cost of power from nuclear stations was that it would be something like twice the cost of power from conventional coal-burning stations. A further difficulty associated with

FIG 3
CROSS SECTION OF SOUTH SIDE OF GORGE SHOWING INSTALLATIONS.



nuclear power stations was the highly specialised staff required to operate and maintain them; such staff is not available in the Federation and owing to the large-scale development of nuclear power stations in the United Kingdom and elsewhere, would have been very difficult to obtain. Furthermore, the isolation of the Federation from the works of manufacturers undertaking the highly specialised work of producing nuclear power station equipment was also a serious disadvantage and finally, the supply, treatment and replacement of fuel elements would have presented very serious problems.

The second of the alternatives listed above—the construction of a large pit-head coal-burning power station near Wankie Colliery — was also judged unsuitable. It would have imposed a large additional strain on the already overloaded coal mining industry which would have required heavy capital expenditure for development. Furthermore, the location of Wankie was not very suitable as the main centre of power production for the Federation (see Figure 1).

The effective choice thus rested between the continued development of isolated coal-fired power stations or the development of a large hydro-electric project coupled with a high voltage transmission system to provide a fully interconnected system with all its advantages for the Federation. Technical plans for these two alternatives were prepared and a careful economic comparison was made. The results of this comparison were given by the Minister of Power to the Federal Assembly in February, 1956. Briefly, the capital cost of the additional coal-burning plant which would have been required over the period 1960-1971 would have been £101 million. The comparable cost of the selected hydro-electric alternative — the Kariba Project — would be £113 million, or some £12 million more. But the saving in coal costs and the longer economic life of the hydro-electric plant meant that over the period reviewed (1960-1971) the accumulated difference in annual production costs in favour of the Kariba Project would be £44 million and that at the end of that period the difference in favour of Kariba would be running at nearly £10 million per annum. Thus, the economic case for the Kariba Project was firmly established.

To implement the decision to proceed with the Kariba Project the Federal Government set up the Federal Power Board under the Electricity Act of 1956. The first duty of the Board was to construct the dam and South Bank power station at Kariba and the 330kV "grid" of transmission lines linking this power station with the principal existing power stations in Northern and Southern Rhodesia (see Figure 1). As soon as this system, known as Stage I of the Project, had been brought into operation, the Board then had the duty to control the output from Kariba and from the interconnected thermal stations so as at all times to meet the total electricity demand on the system at minimum cost consistent with reliability of supply. For this purpose, the Kariba Project includes the construction of a large Control Centre at Sherwood, near Que Que, from which the whole interconnected system of power stations and transmissions lines is controlled on a minute-to-minute basis and from which load is allocated to the various power stations. The Board refund to the owners of the interconnected thermal stations the actual costs of production at these stations and sell back to them in bulk a mixture of Kariba and thermal power under a standard tariff.

The Project was financed by long-term loans. The International Bank for Reconstruction and Development is lending the Board an amount in various currencies equivalent to 80 million dollars, to be used for goods and services purchased outside the Federation. The Colonial Development Corporation is lending £15 million sterling and the Commonwealth Development Finance Company £3 million sterling. The Federal Government has undertaken to make loans to the Board totalling £Rh28 million from monies it will borrow for the purpose, and a further sum of £Rh6 million should it be required. Of this £Rh28 million the Rhodesia copper mining companies have jointly agreed to lend £Rh20 million to the Government; the British South Africa Company to lend £Rh4 million and the Standard Bank of South Africa Limited and Barclays Bank D.C.O., £Rh2 million each.

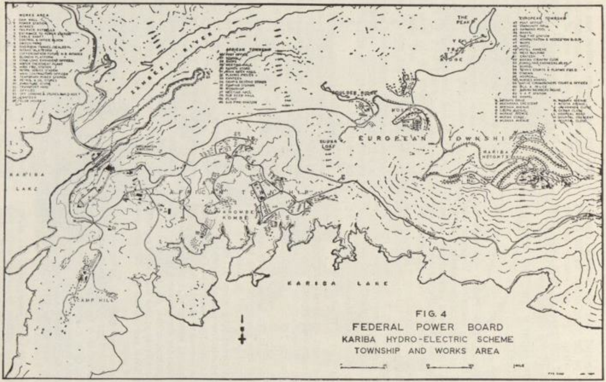


FIG. 4
FEDERAL POWER BOARD
KARIBA HYDRO-ELECTRIC SCHEME
TOWNSHIP AND WORKS AREA

It is expected that the average rate of interest on the loans drawn by the Board will be about 5¼% per annum and the period of redemption of these loans varies between 19 and 33 years.

B. THE DESIGN OF THE KARIBA PROJECT.

1. General.

The design of the Project was entrusted by the Board to Consulting Engineers who worked out detailed proposals for the Board's approval and subsequently supervised for the Board the construction and testing of plant in the manufacturers' factories and the construction of works and the installation and testing of plant on site. All major contracts were placed by competitive international tendering and in general included transport and erection.

2. The Dam and Other Civil Engineering Works.

The Project involved the development for hydro-electric purposes, of a site on the Zambesi River at the Kariba Gorge, approximately 240 miles downstream of the Victoria Falls. The very large civil engineering works in this Project have been fully described in a number of other papers and only a brief resume will be given here.

By damming the river at the Kariba Gorge, an effective nett water head of about 310 feet could be obtained and a large lake could be formed to provide the seasonal and inter-seasonal storage of water required to compensate for droughts and floods. Calculations indicated that the total quantity of energy available at this site would be 8,000 million kWh per annum for the proposed height of dam.

The proposed dam was to be a double curvature concrete arch dam to raise the dry weather river level by about 320 feet. It would have a height of about 400 feet above the foundations, and a crest length of 1,800 feet. The normal top water level proposed was to be 1,570 feet above sea level.

Power was to be generated in two underground power stations excavated in the rock at the North and South flanks of the dam.

The first stage power station was to be in the Southern flank, to accommodate six 100 MW turbo-generator sets, of which five would be installed in the first instance. A cross-section of the works for the first stage at Kariba is shewn in Figure 3.

Individual permanent intakes were to be provided immediately upstream of the dam to lead water to each set, with temporary intakes for the first and second sets at a low level to allow generation to commence before the lake filled.

After passing through the turbines, the water was to be led back to the river channel downstream of the dam through three surge chambers and three tailrace tunnels, i.e., one for each pair of machines.

Accommodation underground was also to be provided for the step-up 18/330kV transformers in a separate chamber adjacent to the machine hall.

The underground works were to be connected to the surface by an access tunnel for vehicles, by a lift shaft, and by a cable shaft. The cable shaft was to accommodate the 330kV cables carrying the electrical output of the station to a switchyard on high ground above the gorge.

Other permanent works at Kariba were to include a control and office building; switchyard; workshops and stores facilities; and housing and amenities for the permanent staff, together with necessary services. In addition, since the site was remote, access roads, bridges, an aerodrome, a hospital, and construction camps were to be built. A general plan of the township and works area is shewn in Figure 4.

The cost of the civil works at Kariba, as described above, was estimated at £39.2 million, and it was considered that the first machine could be commissioned at the beginning of 1960. It was thought that the dam would be completed by mid-1960, but that a start could be made on impounding water in the lake at the end of 1958.

In other parts of the Federation, a system control building was to be constructed at Sherwood, and five substations with their associated buildings, at Kitwe, Norton, Sherwood, Salisbury and Bulawayo.

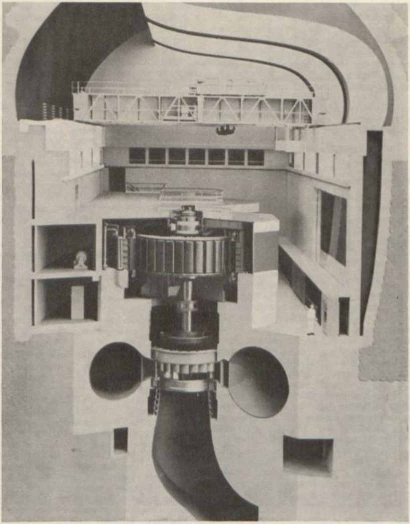


Fig. 5.

As the work progressed, some modifications were made to the original programme, the principal ones being that the height of the dam was to be increased by twenty feet, that the sixth generating set was to be provided in the first stage and that a further substation was to be constructed at Lusaka.

The increase in the height of the dam made it about 420 feet high above the foundations, with a crest length of 2,025 feet. The lake then became 175 miles long, with a total storage capacity of 130 million acre feet. In addition, the assessment of the total energy available was increased to 8,500 million kWh per annum.

3. The Electrical and Mechanical Plant.

(i) *Turbine-Generator Sets.*

The 100 MW turbines are of the Francis type (see Figure 5) which give their rated output of 140,000 B.H.P. at a nett head of 282 feet. The mean nett head will be 310 feet when the lake reaches its normal operating level. The maximum gross head is 352 feet. The generators are of the salient pole umbrella type, that is, with the trust and guide bearing beneath the rotor. The machines run at a speed of 166.7 r.p.m. and have a maximum continuous rating at 0.9 power factor, of 100 MW, the generated voltage being 18kV. The diameter of the stator is 32 feet and of the rotor 25 feet 6 inches. The total load on the thrust bearing including hydraulic thrust is 660 tons. Because of its great weight and large dimensions the generators, after assembly and testing in the makers' works in England, had to be broken down for shipment to site, the stator into quarters and the rotor into many parts, the shaft, the hub, the spider arms, laminated sections for the outer ring and the 36 poles which dovetail into slots in the periphery of this ring. The complete rotor with its shaft assembled for installation weighs nearly 400 tons and requires the two ton power station cranes to be coupled together to lower it into position.

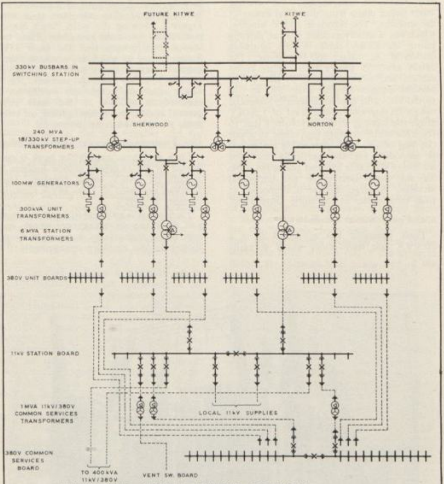
The machine is cooled by water coolers situated outside the stator in the closed air circuit. The turbine and generator bearings are also water cooled with water bled from the penstock. Excitation is by a 364kW 360 volt D.C. machine, on the generator shaft, and controlled by a combination of static and rotating magnetic amplifiers, ending with a flywheel booster. This has a high rate of response to assist in maintaining the stability of the system. The machines are designed for a normal speed rise of 21% when full load is suddenly thrown off, but they are tested to full run away speed, nearly double the normal speed, in the maker's works. A permanent magnet generator is coupled to the main shaft above the excitor for use with the turbine governor.

Auxiliary equipment includes built-in carbon-dioxide fire-fighting equipment initiated by thermostats in the hot air circuit, high pressure oil-operated rotor jacks and a compressed air breaking system. The generators are protected by overall differential protection backed up by denite minimum inverse time relays and over voltage relays.

(ii) *Generator 18kV Switchgear, 18/330kV Transformers and 330kV Cables.*

The 18kV generator switchgear has the high current rating of 4,000 amps and a short circuit capacity of 1,500 MVA. It is of the air blast type and has a total break time of 0.05 seconds. All the connections between the generators, generator transformers, and low voltage switchgear are of hollow square section copper.

Single phase 18/330kV generator transformers are arranged in three banks of three with one standby unit for the station. Each of the three banks has a capacity of 240 MVA and serves two generators which are connected to separate 18kV windings. The transformers are Ydd connected and have no tappings. Voltage control is effected on the generators and by means of on-load tap-change transformers at the receiving stations. The two low voltage generator windings on each single phase transformer unit are placed on separate limbs thus giving a high reactance (25% on 120 MVA base) between them to limit the short circuit duty on the generator switchgear. The reactance between each LV winding and HV winding is 12.5%. Transformer protection consists of balanced earthfault equipment with overcurrent relays for phase faults. Buchholz and winding temperature



KARIBA POWER STATION
SIMPLIFIED DIAGRAM OF CONNECTIONS

FIG. 6

relays are also fitted. Neutral displacement relays are fitted on the 18kV busbars. Cooling of the transformers is by forced oil and water/oil intercoolers, the cooling water being taken from the spiral casing of the turbines. The common 330kV winding, which has a solidly earthed neutral, delivers power via 330kV cables to the switching station at the surface 600 feet above. The cables are 0.85 square inch copper cross-section and were delivered to site in the finished lengths ranging from 560 to 650 yards. The cable is of an unusually advanced design having an impulse level of 1,500kV High mechanical stress is involved due to the hydrostatic pressure equivalent to about 600 feet of oil. One spare cable per circuit is provided for the vertically mounted section of the cable run and one spare cable for the three circuits in the horizontal sections. A surge diverter is connected to each transformer at the cable termination.

(iii) *Power Station Auxiliaries.*

Each generator has connected to it a 300kVA unit transformer which normally supplies all essential auxiliaries for the set. There are also two 6,000kVA station transformers, 18/11kV, which can be connected to either one of two pairs of generators but never to more than one pair at a time. Figure 6, shewing the main Power Station connections will make this clear. These two station transformers feed the main 11kV Station board to which are connected three general service transformers, 1,000kVA, 11/380kV. The common services 380 V board can supply the unit auxiliaries if required in addition to the main other general auxiliaries, station lighting, air treatment plant, de-watering pumps, etc.

(iv) *Transmission System Substation Plant.*

Each generator transformer bank is connected to the switching station busbars by a bulk oil 330kV circuit breaker. These breakers are rated at 7,500 MVA rupturing capacity at 330kV.

Each phase is switched in a separate tank, and there are six breaks per phase, each one being shunted by a linear resistance having its own breaking arrangements. The

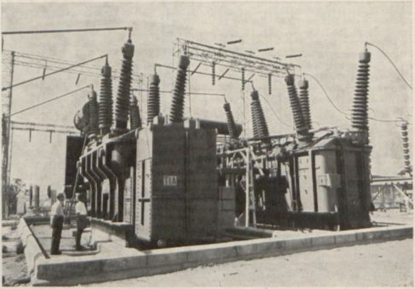


Fig. 7.

switchgear is similar throughout the transmission system except that in the case of breakers used on single circuit lines each phase is capable of operating independently permitting single phase auto-reclosing.

The breakers are capable of interrupting charging currents of up to 300 amps and magnetizing currents of up to 200 amps, without generating excessive over-voltages. Line switches are fitted at each end of every line except at Salisbury but on the single circuit feeders where only two transformers are at present installed a second circuit breaker (bus coupler) is provided to allow maintenance on the line breaker and for connecting and disconnecting transformers.

The transformers in the substation are all three phase units and with the exception of one substation are each of 60 MVA capacity having low voltage windings of 88kV or 33kV; the one exception is Kitwe where auto-transformers are used having a rating of 120 MVA, 330/220kV; a view of one of these transformers is shewn in Figure 7. The substation transformers have on-load tap-change facilities (—4.6% to + 17.6%) but in the case of Kitwe it was necessary to specify separate booster transformers for voltage control mainly because of transport weight limitation. The reactance of the substation transformers was specified as having a maximum value of 11% to improve the system stability. All these transformers have 11kV tertiary windings and advantage is taken to connect 11kV shunt compensating reactors to them at several points on the system. These reactors, each of 20 MVA rating, are used to compensate for part of the reactive power generated by the long transmission lines which might otherwise cause generator instability and other difficulties. They are controlled by 11kV air-blast switchgear.

(v) *Transmission Lines.*

The transmission voltage of 330kV was chosen after detailed technical and economic studies of various alternative voltages. Twin conductors, spaced at eighteen inch centres, of steel-cored aluminium and each having an equivalent copper cross-section of .35 square inch are used for each phase. This conductor arrangement limits corona loss to reasonable limits and reduces the line reactance giving improved system stability.

The possibility of using copper conductors was considered but the cost would have been excessive as compared to steel-cored alumium. The twin conductors are held apart by flexible ring type spacers. The conductor is strung to give a tension of about 20% of ultimate strength at 60 degrees Fahrenheit and Stockbridge vibration dampers are fitted. Suspension insulator strings contain nineteen discs 5¾ inches long, 10 inches in diameter, having a wet withstand value of approximately 600kV at the mean altitude of the line. The impulse level is approximately 1,400kV. Tension insulator strings consist of eighteen discs, 7 inches long and of 11 inches diameter. Double strings are used at tension points and a turn buckle adjusting device is provided to equalise the tension in the two conductors of the phase. Arcing horns are only fitted to the live end of each insulator string except for the first mile from each line termination and at railway crossings where arcing horns are fitted at each end of the string to reduce the impulse level below that of the

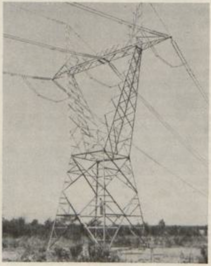


Fig. 8.

substation apparatus. Double overhead earthwires are employed of 19/.104" galvanised steel and give a shielding angle of 25 degrees at the towers and progressively more towards mid span.

Single circuit towers are used throughout the system, even in cases where circuits run parallel for a considerable distance, in order to reduce the risk of outages due to lightning. The towers are constructed of galvanised steel and are of the lattice-type waisted design (see Figure 8). This was shewn to be more economical than the portal type of structure. Other fundamental data are as follows:—

Overall height of intermediate towers	115 feet.
Conductor spacing	37 feet 6 inches
Earthwire spacing	48 feet 2 inches
Normal span length	1,500 feet.

The strain and angle towers are designed to withstand the breakage of a complete phase of line conductors and one earth conductor, at maximum tension. Suspension towers are designed for longitudinal unbalance corresponding to the breakage at normal tension of one of the pair of phase conductors or one earth conductor. All the main tower types were tested to destruction by full scale prototype tests.

Galvanised steel wire counterpoise is laid along the line route where the tower footing resistances exceeded 20 ohms, and for the last mile into each substation double counterpoise is laid irrespective of the footing resistances. The transmission lines are protected by three zone high speed distance protection with carrier acceleration for faults within the second zone. Power swing relays are provided to prevent operation during times of system instability. An exception to this protection arrangement is made on the Norton-Salisbury lines where 330kV breakers are only installed at the Norton end. These lines are protected by single zone high speed distance protection with carrier intertripping. Back-up protection is provided by definite minimum inverse time overcurrent and directional earth fault relays.

A system of high-speed self-locking voltmeters and ammeters is used at both ends of each line to record zero phase sequence components enabling the location of faults to be estimated.

Oscilloperturbographs are provided at certain of the main centres to record the performance of protective gear and circuit breaker operations.

The transmission lines are also used to transmit power line carrier for communication telemetering and supervisory purposes and more detailed reference will be made to this in the next section.

(vi) *Control System.*

The Kariba network is controlled from a Central Control at Sherwood, near Que Que. A view of the Control Room at this Centre is shewn in Figure 9. The control engineers are able to speak over a private telephone communication system (power line carrier) to any of the interconnected power stations or substations to control switching operations and issue loading instructions. Trunk dialling facilities are provided to all stations.

Telephone facilities are reinforced by teleprinters and between Sherwood Control and the Board's Head Office by photo-facsimile equipment. There is a general indication panel giving automatic indications of all important switch and isolator positions on the system. These include twenty-five 330kV oil circuit breakers and associated isolators, all the main transformer LV switchgear and 11kV reactor switchgear.

The general indications arrangements on the control panel are such that they immediately shew up any discrepancy between the mimic diagram and the remote switch position. Provision is made to enable the control engineer to initiate a check on all switch and isolator positions should he wish, the complete check taking only a few seconds for some 168 indications. The general indications can be bunched into groups of up to 96 on a chosen voice frequency telegraph (VFT) channel for transmission from the remote station and are scanned and sorted by means of uniselectors at the terminals. The control engineers are immediately made aware of any important changes in system conditions, whether intentional or due to faults, by visible and audible alarms.

The usual local indications of system frequency, rate of change of frequency, system time and standard time are provided, and in addition the control engineers are kept informed of the load flow (MW and MVAR) at all important points on the system by telemetering.

Indications of busbar voltage, both 330kV and lower voltage (88kV, 33kV, 220kV) are also telemetered to Sherwood Control.

All these facilities are made possible by the use of VFT and power line carrier channels which are transmitted over two phases of each of the transmission lines. Signalling and dialling for telephone operation is by means of VFT transmitted with the speech on a power line carrier channel, separation being by means of filters. There are at present up to six channels of carrier on each transmission line (this may be extended later to eight channels) and associated with each channel there are one speech and six VFT channels. Carrier frequencies used on the system for communications and protection range from 64 to 476 kilocycles and the total number of communications and signalling channels employed on the system at this stage of the development is 71.

Telemetering employs the teleprinter code, a particular letter being associated with each reading to be conveyed from the outstation to the Sherwood Control Centre. VFT channels are used and an electronic pulse generating and scanning device enables six to twelve independent instrument readings to be transmitted over a single channel on a time division principle, the scanning sequence being repeated every 120 milliseconds. The magnitude of an indication is governed by the rate of pulse initiated by the measuring instruments which are of the rotating-disc, induction type. The higher the voltage or the higher the load flow, the higher the pulse rate.

The normal pulse rate for maximum meter indication is either $66\frac{2}{3}$ or $33\frac{1}{3}$ per minute,

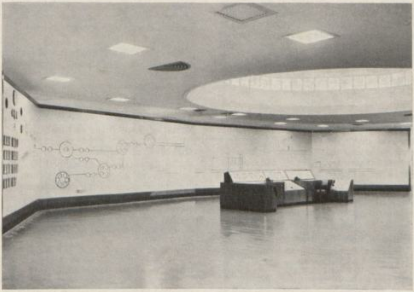


Fig. 9.

depending on the type of instrument. The identifying letter enables the signals to be routed to the corresponding indicating instrument in the control room.

In view of the important services which the power line carrier provides a number of safeguards are built into the system. Standby oscillators are provided for the power carrier racks which switch in automatically in the event of failure of the main oscillator. Auxiliary supplies are generally provided from three possible sources including two of the main substation transformers via an auxiliary transformer and automatic changeover contactor, or from a motor generator set run off the 220V D.C. battery supply. This starts up immediately, should the normal substation auxiliary supplies fail. At Sherwood, there is a further line of defence in the form of a diesel generator set which can be started from the control room.

While the equipment provided for communications and the supervision of the network is of a high standard, and reliable operation is to be expected, Post Office telephones are also installed at all centres, and, as a further insurance, HF radios are provided for communication between the Control Centre and other important operating points on the system. The same radio network is used to maintain contact with the transmission system maintenance organisation whose base depots and line maintenance vehicles are similarly equipped with HF radios.

All this complex electronic and other light electrical equipment requires careful maintenance to ensure proper performance and when it is realised that there are included in this some 6,000 relays and 9,000 radio valves the need for a skilled team of specialists to cover routine maintenance and repair of faults is apparent. With the widespread transmission system extending from Kitwe in the North to Bulawayo in the South — a distance of some 800 miles by road—there are considerable problems in rapid movement of these specialists from one centre to another as it is obviously not possible to have an individual with the required skill at each centre.

C. SOME SPECIAL PROBLEMS OF CONSTRUCTION.

Having thus described the design of the Project, it may be interesting to review some of the special problems which arose during construction and which had to be systematically solved. They included the following:—

(i) *Hydrology.*

It was necessary to determine, as accurately as possible the behaviour of the river, particularly as regards the magnitude of peak floods and their time of arrival at Kariba. Hydrological records, on the whole, were good. Records of water levels at Livingstone had been kept since 1905 and the daily discharges were known, accurately, from 1924 onwards. Water levels had also been taken in the upper level and gauging stations were established at Chirundu downstream of Kariba, at Kariba itself, and on some of the major tributaries.

The vast catchment area covers 256,000 square miles, of which 196,000 square miles lies upstream of Livingstone (see Figure 10). Most of this area is undeveloped and sparsely populated, so that basic meteorological information was scanty and difficult to obtain.

The particular problem of the effect of floods on the construction work could not be entirely solved, but it was greatly eased by making reasonable allowance in the design of the river diversion structures and by establishing a flood warming system which successfully predicted the times of arrival of flood peaks at Kariba.

(ii) *River Diversion.*

The programme and method of diverting the river to allow the construction of the dam foundations in the deep channel posed a specially important problem, since the necessary construction work could only be carried out during the dry seasons, when the flow in the river falls to between 8,000 and 12,000 cusecs.

By the rapid action of awarding a preliminary contract in mid-1955, it was possible to save a year on this work, and this was reflected in the construction programme for the whole scheme.

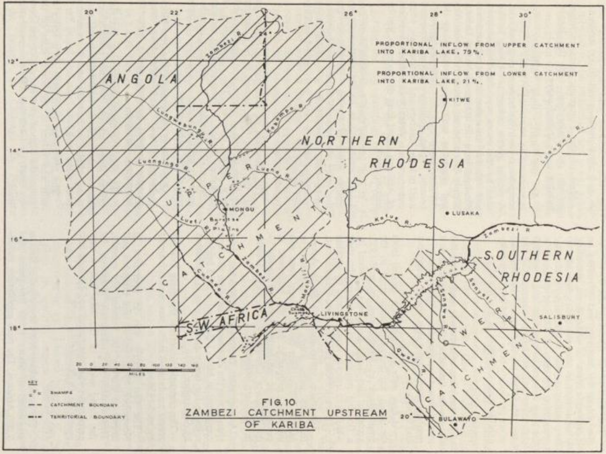


FIG. 10
ZAMBEZI CATCHMENT UPSTREAM OF KARIBA

The method of diverting the river was also solved by designing and providing an ingenious system of coffer-dams, including a semi-circular concrete coffer-dam of 300 feet radius on the North bank; a circular concrete coffer-dam of 370 feet diameter in the deep channel of the river; and a rockfill cofferdam immediately downstream of the site. Many of the operations involved had never previously been carried out on a comparable scale anywhere in the World.

(iii) *Access.*

The problem of access to and about the site, in the time available, appeared at first to be almost insuperable. Nevertheless, it resolved itself mainly into one of economics and hard work.

At first, only a rough track existed from the main Salisbury-Chirundu road to the South Bank at Kariba and, by mid-1955, access to the North Bank was achieved by a floating pontoon bridge across the river which was quickly supplemented by another rough track from the Chirundu-Lusaka road.

The main gravel-surfaced South Access road, 48 miles long, was completed by March, 1957. This North Access road was intended, primarily, for the transport of cement from the main source of supply — the Chilanga Cement Works, near Lusaka in Northern Rhodesia.

A suspension footbridge of 690 feet clear span across the Zambesi at the dam site was completed in May, 1956, and a road bridge, suitable for heavy traffic, was in operation by September, 1956.

The construction of all the main internal access roads at Kariba was well advanced by mid-1956.

The first airstrip was in operation in November, 1955, and it was extended and improved during the ensuing six months. This airstrip was ultimately inundated by the rising water of the lake and a new aerodrome was constructed and brought into operation in November, 1958.

(iv) *Labour.*

The peak labour force employed at Kariba amounted to about 1,500 Europeans and 7,000 Africans. The peak population, including other workers and dependants, was about 2,000 Europeans and 10,000 Africans.

Most of the Europeans were recruited outside the Federation and the largest number came from Europe.

At the start, some difficulty was experienced in recruiting African labour in competition with the large mining concerns. A similar system of contract labour to that used by the mines was therefore adopted, and valuable assistance in recruitment was obtained from the Rhodesia Native Labour Supply Commission. Good welfare services and amenities were also provided in the African Township. As these arangements became known, volunteer labour presented itself in large numbers and even to-day, when construction is virtually completed, numbers of Africans travel long distances to Kariba seeking work.

It is of interest that, even when there was unrest in other parts of the Federation, no trouble arose at Kariba. Throughout the five years of construction there was only one strike which arose from a straightforward industrial dispute and was settled quickly and amicably.

(v) *Housing.*

The provision of construction townships for the labour force proved to be a similar problem to that of access, and was resolved in a similar manner. The construction of townships started in February, 1956, and was substantially complete in eighteen months, some six months' ahead of schedule. A truly remarkable achievement.

After several experiments, concrete block construction was used throughout with asbestos cement roofing, giving virtually permanent buildings.

Not only the necessary housing, but also offices, shops, schools, churches, posts offices, banks, meeting halls, beer halls, stores, canteens, clinics, a hospital and a swimming pool were built.

The townships were sited on a series of hills and ridges at the south sides of the gorge, the highest part being 2,700 feet above sea level, or 1,450 feet above average river level.

Water was pumped from the river to a modern purification plant and then distributed to the residential and works areas, partly by gravity but mainly by further pumping. The rated capacity of this plant was about 600,000 gallons per day of potable water, plus about 400,444 gallons per day of untreated water.

Electricity was provided by a temporary diesel generation station which, in the end, had an installed capacity of about 8½ MW. The output was mainly used for construction work, but it also served the townships. Distribution throughout the area was at 11kV.

Sewerage disposal was by septic tanks serving groups of buildings, the effluent from which was piped to soakaways.

(vi) *Transport* (See Figure 1).

The magnitude of the problem of transporting the vast quantities of plant, equipment, materials and supplies required at Kariba was realised at the outset, and the whole operation was meticulously planned. Sand and stone were obtained locally, but the 400,000 tons of cement required had to be brought by road 110 miles from the cement works at Chilanga. By far the largest portion of the plant and equipment required had to be brought from the factories in Europe and involved transport by road or rail to the docks, by ship to African ports, and by rail and/or road in Africa. Some items urgently required were transported by air. For normal items, a fairly loose degree of co-ordination was maintained between manufacturers, shipping agents, and the Board and their consulting engineers' transport organisation; but the transport of urgent items and abnormally heavy or bulky items was very carefully co-ordinated indeed.

Railway sidings to serve Kariba were built at Lion's Den in Southern Rhodesia and at Kafue in Northern Rhodesia, some 140 and 90 miles respectively, by road from Kariba.

The siding at Lion's Den was equipped with a 100-ton Goliath travelling crane, and the Board also purchased two special transformer well wagons of 110 tons capacity which were operated by Rhodesia Railways.

Two road transport contracts were awarded—one for transporting cement from the factory at Chilanga in Northern Rhodesia together with all other items under 12 tons from the railway sidings at Lion's Den and Kafue to Kariba; and the other for transporting all items over 12 tons to Kariba and to the substations. The contractor who was awarded the latter contract purchased a special 32-wheel road trailer, with a capacity of 125 tons, and had a similar trailer available in the Union of South Africa, in case of damage to the first.

The abnormally heavy items included twenty-six transformers, weighing between 88 and 109 long tons. Due to restriction on road loadings, the transformers normally had to be delivered during the dry seasons. The basic principles adopted were as follows:—

(a) That, as far as possible, at least two alternative methods should be available for transporting all items. This was achieved, except for turbine runners and certain heavy cables, which had to be transported by road from Beira.

(b) That the organisation should be sufficiently flexible to allow for the arrival of difficult items out of turn, due to causes such as delays or acceleration in manufacture, strikes, bad weather, etc. Among other things, this necessitated arranging for special holding areas throughout Southern Africa, but, by dint of complicated juggling of time tables, they were never needed.

(c) That shipment of items from overseas should never be held up because of doubt as to the possibility of transporting them in Africa, except as a last resort. This became a matter of pride, and no items were ever refused, although this incurred many risks, since port authorities would not allow heavy items to be unloaded unless a railway wagon was ready to receive them.

The railway authorities in South Africa, Mocambique and Rhodesia co-operated magnificently and allowed priority to be given to specially urgent consignments. Without this co-operation, it is highly probable that the whole scheme would have been delayed.

Altogether, over 600,000 tons of goods were transported to Kariba, of which about 400,000 tons were cement. The whole transport operation worked smoothly and no delays occurred. Only one important item was damaged and it was, fortunately, relatively easily re-placed.

(vii) *Health.*

The health of the construction force posed another problem, due to the hot climate and the remoteness of Kariba. The nearest doctor was 100 miles away and the nearest hospitals, at Lusaka and Sinoia, were respectively 130 and 150 miles away.

A medical organisation was, therefore, established by the Board, which started in mid-1955, with a small clinic and one medical officer, and was extended until in May, 1957, a modern ninety bedded hospital was opened, complete with surgical and X-ray units and laboratory facilities. The staff consisted of a chief medical officer, surgeon, a medical officer, a matron, and eight nurses, together with the necessary supporting personnel. A dental service was also provided by a visiting dentist.

The effect of the tropical conditions on the labour force, although appreciable, was much less than had been thought likely, and the general level of health was good. As was inevitable, due to the nature of the construction work, and despite every precaution, accidents occurred and deaths were caused.

Special precautions were taken against Malaria and Sleeping Sickness. For Malaria the taking of prophylactic drugs was enforced as far as possible; houses and buildings were sprayed internally with residual insecticides; and larvicidal sprays were used on any pools of water in the vicinity of the townships and working sites. Due to these measures, the incidence of the disease was remarkably low and the few cases encountered had invariably neglected to take the proper prophylactic precaution.

A programme of aerial spraying was carried out in 1956 to eradicate tsetse fly from breeding places near Kariba, and the fly was later controlled by the provision of sheds and barriers on all access roads entering the area.

No cases of sleeping sickness occurred at Kariba itself, and the few cases brought to the hospital all came from some distance away.

(viii) *Design Modifications.*

In addition to the above special problems, there were of course the usual problems of design modifications—civil, mechanical and electrical — which became necessary as the work proceeded and which had to be accommodated into the smooth flow of construction and installation. Some of these caused difficulties requiring urgent action at the time, but all were successfully overcome.

D. CARRYING OUT THE CONSTRUCTION PROGRAMME.

(i) *Civil Engineering Works at Kariba.*

The early period of civil engineering construction was spent in preparatory work; establishing construction plant; developing local access, and diverting the river. The all-out effort commenced on the underground works proper early in 1957, and on the dam in the second half of 1957. Most of the 1¼ million cubic yards of concrete in the dam were placed between September, 1957, and June, 1959 — a period of only twenty-one months. Figure 11 shews the dam under construction with the central coffer-dam and the river flowing through the diversion openings.

The construction of the dam, however, was relatively simple compared with the underground works which were extremely complicated, and involved excavating and concreting a maze of halls, tunnels and shafts. The two main halls were the machine hall, 468 feet long by 75 feet wide by 132 feet high, and the transformer hall, 537 feet long by 55 feet wide by 60 feet high. The total quantity of rock excavated was nearly 800,000 cubic yards, and 184,000 cubic yards of concrete were placed. The six steel penstocks, 18 feet 6 inches in diameter, which lead the water to the turbines, were rolled and welded on site out of 1.125 inches thick steel plate.

The whole construction programme went well and all the target dates were achieved, and in many cases bettered. As could be expected, several minor setbacks occurred, but there was only one major setback — caused by the river itself.

The vagaries of the river during the construction period have become almost legendary. In 1956, when it seemed that the flood season had passed, a cyclone occurred and the accompanying heavy rainfall caused an abnormally late rise in the river, with consequent reduction in the dry season working time.

In 1957, the main flood peak rose to 290,000 cusecs, which was higher than had been known before and equalled the highest flash flood previously recorded. This inundated the North Bank coffer-dam and caused some delay although, fortunately, the damage was insignificant.

In 1958, freak weather conditions gave rise to a flood of almost catastrophic proportions, with a peak of 570,000 cusecs—almost double that of the 1957 flood. This caused delay and damage. The central coffer-dam, within which a start had been made on the main dam foundations, was overtopped and, even worse, a hole developed in the rock foundations beneath the upstream wall of the coffer-dam.

The road bridge was destroyed, and the foot bridge severely damaged. Access roads, offices and stores on both banks of the river were swept from the sides of the gorge. For a period of ten days the underground works had to be sealed off to prevent them from being flooded. During this time, all work at the site was almost totally disrupted.

The peak of the flood occurred on 4th March, 1958, and as soon as it started to recede, restoration of the damage commenced. The roads were repaired within a few days and the suspension foot bridge was re-opened on 10th April, 1958. Repairs to the coffer-dam were not completed until June of that year, and it was September before the new road bridge was in operation.

The falling flood revealed further problems. The main river diversion structures had been damaged, requiring the

Fig. 11.

adoption of a different and more expensive method of sealing off the dam, and enormous quantities of debris had been deposited in the river channel immediately downstream of the dam site. This debris had the effect of raising the tailwater level and, if it had been left, would have brought about a marked reduction in the efficiency of the scheme. A channel, therefore, had to be excavated through the debris to restore the original conditions.

The whole of the construction programme for the dam had to be reviewed, both from the point of view of the delay which had occurred, and of the possibility of a similar flood occurring in 1959. A highly accelerated programme was, therefore evolved which, in the end, led to completion of the dam almost a year ahead of the original schedule. It was also thought prudent to increase the spillway capacity, and the number of sluice gates in the dam was increased fom four to six, giving a maximum discharge capacity of 336,000 cusecs — which, supported by the flood storage in the lake, could accommodate a very much greater flood than had occurred in 1958.

After the revisions had been made, the construction work continued smoothly and impounding of water in the lake commenced in December, 1958, as planned.

In spite, therefore, of the major disruption which was unprecedented in a scheme of this magnitude, all targets were achieved, with a substantial margin in the case of the dam. Figure 12, shows a view of the completed dam with water passing through three of the six spillway gates.

(ii) *Electrical and Mechanical Engineering Work.*

The electrical and mechanical engineering work covered the provision of the power station and substantion plant at Kariba, the 900 miles of 330kV transmission line required, the plant at the receiving sub-stations and the protection, metering, communications and indication plant. Here, the

Fig. 12.

work was of a more normal nature but required detailed and careful execution to ensure co-ordination of manufacture, transport and installation of the very large quantities of plant and to achieve commissioning of each section by the required date. Once again, all targets were achieved and the first three turbine-generators at Kariba, together with the associated sections of the transmission system, were commissioned on

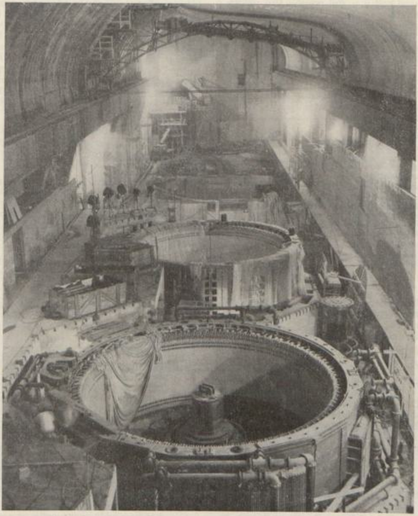


Fig. 13.

the programmed dates. Figure 13, shews a general view of the machine hall with the first three sets under construction.

(iii) *Construction Costs.*

The work of construction is not yet finished and it is still possible that unforeseen contingencies may arise. With this proviso, the present estimates of the cost of the Project are substantially below the original estimates as will be seen from the following figures:—

	Original Estimate £Rh Millions	Latest Estimate £Rh Millions	Increase (+) or Decrease (—) £Rh Millions
Civil Engineering Works. (including engineering fees, expenses and contingencies).	39.2	40.6	+1.4
Electrical and Mechanical Works. (including engineering fees, expenses and contingencies).	27.5	21.9	—5.6
Other Expenditure. (re-settlement of displaced people, administration, medical services, preliminary investigations, etc.).	4.3	5.0	+0.7
Finance Charges. (interest and other charges on loans).	8.5	7.4	—1.1
TOTAL:	79.5	74.9	—4.6

In comparing these estimates it should be remembered that in addition to covering all that was provided for in the original estimates the latest estimate also covers:—

(a) Dam 20 feet higher.

(b) Substation to give supply to Lusaka.

(c) An additional 100 MW turbine-generator.

Despite the increased provision of plant and despite the phenomenal floods and other difficulties during constructeion the present estimate of cost is well below the original estimate.

E. THE KARIBA PROJECT IN OPERATION.

(i) *The Federal Power Board's Bulk Supply Tariff.*

The Federal Power Board supply only in bulk and have but first consumers — three Municipalities, an Electricity Supply Commission and a private power supply company. Considerable thought was given to the establishment of the initial tariffs. It was obviously desirable that these initial tariffs should not require early alteration. On the other hand, they must be in a form providing from the start the maximum incentive to development of load so that the heavy capital investment at Kariba might soon be brought into beneficial use. Furthermore, account had to be taken of the fact that the public naturally expected to see some immediate benefit from the bringing into operation of the Kariba Project in the tangible form of reduced costs for electricity supply.

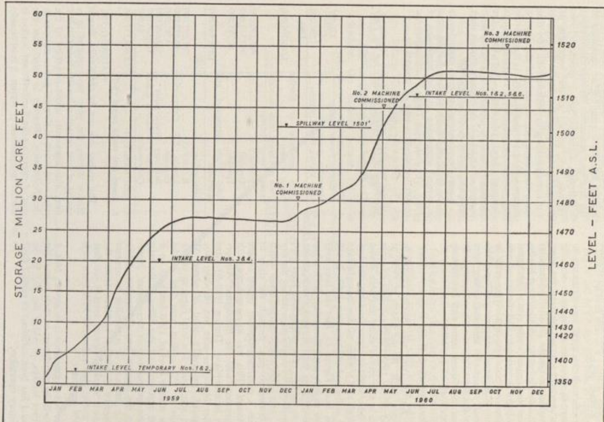
Although the Kariba Project is inherently a very low cost power scheme, it was nevertheless not easy to satisfy these requirements, for three reasons:—

1. During the first two or three years while the Kariba Project was under construction and plant being brought progressively into operation the output from Kariba would necessarily be relatively limited and hence the cost per unit supplier relatively high.
2. In accordance with the terms of the Loan Agreement with the World Bank, The Federal Power Board is bound to provide for half the capital cost of Stage II of the Project out of revenue from Stage I. The sum involved is very considerable and may be about £25 million.
3. The Board is bound to re-pay the loans raised for Stage I within the periods of these loans, which are in general shorter than the economic life of the plant to which they relate.

All these factors tend to make the initial cost of power from Kariba much higher than the ultimate cost will be. It was therefore decided to frame a tariff on the following principles:

(a) All Undertakings should pay for the supplies they now consume at their present production cost.

(b) All Undertakings should be able to purchase additional supplies at a uniform price fixed at a level equal to



KARIBA LAKE – INITIAL FILLING CURVE Fig. No. 1[illegible] little more than half the present average price.

The effect of this tariff was to secure to the Board the revenue necessary to meet the present production costs while at the same time making available to all Undertakings immediately the benefits of additional Kariba power at very much lower cost. The actual form of the increment tariff finally chosen was the normal two-part type with a relatively high fixed component (£7 per kW of annual maximum demand) since over 90% of the Board's costs of production is in the fixed component, and a very low running component (0.1d. per kWh).

(ii) *The Operation of the Project to Date.*

The Kariba dam was finally closed in December, 1958. By the middle of 1959, at the end of the 1958/59 flood season, some 27 million acre feet of water had been stored in the lake, and the water level had reached 1475 feet a.s.l.) when it was brought into service at the end of December, 1959. It will be seen from Figure 14, that the lake level then fell slightly until December, 1959, when the run-off from the following season's rains began to be felt. The fall in lake level was, of course, due to evaporation during the dry season, and to the compensation water which was allowed to pass through the dam to maintain a minimum flow of 10,000 cusecs downstream. This was in accordance with the agreement with the Portuguese Authorities in Mocambique. During 1959-60 rains a further 24 million acre feet of water was impounded, making a total of about 51 million acre feet. The total capacity of the reservoir is 130 million acre feet at the normal storage level of 1590 feet a.s.l. so it may be expected that the filling of the lake will take another two or three years. However, at the present level (December, 1960) of 1,513 feet a.s.l. it is possible to operate the number 3 and 4 turbines from the permanent intakes (invert level 1,460 feet a.s.l.) and to obtain about 90 MW from each 100 MW generator.

After No. 4 generator is in service, Nos. 1 and 2 will be transferred to their permanent high level intakes, provided the rise in the lake level has been sufficient to permit their satisfactory operation.

It will be seen, therefore, that at the present lake level water for the operation of the first four generators on restricted output is already assured. No. 3 generator was brought into service at the beginning of November and generator No. 4 is planned for commissioning in March, 1961. By that time, the maximum capacity of the Kariba station will be about 350 MW. It is probable that when the station is operating at its designed head of about 310 feet, the generators will be capable of a continuous output of about 112 MW each, though their designed rating is only 100 MW.

It may be of interest to give some details of the result of the operation of Kariba since it started generating at the beginning of 1960. The following Table 1 summarises the results for the first year of operation:—

TABLE 1.

Summary of Operation Results for the Year Ended 31st December, 1960.

	kW.
1. Maximum generation capacity at Kariba Power Station	270,000
2. Maximum generation sent out from Kariba Power Station	237,000
	kWh.
3. Units generated at Kariba Power Station	1,047,506,000
4. Units purchased from interconnected Power Stations:	
Salisbury	405,190,000
Umniati	397,323,000
Lusaka	46,785,000
5. Total Units generated and purchased	1,896,804,000
6. Units sold:	
R.C.B.P.C.	761,992,000
Lusaka E.S. Corporation	47,852,000
Impresit	9,581,000
Salisbury Municipality	509,826,000
Southern Rhodesia E.S.C.	519,824,000
Cementation	56,000
7. Total Units sold	1,849,131,000
8. Losses and works power (5–7)	47,673,000 (2.5%)

The energy sent out by the Kariba Power Station during the year has resulted in a saving of coal consumption of about 630,000 tons: this represents about one-third of the total coal burnt in thermal power stations in the Federation. Bearing in mind that the cost of operating the Kariba Power Station is almost independent of output, it is obviously in the interests of the electricity supply industry as a whole to operate the plant at the highest possible load factor. For the first twelve months of operation the Kariba generating plant load factor was 78%. When the Kariba plant is fully installed the station load factor may be of the order of 70%.

(iii) *System Commissioning Tests.*

Owing to the necessity for commencing supplies to the Copperbelt area at the earliest possible date, the Kariba-Lusaka-Kitwe lines and associated substations were brought into service when only one generator was available at the Kariba Power Station. This introduced some special problems, since the charging current of these transmission lines corresponds to some 160 MVA, and, even with the two shunt reactors in circuit at Kitwe, exceeds the generator rating. This is not serious from the viewpoint of the generator current loading but the possible effects of self excitation of the generator has to be borne in mind. Figure 15 shews the leading current excitation characteristic of generator No. 1 at Kariba. It will be seen that at a leading current loading of 160 MVA the machine is approaching the condition of self-excitation which could lead to excessive voltages on the generator and substation equipment. It can be shewn that the limit of voltage stability in the absence of a high-speed automatic voltage regulator occurs when the machine excitation is zero at normal generator voltage. With a high-speed voltage regulator system capable of providing negative excitation, however, the limit is extended. To ensure that in fact dangerous conditions were not likely to arise, a series of tests were carried out during the commissioning period. The results of these tests indicated that zero excitation conditions might be approached during line charging operation, and that after some adjustment the generator voltage regulators were capable of preventing excitation instability even under these adverse conditions.

Tests were also carried out to confirm the performance of the 330kV switchgear and

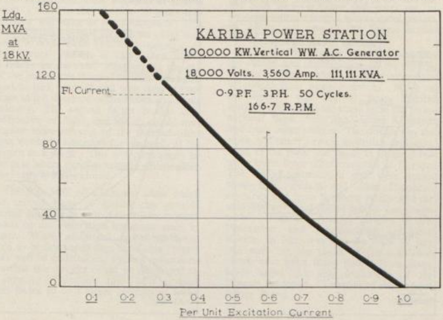


Fig. 15.

to calibrate the fault locating equipment. These tests involved fault-throwing on the 330kV lines. The opportunity was also taken by the Federal Post Office and the Rhodesia Railways to measure interference voltages on their communication circuits during fault conditions. The results of these tests have not yet been fully analysed.

E. THE FUTURE.

From what has been said above, it is clear that the Kariba Project is off to a good start and that the objective of providing the Federation with an abundant supply of power at a reasonable cost is well on the way to being achieved. To conclude this paper it may be of interest to attempt to look into the future — although this is always a rather hazardous undertaking!

After the completion of Stage 1 at Kariba — the installation of the first six machines in the South Bank Power Station — it is obvious that the next major provision of generating plant will be the second stage of Kariba. As at present planned, this provides for a North Bank Power Station with a probable capacity of about 900 MW. Since the dam is already built and the reservoir will serve both power stations, the cost of the second stage of the Project will be much less per kW than the cost of the first stage; the relative figures being about £125 per kW for the first stage and about £55 per kW for the second stage. It is for this reason that the Board has been able confidently to quote a low incremental tariff in the knowledge that the Federation can look forward to a long period of progressively falling bulk supply costs. With the second stage there will of course come re-inforcements of the transmission system and it is planned that the single circuit lines to Bulawayo and to the Copperbelt should be duplicated, thus greatly increasing security of supply. Figure 16 shews the transmission system as provided for Stage I of the Project and for comparison the transmission system which it is planned to provide when Stage II is fully developed.

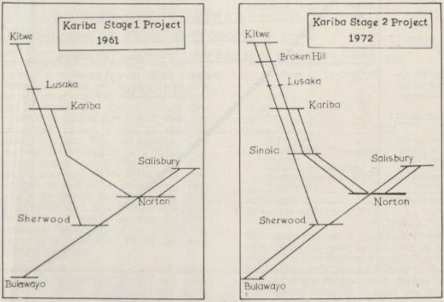


Fig. 16.

A word should be said here about the role of the coal-fired generating stations interconnected with Kariba and now operated as an integral part of the system. If it is remembered that the object of Kariba is primarily to provide additional capacity to meet normal growth of load rather than to displace the thermal stations, then it will be realised that these stations will have a life very similar to that which they might have expected under any other system of development of the power system. They are, in fact, likely to continue to be kept in service until the end of their normal economic life, but like most stations the amount of use which will be made of them will tend to be reduced over the years as they are displaced by more modern plant and relegated first to peak load and ultimately to standby operation. There are, however, two important factors which will especially effect the operation of the thermal stations connected to the Kariba grid. Firstly, there will be a period after the rapid installation of six machines at Kariba when a considerable surplus of generating capacity will exist in the Federation. This condition may persist for several years and, while it does, more restricted operation of the thermal stations is likely than would normally be the case. However, at the end of the period the thermal stations will again start to pick up load and take their normal place in the structure of the electricity supply industry. The second factor is that considerations of local security of supply may require more running of the thermal plant than would be necessary for the needs of the system as a whole. This will particularly be the case where supplies initially will be given over only a single circuit.

The 900 MW of additional plant which the second stage of Kariba can provide should meet the growth of electricity requirements in the Federation for many years to come. When additional power resources need to be developed then the Kafue Project may well be undertaken. Present indications are that this Project could be developed to a capacity of perhaps 1,000 MW at high load factor or to a larger capacity at lower load factor, and that the cost per kW would be comparable with the Kariba Project. The transmission costs would of course be less, since the Kariba-Kitwe lines have been routed so that they pass close to the probable site of the main Kafue power station.

Looking still further ahead, the time will come when the loans raised to finance the Kariba Project are fully re-paid. The plant which they have provided will, however, still have many years of useful life and the cost of electricity production will then fall still further. If the other side benefits which the Project has created are also taken into consideration, the Kariba Lake with its potential for tourism, transport and commercial fishing, the provision of nearly 100 miles of additional public roads, the regulation of the River Zambezi with the resultant implications for river transport and riverine agriculture, the creation of Kariba township with its hospital, airfield, schools and other amenities —the Federation may well feel satisfied with the bold decision taken five years ago to proceed with the largest water power project in Africa and one of the largest in the World.

In conclusion, it must be emphasised that the design and construction of the Kariba Project is a fine example of the co-operation of people from many countries. Much of the finance was derived from Federal resources but much too came from the International Bank, from the United Kingdom and from other sources. The design was the work of French as well as British engineers. Most of the plant was made in England but some came from other countries in Europe. The skilled construction staff were drawn from Italy, Britain and other European countries and from Southern Africa and the unskilled and semi-skilled labour was drawn mainly from the African peoples of the Federation and neighbouring countries. Kariba, in fact, was not the work of any one man but the result of the combined efforts of a great many people from many lands under the able leadership of Sir Duncan Anderson, Chairman of the Federal Power Board.

Supervisory Remote Control of a Distribution System

By

E. BROD, Dipl. Ing., A.M.I.E.E.

Summary.

This paper describes equipment which has been installed in Salisbury for the effective control of the Distribution System from a Central Control Room. Two different control systems are described. One system, usually called the Direct Wire System, requires one or more pilot wires between the control point and each controlled substation for each function; whilst the other system requires only a very limited number of pilot wires in order to carry out a large variety of different functions. For this system the term Supervisory Control System is usually applied. In this paper, a system used for indicating and alarm functions is called a Supervisory System, while a system used for switching and telemetering functions is termed a Control System. A system combining all these functions is then denoted by the usual term, Supervisory Control System.

Contents.

1. INTRODUCTION.

1.1 *Reasons for Installation.*

For many years the Salisbury Municipal Electricity Department has maintained a 24 hour service for attending to consumers' fault calls, and for dealing with distribution outages. This service operated efficiently and

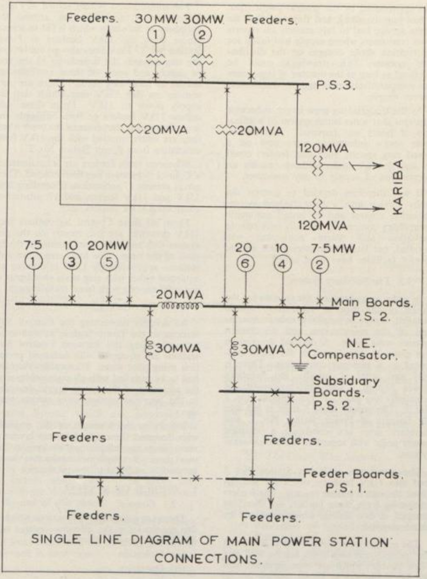

Feeders.
30MW
30MW
Feeders.
1
2
P.S.3.
20MVA
20MVA
120MVA
KARIBA
120MVA
7·5
10
20MW
1
3
5
20
10
7·5MW
6
4
2
20MVA
Main Boards.
P.S. 2.
30MVA
30MVA
N.E.
Compensator.
Subsidiary
Boards.
P.S. 2.
Feeders
Feeders.
Feeder Boards.
P.S. 1.
Feeders.
Feeders.
SINGLE LINE DIAGRAM OF MAIN POWER STATION CONNECTIONS.

Fig. 1.

was appreciated by the general public. But it had one drawback and this was, that the faults service had to rely entirely on reports from consumers whose supply had failed for information about outages on the distribution system. This drawback could be tolerated as long as the number of consumers was comparatively small and the distribution system simple.

As the Undertaking grew larger, it became apparent that some better system of notification of faults was required. In addition, some major substations were now on a closed ring system, such that feeders could be lost through faults without causing an interruption of supply to any consumer.

It was therefore decided to convert the faults service into a fully fledged system operation control and to install automatic supervisory equipment. Initially only remote indication and alarm equipment was installed, but lately telemetering and remote control facilities have been added.

1.2 *The Salisbury System.*

In order to understand the reasons for the choice of the type of supervisory system installed, it may be helpful if a short description of the transmission and distribution systems were given. A detailed description was given by Mr. Lynch in the paper presented to a previous convention. There is only one point of supply: the Salisbury Power Station. This station consists of essentially two parts: Power Stations Nos. 2 and 3. The supply from Kariba is fed into the busbars of Power Station No. 3, and therefore does not constitute a separate supply point with regard to the transmission system.

The generators at Power Station No. 2 feed into 11kV busbars, which are sectionalised through a busbar reactor. The feeders emanating from these busbars are therefore grouped in two halves, which must not be interconnected.

The generators at Power Station No. 3 and the transmission lines from Kariba feed into 33kV busbars which are interconnected with the 11kV busbars at Power Station No. 2. Figure 1 shows a single line diagram of the Power Station connections.

The transmission system shown in Figure 2 consists of a 33kV ring around the periphery of Salisbury which is fed in several places from the 33kV busbars at Power Station No. 3. 33kV lines also go out beyond the ring towards the boundaries of the area of supply and some of these are interconnected to form ring feeds. There are substations on this 33kV ring which step the supply down to 11kV. From these substation 11kV feeders go both outwards and inwards towards the centre of the town where they are interconnected with the 11kV feeds emanating from Power Station No. 2.

Wherever main feeders are interconnected a Control Substation has been erected. There are at present 17 substations controlling both 33kV and 11kV feeders and 17 substations controlling 11kV feeders only.

From all these Control Substations local 11kV networks are fed, mostly on the ring system with normally open points on the far ends of the rings. The local step-down substations, approximately 1,200 in number are equipped either with ring main switchgear or are solid tee-offs with fused transformers.

1.3 *Pilot Cables.*

All feeders connecting the Control Substations to the Power Station as well as all interconnecting ties between Control Substations are equipped with balanced protection using pilot wires. Pilot cables therefore had to be installed with all main cables since the inception of the system layout described in the previous section, over twenty years ago.

Thanks to the foresight of the engineers who designed the original system layout so many years ago, all pilot cables have at least two pairs of telephone conductors incorporated in addition to the pilot cores.

2. CHOICE OF SYSTEM.

2.1 *General.*

There are generally five functions which are required for the effective control of a distribution system. They are:

(a) Indication

(b) Operation

(c) Telemetering

(d) Alarms

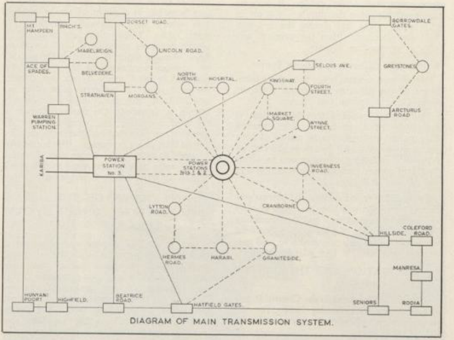


Fig. 2.

(e) Telephones.

Each of these functions can be carried out by various kinds of control systems, such as the Direct Wire System and the Supervisory Control System which are employed in Salisbury. Both systems are equally reliable and the choice of system and of transmission medium for any particular function depends entirely on questions of economy and feasibility related to local conditions. Some of the factors which have to be taken into account are discussed in the articles listed at the end of this paper.

The choice of systems made in Salisbury need not therefore be generally applicable, and local conditions may require a different approach in each case.

Both systems use telephone-type apparatus in conjunction with interposing relays and instrument transformers. Pilot cables with very small conductor sizes can therefore be satisfactorily employed over considerable distances. The conductor chosen was 1/.040 copper conductor, paper or P.V.C. insulated and laid up in pairs, except for distances in excess of 15 miles, where 1/.064 copper conductors are used.

2.2 *The Direct Wire System.*

This system is used for three functions only:

(a) Gas Alarms

(b) Indication of Ripple Control

(c) Indication of Sensitive Earth Fault Relays.

The reasons for choosing the Direct Wire Systems were: firstly that these functions could not easily be accommodated within the Supervisory System chosen: and, secondly the availability of a sufficient number of spare cores in the pilot cables. It may be mentioned here that the number of cores in some pilot cables laid during the last few years has increased from the original two pairs to as many as 30 pairs.

2.3 *The Supervisory Control System.*

For all requirements other than those mentioned in the previous paragraph a Supervisory Control System was chosen.

The method adopted for this System is the display of a substation on a common diagram and its operation by means of keys and push buttons. All functions are carried out with a coded signalling system in which a train of pulses performs the selection and operation of all devices.

Equipment for indications and alarms was installed first and was later extended to cater for remote switching and telemetering facilities. One pair of pilot wires is required for indication and alarms, and a second pair for remote operation and telemetering.

3. APPLICATION OF THE DIRECT WIRE SYSTEM.

A free standing panel in the Control Room contains rows of indicating lamps, one for each alarm or indication enumerated below.

3.1 *Gas Alarms.*

All Gas Pressure Cables are equipped with devices which indicate the presence of gas leaks. The operation of such a device causes an alarm and the lighting up of the appropriate indicating lamp.

3.2 *Ripple Control.*

At present, three channels of the Ripple System are used for the switching of water heaters which are divided into 3 groups. A further 2 channels are used for street lighting which is divided into 2 groups: lights that burn all night, and those which are switched off at 1 a.m. Indicating lamps show which of these 5 channels are left in the "on" position.

3.3 *Earth Fault Relays.*

A novel type of very sensitive earth fault relay was recently developed by the Salisbury Electricity Department. In addition to its normal function as an earth fault relay, it also gives warning of small leakages to earth such as those caused by faulty insulators or tree branches in close proximity to conductors which may eventually develop into earth faults. These relays are installed on circuit breakers controlling 11kV overhead lines. Message registers, counting the number of warning operations of these relays are installed in the Control Room, one counter for each relay. If sufficient pilot cores are not available, only one counter for each substation is installed. On the occurrence of repeated warnings, the overhead lines in question are patrolled and the faults rectified before they cause an outage. It is hoped that a paper describing the design and operation of this relay may be presented to this Association at some future Convention.

4. APPLICATION OF THE SUPERVISORY CONTROL SYSTEM.

4.1. *General.*

The method of display and operation of the supervisory system is similar to several widely used standard systems, and was designed departmentally in consultation with the suppliers of the equipment. It was adopted because it appeared to be the one best suited to local conditions. The system used was designed by the suppliers, but various modifications and refinements were carried out by the Department after installation. The system is comprehensive, flexible and very simple to operate. In view of the large size of the system diagram, containing over 1200 substations and numerous isolating points on overhead lines, which occupies a complete wall in the Control Room, it was decided to keep this diagram hand-dressed. A common diagram in the centre of the control desk displays all conditions prevailing in a Control Substation and illuminated windows on the wings of the desk indicate which substation is presently displayed. Figure 3 shows a photograph of the Control Room.

As all substations controlling the 11kV transmission network are interconnected, irrespective of their source of supply, i.e. the 11kV busbars of the Power Station or a step-down point from the 33kV system, it was decided to separate the Supervisory System controlling the 11kV substations from that controlling the 33kV substations. Two

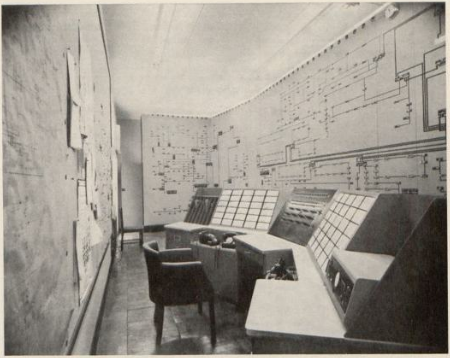


Fig. 3.

entirely independent systems each with a separate common diagram and separate operation keys were therefore installed, and each step-down substation was split into 2 parts, 3 33kV and an 11kV substation.

A total of 20 channels are available for each substation allowing for the indication of a maximum number of 20 facilities and for the control of a maximum of 18 facilities.

The whole installation caters for 20 — 33kV substations and 40 — 11kV substations, but is capable of being extended.

The following facilities are available for each substation:

(a) The indication of the position of all switchgear;

(b) Alarms indicating the tripping of a switch;

(c) Alarm on the operation of fire-fighting equipment;

(d) Indication of the position of switches which make the fire-fighting equipment inoperative;

(e) The operation of circuit breakers, interlocked with a warning signal;

(f) Buchholz relay alarms;

(g) Telemetering of ammeter and voltmeter readings;

(h) Telemetering of battery voltages;

(i) Telephones.

4.2 *The Common Diagram.*

The common diagram consists of 20 pairs of lamps, each pair corresponding to one of the 20 channels available, one lamp showing

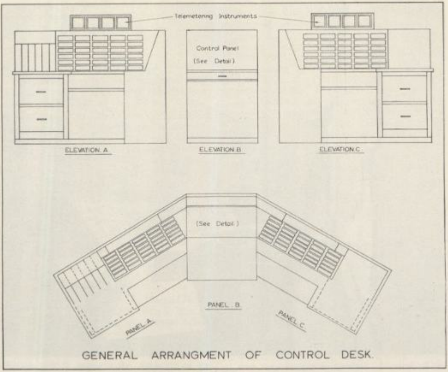


Fig. 4.

the device in the "on" position and the other in the "off" position. When a display is being given either one or the other of the 20 lamps must be lit up. Where, however, the total number of switches in a substation is less than the maximum allowed for, the redundant lamps are automatically blanked out to avoid confusion.

The 20 channels have been allocated as follows:

(a) On the 33kV system: 2 channels for fire-fighting equipment, 4 channels for Buchholz alarms, 1 channel for the warning of a switching operation, and 13 channels for circuit breakers.

(b) On the 11kV system: 2 channels for fire-fighting equipment, 1 channel for a telephone, 1 channel for the warning of a switching operation, and 16 channels for circuit breakers.

The illuminated windows on the wings of the control desk have transparent covers on which are engraved the name and number of the substation, a single line diagram showing all the switches in their correct sequence with their circuit labels and their normal position, whether "on" or "off". This is indicated by coloured pegs matching the indicators on the system diagram which can easily be changed.

A set of keys, one for each substation, is provided which selects the substation to be connected to the common diagram.

A further set of keys, one for each switch, selects the particular switch which is to be operated or telemetered. Push buttons and keys common to the whole equipment initiate closing, tripping, telemetering and telephone operations.

On top of the control desk are mounted the instruments for telemetering. There are

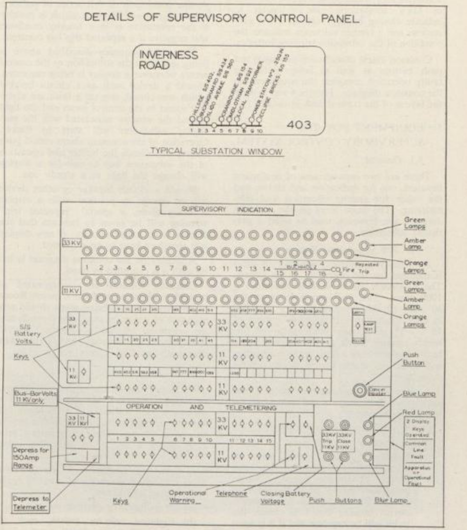


Fig. 5.

2 ammeters for each system, one scaled 0-600 amps and the other 0-150 amps. The 600 amp ammeter is normally in circuit, but should the reading be too low, the other one is connected by means of a key. One voltmeter is provided to indicate busbar volts in 11kV substations, one voltmeter to indicate closing battery volts in 33kV substations and a further voltmeter indicates the condition of the substation tripping batteries.

Common alarm cancellation and lamp test push buttons as well as lamps indicating faulty operation complete the equipment on the common diagram. Figures 4 and 5 show the layout of the control desk in detail.

5. EQUIPMENT FOR THE SUPERVISORY CONTROL SYSTEM.

5.1 *General.*

There are two separate sets of equipment installed, one for indication and alarms and the other for remote operation and telemetering. The same keys on the common diagram are, however, used to select a particular substation.

5.2 *The Supervisory System.*

As already mentioned, one pair of wires is required for the operation of the system. The maximum allowable loop resistance is 1000 ohms. This line loop is fed from the 30 volt 10 Ah tripping battery installed in each substation with a steady current of 18 — 21 mA. Any interruption of this steady current, such as one caused by a faulty equipment or a fault in the pilot cable, will cause the alarm hooter in the control room to sound.

A complete sequence of pulses lasts approximately 5 seconds and comprises the following elements:

(a) A preliminary negative pulse;

(b) A starting negative pulse:

(c) Twenty signalling pulses, each of about 100 m. sec. duration and spaced by similar intervals, whose polarities depend upon the position of the 20 devices. If for instance, circuit breaker No. 1 is closed, the pulse will be negative and if it is open it will be positive.

(d) A long negative pulse of about 200 m. sec. duration, used for the checking feature.

(e) A negative check pulse of normal duration.

At the conclusion of this series of pulses a steady signal will be given which is positive if the substation is in a healthy condition and negative if a repeated trip has occurred.

The entire sequence described above is being sent from the substation to the control centre whenever a display is being requested. Should a device such as a circuit breaker which was closed, trip on a fault, an alarm will sound in the control room and the light behind the window associated with the particular substation will start to flicker. Operation of the common alarm cancel push button will silence the hooter and operation of the substation key to call for a display will change the light to a steady one.

Should a circuit breaker or other device trip or change its position while a display is being given, a special "repeated trip" warning will be given to indicate that the display is no longer correct. A new display will therefore have to be requested.

A display on the common diagram is left on until it is cancelled by hand.

Checking features are incorporated at both the substation and the Control Room to prevent a display being given should any sequence of pulses be mutilated through any mal-operation of the equipment. Should more than one display key have been operated, one display only will be given.

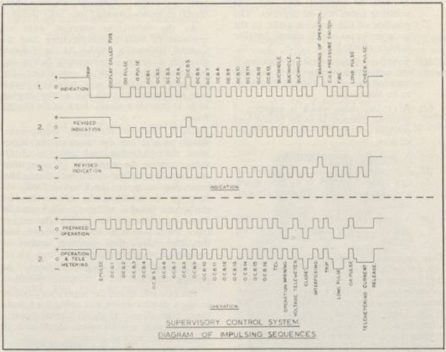
5.3 *The Control System.*

As in the case of the supervisory system, one pair of wires is required with a maximum loop resistance of 1000 ohms, fed from the control room battery with a steady current of 10 mA. This steady current provides again a check on the pilot cable equipment.

A complete sequence of signals lasts approximately 4 seconds and consists again of 24 pulses as follows:

(a) A preliminary positive pulse.

(b) Eighteen selector pulses, each of about 75 m.sec. duration, of which



1. INDICATION
TRIP
DISPLAY CALLED FOR
00 PULSE
0 PULSE
WARNING OF OPERATION
FIRE
LONG PULSE
CHECK PULSE
2. REVISED INDICATION
3. REVISED INDICATION
INDICATION
1. PREPARED OPERATION
2. OPERATION & TELE METERING
TEL
VOLTAGE TELEMETER
CLOSE
INTERPOSING
TRIP
LONG PULSE
OK PULSE
TELEMETERING CURRENT
RELEASE
OPERATION
SUPERVISORY CONTROL SYSTEM
DIAGRAM OF IMPULSING SEQUENCES

Fig. 6.

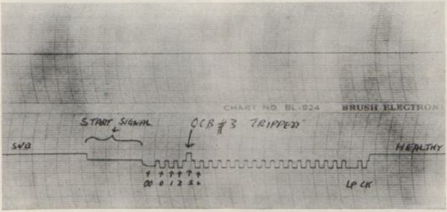


CHART NO BL-024
BRUSH ELECTRON
START SIGNAL
OCB #3 TRIPPED
SVB
HEALTHY
00 0 1 2 3
LP CK

Fig. 7.

17 will be positive and one, the selecting pulse, will be negative. The position of the negative pulse in the train indicates which circuit breaker is to be selected.

(c) A voltage pulse which is negative if the substation voltage is to be telemetered and positive if any current is to be telemetered.

(d) A closing pulse which is negative if a circuit breaker is to be closed and positive under all other circumstances.

(e) A positive interposing pulse.

(f) A tripping pulse which is negative if any circuit breaker is to be tripped, and positive under all other circumstances.

(g) A long negative pulse of about 200 m.sec. duration used as a checking feature.

This sequence of signals is sent from the Control to the appropriate substation. If the substation has received these signals correctly a positive check pulse is sent back from the substation to the Control. Receipt of this check pulse clears the line loop for telemetering. The operation of a circuit breaker cannot however be initiated until a warning signal has been sent over the supervisory system. Release of the key operating the warning signal clears the control system for the operation of a circuit breaker.

This warning feature, which sounds a hooter in the substation has been incorporated in order to guard against the possibility of maintenance fitters, working in the substation. If a switching operation should not have been carried out within half a minute of a warning having been given, the line loop is released and the whole procedure has to be restarted.

Whenever a switching operation is carried out on a particular circuit breaker, the current of that circuit is automatically telemetered. It is, however, possible to telemeter any circuit without a switching operation being carried out.

All telemetering is carried out with a weak direct current potential of negative polarity which operates directly a moving coil instrument. Ammeter readings have therefore to be converted into D.C. voltages.

As the substation selection keys are common to both the Supervisory and the Control Systems, a display on the common diagram is given automatically before any telemetering or switching operation. The successful completion of a switching operation automatically calls for a new display, so as to provide a visual check at the control room.

Check features are again incorporated which prevent any operation of the equipment through either mal-operation of the equipment or the operation of more than one key. Should mal-operation occur, a blue indicating lamp on the Control Desk will light up. In addition, the selector key for the circuit breaker to be operated must be depressed with one hand while the trip or close push button is being depressed with the other hand, thus guarding against an accidental switching operation.

Figure 6 shows diagrammatically the pulsing sequences for a complete operation.

The first line shows the supervisory system giving a display which was called for following a trip alarm. It shows circuit breaker No. 5 tripped, and all others closed and all relays in the normal position.

The fourth line shows the control system. Warning has been given that circuit breaker No. 5 will be closed.

In the second line the supervisory system indicates that the warning hooter has sounded in the substation.

The fifth line shows the control system sending the closing signal for circuit breaker No. 5 and at the same time telemetering the circuit of breaker No. 5.

The third line shows again the supervisory system giving the control display and showing circuit breaker No. 5 closed.

The actual shape of the pulses can be seen in Figure 7 which is the photograph of an oscillogram taken during commissioning tests.

5.4 *Additional Equipment.*

In addition to the supervisory control equipment which consists essentially of relays, selector switches and other Post Office type equipment, further apparatus is required in all substations to connect the supervisory equipment to the switchgear.

5.4.1 *Indication and Alarm.*

Auxiliary contacts are fitted to each circuit breaker to indicate whether it is closed or open. A relay is fitted in the common circuit from the tripping battery to the switchgear to initiate the switch tripping alarm.

5.4.2 *Fire-Fighting Equipment.*

This equipment, which releases carbon dioxide on the operation of fusible links, incorporates a pressure switch which actuates the fire alarm in the Control Room. It also incorporates a manually-operated lock-out switch which has to be operated whenever the substation is being entered for maintenance purposes to guard against the accidental release of carbon dioxide. The position of this lock-out switch is indicated on the common diagram in the same manner as any circuit breaker. The control engineer is therefore warned if this switch is being operated and can ascertain during his periodical checks, if the lock-out switch has been restored to normal.

5.4.3 *Remote Operation.*

Interposing mercury type relays are fitted to each circuit breaker. These relays are connected to the closing and tripping circuits on the switch control handle. Figure 8 shows such a relay without its perspex cover.

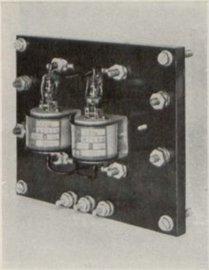


Fig. 8.

5.4.4 *Telemetering.*

Interposing current and voltage transformers with rectifiers are connected to corresponding instrument transformers on the switchgear and to the closing batteries. Figure 9 shows an interposing current transformer with its rectifier and diodes for surge protection, with the cover removed.

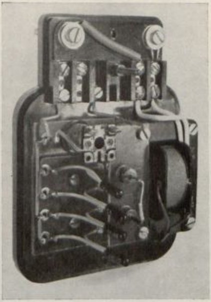


Fig. 9.

The voltage of the tripping batteries is metered directly as they supply the supervisory equipment.

5.4.5 *Warning Hooter.*

This hooter is installed in each substation and operates from the tripping batteries.

Fig. 10.

5.4.6 *Telephones.*

A telephone is installed in all 11kV substations. As all substations with 33kV switchgear also contain 11kV switchgear, one telephone is sufficient for both.

5.4.7 *Buchholz Alarms.*

Ordinary alarm relays energised from both the Buchholz alarm floats and from winding temperature indicators with maximum pointers operate the supervisory alarms.

5.5 *Cubicles.*

5.5.1 *Control Room.*

The equipment at the control room is installed in two places. The common diagram equipment such as lamps, keys, push buttons, meters and hooter are mounted on the control desk. All other equipment such as stepper switches, relays, condensers, resistances and terminal equipment is housed in 4 steel cabinets, 2 measuring 6′—0″ x 4′—8″ x 1′—4″ and 2 measuring 4′—0″ x 4′—8″ x 1′—3″ which are are installed in a special room adjacent to the control room. The battery required for the control equipment is housed, with

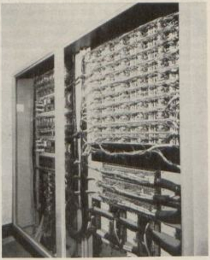


Fig. 11.

its trickle charger, in a special battery room which contains also the battery for the mobile radio equipment. Figure 10 shows a front view and Figure 11 a rear view of one of the steel cabinets.

5.5.2 *Substations.*

In each substation there are 2 wall mounted sheet steel cubicles, one measuring 1′—4″ x 2′—0″ x 11″ for the supervisory equipment and one measuring 1′—4″ x 2′—8″ x 10″ for the control equipment. These cubicles contain all equipment with the exception of the interposing relays and

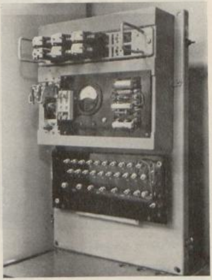


Fig. 12.

interposing instrument transformers which are mounted on the switchgear control panels. Figure 12 shows the supervisory cubicle and Figure 13 the control cubicle.

As this equipment is very compact, no difficulties were experienced in finding sufficient wall space in all substations. Figure 14 shows the control room in a step-down substation with two sets of cubicles on either side of the substation L.T. distribution board.

6. OPERATION OF THE SUPERVISORY CONTROL SYSTEM.

6.1 *General.*

A brief description of the actual operation of the system will help to clarify the design features described in preceding paragraphs.

It has to be emphasised again that there are two entirely independent systems installed, one for the 33kV network and one for the 11kV network. All equipment on the Control desk is therefore duplicated and can be operated independently and simultaneously. In order to distinguish the two equipments, every item is carefully labelled and in addition, all keys for the 33kV network are coloured yellow while the keys for the 11kV network are black. The engraving of the transparent substation windows is in red for the 33kV substations and in black for the 11kV substations.

The indicating lamps of the common diagram are coloured green to show open devices and amber to show closed devices. The only exceptions are the lamps which indicate the operation of the fire-fighting equipment which are coloured red and the lamp indicating an incoming telephone call from a substation which is blue. This lamp is duplicated on top of the desk.

6.2 *Indication.*

If a display of a substation is required, the respective substation key which is labelled with the substation number is turned downwards. It stays in this position until released by hand. Immediately the white lamp behind the substation window lights up, and after completion of the pulsing sequence the lamps on the common diagram give a display of conditions in the substation. Returning the key to the neutral position disconnects the substation from the common diagram, but leaves the light on behind the substation window. Turning the

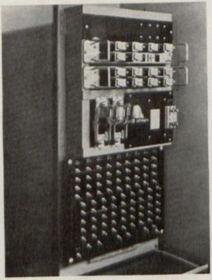


Fig. 13.

Fig. 14.

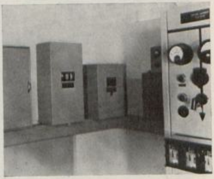


Fig. 15.

key upwards extinguishes this light. This is an important feature which will be explained in the next paragraph.

As mentioned before, should any device in the substation which is being displayed change its position a general repeated trip alarm sounds which lights up a special white lamp. This is an indication that the display on the common diagram is no longer correct. The substation key must now be released and depressed again, thus calling for a new display.

6.3 *Alarms.*

Should a circuit breaker in a substation trip, or should any other device such as fire-fighting equipment or a Buchholz relay operate, the alarm hooter sounds and the light behind the window of the substation in which the tripping has occurred will start flashing. Depression of an alarm cancellation push button will silence the hooter. Depression of the appropriate substation key will give a display and convert the flashing light into a steady light. A comparison of this display with the single line diagram on the substation window will indicate which device has changed its position from normal.

It sometimes happens that circuit breakers in two substations trip simultaneously. In this case the flashing lights will appear behind the windows of both substations. One display will be requested by depressing the substation key and the light behind a second substation window, whose corresponding key is not depressed, will serve as a reminder to call for a display at a later stage.

A fault in the pilot cable or terminal equipment connected to the pilots of the supervisory equipment will sound the ordinary alarm hooter. The flashing light will indicate which substation is affected, but no display will appear on the common diagram on depression of the substation key. The flashing light also cannot be changed into a steady light until the fault has been attended to.

A fault in the pilot cable of the control equipment will light up a red lamp behind the substation window as well as a common red "line fault" indicating lamp.

6.4 *Telephones.*

The operation of a call push button on the telephone in a substation will cause an alarm in the control room in the same way as a switch trip. The display will show the lamp marked "Telephone" lit up. When a display has been called and the telephone key been depressed, the telephone connection will be established. If the control room wishes to call a substation, it is only necessary to depress the substation key and the telephone key. An audible signal will be given in the substation.

6.5 *Telemetering.*

If the ammeter reading of a particular circuit is required, the substation is selected by depressing the appropriate substation key, the circuit breaker is then selected by pushing the appropriate switching key downwards where it remains until released by hand. This brings the higher range ammeter on the control desk in the circuit. Should the reading be too low, the common ammeter telemeter key is depressed and the lower range ammeter is put in circuit.

For voltmeter readings the procedure is simpler. The substation is selected in the usual way and depression of a common key will give an indication of busbar volts. This facility is available only in 11kV substations at present. Depression of a second common key will give an indication of the closing battery voltage. Closing batteries are installed only in 33kV substations. The operation of two other common keys will put the tripping battery voltmeter into circuit of either an 11kV or a 33kV substation.

6.6 *Switching Operations.*

As described previously, closing or tripping a circuit breaker requires selection of the substation, operation of the switching key upwards in which position it has to be held against a spring return, and depression of the common close or trip push button.

It should be emphasized that any maloperation of the equipment, or the accidental depression of more than one substation or switching key simultaneously, will result in non-operation of the equipment.

At present, the only circuit breakers connected to the remote control system are those in the 33kV substations. The circuit breakers in the 11kV substations are not equipped with electrical closing devices with the exceptions of some having auto-reclosing relays. The cost of the conversion of all circuit breakers to electrical closing does not seem warranted, with the exception of a few which control ties between the 11kV and 33kV systems. These will be equipped with closing solenoids in the near future and then connected for remote control.

6.7 *Routine Operation.*

A very important consideration in the use of a Supervisory Control System is complete reliability. It has been found in practice that due to the fact that contacts on all telephone type equipment are self-cleaning, frequent operation of the equipment will ensure that contacts are always clean and that dust or other matter does not settle on any moving parts.

For this reason the practice has been established to operate the entire system at regular intervals.

At the beginning of every 8 hour shift the operations controller calls for a display of every substation, thus checking the position of every circuit breaker and other device. If time permits, telemeter readings of all currents and voltages are also taken at every shift, but if this is not possible, they are taken once every 24 hours.

Switching operations cannot, of course, be carried out regularly. But as the 33kV system is at present operated with open rings, the open points can be changed. This allows the opening and closing of some circuit breakers at least in every substation, thus ensuring the functioning of each substation equipment. The interposing relays on circuit breakers controlling spur lines are not operated except when actually required for general switching operations. These relays are however of the mercury type which is extremely reliable and it is therefore felt that the absence of check operations will not impair the reliability of the equipment as a whole.

7. COSTS.

7.1 *The Direct Wire System.*

All equipment for use with this system was designed and constructed departmentally. Most of the components were purchased locally, but some were drawn from existing stocks. It is therefore not possible to give a reliable figure of the total costs incurred by the Department, particularly because no check was kept on the time required for the design work.

7.2 *The Supervisory Control System.*

The equipment for this system was purchased by public tender. The lowest tender was accepted which was substantially lower than any other. The equipment for the control room including the operating desk cost £5,400. This sum includes installation charges.

The common equipment installed in each substation was £423 per substation. To this sum must be added the cost of interposing relays and instrument transformers which was £57 per circuit breaker.

Installation costs varied between £250 and £350 per substation.

7.3 *Pilot Cables.*

The total installed system comprises some 170 miles of pilot cable, of which half the mileage consists of cable having 2 pairs of 1/.040" telephone conductors in addition to the pilot cores. As mentioned before, a large quantity of this cable had been installed for a number of years. The cost of the two telephone pairs was never ascertained separately but it can be assumed that it was no more than the cost of the copper and insulation of these conductors, as they occupy the space of the wormings normally used in pilot cables. The price of such cable is approximately £130 per 1,000 feet.

Approximately 20 miles of pilot cable consists of 5—10 telephone pairs in addition to the pilot cores and some 60 miles contains 20 or 30 telephone pairs. The conductor size in these cables is often increased to 1/064" in order to reduce the loop resistance on long runs.

The additional cost of further telephone pairs in a pilot cable is £4 to £5 per pair of 1/040 conductors per 1,000 feet and £7 per pair of 1/064 conductors, in addition to the cost of the 2 pair pilot cable quoted.

8. OPERATING EXPERIENCE.

The Direct Wire System has been operating almost faultlessly for several years.

The Supervisory equipment has now been in operation for five years, but the Control System has only recently been installed and is not yet fully operational. The following remarks refer therefore to experience with the Supervisory System only.

Mal-operation of the equipment in the Control Room is very rare but faults on any one of the substation units occur on the average once a month. They are detected during the 8 hourly checks and rectified within a few hours. These faults usually require either the adjustment of a relay or the replacement of a condenser or resistance. Certain modifications which were carried out also reduced the proneness of some relays to maladjustment.

Faults on the pilot cables were at first more frequent, but as all weak spots, such as bad joints, are gradually eliminated, they diminish in frequency very rapidly.

Damage to substation equipment occurred on two occasions and was traced to over-voltages induced in the pilot cables during the passage of heavy fault currents through the high tension cables which are laid in the same trenches adjacent to the pilot cables. Post Office type surge arrestors were fitted to both ends of every pilot core used for supervisory equipment and appear to have cured this trouble.

No routine maintenance has so far been carried out on any part of the supervisory installation, as the very low incidence of faults did not warrant it. With the commissioning of the Control Equipment which contains many more parts than the Supervisory Equipment this position may change. Testing equipment has therefore been constructed which will enable the routine checking of substation equipments to be carried out. It is proposed to carry out routine checks monthly at first. Experience will indicate whether the interval between checks can be lengthened.

In general it can be said that the supervisory equipment has given excellent service and judging by its performance, an equally good service is expected of the control equipment.

The time required for the restoration of supplies following outages of distribution equipment has been appreciably shortened, and control of the transmission network has been immeasurably eased. It is felt therefore that the installation of the Supervisory Control Equipment has been justified in every respect.

9. ACKNOWLEDGEMENTS.

The author wishes express his thanks to the City Council of Salisbury for permission to publish this paper, to the City Electrical Engineer for his encouragement and advice and to several of his colleagues for their assistance. Finally the author expresses his thanks to the A.M.E.U., for having given him the opportunity to present this paper.

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The Utilisation of Hydro Electric Power in the Union of South Africa

by

C.E.R. LANGFORD, M.I.E.E., M.(S.A.) I.E.E.

1. INTRODUCTION.

In his address at Durban a year ago, your President drew attention to the power potential of Natal's water resources, and quoted a few figures which were sufficient to stimulate interest in this field. He also said "it is therefore in this direction that I feel very careful and comprehensive investigations should be made during the next few years." Although considerable care has been taken in its preparation, I make no pretence that this paper is a comprehensive investigation. It is, however, my hope that it will lend weight to your President's remarks, and give rise to the detail investigations that are a necessary preliminary step before any hydro electric scheme can come into being.

It is irrefutable that the basic use of the water that falls on the land is to support the population — to produce food (either where it falls or by irrigation), to meet the domestic requirements of the people, and to fulfil the needs of industry. But while this is accepted, a considerable quantity of water flows into the sea annually having commenced its journey at a fairly high altitude, and the purpose of this review is to examine the energy potential of some of South Africa's waters. Our objective is only to extract this energy (in the form of electricity) from the water in its journey from the hills to the sea, leaving the water unaffected and still capable of serving the basic needs of the people in many other ways.

South Africa has to-day reached the stage when it has several major transmission networks, fed by large thermal power stations, supplying several thousand million units annually. The transmission systems are expanding steadily, and the day is not far distant when the three major grids — Natal, Transvaal and Cape Western — could conceivably be interconnected. The interconnection would save on standby generating plant, but the considerable increase in demand each year would still require additional generating plant to be brought into service from time to time. It should be the continual aim to keep the cost of new power as low as possible. This paper examines the water resources of the country to see where, and whether, economical hydro power can be found to help meet the increasing demand.

In the past, the approach has been to look for hydro electric schemes capable of existing on their own and, while a few of these might be practicable, this study aims at finding large blocks of hydro power that could be integrated with the expanding thermal sources of supply.

One of the greatest difficulties in developing a hydro electric scheme is to justify the early stages when the large and generally expensive civil engineering work is producing only a small proportion of the total output of which the scheme is capable. This is true of an isolated hydro electric scheme. However, where a hydro electric installation is integrated with a large existing thermal system, it may be possible and economic to obtain a high degree of utilisation of the available energy from the water resource right from the inception of the scheme. In this way, the cost of hydro development might to-day compare not unfavourably with the cost of thermal development. With the advent of hydro electric works, other benefits would accrue to the country in that a considerable degree of river regulation and flood water control would be achieved, making it cheaper and easier to implement irrigation schemes and urban water supplies.

2. HISTORICAL SURVEY.

While a good deal of investigation was done 40 years ago, and presented as a paper

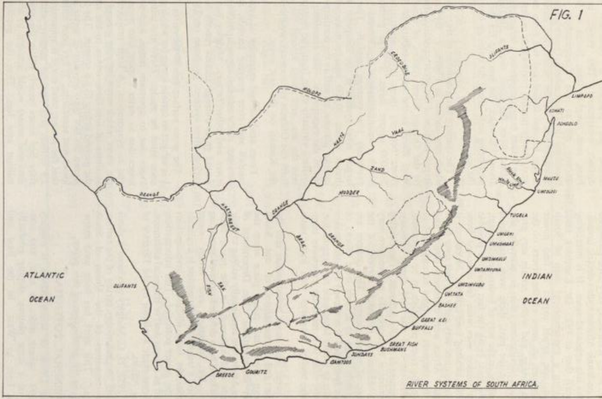


FIG. 1

RIVER SYSTEMS OF SOUTH AFRICA.

by Dr. F. E. Kanthack, very little published work on South African hydro electric investigations has appeared since. It is interesting to recall that in 1920, Dr. Kanthack said, "studying a topographical map of South Africa, one would expect to find power possibilities on most of the rivers of the coastal fringe, and within certain very pronounced limitations, this is actually the case." In the past, there were undoubted difficulties in the way of hydro development, not the least being the fact that the possible power station sites were far removed from the then existing load centres. Moreover, it became evident very early on that river flows in South Africa were extremely erratic and very few records had been accumulated to enable the river potentials to be appraised. In addition, coal was very cheap. To-day, the picture is totally different. The existing transmission networks do not require very much extension to reach certain of the sources of water power. The systems are sufficiently large to absorb large blocks of energy (provided it is cheap) and this makes it easier to justify large scale river regulation. Finally, coal is a relatively expensive commodity to-day compared with forty years ago.

A great deal more investigation into the nature and potentialities of our South African rivers has taken place since the earlier investigations. The Department of Water Affairs are continually adding to their records and although, in the main, their efforts have been directed towards providing water for irrigation and urban water supplies, a wealth of information is available to from the basis of further investigations into the power potential. This information, as well as a great deal of technical assistance, has been made avaliable by the Director of Water Affairs.

In 1952, D. C. Midgley produced a thesis entitled "A preliminary survey of the surface water resources of the Union of South Africa." This work has been used extensively in the production of this paper.

3. GENERAL POTENTIAL.

The Union of South Africa is roughly 470,000 square miles in area, and consists of a large plateau sloping gradually from East to West. In the East and South, the plateau is bounded by a distinct escarpment. This range, in the East, runs roughly from North to South, starting off as the Zoutpansberg, then becoming the Drakensberg, Quathlamba and Stormbergen. In the south, the mountain ranges become folded and run from east to west, finally turning northwards in the west. The folded ranges comprise a series of steps inland from the coast over a distance of about 300 miles, the first step for the most part being only about 50 miles or less from the sea.

The country has a number of river systems which are shown in Figure 1. By far the largest portion of the great plateau is drained by the Orange River system, of which the Vaal River is the major tributary. These rivers between them drain approximately 236,000 square miles, a large portion of which unfortunately is blessed with extremely low average rainfall. The next largest river system is the Limpopo which drains about 70,000 square miles of the interior plateau, as well as the northern-most tip of the escarpment. The remaining river systems virtually drain from the escarpment into the sea, and range around the coast from the Olifants river on the west coast to the Komati on the east coast.

From analysis and extension of available rainfall and river gauging records, and a detailed study of the topography, vegetal cover and other factors, Midgley has estimated gross average annual runoffs for the various river systems, as shown on Table 1.

The gross surface runoff shown in Table 1 is subject to certain losses for which allowance must be made. There are unnatural losses due to upstream usage, and natural losses due to water seeping into river beds and to evaporation. A large proportion of the water which seeps into the ground does, at times of low flow, return to the stream, the ground acting like a sponge. The figures shown do not take account of water usage, losses and accretions. It has been estimated that the present total usage is approximately 2.8 million acre feet per annum, while the river bed losses (nearly all in the arid and semi-arid areas) would amount to about 6 million acre feet. Thus the average net

TABLE 1.

Region Number	Drainage System	AREA IN SQUARE MILES Gross	Ineffective (No run-off)	Net	Gross average annual surface runoff from net effective area. (acre-feet)
100	Limpopo	70,549	7,660	62,889	5,531,520
200	Komati	11,866	51	11,815	3,264,570
300	Vaal	75,730	23,115	52,615	4,058,140
400	Orange (excluding Vaal)	160,302	44,851	115,451	6,347,710
500	Olifants	17,993	776	17,217	865,850
600	Cape Western	11,187	2,499	8,688	57,860
700	South Western	9,834	2,637	7,197	1,695,060
800	Breede	5,987	455	5,532	1,539,850
900	Gouritz	17,546	71	17,475	544,760
1000	Outiniquas	2,807	15	2,792	549,490
1100	Gamtoos	13,270	103	13,167	458,130
1200	Algoa Bay	1,000	—	1,000	122,190
1300	Sundays	8,061	—	8,061	240,820
1400	Great Bushmans	2,202	367	1,835	66,990
1500	Great Fish	11,724	910	10,814	541,490
1600	Amatola	3,081	—	3,081	432,480
1700	Great Kei	7,989	—	7,989	988,160
1800	Transkei	18,201	—	18,201	7,994,240
1900	Natal	7,127	—	7,127	3,218,500
2000	Tugela	11,257	—	11,257	4,114,070
2100	Zululand	23,078	—	21,415	6,149,750
Totals	Whole Union (including Swaziland and Basutoland)	490,791	85,173	405,618	48,781,630

surface runoff of the Union, reaching the sea, is approximately 40 million acre feet per annum, this being roughly 8% of the average rainfall or just over 1¼ inches averaged over the whole surface.

This net average runoff is referred to as the mean annual runoff (MAR) and is the volume of water, expressed in acre feet, flowing in the river system in an average year. It will be fully appreciated that in some years considerably less flow than the MAR is experienced and in some years considerably more.

If but half of the mean annual runoff reaching the sea could be utilised at a head of 400 ft., it would provide more than 6,000 million units, i.e., about one-third to the total electrical energy used in the Union in 1959. Bearing in mind that much of the water comes from altitudes in excess of 4,000 ft. above sea level, it should be possible to find some sites where large blocks of hydro electric power are economically feasible.

An analysis of Table 1 in relation to the Union's present power requirements very quickly restricts the scope of investigations.

The Limpopo and Komati rivers flow largely in adjoining territories and are also very far from any major load.

The Vaal and the Orange rivers are well situated with respect to load centres, and carry a lot of water — in fact about one-fifth of the total runoff of the Union.

The Vaal with its existing development and usage combined with the terrain through which it flows, provides no major hydro electric possibility, though it may be of interest to examine the cost of units that could be generated from the water flowing through Vaaldam. The Orange, however, has several possibilities, which are dealt with in detail later.

The remaining river systems draining the escarpment do not really offer much scope until one reaches the Transkei and Natal, where one finds that the four river systems listed, (Transkei, Natal, Tugela and Zululand), account for nearly half of the total Union potential. All these river systems are in areas where present water usage is relatively limited, losses due to evaporation least, and perennial rivers plentiful.

Although the potential of the Transkei is fairly high, there is at the moment insufficient load to justify development of any major scheme. If, however, there is large scale development of the Bantu Areas, there may well be a case for hydro power, particularly as the alternative thermal power would be relatively expensive. This potential is reviewed later in the Paper.

In Natal and Zululand, we have nearly one-third of the Union's water resources, and the power potential is considerable. In order to keep this paper to a reasonable length, only the more promising rivers in this region have been examined, these being the Tugela and the Pongola.

4. UTILISATION OF WATER.

(i) *General characteristics of S.A. Rivers.*

The long-term MAR figures shown in Table 1 give only a broad picture of the river flow. These represent total flows in an average year, whereas actual discharges during the year may vary in some rivers from nil to a hundred or more times the mean annual discharge. During some years, actual total flow is well below the MAR, while during others it is considerably in excess. This characteristic, which is more accentuated in the Union than in many other countries, presents the problem underlying river regulation, particularly from the point of view of power generation, for which the water supply must be reasonably constant throughout the year and from year to year. Midgley and others have shown that in order to achieve reasonably accurate assessments, say, within ± 10%, MAR's should be based on observations over a period of at least 30 years.

Long term records are also necessary when it comes to assessing the capacity of storage required to withstand a given drought. For every river there is a typical relationship between storage and permissible sustained yield; a typical curve for a Natal river, in which these variables are expressed as percentages of the MAR is shown in Fig. 2(a). The lower curve is the yield after allowing for evaporation losses. It is clear

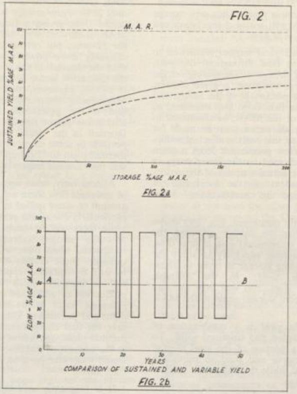


FIG. 2

FIG. 2a

FIG. 2b

that the curve represents a law of diminishing returns.

(ii) *Assessment of River Potential.*

As may be well appreciated, the usefulness of natural stream flow in South Africa, i.e., not regulated by storage, is extremely low. Unregulated flow is in any case restricted to perennial streams. The sustained yield from unregulated rivers is the minimum flow experienced during severe drought and this figure for South Africa averages probably less than 3% MAR. Seasonal yields, occurring during the summer months over the greater part of the Union for 70 years out of 100, have been estimated by Midgley at about 20% MAR, with failures lasting generally less than two consecutive seasons. This type of flow is of limited use for hydro electric development and so it is necessary to resort to storage.

With storage there are three types of yield that can be considered. These are:—

(a) intermittent yield (seasonal regulation),

(b) sustained yield,

(c) variable yield.

(a) With seasonal regulation it is permissible to draw off in the dry season the water than has accumulated in the wet season. On this basis it has been calculated that with storage equivalent to the MAR, it is possible to use up to 90% MAR for 70 years out of 100 with failures seldom exceeding two consecutive years. Thus with storage equal to the MAR, seasonal regulation will give a utilisation of 63%.

(b) Sustained yield implies regulation to give a uniform flow throughout the year, irrespective of droughts. Depending on the characteristic of the river, a given storage, expressed as a percentage of the MAR, will allow a certain firm flow, also expressed as a percentage of the MAR, as illustrated in Fig. 2(a). An allowance must be made for evaporation and this has the effect of reducing the firm flow permissible from a given storage, as indicated by the lower curve in Fig. 2(a). The actual amount of the reduction is dependent on the local rate of evaporation and the characteristics of the storage basin.

As previously mentioned, Fig. 2(a) shows that the greater the storage provided, the smaller is the incremental gain in firm flow, and it is, therefore, necessary to study the costs of providing storage in order to assess the optimum yield. In the example illustrated by Figs. 2(a) and 2(b) the sustained yield from storage equal to the MAR is 50% MAR.

(c) Variable yield is a combination of seasonal regulation and sustained yield. To achieve this, a portion of the total storage is kept in reserve and used to provide a sustained yield while the balance is used as seasonal storage.

Again consider a total storage equivalent to the MAR, but in this case reserve 25% for sustained flow and use 75% for seasonal flow. In the example of Fig. 2(a), the 25% MAR storage will allow a sustained flow of 26% of MAR, while the remaining 75% of the storage will give flow of 90% MAR which will be available for 65 years out of 100. The same storage thus gives:—

90% MAR for 65 years, and

26% MAR for 35 years, which represents an average utilisation efficiency of 67.6%.

Fig. 2(b) has been prepared to illustrate the overall gain by working on the basis of variable yield. This figure has been plotted to show the annual flow over a 50 year period on the basis of 100% MAR provided as storage. The sustained yield would be 50%, shown by the line AB. If, however, only 25% of the storage is reserved for sustained flow, giving a flow of 26% of the MAR, a flow of 90% MAR can be taken for 32 years out of the 50. There is considerably more power above the line AB than the shortfall in the 18 "lean" years, and the utilisation factor is improved from 50% to 67.8%. However, from the point of view of producing electricity, this form of operation is not practicable unless there are alternative power sources to make up the shortfall in the "lean" years. It might be possible in some cases to retain obsolescent thermal plant to "firm-up" the hydro power and thus achieve improved water utilisation.

Alternatively, when operating on the basis of sustained flow there will be a considerable amount of water spilled in the rainy seasons, particularly during the years of high rainfall, while there will be occasional periods, but probably seldom exceeding 3 years in succession, when there will be little or no spillage. Some of this excess water could be used by installing appropriate additional turbine capacity which would permit the production of additional power when there is excess water at the cost merely of the plant and penstocks. This generation would save the fuel charges on the corresponding thermal plant, and allow a partial reduction in the amount of standby thermal plant that would otherwise have to be provided.

(iii) *Silt*.

It is frequently said that silt is a major problem when it comes to storage in South African rivers. While this is to a certain extent true, it is a problem that to-day can be reasonably well handled. A great deal of investigation has taken place into the silt burden of various rivers and quite accurate information is available as to the volume of silt likely to be deposited under natural conditions in a reservoir.

When designing storage works, allowance must be made for the accumulation of silt, and it is possible to calculate the life that can be expected from a particular reservoir basin from the point of view of silting, and provision can be made either for separate silt basins or for "dead" storage in the main basin. When considering storage dams for hydro-electric works, as distinct from irrigation works, the "dead" storage may not be such a serious matter. To produce power one wants both head and volume of water; provision of "dead" storage increases the head available on the "live" storage. Silt can therefore be dealt with fairly readily — in fact, adequate "dead" storage would very often be inherent in a dam designed primarily for hydro electric purposes, since some "dead" storage is probably an automatic result of establishing the head and limiting the drawn-down to that for which the turbines are designed.

It is hoped that as soil conservation measures are extended there will eventually be a decrease in the silt burden in the rivers, though this will also result in a reduction in water available.

(iv) *Evaporation.*

In South Africa, particularly in the arid areas, evaporation has an appreciable effect on the quantity of water available from storage. Here too extensive investigations have been carried out over a number of years, and information is available to enable satisfactory allowances to be made when calculating the yield from storage.

In recent years, there has been a great deal of research into means of treating water surfaces so as to reduce evaporation. Considerable claims have been made for the use of cetyl alcohol powder, but tests in the Union have indicated that these claims cannot be substantiated. However, it is not unreasonable to hope that success in this field will eventually be achieved.

5. ORANGE RIVER SCHEMES.

On the Orange River, several schemes have been investigated. Three which are concerned primarily with the production of hydro electric power are listed below, although several other projects have been suggested.

(i) The Ox-Bow Lake Scheme in the upper reaches of the river in Basutoland;

(ii) The Vanderkloof Scheme near Hopetown, and

(iii) The Oranjedam near the mouth of the river.

The Reports published on these schemes to date are all in the nature of preliminary studies.

(i) *The Ox-Bow Lake Scheme.*

In February, 1956, Mr. Ninham Shand presented a report to the Basutoland Government entitled "A Report on the Regional Development of the Water Resources of Basutoland." This work dealt with three possible developments on the upper Orange River system, the most attractive of which was the Ox-Bow Lake Scheme on the Malibamatso River, one of the main source tributaries of the Orange.

This scheme consists of building a rock-fill dam across the river at an altitude of about 8,200 feet above sea level. A tunnel approximately four miles long through the Maluti Mountains enables the water to be dropped into a tributary of the Caledon, the Hololo River, by way of which the water, if not used for other purposes, would eventually return to the Orange River. By this means, the water from the Ox-Bow Lake commands a head of nearly 2,000 feet and is able to produce a considerable amount of energy. The general layout of the scheme is shown in Fig. 3, from which it will be seen that further tunnel system taking the water off from the Hololo River through another tunnel enables an additional 800 ft. head to be used.

Since 1956, investigations have been proceeding with the collection of hydrological data in the catchment areas and the preparation of accurate maps. A further report is at present in hand and is expected to give more accurate assessments of the hydro electric potential and more detailed estimates of costs. This report should be completed towards the end of 1961.

In addition to using the waters of the Malibamatso River, it has been pointed out that it might be practicable to tunnel through the various divides and collect, into the Ox-Bow Lake, water from several other rivers, namely the Motete, Matsoku and Khubelu. All these rivers eventually join up to become the Orange. At present, however, no real assessment is possible as to how much extra water will be available from these other rivers, but they could conceivably double or even treble the Ox-Bow potential.

The preliminary assessment of the Ox-Bow Scheme indicated that the Malibamatso

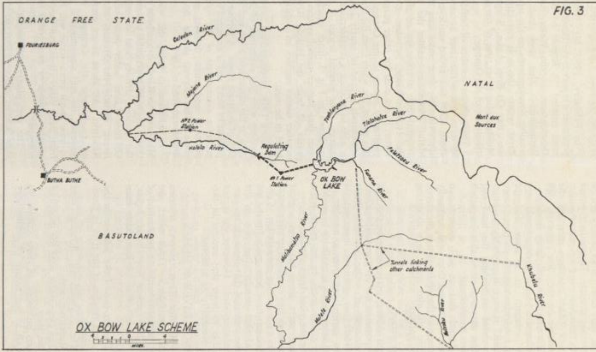
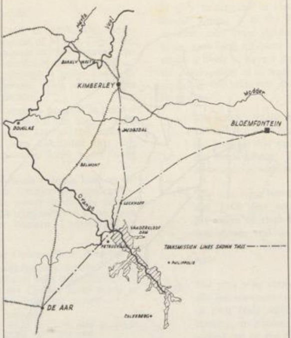


FIG. 3

OX BOW LAKE SCHEME

FIG. 4



VANDERKLOOF SCHEME

SCALE 1:1,500,000

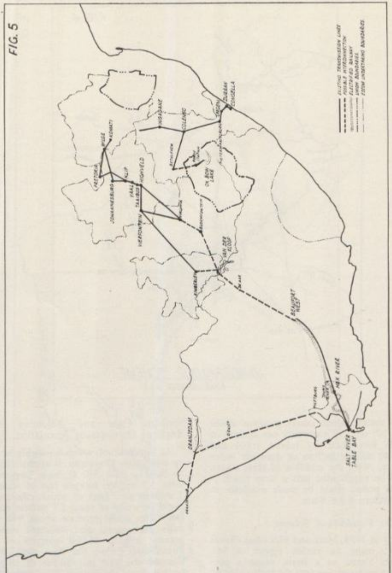
River system alone could produce about 395 x 10^6 units of electricity per annum, or slightly less electricity (about 10%) and some 40 million gallons of domestic water per day. With the addition of three rivers, it will be appreciated that a large block of electric power could be made available in the northern Free State.

(ii) *The Vanderkloof Scheme.*

Early in 1959, Merz and McLellan (South Africa), using an earlier report of Mr. Ninham Shand as a basis, made a preliminary investigation into the hydro electric potential of the Orange River at Vanderkloof. This was done at the request of the Northern Cape and Adjoining Areas Regional Development Association.

At Vanderkloof, which is roughly 50 miles up river from Hopetown, it appears feasible to build a dam 350 ft. high, impounding some 3.3 million morgen feet of water (or 7 million acre feet) of which effective use could be made of some 1.5 million morgen feet. This could produce about 940 x 10^6 units per annum and sufficient water to gravity irrigate 95,000 morgen of land immediately below the dam itself, not to mention the vast possibilities of irrigation further down the Orange River through the regulated flow that will result from the production of electricity.

FIG. 5



PRETORIA
KOMATI
JOHANNESBURG
KLIP
VAAL
HIGHVELD
VIERFONTEIN
TAAIBOS
INGAGANE
COLENSO
DURBAN
CONGELLA
OX BOW LAKE
VAN DER KLOOF
KIMBERLEY
BEAUFORT WEST
HEX RIVER
SALT RIVER
TABLE BAY
ORANJEDAM
EXISTING TRANSMISSION LINES
POSSIBLE INTERCONNECTION
ELECTRIFIED RAILWAY
UNION BOUNDARIES
ESCOM UNDERTAKING BOUNDARIES

Figure 4 shows the situation of the Vanderkloof Scheme as at present envisaged.

(iii) *The Oranjedam.*

Towards the end of 1959, Dr. Henry Olivier, at the request of Mr. D. J. Scholtz, M.P. for Namaqualand, investigated the hydro electric potential of the Orange River where it passes through a gorge about 80 miles from its mouth. This site has been named the Oranjedam.

At this site it appears possible to build a dam between 500 and 550 feet high creating a reservoir of some 110 to 120 miles in length. It has been calculated that this scheme could produce 2,250 x 10^6 units per annum.

While there is some existing load on the west coast from Oranjemund southwards, the bulk of the power from this scheme would have to be transmitted to Cape Town and the Cape Western Undertaking of Escom.

Summary of the Orange River Potential.

From the investigations detailed above, which are not all that have been carried out, it appears that the Orange River could at least produce the following power:—

	units p.a.		
Ox-Bow Lake	395 x 10^6	90 MW	installed*
Vanderkloof ...	940 x 10^6	210 MW	,,
Oranjedam ...	2250 x 10^6	500 MW	,,
TOTAL	3,585 x 10^6	800 MW	

Figure 5 shows the above three scheme in relation to existing transmission networks together with possible interconnection to facilitate using the hydro electric power. It should, of course, be borne in mind that, at the best, only a small proportion of the projects shown on this figure could be in existence by 1970.

6. TUGELA RIVER.

General.

Tugela River system drains a catchment area of approximately 11,200 square miles, lying between the Drakensberg in the west and the Indian Ocean in the east. Its basin, roughly rectangular in shape with a short handle joining it to the Indian Ocean, is divisible into three significant topographic areas, each with a typical surface formation which is likely to have a strong influence on the development of its water resources. Disregarding the relatively small coastal area, these are:—

(a) The area above the 4,500 foot contour (20 miles of river bed) which includes the foothills and main escarpment of the Drakensberg. This is hilly and mountainous with steep escarpments.

(b) The area lying between the 4,500 and and 3,000 feet contours (involving 210 miles of river bed) with rolling countryside and in which the river valleys are relatively shallow and wide.

(c) The area lying between the 3,000 and 500 feet contours (involving 140 miles of river bed) which is very broken country, intersected by deep gorges carved out by the rivers and streams. In this zone there is very little level or mildly undulating land and the rivers are at great depths below the surrounding country.

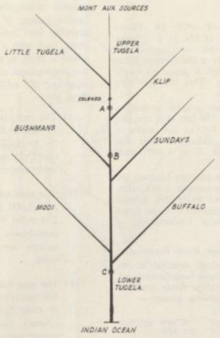
From these divisions, (b) should be investigated to provide the long-term regulation, while (c) should provide in the main the heads for power generation.

Figure 6 shows diagramatically the main river system, while Table 2 shows the extent of the catchment areas and the mean annual run-offs.

An interesting comparison between the Vaal and Tugela River systems is shown in Table 3.

* The installed capacity has been worked out on the basis of a load factor of approximately 50%.

FIG. 6



TUGELA RIVER SYSTEM

TABLE 2

	Area in sq. miles	M.A.R.
Upper Tugela, including Klip River	3,266	1,300,000 acre feet
Lower Tugela	750	360,000 „ „
Sundays	970	240,000 „ „
Mooi	1,150	500,000 „ „
Buffalo	3,990	1,200,000 „ „
Bushmans	1,074	500,000 „ „
TOTAL	11,200	4,100,000 acre feet

TABLE 3

	Vaal Basin	Tugela Basin
Total area — square miles	75,000	11,200
Mean annual run-off — acre feet	4,000,000	4,100,000
Population — all races	3,000,000	552,000
Population supplied by urban water undertakings	1,700,000	64,000
Total capacity of storage reservoirs — acre feet	1,400,000	Negligible
Area under irrigation — morgen	60,000	9,400
Length of main river bed — miles	approx. 650	315
Total fall — feet	approx. 2,500	10,000

From this comparison it will readily be seen that there is considerable scope for development of the Tugela and that, in particular, it should be possible to produce a significant amount of hydro electric power between Colenso and the sea.

As far as records go, the Tugela river was first looked into by Mr. Hangartner at the instigation of Dr. Kanthack, in whose 1920 paper Mr. Mr. Hangartner's estimates were published. Amongst a number of sites listed there were three at which heads of between 410 and 600 feet could be obtained without involving unreasonable lengths of canal. Although existing records do not reveal the exact sites examined by Mr. Hangartner, it is fairly clear from contour maps that the 600 feet head must have been just below Colenso, while there are several places lower down where heads of 400 feet can be obtained. With the assistance of the Water Affairs Department the development of three sites has been examined in the light of present-day knowledge of river regimes and modern dam-building techniques.

Possible Development on the Tugela.

SITE A.

A few miles downstream of Colenso the the river falls fairly rapidly and it appears possible to construct a wall approximately 300 feet high and, by means of a canal approximately eight miles long, to command a head of over 500 feet.

The Water Affairs Department have investigated a number of storage sites upstream from Colenso, and at one of these, known as Gorge, it is possible to design for a firm flow of 500 cusecs at a reasonable cost. With additional storage at Colenso itself, assuming only the top 50 feet of a reservoir there to be available for regulation, it has been estimated that a steady flow of about 670 cusecs can be sustained: with a head of 500 feet this will produce only 196 x 10^6 kilowatt-hours per annum. Alternatively, the combined Colenso and Gorge storage could be operated on a variable flow basis to yield 400 cusecs minimum flow and 1150 cusecs for 65 years out of 100, with a maximum dry period not exceeding three years. On this basis, the energy available over a 100 year period would average 260 x 10^6 kilowatt-hours per annum. For 65 years out of the hundred there would be 335 x 10^6 kilowatt-hours per annum available for the system, while the minimum energy during the 35 "lean years" would be 120 x 10^6 kilowatt-hours per annum. This means that there would have to be sufficient standby plant on the system to make up the shortfall in these years (one 60 MW machine would suffice). The calculations in Section 9 of the paper are made on the basis of the average energy available, i.e., 260 x 10^6 kilowatt-hours per annum.

This supply could easily be fed into the existing transmission system at Colenso power station. Assuming that the hydro plant would largely be contributing peak units, i.e., operating on a comparatively low load factor of about 25%, the station would have to have approximately 120 MW of plant installed. During times of good river-flow this plant could be run at a higher load factor.

SITE B.

Site B is situated a few miles above the confluence of the Bushmans river. The flow provided by the storage at Site A and Gorge would be augmented by contributions from the Klip River.

At Site B it would seem practicable to build a will 120 feet high. Storage of 120,000 acre feet at this site will give a sustained flow of 870 cusecs or a variable flow of 520 cusecs minimum and 1,480 cusecs for 65 years out of 100. A canal approximately 17 miles long from this site would command a head of 430 feet. This site with 150 MW of plant would be capable of producing 300 x 10^6 kilowatt-hours per annum.

SITE C.

At this site practically the full flow of the Tugela river system becomes available. In this section the gradient of river is relatively flat and head would have to be created by damming up the narrow river valley. Whilst there are a number of possible sites that merit detailed investigation, one particular site has been selected for the purpose of this exercise. At this point it would appear feasible to construct a wall approximately 300 feet high in a narrow gorge and a tunnel one mile long would give a further 200 ft. head. With the storage already provided on the river at sites A and B, together with regulation in the upper reaches of the Buffalo, and using the top 100 feet of this dam, it should be possible to obtain a sustained flow of at least 3300 cusecs. With the 100 feet draw-down, the mean head available at this site would be 450 feet. The site has thus a potential of 1,000 x 10^6 kilowatt-hours per annum, from an installed plant capacity of approximately 300 MW.

Summary.

Preliminary investigations indicate that the three sites are capable of producing nearly as much energy as was supplied by Escom to the whole of Natal in 1958. At the present rate of growth of power consumption, the hydro installations envisaged above would meet Natal's increasing demand for a period of about eight or ten years.

The suggested broad programme of development of the Tugela river illustrates an important characteristic of river utilisation. This is that by commencing regulation works in the upper regions of a river system, the regulated flow can be used several times over in the lower reaches of the river. Moreover, the development of the river potential can take place in stages, keeping in step with the growth of the electrical system and the demand.

7. PONGOLA RIVER.

Next to the Tugela, the Pongola river is the largest in Natal. The river rises at an altitude of more than 7,000 ft. above sea level, falling fairly rapidly to an elevation of 3,000 ft., where it flows through the middleveld zone. Here the river is contained in a narrow valley. Shortly after being joined by the Bivani river, and some 140 miles from the source of the Pongola, the valley broadens out into two relatively wide basins, both below 1,000 ft. in elevation. The first of these has been used as the Pongola Government Irrigation Scheme, while the lower has now been reserved as the storage basin for the Pongolapoort Dam.

Any development of power on the Pongola River, other than that which can be produced at the Pongolapoort Dam, must take place in the upper reaches of the river or in the middleveld zone. Basic storage would have to be developed in the upper reaches of the river system and in the narrow valleys it will be necessary to build high dams which would provide some additional regulation and create head. It might even be possible, where the river falls rapidly, to obtain more head by means of canals or tunnels. The investigations of Hangartner and Tonnessen in 1920 estimated that the Pongola could produce nearly 1,000 million units per annum and this potential is certainly worth detailed investigation in the light of modern knowledge and dam building techniques.

8. TRANSKEI AREA.

The Transkei is the centre of a good deal of interest at the present stage of South Africa's development. We are told that it is the Government's intention to develop the area and, in particular, to foster the growth of industry. Power, at reasonably economic rates, is an essential for modern industry, and its production in these somewhat remote areas will be a major problem to be tackled before any real development can take place. If thermal stations are to be considered, they will have to be sited within reach of adequate water and rail access. The latter may necessitate the building of special railway lines which, to obtain a true comparison, should be added to the capital cost of any thermal power station. All these factors considered, it is extremely unlikely that power from thermal sources in the Transkei could be produced for less than 1½d. per unit.

It has been estimated that this 18,000 square mile region loses water to the Indian Ocean at a minimum rate of 150 million gallons per day. This area is the best watered in the Union, having a run-off of twice that of the Vaal from a catchment less than one-quarter the size. However, a great deal of work is still required to obtain sufficiently accurate information to form the basis of reliable studies. For example, silt in this area would be a major problem.

There are already a few hydro developments in the Transkei, e.g., the town of Umtata obtains its main requirements from the Umtata River. There are numerous possibilities for small power generation schemes all over the area, either as run-of-river schemes or requiring only moderate storage.

On the Bashee River, D. C. Midgley has estimated that a modest amount or regulation would give a minimum flow of 300 cusecs and this could be used to produce 15 MW of firm power.

The Umzimkulu river also has numerous spectacular waterfalls. This river however has a comparatively steep gradient along its entire length, and would require a fairly high dam to arrest its flow. Nevertheless, power installations of the order of 7 MW should be possible.

Thus, it is quite apparent that the Transkei has considerable power potential, a large portion of which could be developed with reasonable economy in comparatively small stages. This sort of development would fit in particularly well with the building up of the territory, and it is hoped that these sources of power will be fully investigated when the time comes.

9. COSTS.

(i) *General.*

There is no doubt whatsoever that the fundamental fact which will finally determine whether or not hydro electric power comes into being in South Africa is the question of cost. There are certain other factors, such as the general benefit to the country of river regulation and the utilisation of a non-wasting asset, but these can only help to swing the balance if the cost of hydro power compares favourably with the cost of thermal.

For the comparison with hydro electric possibilities, it is proposed only to examine the present costs and trends of conventional coal-fired steam generating plant without complicating the issue by considering nuclear generation. This is a separate problem and one which will also eventually have to be decided on the basis of economics, although the day may well come when we will have in South Africa a nationwide system embodying all three forms of generation.

(ii) *Costs of Thermal Generation.*

The cost of producing electricity at the power station busbars is made up of three components. These are:—

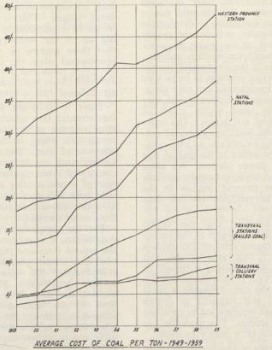
(a) the annual charges on the capital invested,

(b) fuel costs, and oil water and stores, and

(c) operating and maintenance costs.

It has been the constant endeavour of planning and generation engineers to try to keep down the cost of producing electricity, but the only means at their disposal is resorting to larger power stations and machines, and higher steam conditions, which result in a lower cost per kilowatt installed and which give an improved heat rate. Against this there are several factors

FIG. 7



AVERAGE COST OF COAL PER TON - 1949-1959

— higher interest charges on capital, increases in the cost of coal, and increases in the cost of labour. These seem to have outweighed the falling construction costs and the improvement in efficiency, and the nett result has been a steady rise in the cost per unit sent out from power stations in South Africa. It is extremely difficult to see when, if ever, there will be a change in this trend insofar as thermal generation is concerned.

From the figures published in the 1959 Electricity Supply Commission Report (assuming that five-sixths of the loan and reserve charges are on account of generating plant, and one-sixth on account of transmission), it would appear that the average generation cost is made up of the following proportions:—

(a) loan charges .... 37% (approximately half being interest and half redemption and reserve funds)

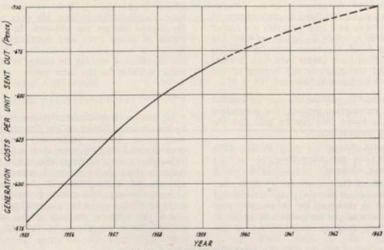
(b) coal costs 38.5%

(c) operating and maintenance 14.5%

Of the above figures, more than half, i.e., coal costs and operating and maintenance, are subject to inflation, after any given station is built.

Figure 7(a) illustrates what is happening to the costs of coal delivered to various

FIG. 8



GENERATION COSTS PER UNIT SENT OUT. FOR COMBINED NATAL UNDERTAKINGS

power stations in South Africa. It is clear from this that, at present, increases in the cost of railage have the greatest bearing on the rising prices, but even in the cases of power stations on the coal fields, there is an upward tendency in all the curves.

In recent years, information has been published in the Annual Escom reports, from which it is possible to derive total generation costs per unit sold or sent out from various power stations. The generation cost per unit sent out for the combined Central and Southern Natal Undertakings has been taken out for the years 1955 to 1959 and these are shown in Figure 8. It will be seen from this curve that, although the upward trend may continue for some time, there appears to be a decrease in the rate of rise.

From the published information, Table 4 shows the generation costs per unit sent out for various Escom Undertakings in 1959.

TABLE 4

Generation Costs — 1959

Undertaking	Total units sent out x 10^6	Total generation cost £ x 10^6	Cost/Unit pence
Natal (Central & Southern)	1,931	5.331	0.663
Cape Western	920	3.663	0.956
Rand & O.F.S.	11,157	17.966	0.386

(iii) *Cost of Hydro Generation.*

These costs are made up of the same components as thermal stations, except that there are no fuel charges and much reduced operating and maintenance costs. Greater capital costs are involved in construction of hydro stations as a rule, and this is a factor which tends to offset the saving on fuel. On the other hand, the main assets of a hydro power station have longer lives than thermal plant and consequently the burden of the annual redemption is lessened.

Dependent largely on the rate of interest and the redemption periods, the generation costs of a hydro unit can be split into the following proportions:—

Capital charges	90% — 85%
Operating and maintenance charges	10% — 15%

As both of these costs are virtually constant, whether or not the power and energy the plant is designed for is actually produced, the cost per unit sent out varies as the ratio of designed output to actual output. It is, therefore, important that if hydro electric units are to be cheap, the greatest possible use must be made of the potential right from the start. Of these costs only 10 — 15% are subject to inflation once the scheme is constructed. Hydro power stations have a comparatively long life over which the capital charges are constant. In a condition of rising costs and devalutation of money, a long period of constant charges has the effect of making the energy relatively more valuable in the later years.

(iv) *Costs of Orange River Schemes.*

In Section 5, brief descriptions of three hydro electric schemes on the Orange River were given. In the preliminary investigations of these schemes, costs were estimated, although it must be emphasised that these estimates had to be made of necessity on very broad assumptions. It may be of interest, however, to compare these costs with the 1959 costs of the Undertakings into which the various projects might supply power. These are shown in Table 5.

TABLE 5

Comparison of hydro and thermal costs

Hydro Scheme	Cost per hydro unit supplied	System into which power would be fed	1959 cost of thermal units generation only	Coal Cost component	1959 average selling price/unit
Ox-Bow Lake	0.345d.	Natal	0.663	0.315	0.822
Vanderkloof	0.47/.39	Cape Northern	0.386*	0.118*	1.1509
Orangedam	0.46	Cape Western	0.956	0.334	1.2317

* This price is for the Rand and O.F.S. Undertaking which supplies the Cape Northern Undertaking. The Vanderkloof costs however include transmission, and therefore should be compared with the average selling price in the Cape Northern Undertaking.

Although the figures shown in Table 5 must be treated with some reserve, there certainly appears to be a case for detailed investigation into these possible sources of power.

(v) *Economics of Development of Tugela Power.*

In Section 6, an indication was given of the possible power that might be developed in stages on the Tugela river. We have also seen that, in 1959, the cost per unit generated in Natal was .663d. and the trend indicated still further increases. This trend may be arrested (or even reversed slightly) when Ingagane power station comes into operation in 1963/64. If it is assumed that hydro power could be sold at a maximum cost of 0.65d. per unit, the revenue obtainable from each scheme can be derived and, on the basis that the capital charges and running costs would be not more than 7½%* of the capital spent, we can estimate the maximum amount of capital which could be invested in hydro electric works on the river. These figures are set out in Table 6.

TABLE 6

	Annual Units Available	Annual Units sent out (97.5%)	Annual Revenue (at 0.65d. /unit)	Capital which could be spent
Scheme A (Colenso)	260 x 10^6	254 x 10^6	£688,000	£9.15 x 10^6
Scheme B (Bushmans River)	300 x 10^6	292 x 10^6	£790,000	£10.5 x 10^6
Scheme C (Lower Tugela)	1000 x 10^6	975 x 10^6	£2,640,000	£35 x 10^6

Scheme A requires 120 MW of plant — say six sets of 20 MW each. It is reasonable to assume that the electrical and mechanical equipment in the station will cost approximately £1.92 x 10^6, while the transmission required to connect this station to the existing system at Colenso is estimated to cost £200,000. This leaves approximately £7.0 x 10^6 to be spent on the civil engineering works.

It has been estimated that the cost of the Gorge Dam will be £2.8 x 10^6 and that of a 300 ft. high dam below Colenso £2.5 x 10^6. It is necessary to add to these figures an amount to cover the canal, penstocks, surge chamber and power house, which have been estimated to cost £1.5 x 10^6. Thus, the total civil costs might be approximately £6.8 x 10^6, which means that the first stage of the Tugela development appears to be possible at a lower cost than the 1959 average thermal generating cost in Natal.

Having now obtained a regulated flow of 730 cusecs at an altitude of 2,500 feet above sea level, considerable further use can be made of this as it flows to the sea. Although the possible site at the Bushmans confluence has not been examined, it is believed that the total civil works here would not exceed the costs for the Colenso installation. These works still further increase the water available and it is not unreasonable that a scheme making use of the full flow of the river below the confluence of the Buffalo river can be built for not more than £18 million, which would result in halving the costs of generation. If this site is still sufficiently far upstream, it is not inconceivable that other falls could be made use of, either by means of tunnel or canal deviations, again making use of the water at very low cost. It is, therefore, quite possible that, having done most of the regulation upstream, the sites on the lower reaches of the Tugela could produce power at a cost considerably less than the present thermal stations, and possibly at a cost comparable with a station the size of Ingagane, built on a coalfield.

Even with collieries immediately adjacent to the power station, the output is very much dependent on a large labour force, and the coal itself is a wasting asset. Neither of these two disadvantages are present in the case of a hydro electric power station.

10. COMBINED OPERATION OF HYDRO AND THERMAL PLANT.

(i) *General.*

From one point of view the operation of a hydro power station is considerably less complicated than that of a thermal station. In the latter there are boilers with their requirements of make-up water and coal or oil, and high speed turbines with their accessories and cooling water. All these items of plant make the starting up and shutting down of steam turbines a com-

* 6½% interest and redemption over 50 years plus 1% for operation and maintenance.

paratively lengthly process. Hydro turbines on the other hand are dependent merely on the opening and closing of valves, and although not quite as simple as turning on a tap, it is a good deal easier to run-up or shut-down a water turbine than a steam turbine. On the other hand the proper operation of a larger reservoir or series of reservoirs needs careful study and constant review.

This feature of greater flexibility in a day to day operation is the basic reason why it can be advantageous to have both types of plant on a system. It means that the hydro plant can in general be used to meet the peak requirements of the daily load curve, while the thermal plant can supply the steady base load. This form of operation, saving the costs of bringing up and banking of boilers, plus the necessity of having thermal machines running for some time before they are actually required, could well result in an improvement of the operating efficiency.

In South Africa, the seasonal variation of the rivers is such that storage is essential for the production of electric power. This means that it will always be practical to run a comparatively large amount of plant for a short time, drawing the available water off at a high rate for this time, and using the rest of the daily (or weekly) cycle for replenishing the storage. Earlier in this paper I have stessed the utilisation of the total energy output of the water resource, but this output can be used at a high rate over a short time simply by installing more plant and larger penstocks. By running hydro plant at a low load factor (many of the Scottish Hydro Board stations run at a load factor of 20% or less), the capital cost per kilowatt available can be considerably reduced.

When the pre-existing system is predominantly thermal, it will usually be preferable, for the reasons stated above, to develop such water power as can economically be justified in comparison with thermal power with the greatest installed capacity, i.e., the lowest firm load factor which the system can accept in conjunction with the more or less fixed amount of energy. This large installed capacity will also permit of the use of flood water which would otherwise be spilled and thus additional energy can be produced at certain times, saving fuel costs on the thermal stations.

(ii) *Practical Operation.*

Figure 9 (a) shows a typical annual load/duration curve representing a system having an annual load factor of about 50%.

If this load has to be met by thermal plant alone, machines will, so far as possible, be brought into operation sequentially in ascending order of their fuel cost per kilowatt-hour sent out. This generally results in the oldest and least economical machines running on peak load only.

It is not possible however to achieve the theoretical optimum use of plant in practice; factors such as reduced availability of base-load plant, lack of flexibility of thermal peak load plant, transmission limitations and operating difficulties (such as the tendency to run up the peak-load plant sooner than is necessary, or even completely unnecessarily) result in the less efficient stations generating more than their theoretically desirable quota, and the more efficient stations generating less. Fig. 9 (a) has superimposed on it the blocks of energy generated by different plants grouped in order of fuel costs per kilowatt-hour sent out. It can be seen quite clearly how the less efficient machines being run to meet the upper 40% of the demand produce considerably more energy than the theoretical optimum.

Consider now the same load/duration curve with a portion of the energy available from hydro sources. Assume that the total hydro energy available is a relatively small proportion of the total system requirements, as would be the case with almost any hydro development in South Africa. This means that the installed capacity of the hydro plant could be determined independently of the load. The hydro station could be built as a base-load plant, operating at an annual load factor of 100%, or the total block of energy could occupy any position on the load curve, ultimately operating entirely as peak load plant. Three possible positions are shown in Fig. 9 (b), each of the hatched areas representing an equal quantity of

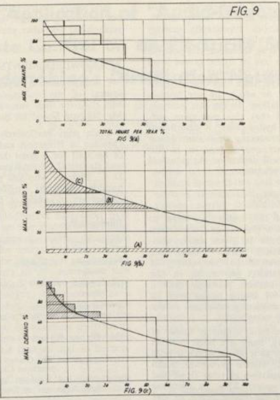


FIG. 9

energy. Position 'A' represents base load plant operating at 100% load factor and having a total installed capacity of 'X' kilowatts. Position 'B' represents plant operating at a load factor of 50%, i.e., the installed capacity now being 2x, while Position 'C' represents plant operating at a load factor of about 10%, i.e., an installed capacity of 10X.

It might possibly be found from a detailed study of the system conditions and the costs of the hydro plant, that it appears advantageous to supply the upper energy requirements from hydro sources. This conceivably could result in plant utilisation as illustratde in Fig. 9 (c). Owing to its greater flexibility, the hydro plant can be brought into service (and taken out) more efficiently than steam plant which results in a closer approach to the theoretical optimum plant operation over the portion of the curve supplied by hydro plant. This means that a greater proportion of the total energy requirement is left to be supplied by the more efficient of the thermal plant, resulting in greater overal efficiency and a reduction of system cost.

It must be emphasised that there are many factors which determine the optimum integration of hydro and thermal plant on a common system. The basic consideration must, in most cases, be costs, influenced to a greater or lesser degree by the physical arrangements of the system, operating conditions and the load characteristics. The cost of hydro power depends fundamentally upon physical factors – topography, geology and hydrology — which are not subject to human control. It is, therefore, not possible to determine the cost of hydro power from general experience of what has been achieved elsewhere, since this cost depends upon the extent to which the site favours economic exploitation. In the last analysis, it may be said that the maximum permissible cost of hydro power is determined by the cost of producing equivalent power from some other source, and it is this criterion which will determine the practical level of hydro development.

11. CONCLUSIONS

The object of this paper has been to endeavour to show that water as a source of electricity should be given serious consideration in South Africa. There are undoubtedly resources that are worthy of detailed investigation, and it is, in the opinion of the author, probable that a certain amount of hydro power will be found to be economically beneficial to the present electricity supply.

Apart from the basic economic factor of cheaper electricity, there are other benefits to the community as a whole which it is as well to consider. Hydro power in South Africa means regulation of river flows and conservation of water. This, as everyone knows, is one of the major needs of our country, and one in which development is always hamstrung on account of capital requirements. Production of electric power can possibly provide a lot of the capital necessary for regulation and thereby cheapen irrigation works and conservation of water for domestic and industrial purposes.

And lastly, water power, unlike coal, is not a wasting asset, it is being constantly replenished year after year in a never ending energy cycle.

ACKNOWLEDGMENTS

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The Application of "Audio-frequency" Remote Control on an Electricity Supply Undertaking's Distribution Network

By

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SASOLBURG

1. INTRODUCTION:

Ever since the development of the township of Sasolburg in 1952 the large increase in the cost of distribution equipment over recent years has set the problem of keeping the capital investment within reasonable proportions to the energy handled, so that electricity could be supplied at an economic tariff to consumers in this new town that was to be associated with the Union's first Oil from Coal project. Furthermore, as it had been decided to establish an all-electric township, the question of reducing the peak demands on the electrical distribution system on account of the present day high maximum demand charges had to be considered.

It was, therefore, realised that some means of controlling the load on the distribution system which would enable the reduction of system peaks without decreasing the revenue earning energy sales, would be of immense value. Subsequent investigations established that such a method of control had in fact been in existence for some considerable time, which is commonly known as load or ripple control. This control is achieved by injecting signals into a distribution network which can then be absorbed by signal sensitive relays installed upon the consumers' premises, which will carry out any required switching operation by briefly disconnecting those circuits which could be controlled during the peak periods.

A consuming device which most readily lends itself to being controlled in this manner is undoubtedly the domestic water heater which is to be found in practically every modern home to-day and which accounts for quite a considerable amount of the total electric energy consumed upon domestic premises. In the case of Sasolburg it was established that approximately 33% of the total load taken during peak periods was accounted for by domestic water heaters so that the control of these could therefore lead to a substantial reduction in the peak demands on the distribution system.

In addition it was realised that various other applications exist apart from the business of keeping the load down which could be performed with this equipment, a typical example of which is the remote control of streetlighting installations with the advantage of considerable savings in cable costs.

A thorough study was therefore made of the various methods available to control the load on a distribution system and audio-frequency remote control equipment was eventually introduced towards the middle of June, 1959. It will now be the object of this paper to give an account of the various factors which led to the choice of the particular system employed and the general effect load shedding has had upon the distribution system as well as the consumer. In addition, operating experience and some other applications of the remote control system may be of interest.

2. REMOTE CONTROL SYSTEMS IN GENERAL:

Before it was decided to install a remote control installation, investigations established that various methods of load control are in existence to-day, and that certain essential requirements had to be fulfilled before such a system could be justified under present day conditions.

(2.1) *Requirements of a Remote Control System.*

Briefly these requirements are the following:—

1. The system must possess a multiplicity of control channels to allow the control of a number of various consuming devices and other equipment.
2. The system must have sufficient range to extend to the geographical limits of the distribution network.
3. The system must be insensitive to extraneous interference and network disturbances.
4. The system should not interfere with other services such as telephone, radio and television, nor impose any limitations on the manipulation of the power system.
5. The system should be flexible; in other words, should not be tied down to a fixed programme.
6. And, finally, the most important aspect of all, the total annual cost of the remote control installation must be small in relation to the monetary value of the peak loads and capital investments saved thereby.

It was therefore, important to compare these basic requirements with the various control systems which are in use at present in order to establish which system would prove to be the best for the duty required in Sasolburg.

(2.2) *Various Methods of Load Control.*

There are a number of system which have been, or are in use to reduce peak loads and these include the following:—

1. Multiple tariff metering.
2. Time switch control.
3. D.C. Signal tranmission through the low voltage network.
4. Audio-frequency signal transmission through the distribution mains.

Although multiple tariff metering is not in general use in South Africa, they have enjoyed great popularity in Europe. As a means of reducing peak loads however, the system suffers from inflexibility and its reliance upon each individual consumer seeking his own economic advantage at all times. On the other hand it does appear that the possibility exists of using multiple tariff metering in conjunction with a remote control system whereby the energy consumed by the domestic storage heater during any peak period can be metered separately. Whether this would have the same effect as would be the case with direct control seems unlikely as the extra cost of a double tariff meter has to be taken into account. By this means, however, flexibility of the switching programme could be achieved in a multiple tariff metering system. It would have been of interest to investigate this possibility further but unfortunately this means of controlling the load has not yet been tried out in practice.

Time switches have given very long and valued service in the task of reducing peak loads but time switches without clockwork mechanism are vulnerable to all breakdowns in power supply, whereas time switches with clockwork mechanism, though reliable, are expensive. In addition they can only operate to a fixed programme and through one channel so that maintenance and adjustment costs on time switches will tend to be rather high.

A pilot wire network for the control of peak loads can hardly be given thought to-day as the cost of installing and maintaining such a system must be geographically just as extensive as the distribution network and would impose an insuperable obstacle for most Electricity Supply Authorities.

The transmission of D.C. signals through the neutral of the low voltage network which has been used extensively has the serious disadvantages of being limited to one signal channel and that a great number of injection points must be provided. Unless an additional superimposed control network is provided this system can also only work to a fixed programme.

Turning finally to the principle of audio-frequency injection it was observed that it can meet all the requirements mentioned above. With proper design the provision of a multiplicity of control channels is easy, the audio-frequency impulses can be transmitted to all points in the network to be controlled, the energy of the control signal can be kept well below the level liable to cause interference to telephone, radio and television equipment. The system can further be rendered practically immune to external sources of interference whereas the flexibility of the system is undisputed.

(2.3) *Audio-Frequency Remote Control.*

Briefly the principle of operation of audio-frequency injection is as follows.

The centralised remote control installation comprises injection equipment located at some central point, the function of which is to inject audio-frequency impulses through a coupling circuit into the distribution network. These signals are then transmitted through the power distribution network to the audio-frequency sensitive relays, one of which is connected between the 220 volt phase and neutral of each circuit to be controlled on the consumers' premises. As an examination of the different systems of audio-frequency remote control will indicate, many different principles exist, the earliest of which was the multiple frequency system in which every different command whether ON or OFF, was allocated to a different frequency and detected by a series of frequency sensitive elements in the receiving relays. As the number of separate channels available was limited by the few frequencies which could be transmitted without mutual interference, this method of injection eventually fell out of favour.

Another system consists of a single audio-frequency carrier, modulated with a number of various low frequencies. After the detector stage these act upon a number of frequency sensitive elements in each relay but for mechanical reasons, the number of different channels which could be controlled in this way is very limited.

A radical departure from the foregoing principles, however, was the adoption of the selector principle, the most significant of which is the "impulse interval" system in which a start impulse causes the mechanical selector in the relay to start rotating. To switch on the loads in the various channels further impulses are transmitted at *definite* intervals after the start impulse, the *length* of the interval determining which channel is to be switched ON in each case, which meant that a multiplicity of control channels could be allowed for.

It was therefore decided to install "audio-frequency" remote control equipment in which the "Selector principle" was adopted, as it proved to be the best for the duty required in Sasolburg and the least likely to cause inconvenience to the consumers.

(2.4) *Basic Features of "Audio-Frequency" Remote Control Design.*

It was interesting to note that considerable differences exists among manufacturers of remote control systems, regarding the preferred frequencies of signal injection. Whereas in certain continental and U.K. systems the trend was towards the lower frequencies, general opinion seemed to favour the following:—

1. High injection frequencies preferably between 750 and 1600 c.p.s.
2. Parallel injection at the main busbars.
3. Injection at the intermediate voltage level.
4. Decentralisation of transmitters when necessary.
5. The view that remote control installations, being a subsidiary installation, must be designed to operate satisfactorily irrespective of any switching or inter-connecting operations that might take place in the network.

The choice of frequency may vary between very wide limits as the transmission characteristics of a network can vary and experience has shown that an optimum frequency usually exists for any given network. Cables and power factor correction condensors represent shunt connected capacitive impedances at audio-frequency so that if their capacity is large enough these shunt connected components can drain away a large proportion of the audio-frequency energy and thereby seriously reduce the signal voltage. On the other hand again the impedance of overhead lines and transformers rises in proportion to the control frequency which means that signal attenuation over long lines and through transformers would be greater at the higher frequencies than at the lower ones.

The fact that the propagation characteristics of a network are better at the lower frequencies than at the higher ones, is however alone not sufficient to justify the choice of a lower frequency because the problem of power factor correction condensors which will drain off an excessive amount of energy at *any* frequency, can be overcome by the use of series connected audio-frequency chokes, the size and cost of which is very much lower at the higher frequencies. Therefore, only after a thorough survey of the network characteristics has been made can a sound decision be taken regarding the frequency to be adopted for the remote control installation. However, the most important consideration in determining the injection frequency level is the interference problem which will be discussed in detail later.

The location of transmitters will depend upon whether the signals are injected in the low voltage (380 volt), the intermediate voltage, (6.6 or 11 K.V.) or even the extra high voltage level. The injection at the low voltage level will only be an economic proposition in small towns whereas injection into the 11 K.V. network at each stepdown transformer sub-station is the preferred solution, and is the method which has been adopted in the Sasolburg installation. Although injection at the extra high voltage level may at first seem attractive because of economy on transmitting stations, the serious disadvantage is that signal attenuation will be greater because two stepdown transformations, i.e. from the EHT to HT and from the HT to LT level are encountered and may lead to insufficient voltage at the receiver, unless a high signal voltage at low frequency is chosen. This again will mean loss in energy towards the extra high voltage level as there is usually only one transformation from the EHT to the HT level and the transformer impedance is lower at the lower frequencies. This all means then that a larger and more powerful and expensive transmitter has to be installed.

The degree of centralisation will depend upon the natural growth of the network and whereas the provision of additional high voltage stepdown transformer stations is easily predictable, the extra high voltage substation is usually only increased in size, which makes the problem of extra high voltage injection more complicated and expensive on account of the possible losses in signal strength. Therefore, if 6.6 or 11 K.V. injection is adopted additional transmitting plant can easily be installed in each stepdown transformer station thus safeguarding against loss in signal voltage and possible interferences at the remote ends in the network, with the added advantage that the capital outlay is kept within sensible proportions to the expansion of the network.

3. THE SASOLBURG REMOTE CONTROL INSTALLATION.

The following is a short description of the Sasolburg remote control installation.

(3.1) *Injection Equipment*:

The method of injection normally adopted is either series injection or parallel injection. In the case of the Sasolburg remote control installation parallel injection was adopted. In the case of parallel injection the coupling circuit is connected on a 3-phase basis between the main 11 K.V. busbars and neutral as shown on the principle line diagram Fig. 1.

The main components of the parallel injection equipment are the insulating transformer T, the condensors C, and the tuning coils L, and all are mounted together in a coupling cell or cubicle in the manner shown in Fig. 2.

Fig. 1.
PRINCIPLE LINE DIAGRAM.

Fig. 2.
COUPLING CELL FOR PARALLEL INJECTION. SHOWING INSULATING TRANSFORMER (front), COUPLING CONDENSORS (rear) and TUNING COILS (centre).

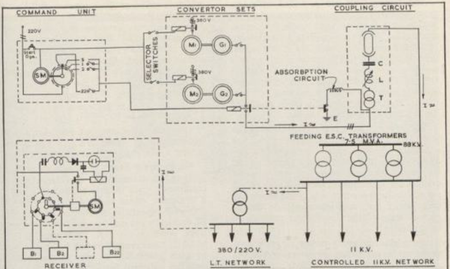
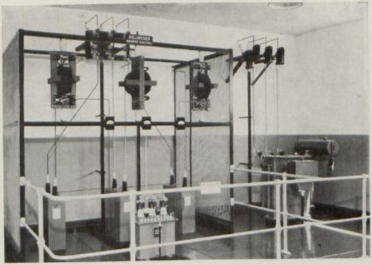


FIG.1. PRINCIPLE LINE DIAGRAM.



The tuning coils are provided with tappings allowing their adjustment so that the induced e.m.f. of the signal generator works against a unity power factor impedance under normal full network load. The insulating transformer is also fitted with tappings allowing variation of the signal strength voltage to suit the degree of attenuation actually encountered in the network.

The audio-frequency energy is produced by two convertor sets as shown in Fig. 3.

The control board incorporates two automatic star/delta motor starters for the two convertor sets, a compensation cabinet which allows the selection of either convertor set for automatic operation and an impulse cabinet for transmitting the audio-frequency signals to the secondary side of the insulating transformer for super-imposition on the 50 cycle voltage of the distributing network to be controlled.

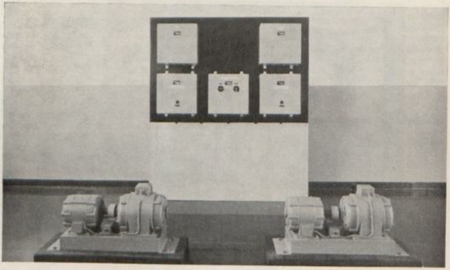
The audio-frequency power of each convertor set on the Sasolburg system is 5 K.W., which is sufficient for a network full load of 7.5 M.W., the second convertor set at present being used only as a standby unit. Should the network full load however, reach 15 M.W., both sets can be put into operation to obtain increased audio-frequency power with the increased network impedances. Additional convertor sets can of course be installed in future when required.

(3.2) *Control Equipment:*

The fully automatic but very simple control panel is as shown in Fig. 4 and is built in next to the main-substation control board.

The control panel or command unit is designed for transmitting 22 different double commands, each double command allowing a consumer group to be switched both ON and OFF repeatedly, as often as desired. The 22 manually operated control switches have three positions — ON, OFF and AUTOMATIC—one control switch being allocated to each channel. If one of the manual switches is turned from the ON to the OFF for example, the convertor sets are started and impulses injected in accordance with the setting of ALL control switches. Thus, every time the transmitting plant goes into

Fig. 3.
TWO CONVERTOR SETS OF 5 K.W. AUDIO-FREQUENCY POWER EACH AND CONTROL BOARD.



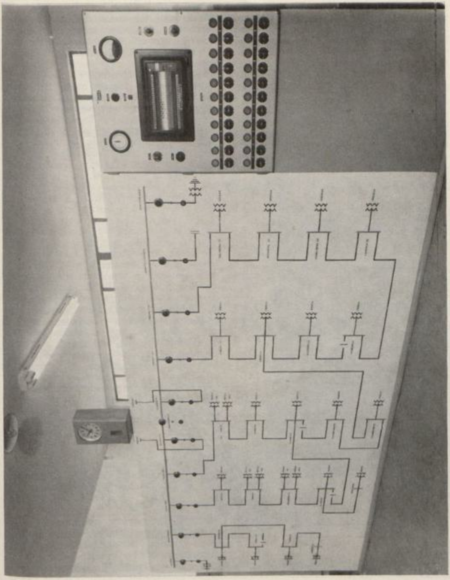


Fig. 4. THE CONTROL PANEL.

operation not only is the required command changed but also the commands already given in all other channels during previous transsmissions are confirmed. This is particularly valuable during breakdowns in power supply in sections of the network in case the injected pulses were not received by receivers in the affected section.

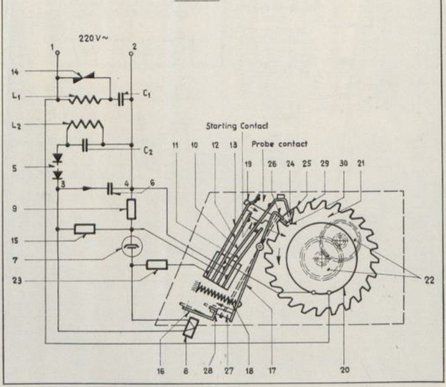
The time required for transmitting all or any combination of the 22 double commands amounts to three minutes. Whenever the control switches are set to AUTOMATIC a built-in programme clock will take over the functions of the manually operated control switches. The drum has 23 parallel grooves in which pins corresponding to the ON and OFF signals can be set which then automatically actuate micro switches in parallel with the manual switches, whereas receivers in the control panel supervise the correct transmission of the commands over the entire network.

(3.3) *The Receiving Relay*:

The electrical diagram of the Receiving Relay, which can be considered as one of the most important components in a remote control installation, is as shown in Fig. 5.

Fig. 5 shows the electrical diagram for the romote control relay. L_1 C_1 L_2 and C_2

Fig. 5 Electrical Diagram of Receiving Relay.



represent the components of a double stage band filter with inductive coupling between the two filter sections. During an audio-frequency impulse, the output of the second stage is rectified and charges the condenser (6), the voltage of which rises exponentially with time. Once the ignition voltage of the glow tube (7) has been reached, the condenser (6) discharges through the auxiliary relay (8). When the relay armature (28) is attracted the support for the plate (17) is removed, and under the tension of the spring (18) the starting contracts close, thus connecting the 220 volt a.c. supply to the small synchronous motor (20). In this manner the selector mechanism starts to rotate, the motor remaining under voltage until a complete revolution has been performed, at which point the starting contacts open again automatically. At the instant at which the starting contacts close and the motor (20) starts, the probe contacts also close. Every time the follower (24) passes a tooth of the cam (25) the probe contacts again open for a short period. Normally these shunt the glow tube (7) and resistor (9), thus short-circuiting the condenser (6) through the auxiliary relay (8). Every time the probe contacts open however, this shunt is removed and voltage can build up on the condenser (6) again, provided of course that an audio-frequency signal is being received at the terminals during that period. As soon as the probe contacts close and the shunt is reapplied, the condenser (6) discharges violently through the relay (8) attracting it once again and causing the plate (17) to be rotated by the tension of the spring (18). Every time this occurs the plate (17) closes mechanically any relay switch connected to the relevant channel.

Therefore the presence of an active impulse will start the relay and switch on the relevant channels whereas the absence of an active impulse will switch OFF the required channels.

Fig. 7 represents a typical signal transmission series in the impulse interval system. Each pulse represents the superimposition of an audio-frequency voltage of constant frequency onto the intermediate voltage network. In Fig. 7 the control impulses would switch ON the loads allotted to channels 2, 8, 9, 12, 16, 17 and 22, whereas channel 0 represents the start impulse for ALL receiving relays. The very important innovation which has been made on this system is that it is not necessary to have a separate

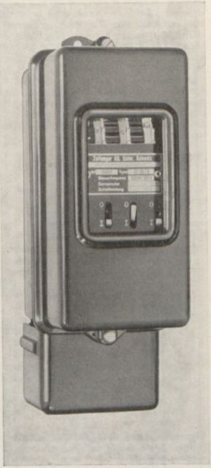


Fig. 6.

THE REMOTE CONTROL RECEIVING RELAY.

channel for the ON and the OFF signals, for any given load group. If any desired load is to be switched ON or to be left switched ON an audio-frequency impulse is injected into the network at the *correct interval* after the start impulse. If, on the other hand, it is desired to switch a load OFF or to leave it switched OFF a pause is made at the *correct interval* after the initial start impulse. The "impulse interval" system as normally executed can, therefore, allow 22 DOUBLE COMMANDS in each transmission, i.e. 22 different load groups can be switched ON or OFF as desired. If the transmission of a very large number of double commands should be required, then each transmitting unit can be extended to be capable of transmitting up to hundreds of double commands by simply fitting further control panels.

(3.4) *Installation of Receiving Relays on Consumers Premises*:

As it had already been considered to introduce load shedding equipment as far back as 1952, the actual installation of receiving relays on consumers premises was fairly simple due to the following reasons.

1. As practically 99% of all the domestic consumers in Sasolburg have domestic water heaters installed all consumers' main boards are wired with the necessary loops for the installation of receiving relays.
2. The Electricity Supply Regulations promulgated in 1959 gives the right to the Supply Authority to install receiving relays on all water heater circuits.
3. The receiving relay is supplied complete with a very simple mounting bracket which allows the installation or removal of a receiver by simply attaching or removing the top relay cover screw.

Figure 8 shows a drawing of the standard 50 amp. Main Board installed in domestic premises capable of serving an all-electric home, and the position of the receiving relay. As a total of 1523 receiving relays had to be installed on all existing domestic water heater circuits, the actual time necessary to carry out the work was approximately 10—15 minutes per receiving relay, which meant that the installation of relays was done very expediently.

As the L.T. distribution system has ordinary 3 phase 4-wire underground mains and single phase service connections have been arranged to all residences with the same number of houses on each phase, a good overall balance on the distribution system is obtained. The receiving relays have now been divided into eight channels and it is therefore possible to shed the water heater load at one-eighth of the total connected load on the operation of each individual channel with equal affect on each phase of the distribution system.

(3.5) *Testing of Receiving Relays*:

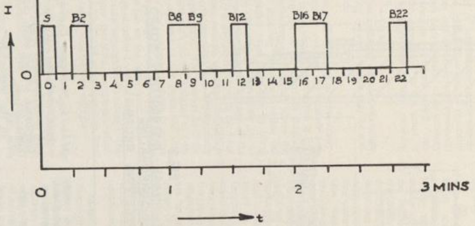
A very simple but effective portable relay testing unit has been supplied together with the equipment which makes the testing of receiving relays before being installed or during service a very simple matter.

This testing unit consists of a valve-generator which is capable of producing the required injection frequency current together with a control unit which can simulate any operating sequence normally executed by the master control board. Receiving relays are therefore tested and set to the required channel before being put into service which eliminates the possibility of a faulty receiving relay being installed. Furthermore, should a receiving relay fail in service it is a very simple matter to test the relay on site without the necessity of having to remove the relay.

These are important features of an audio-frequency remote control installation as the testing and maintenance of receiving relays should be straight-forward, and experience has shown that existing staff employed in a standard testroom can very easily cope with this kind of work. I therefore feel that the argument raised in the past that special trained staff and equipment is necessary to

Fig. 7

GRAPHICAL REPRESENTATION OF A SIGNAL TRANSMISSION. ORDINATE : INJECTED AUDIO-FREQUENCY CURRENT : ABCISSA : TIME.



ORDINATE: INJECTED AUDIO FREQUENCY CURRENT
ABCISSA: TIME

FIG 7

GRAPHICAL REPRESENTATION OF SIGNAL TRANSMISSION

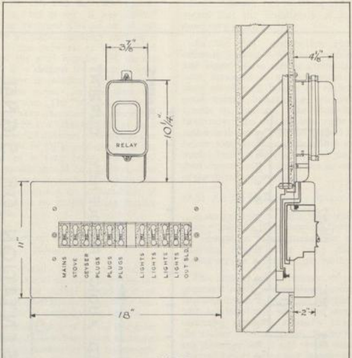


FIG.8.

50 AMP SINGLE-PHASE DISTRIBUTION BOARD INCORPORATING RECEIVING RELAY

successfully operate and maintain a remote control installation can be discarded with present day remote control equipment.

4. OPERATIONAL FEATURES AND EFFECT:—

The most important aspect of remote control operation is undoubtedly the interference problem and its effect upon the injection frequency of a remote control installation.

(4.1) *The Interference Problem*:

Interferences that may be encountered with audio-frequency control are basically interference voltages which can be of the following types.

(i) The semi-steady state interference voltage in the low tension network which rarely exceeds the level of 0.4. volts.

(ii) Surge-like interference voltages of many volts amplitude with exponentially decaying audio-frequency components. These are mainly due to the connection and disconnection of load and transformers, or to paralleling operations and lightning surges.

(iii) Trains of interference surges similar to the second class due to repetitive sources ond other devices connected through poor contacts or to mercury arc traction rectifiers which may become cumulative to the point of causing operation of the receiving relays.

(iv) Possible spill-over signals from neighbouring networks which may be controlled.

To eliminate the influence of semi-steady-state interference voltages the receiver acts as follows. It has already been shown in Fig. 5 and description of the electrical diagram how an audio-frequency signal starts the receiver by inducing resonance within the double frequency band filter then by being rectified and charging the condenser (6) to the point where the ignition voltage of the glow tube (7) is exceeded. Now, if the filter output voltage remains constant the voltage across the condenser (6) rises exponentially to the changing time. The receiver has now been designed such that if a signal of only 1.0 volt is applied to the input the time required for the condenser voltage to attain the ignition voltage of the glow tube is only five seconds but on the other hand, with an input voltage of below 1 volt of say 0.9 volts, the ignition time approaches 60 seconds. This design feature therefore, completely eliminates the possibility of relay operation from semi-steady-state interference voltages.

Surge-like interference voltages on the other hand, may reach 100 volts in amplitude but these are usually only of about 10 milliseconds duration. Even if the energy level of these signals exceeds 100 mWs (which is the energy necessary for an authentic audio-frequency signal to cause operation of the relay) the non-linear resistor (9) with its sharp cut-off at 4 or 5 volts severely limits the voltage finally appearing across the secondary terminals of the filter circuit and therefore offers full protection. This voltage usually occurring as it does for only 10 milliseconds or so is insufficient to charge the condenser sufficiently to start the receiver.

In the case of repetitive surges the non-linear resistor also greatly reduces the amplitudes of the initial peaks of each surge having the effect of draining off the condensor charge during the intervals between the individual surges in the train which normally are of only a few milliseconds duration. This then prevents the trains from becoming cumulative to the point of causing relay operation. In addition every transmitting plant is provided with standard protection against interference voltages and possible spill-over signals from neighbouring networks, consisting of a two-way contractor for control purposes incorporating an absorption circuit. In its rest position this contactor connects the 11 K.V. sub-station busbars to earth through the coupling circuit and an additional tuned coil which are all tuned to resonate at the required audio-frequency injection frequency level. This means that any interference voltages or spill-over signals appearing close to the injection frequency level are effectively short-circuited whenever on active audio-frequency signals are being injected or during pauses between actual impulses. And finally as will be seen from the graphical repersentation of a typical signal transmission, the long impulse duration of 7.5 seconds leads to the receivers a control energy which lies far above normal interference levels.

In the case of the Sasolburg installation a thorough initial survey was made to determine the correct frequency for injection which showed the optimum frequency to be in the region of 1050 c.p.s. No interference voltages of any magnitude were detected when the initial survey was made but it is of interest to note that subsequently a significant interference voltage at 1150 c.p.s. was detected to the point of becoming cumulative and causing relay operation. A subsequent survey brought to light that this steady interference voltage originated from mercury-arc-traction rectifiers installed on the S.A.R.

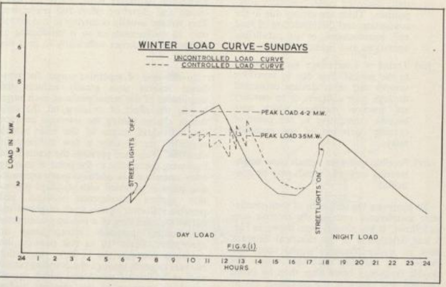
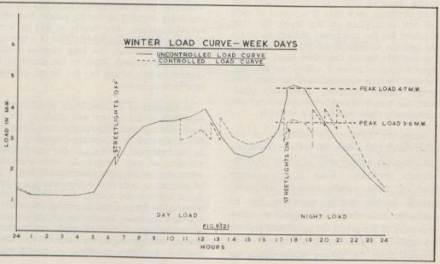


Fig. 9 (1) to 9 (4).
DAILY LOAD CURVES ON THE SASOLBURG DISTRIBUTION NETWORK.



Electrification system when these were commissioned some months later. These mercury-arc-traction rectifiers are being fed from the same 88 K.V. circuit feeding the Sasolburg network and are situated only some 4 to 5 miles from the Sasolburg Main Stepdown Transformer Station. As a single frequency absorption circuit had been supplied which was mostly effective in absorbing interference voltages at 1050 c.p.s. interferences from the 1150 c.p.s. frequency level was appearing close to 1050 c.p.s. to the point of causing relay operation. A slight modification to the absorption circuit had therefore to be made and by fitting additional small condensers into the tuned circuit double frequency absorbtion was achieved so that any interference voltages within these limits could be absorbed as well.

No further trouble from interferences has since been experienced in the network but from the foregoing it will be realised that possible interferences that may be encountered in a distribution network are the most important factors when determining the injection-frequency of a remote control installation. Furthermore a flexible absorption circuit that can be adjusted at no large expense is essential for an audio-frequency remote control installation so that any possible future interference voltages can be rendered harmless and trouble free operation can be achieved.

(4.2) *Effect on the System Load*:

It is of interest to detail some of the aspects of the automatic control carried out on domestic water heaters and street lighting in the Sasolburg network with special reference to the actual times these heaters are being controlled and the effect this has had upon the system load factor.

Fig. 9 (1) to 9 (4) represent typical daily load curves for winter and summer months on the Sasolburg system with and without load shedding.

These load curves are compiled from past winter and sumer loads actually recorded so that the reduction in peak loads can be regarded as fairly accurate. The following main data characterised the network under control.

(i) Installed transformer capacity at the main stepdown transformer station .... 7500 K.V.A.

(ii) Rated load of domestic water heaters being controlled .... 3650 K.W.

(iii) Number of receiving relays installed on domestic water heater circuits 1523

(iv) Rated load of domestic water heaters per receiver installed .... 2.4 K.W.

(v) Rated load of street lighting system 300 K.W.

From the daily load curves one can clearly observe the effect of the switching "ON" and "OFF" of the domestic water heaters and street lighting with the aid of remote control equipment, during certain times of the day. The water heaters are switched off during the morning and evening peaks as and when required. Of the 22 double commands that can be performed with the remote control installation the allocation of channels is as follows:—

10 channels for domestic water heater control;

2 channels for street lighting control;

3 channels for Bantu Township Supply control;

7 channels are available for other applications.

The domestic water heaters are at present being controlled by eight channels which can be switched on or off in any desired group for load shedding purposes, depending upon the number of kilowatts that must be reduced from the peak. During the morning peaks the water heaters are only switched OFF when necessary and in this respect it is of interest to note that the Sunday morning peak is higher than for any other normal weekday. As the load on the Sasolburg system is purely domestic, this can be accounnted for by the fact that most consumers have their stoves in use on a Sunday morning preparing their Sunday dinners.

The maximum hourly demands recorded during these Sunday morning peaks was as

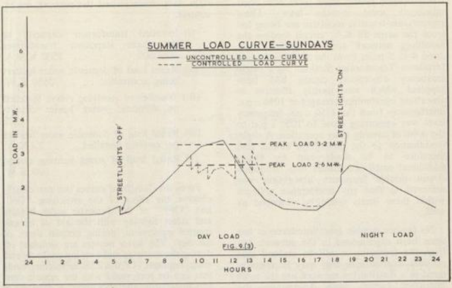

SUMMER LOAD CURVE—SUNDAYS
UNCONTROLLED LOAD CURVE
CONTROLLED LOAD CURVE
LOAD IN M.W.
STREETLIGHTS 'OFF'
STREETLIGHTS 'ON'
PEAK LOAD 3·2 M.W.
PEAK LOAD 2·6 M.W.
DAY LOAD
NIGHT LOAD
HOURS
24 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
1 2 3 4 5 6

FIG. 9(3).

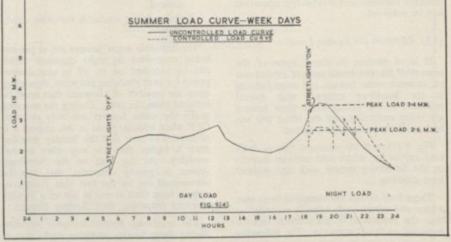

SUMMER LOAD CURVE—WEEK DAYS
UNCONTROLLED LOAD CURVE
CONTROLLED LOAD CURVE
LOAD IN M.W.
STREETLIGHTS 'OFF'
STREETLIGHTS 'ON'
PEAK LOAD 3·4 M.W.
PEAK LOAD 2·6 M.W.
DAY LOAD
NIGHT LOAD
HOURS
24 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
1 2 3 4 5 6

FIG. 9(4)

follows during the summer and winter months:

Winter morning peak without load shedding .... 4.3 MW.

Winter morning peak with load shedding .... 3.5 MW.

Summer morning peak without load shedding .... 3.20 MW.

Summer morning peak with load shedding .... 2.6 MW.

Therefore, the switching off of the water heaters resulted in a total reduction of 800 K.W. and 600 K.W. respectively which is nearly 22% and 17% of the total installed water heater load. The water heaters are switched on again in staggered groups which is necessary to avoid second peaks which may be far in excess of the recorded peaks during the switch-off period, as it was found that approximately twice the total load shed is restored when the water heaters are

The staggering of the switching ON and OFF of the water heaters further results in an even period all water heaters are kept swiched off which amounts to approximately 2½ hours during the Sunday morning peaks. The water heaters are switched off again during the evening peaks but the operation differs somewhat from that found suitable for the morning peaks as all the water heaters are not switched off in closely staggered groups. The reason for this is that experience has shown that if all the water heaters are switched off in closely staggered groups as is the case during the morning peaks, then the last group can only be switched on again after approximately 2½ hours if a second peak is to be avoided. This, of course, immediately led to consumer complaints of an insufficient supply of hot-water during the evenings from the last groups to be switched on again. The demand for hotwater during the evening peak is therefore, much higher than during the morning peak. A switch-off period of approximately 2½ hours during the morning peak on the other hand, did not appreciably affect the supply of hotwater to cause any inconvenience as no complaints were received.

As will be seen from the load curves, the weekday evening peak is higher than the weekday morning peak and control is therefore essential during the weekday evening peak. The water heaters are normally switched off in three groups during the evening peaks. Two groups are switched off when the streetlights are switched on. A third group is switched off when the first group is switched on again. This allows the first groups to be restored again after approximately 1½ hours switch-off without creat agniosec

creating a second peak. The third group is switched on again in two stages which then gives an even switch-off period for all water heaters of approximately 1½ hours during the evening peaks without creating second peaks or causing any inconvenience to the consumers. This method of control resulted in the following maximum hourly demands being recorded during the evening peaks.

Winter evening peak without load shedding .... 4.7 MW.

Winter evening peak with load shedding .... 3.6 MW.

Summer evening peak without load shedding .... 3.4 MW.

Summer evening peak with load shedding .... 2.6 MW.

Therefore, the switching off of the water heaters during the evening peaks resulted in a total reduction of 1100 K.W. and 800 K.W. respectively which is 30% and 22.0% of the total installed water heater load.

(4.3) *Comparison of the Daily Load Curves With and Without Load Shedding*:

It is now of special interest to compare the main data with and without load shedding for winter and summer loads.

	WINTER LOAD CURVE Without load shedding	WINTER LOAD CURVE With load shedding	SUMMER LOAD CURVE Without load shedding	SUMMER LOAD CURVE With load shedding
Total energy sold over 24 hours	58,000 Kwh	58,700 Kwh	43,480 Kwh	43,720 Kwh
Morning peak loads	4.3 MW	3.5 MW	3.20 MW	2.6 MW
Reduction in morning peaks		0.80 MW		0.60 MW
As % of installed water heater load		22%		17%
As % morning peak		19%		19%
Evening peak loads	4.7 MW	3.6 MW	3.4 MW	2.6 MW
Reduction in evening peaks		1.1 MW		0.8 MW
As % of installed water heater load		30%		22%
As % of evening peak		23.5%		23.5%
Daily load factor	51.5%	68%	53.5%	70%
Morning load shed per receiver installed		.525 KW		.400 KW
Evening load shed per receiver installed		.720 KW		.525 KW

The evening peak load was therefore reduced by an average of nearly 24% whereas the morning peak load was reduced by an average of 19%. To account for this difference in load shed during the morning and evening peaks the demand for hotwater is greater during the evening peaks. This is also shown by the percentage of the total installed water heater load that is reduced from the peaks during these periods. Although tests have shown that at least 33% of the total load taken during peak periods is accounted for by domestic water heaters, the reduction in peak load was only approximately 24%. This is due to the fact that the water heaters are not swiched off for unnecessary long periods as this will cause inconvenience and lead to complaints of an insufficient supply of hotwater from the last groups to be switched on again.

The above method of control was however found to give the maximum possible reduction in peak load without creating second peaks or causing inconvenience to the consumers. In this respect I would therefore suggest that the maximum period a domestic water heater of 30-gallon capacity should be controlled in 2½ hours during the morning peaks and 1½ hours during the evening peaks which will allow ample time for the water to reheat for later requirements.

The important results achieved from the foregoing loadshedding operation is however that it was possible to reduce a maximum of 0.72 KW per receiving relay installed during the winter months and 0.525 KW per receiving relay installed during the summer months. As an average over one year, therefore, a total reduction of 0.6 KW per receiving relay installed is achieved which is approximately 25% of the total installed water heater load. It is also known that some Supply Authorities who operate load shedding have claimed very much higher figures per receiving relay installed but I think this may be due to either longer periods of control or to diversity of habits as it was found that the higher the social standard of living the higher the consumer's reduction in load would be. The above figure of 0.6 KW reduction in peak load per receiving relay installed is therefore regarded as a fairly accurate average figure for the class of consumer in Sasolburg. The average monthly load factor was about 50% before load shedding was applied whereas the the effectseffect of load shedding was an improvement in the load factor to an average of about 63%.

(4.4) *Effect Upon the Consumer*:

As could be expected with any form of control over a consumer's free use of an electrical appliance, it was with some suspicion that consumers at first accepted the installation of receiving relays upon the premises.

The first complaint came from a group of consumers who had receiving relays installed during April and May 1959. The general complaint was that an immediate increase in their electricity consumption took place since the relay had been installed. Needless to say, that as control was only commenced towards the end of June, 1959, this complaint soon disappeared, as it was purely incidental that the installation of receiving relays happened to coincide with the seasonal increase in electricity consumption. Generally speaking however, the incidence of consum er complaints has been negligible. In this respect it was interesting to note that in the few odd cases where a complaint of an insufficient supply of hot water was received and it was found that the receiver had not functioned correctly, the consumer had as a matter of habit switched off the supply to the water heater circuit during the switch off period and had left it off until the following morning. This then naturally meant that the injected signals could not be received by the relay until late the following morning or evening when the next series of impulses was being transmitted, and the supply to the water heater circuit had been restored. This could of course have been avoided by connecting the receiver before the protective circuit breaker or fuse direct on to the busbar but this would have been contrary to the requirements of the Standard Wiring Regulations and protection for the receiver is desirable. However, as soon as the consumer realised that this was not leading to any savings on his monthly power bill, this practice seems to have ceased, as no further complaints of this nature were received. Only in cases where the consumer happens to drain the water heater completely just before being controlled would the interruption of the supply to the storage heater circuit cause any real inconvenience, as this means that the consumer has to wait 1½ hours longer for his water to heat up again as would have been the case without control, but I am of the opinion that it is mainly due to the following reasons that no inconvenience or change has been noticed by consumers.

1. There is ample hot water in the water heater for the early evening and morning requirements of most householders.
2. Control over morning hot water is restricted to Sundays and on certain week-days only.
3. As the switch-off period is restricted to 1½ hours during the evening peaks there is ample time for the water to heat up again for later requirements.
4. A switch-off period of 2½ hours during the morning peaks does not appreciably effect the supply of hot water as no complaints were received in this respect.

5. THE ECONOMIC ASPECT OF A REMOTE CONTROL SYSTEM.

The economics of a remote control system which is the most important aspect, depends mainly upon the following two points.

1. The fact that the capital outlay and running costs in providing a supply of electricity can be reduced mainly because the load factor of an electricity supply system can be improved if sufficient electrical apparatus exists that can be switched off during the peak periods.
2. The fact that with the aid of a remote control system new street lighting installations can be made much cheaper as compared with a separate pilot wire or cable network.

In most cases it will be found sufficient to have only one of these two main points to justify the capital outlay for the purchase of a remote control system, but can obviously be improved when it can be applied for both points together.

In order to calculate the economic advantages when used for the improvement of the load curves the following information must be available.

1. How many Kilowatts can be cut-off from the peak with the aid of the remote control installation?
2. What is the monetary value of the kilowatts that have reduced from the peaks?
3. What is the average cost of installing one receiving relay including part costs of the transmitting plant as well as service costs and extras?

The answer to question 1 will be found in actual operating results obtained with the Sasolburg remote control installation. As was shown earlier on in this paper it was possible to reduce an average of 0.6 Kilowatts per receiving relay installed from the peaks on the Sasolburg network. Although some Electricity Supply Undertakings may have achieved a reduction of more than 1 kilowatt per receiving relay installed, which is most probably due to diversity of habits of the various consumer groups and longer control periods, the following economic calculation will be based on 0.6 Kilowatts which is an actual obtained average figure.

The answer to question 2 is best illlustrated by giving the actual effect on —

1. Capital Investment, and
2. Running costs of the Sasolburg Electricity Supply Undertakings distribution system.

(5.1) *Effect on Capital Investment*:

As mentioned previously a substantial increase in the cost of distribution equipment has taken place since Sasolburg was developed in 1952, and an analysis of the investment per kilowatt on the Sasolburg network resulted in the following average figures:

(1) Transformation from the E.H.T. level to the H.T. level and underground H.T. distribution	£15 0 0
(2) Transformation from the H.T. level to the L.T. level and underground L.T. distribution	£35 0 0
TOTAL CAPITAL INVESTMENT PER K.W.	£50 0 0

From internationally approved figures which exist concerning the capital investment per kilowatt, the accepted average figure for distribution costs at present appears to be about £85 per K.W. The above figure of £50 per K.W. can therefore be regarded as not too high under present day conditions and for the purpose of the following calculation, comparison will be made to this figure.

The cost of the Sasolburg remote control installation consisting of transmitting plant and 1700 receiving relays is as follows:

(1) Price per receiving relay including installation costs	£9 10 0
(2) Part cost of the transmitting plant and all equipment relating thereto	£2 6 0
(3) Contingencies	£0 4 0
TOTAL PER INSTALLED RECEIVER	£12 0 0

Each proposed new kilowatt installed on the Sasolburg network will therefore cost approximately £50. On the other hand as each receiving relay installed can reduce the peak by approximately .6 K.W., this means that for every 1.7 relays installed the peak can be reduced by 1 K.W. As the cost of 1.7 relays is approximately £20.0.0. the saving on capital investment with remote control equipment on each kilowatt of reduced peak load is:

£50 — £20 = £30. 0. 0.

In other words, on any proposed new extension of the distribution system about £18 less per installed receiver will be spent. As the above calculation is based on new raised capital for investment, the actual calculation, when based on annual capital costs, will be as follows:

	per annum
Interest and redemption per annum on £50 per K.W. of new investment capital	£3 17 9
As one relay can reduce 0.6 K.W. from the peak the saving per annum per receiver installed would be 0.6 x £3.17.9. which is	£2 6 8

As the cost of the receiving relay including its part cost of the transmitter and all extras is £12.0.0., it can therefore be amortised in approximately 5 years.

(5.2) *Effect on Running Costs*:

The effect on running costs of the Sasolburg Electricity Supply Undertaking distribution system is best illustrated by the graphic reproduction of the unit costs and load factor for the past four years shown in Fig. 10 together with the yearly load curves as illustrated in Fig. 11.

It must be observed that the steady rise in total unit costs over the past four years is due to tariff increases at the beginning of 1957, 1958 and 1959, imposed by the Electricity Supply Commission with the result that the cost of Electricity reached a maximum in the Sasolburg area at the beginning of 1959. A further increase in the unit costs was imposed by Escom. during April 1960 and during June 1960 a result of increased coal costs at the Commission's Generating stations. In the following calculation of the percentage saving attained in total unit costs, these facts will therefore have to be taken into account if a true comparison is to be made.

As will be seen from the load curves, load shedding was commenced during June 1959 when approximately 400 relays had been installed. As the installation of all 1523 receiving relays on water heater circuits was only completed by the end of November 1959, the calculations will be based on the total unit costs after all 1523 receiving relays had been installed. The average cost per unit bought for the five-month period from January 1959 to May 1959 immediately prior to load shedding was as follows:

Kilowatt cost per unit bought	0.4350d.
Unit cost per unit bought	0.2180d.
Total cost per unit bought	0.6530d.

The subsequent reduction in total unit costs as a result of the savings in Kilowatt demand costs can be clearly seen from the curves in Fig. 10. By the time the installation of all relays was completed the average cost per unit bought with load shedding up to the end of September 1960 was as follows:

Kilowatt cost per unit bought	.3384d.
Unit Cost per unit bought	.2413d.
Total cost per unit bought	.5797d.

Therefore, the actual saving on Kilowatt demand charges per unit bought was as follows:

Kilowatt cost per unit bought without load shedding	.4350d.
Kilowatt cost per unit bought with load shedding	.3384d.
Saving in Kilowatt cost per unit bought	.0966d.
% Saving in Kilowatt costs per unit bought	22%

For a true reflection of the percentage saving made possible on the total unit costs the recent increases in the unit costs must be taken into account, which will then give a total cost of .6763d. per unit bought without load shedding.

THE TOTAL SAVINGS MADE POSSIBLE per unit bought will then be as follows:

Total cost per unit bought without shedding	.6763d.
Total cost per unit bought with load shedding	.5797d.
Total saving in unit cost	.0966d.
% Saving in total unit cost	14%

The possible savings on the Sasolburg Electricity Supply Undertaking's electricity account for the year 1960/61 based on an estimated total unit consumption of 16,000,000 units per annum will then be 16,000,000 units x 0.0966d. per unit, which is approximately £6,400. A otal of 1,600 relays will be installed on all water heater circuits before the end of the present financial year so that the annual savings on maximum demand charges per receiver installed will therefore be £4.0.0. The annual maintenance costs of the remote control installation must however be taken into

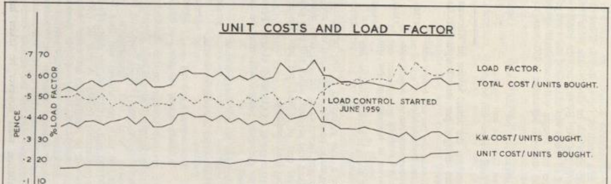

UNIT COSTS AND LOAD FACTOR
PENCE
% LOAD FACTOR
·7 70
·6 60
·5 50
·4 40
·3 30
·2 20
·1 10
LOAD CONTROL STARTED
JUNE 1959
LOAD FACTOR.
TOTAL COST / UNITS BOUGHT.
K.W. COST / UNITS BOUGHT.
UNIT COST / UNITS BOUGHT.

FIG.10

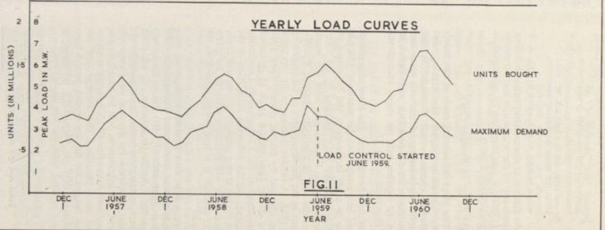

YEARLY LOAD CURVES
UNITS (IN MILLIONS)
PEAK LOAD IN M.W.
2 8
7
1·5 6
5
1 4
3
·5 2
1
UNITS BOUGHT
MAXIMUM DEMAND
LOAD CONTROL STARTED
JUNE 1959
DEC
JUNE 1957
DEC
JUNE 1958
DEC
JUNE 1959
DEC
JUNE 1960
DEC
YEAR

FIG.11

account to arrive at a NETT figure, and in this respect the maintenance figure for the remote control installation has been based on five shillings per annum per receiver installed.

(5.3) *Maintenance Costs of the Remote Control Installation*:

As pointed out previously the consumer complaints has been very low so that the maintenance costs of the remote control installation and associated receiving relays over the past 18 months has been negligible. A few minor initial teething troubles were however experienced but these were mostly confined to faulty wiring in connecting up the relay itself and could in any case not be tied down to a fault of the relay or the remote control installation itself. It is sometimes said that consumers will soon attempt to interfere with the operation of the relays and that once the switching times are known they will succeed in by-passing the operation of the receiving relays. As the switching sequence of the various consumer groups is constantly being varied to suit the seasonal demands this seems very unlikely. Some consumers have however tried to by-pass relay operation by interrupting the supply to the receivers during an impulse series which naturally stopped the relays from operating. Apparently the idea was to restore the supply again after the 3 minute impulse series in order to retain a supply to the water heater during the switch-off period. Unfortunately for the consumer however this has the opposite desired effect, because the receiver has been designed so that the injection of an active impulse will START the receiver and switch ON the required channels where as the absence of an active impulse will switch OFF the required channels. As the starting contact of the relay is closed once the START impulse has been injected an interruption to the supply does not open these contacts but only stops the relay from operating. Restoration of the supply after an impulse series will therefore set the receiver in motion again, and as active impulses are absent, will merely switch OFF the various channels. What this in fact means is that the consumer will switch off his controlled circuit in any case. Only if the supply is interrupted *before* active impulses are being injected will it be possible to by-pass relay operation but as these times are constantly being varied, trouble from this source has not yet been experienced.

In view of past experience with the remote control installation I am therefore of the opinion that the estimated figure of 5/- per annum per receiver installed will cover all possible future expenditure in maintenance costs of the receiving relays and associated equipment. The nett possible annual savings on maximum demand charges per receiver installed can therefore be taken as £3.15.0.

(5.4) *Summary*:

To summarise briefly then, the possible NETT annual savings with a remote control installation on both capital investment and running costs, is as follows:—

(1) Annual savings on capital investment per receiver installed	£2 6 8
(2) Annual savings on running costs per receiver installed	£3 15 0
Total Annual Savings/Receiver Installed	£6 1 8

It can therefore be concluded that a remote control installation as applied to the Sasolburg network with the actual obtained reduction of 0.6 K.W. off the peaks per receiver and a total cost of £12.0.0. per receiver installed, will pay for itself within a period of 2 years.

6. OTHER APPLICATIONS.

(6.1) *Remote Controlled Street Lighting Installations*:

Apart from its use as a means of shedding the load during the peak periods, the financial savings that are possible when remote control equipment is also used for controlling a street lighting installation is of major importance.

Normally a street lighting installation consists of a separate cable or pilot wire network the control of which is supervised by either time switches, or photo electric cells etc. The cost of such an installation on account of the vast geographical limits of the Electricity Supply Undertakings network, will tend to be rather high and therefore also one of the main reasons why most street lighting installations leave much to be desired for. In the case of a remotely controlled street lighting installation the cable or pilot wire network can be dispensed with in the following manner. The street light is connected through a short length of cable or pilot wire to the nearest existing low-tension main which is feeding either houses or other low-tension consumers. Each street light is then equipped with a protective fuse and remotely controlled receiving relay the function of which will be to automatically switch "ON" and "OFF" the street lights at the required times.

The cross section of cables necessary for a separate street lighting cable network will have to be large enough to maintain sufficient voltage at the end of the lines. On the other hand it was found, that sufficient voltage could be maintained with a smaller cable in the tee-off circuits from existing low tension mains as the street lighting load was small in relation to the system load and could be evenly distributed over the entire lowtension network without affecting the cross section of existing low-tension distributors.

In the case of a recent new Sasolburg extension to the street lighting installation the estimated cost of a remotely controlled system and a conventional cable network system was as follows:—

COMPARISON OF EXPENDITURE ON A STREET LIGHTING INSTALLATION WITH AND WITHOUT REMOTE CONTROL

Without Remote Control and With a Separate Cable Network.

Substation Control panel including time switches, control gear and street light feeder	£150
20,000 ft. of cable @ 2/6 per ft.	£2500
20,000 ft. of cable laid @ 1/- per ft.	£1000
125 Lighting standards @ £7.0.0.	£875
125 Street light lanterns @ £3.0.0.	£375
Pole erection costs	£200
Cable connection costs	£100
	£5200
Plus Contingencies	£520
TOTAL COST	£5720
COST/STREET LIGHT (SAY)	£46

With Remote Control and Without a Separate Cable Network.

1600 feet of cable @ 1/6 per ft.	£120
1600 feet of cable laid @ 1/- per ft.	£80
125 Receiving relays @ £12.0.0.	£1500
125 Lighting standards @ £7.0.0.	£875
125 Street light lanterns @ £3.0.0.	£375
Pole erection costs	£200
Cable connection costs	£400
	£3550
Plus contingencies	£350
TOTAL COST	£3900
COST/STREET LIGHT (SAY)	£31

The saving per street light erected on an underground remotely controlled street lighting system therefore amounts to ± 33%. The full cost of the receiving relay and part costs of the transmitting plant has also been proportioned to the street lighting installation so that the above comparison can be regarded as fair, when the system is used for *both* load shedding and street lighting control.

However, it is interesting to note that if a remote control system is used solely for controlling a street lighting installation then the full cost of the receiving relays and transmitting plant will have to be borne by the street lighting installation. The transmitting plant alone would cost approximately £4,000 including all erection costs, spares, testing apparatus etc., which means that for a minimum quantity of 275 receiving relays the cost of the transmitting plant alone would amount to approximately £15 per receiving relay installed. Therefore once the street lighting system is large enough and in excess of say, 300 street lights, the provision of a remotely controlled installation already becomes a payable proposition.

As mentioned previously therefore the provision of a remote control system can be fully justified when used either for load shedding or for the control of a street lighting installation, but when used for the control of both however, the justification for the capital outlay involved is immediately improved.

The overall unit consumption of a remotely controlled street lighting installation although not metered separately, can very easily be calculated as the actual burning hours of all lamps are accurately determined by the switching times of the 24 hour programme clock. An argument sometimes raised against a remotely controlled underground street lighting installation is that a multiplicity of tee-off cable connections from existing low tension underground mains will eventually lead to unnecessary interruptions in the power supply to the consumers in the event of trouble in the tee-off circuits. In Sasolburg where normally 6 house service connections are teed-off one single low tension underground distributor cable, experience has shown that during 8 years of service no tee-off cable joint trouble has been experienced apart from the occasional damage to underground cables by other instances when crossing these services.

As a result of improved cable jointing practice and with correct supervision, I think this is a risk worth while taking particularly in view of the large financial savings made possible thereby.

(6.2) *The Application of a Remote Control System in a Bantu Township*:—

Apart from load shedding and for street lighting control further interesting applications of the remote control system were to be found in controlling the supply of electricity in various sections of the Bantu-Township.

In the Sasolburg Bantu-Township provision is made for the housing of

(1) Unmarried Bantu's in Hostels

(2) Factory Employees in Compounds, and

(3) Married Bantu's in married Quarters.

In the Bantu-Hostel area it was found that the electric lights, in most of the Bungalows and Ablution Blocks were never switched off during the day time. As a result of the subsequent high consumption in electricity in this area a request was received from the Hostel Superintendent whether something could be done in this respect. As the installation of time switches with associated control gear or manual control would become uneconomic because of high maintenance and adjustment costs, it was decided to investigate the possibility of controlling the supply of electricity to these bungalows by the installation of receiving relays direct onto the supply mains. As the receiver is rated at 25 Amps at 220 Volts for pure ohmic loads and as the lighting load per bungalow was only about 3 Amps, 5 bungalows could be controlled by one receiver. This arrangement was found very satisfactory and at present power is only made available between sunset and sunrise and is controlled from the central transmitting station, thus eliminating maintenance and adjustment costs on individual time switches. Consumption of electricity in this area has since returned to normal.

In the Compound Area of the Bantu-Township the Bantu Employees of the S.A. Coal, Oil and Gas Corporation's factory are being housed. Although a similar problem confronted this section of the Bantu-Township regarding electric lights that were never switched off during the day time the solution here was not so simple. Firstly the majority of Employees housed in the Compounds do shiftwork and as such make use of the Quarters and Ablution Blocks at various hours of the night. Therefore, a switching programme had to be determined, and after a survey was made of the actual times during which a supply of electricity had to be made available to the Quarters and Ablution Blocks, receiving relays were installed. It was then a very simple matter to achieve any switching operation required by the Compound Manager by selecting the desired times on the 24 hour programme clock in the central transmitting station. Furthermore, as 22 double commands can be transmitted with this installation it was possible to allocate the necessary channels required for the control of electric lighting in the Bantu Township without interference to other preferential channels.

In the remainder of the Bantu Township, that is in the married quarters, each house has been provided with a supply of electricity together with street lighting which has been made available in every street. The street lighting installation is remotely controlled and as already shown in detail in this paper, this was only made possible by the financial savings obtained thereby as the funds made available for this kind of service in the Sasolburg Bantu Township was very limited.

Once a supply of electricity has therefore been made available to the individual homes in a Bantu Township then adequate street lighting which is also regarded as an essential service judging from previous papers and discussions delivered at these Conventions, can be provided very economically with the aid of a remote control system.

7. CONCLUSION.

I think I would be failing in my duty if I did not point out that success with load shedding can only be achieved if the network under control has sufficient electrical apparatus which can be switched off during the peak periods. Indications, however, are that the sale of domestic water heaters in this country and elsewhere over the past few years has reached such proportions that most Electricity Supply Undertakings must be supplying a fair amount of power to this kind of domestic apparatus. In this respect it may be of interest to refer to the following extract from a paper read at the twelfth British Power Convention held at Bournemouth, United Kingdom last year, by T. E. Daniels on "Electricity in the home."

"Disposals of electric immersion heaters in the last year or two give a clear indication that we are rapidly moving towards nearly 100% saturation in those premises where the plumbing arrangements permit a heater of this kind to be used.

It may be that the time is opportune for us to consider seriously that builders of new property should install hotwater vessels of not less than 50-gallons capacity with sufficient accommodation for them to be properly heat-insulated, if not now, at a later date so that the load can be taken at off-peak hours either by local time-switches or by means of supervisory control. We may be wise in making our plans now for water heaters with loads of perhaps 5 K.W. and to be considering the appropriate ways of connecting these."

I am of the opinion that this may become an important aspect of domestic power supply in this country as well, because most Electricity Supply Undertakings will be, or are already faced with a similar problem. In this respect load shedding experience in Sasolburg has also shown that at least 33% of the total load taken during peak periods is due to the water heater load and that approximately 25% of the total installed water heater load could be shed during peak periods. It was further established that the control of a 30-gallon capacity water heater is rather critical as the switch-off period had to be kept within reasonable limits if inconvenience to the consumers was to be avoided which is essential with any load shedding operation. The installation of a 50-gallon capacity domestic water heater on the other hand would naturally mean that far greater success with load shedding can be achieved as the switch-off period can be increased considerably. It should then be possible to fill up the valleys on the load curves that normally exist between 22.00 hours and 4.00 hours with a resultant greater improvement in the load factor. The installation of a 50-gallon capacity domestic water heater, apart from its initial greater installation cost, must therefore eventually pay handsome dividends as the sale of electricity during the off peak periods can be at a very low tariff.

Generally speaking, however, it can be said that a remote control installation will be justified where the Electricity Supply Undertaking makes special efforts or already has a sufficient number of domestic water heaters installed so that the load factor can be improved by the additional sale of electricity during the off peak hours. This will also apply to electric storage heaters which are becoming increasingly more popular for the space heating of offices and public buildings during the off peak hours.

Briefly then the following conclusions can be made when considering this question of remote or load control: —

1. Once an Electricity Supply Undertaking's distribution network has sufficient electrical apparatus installed which can be switched off during the peak periods load shedding becomes economically justified both on capital investment and running costs of the distribution system.
2. Technically the system must be of a very sound design if trouble from interference voltages is to be avoided and the maximum benefits can be derived from the load shedding operation. At the same time simplicity of construction of the various components must be observed so that normal test room facilities and staff can handle the maintenance of the system.
3. From operating experience it has been established that the maximum period a 30-gallon capacity water heater can be controlled is approximately 1½ hours during the evening peaks and 2½ hours during the morning peaks without inconveniencing the consumers.
4. The sale of domestic water heaters in this country and elsewhere seems to indicate that most Electricity Supply Undertakings must at present be supplying a considerable amount of power to this kind of apparatus during peak load periods. In the case of Sasolburg this amounts to approximately 33% of the total load taken during peak periods, whereas 25% of the total installed water heater load could be shed during peak periods.
5. It would appear that the installation of larger capacity domestic water heaters on domestic premises will eventually be justified especially as these can be heated up during the off-peak hours without causing inconvenience to the consumers particularly as the domestic demand for power must increase with the rise in the living standard of our consumers.
6. Apart from the business of keeping the peak load under control, the supervisory control of new street lighting installations becomes an economic proposition.
7. Once a remote control system of a suitable type has been installed it is soon realised that many additional functions can be performed which will suggest themselves almost immediately to the Supply Authority Engineer with a particular problem of this nature.

It must, however, be appreciated that the installation of a remote control system by any Electricity Supply Undertaking intended primarily to keep the system peaks under control, will need a thorough and careful analysis of the load characteristics of the system but at the same time it was pointed out that other applications exist, apart from the business of keeping the peak loads down, which can fully justify the installation of such a system.

In conclusion it is hoped that this paper will serve a useful purpose in making available some information relating to this question of load or remote control and I would like to thank the Sasolburg Village Board of Management for the opportunity of presenting this paper to the Association.

ANNUAL REPORT OF THE SECRETARIES

To the President and Members of the Association.

Mr. President, Gentlemen,

It gives me great pleasure to submit to you the Annual Report of your Association together with the Revenue and Expinditure Account and Balance Sheet for the financial year ended 28th February, 1961.

Obituary:

I deeply regret having to record the passing of Members and others who have been connected with the Association. Firstly, I wish to refer to the tragic death of Councillor M. Gild of Durban, whose aircraft was reported missing on the eve of the 34th Convention. Councillor Gild served on the Executive of the Association.

Another Councillor representative to the A.M.E.U., Councillor A. Markman, one of Port Elizabeth's most popular and successful Mayors from 1958 to 1960, passed away at the beginning of December, 1960.

One of our very early Members, Mr. G. Mercier (an Associate Member at the time of his death) and who was elected a Member of the Association in 1919 when in the service of the Bethal Municipality, died in September, 1960.

The Association and its Members lost a great friend in the passing of Major S. G. Redman on the 4th June, 1960. Major Redman came to South Africa in 1937 to become the first resident partner of Merz & McLellan (South Africa). From that year onwards until 1959 Major Redman attended every Convention of the Association. In 1956 the Association extended honorary membership to him. In the death of the Major the A.M.E.U. and all others who were privileged to know him have lost a sincere friend, a gentleman in the fullest sense of the word.

Thirty-fourth Convention:

The 34th Convention of the Association was held in Durban from Tuesday, 3rd May, 1960, to Friday, 6th May, 1960. Delegates were welcomed by His Worship the Mayor of Durban, Councillor Cyril Milne, who also officially opened the Convention. The total attendance of members, delegates, representatives, officials, visitors and ladies amounted to 501.

On behalf of the President, Members of the Association and all others who attended the Convention held in the Durban City Hall I have pleasure in recording appreciation to His Worship the Mayor and City Councillors of that city for the hospitality extended to those who attended the Convention. I also wish to extend sincere thanks to the City Council and to the various officials thereof for their unstinted assistance in the organisation of the Convention.

To the President I have much pleasure in placing on record the appreciation of all concerned for his dignified and effective discharge of his duties. Our grateful thanks are also extended to Mrs. Simpson for her support.

Although I do not wish to introduce the precedent of referring to the Presidential Address in the Annual Report, I crave Mr. Simpson's indulgence in this instance to refer to one aspect of his address at the Durban Convention. He referred to the possibilities of hydro generation of electricity with particular reference to Natal. It is significant that following from this we are going to have the pleasure of having presented to us at the 35th Convention a most important paper entitled "The Utilisation of Hydro Electric Power in the Union of South Africa."

The first paper presented to the Convention was "Some Economic Aspects of Nuclear Power Station Operation" by Mr. W. Eric Phillips, D.Sc. Eng., LL.D. (Alberta), M.I.E.E., M.(S.A.)I.R.E., Sen. Mem. I.E.E., Professor of Electrical Engineering, University of Natal, which was a further valuable contribution on this aspect of electricity supply which although not yet of practical importance to Municipal Electricity Undertakings in Southern Africa is one which they cannot afford to lose sight of in the point of view of future developments.

The next paper to be presented was "A Survey of the Control of Stage Lighting", by Mr. J. T. Wood. In its presentation Mr. Wood referred to certain aspects of this subject which were not covered in the printed version of the paper, and in particular dealt with equipment now available for small halls at a moderate price.

The final paper "Electrical Protection of Distribution Systems" by Mr. J. Michel-Smith, B.Sc. (Eng.), formerly of the Electricity Department, City of Durban, evoked informative discussion.

The symposium on the Supply of Electricity to Native Townships was a most successful feature of the Convention and I wish to thank all those who prepared contributions. To Mr. G. Masson of the Electricity Department, Johannesburg, we are particularly grateful for his detailed work in preparing a report on electrical work planned or in progress in the Native areas. The exchange of information through the symposium was, we are confident, of value to all Members involved in the problems of electricity distribution in Native areas.

The high standard of Members' Forum was again well maintained and our thanks are again due to Mr. J. Mitchell for conducting the Forum. A number of questions proposed to the Forum concerned economic aspects of Municipal Electricity Undertakings and the hope was expressed that this most important aspect would be dealt with further at a subsequent Convention. The suggestion is receiving the most serious attention of the Executive Council.

The Convention unanimously accepted the recommendation of the Executive Council that Councillors C. F. Castelyn and L. P. Davies of Bloemfontein and Springs respectively be elected Honorary Members of the Association.

It was unanimously agreed to accept the invitation of Livingstone to hold the 35th Convention in that town.

Membership:

The following new members were elected during the year ended 28th February, 1961:

Councillor Members:

Walvis Bay Municipality.
White River Municipality.
Vanderbijlpark Municipality.
Carletonville Municipality.
Knysna Municipality.

Engineer Members:

U. B. Gresse (Nelspruit).
W. Bozycsko (Edenvale).
F. R. Waldron (Walvis Bay).
J. J. Boshoff (Ceres).
H. J. Gripper (Knysna).
J. W. Pretorius (Nigel).

Associates:

J. J. Greef (White River).
V. G. Flint (Middelburg, Transvaal).

Associate Members:

W. P. Ford (Central Electricity Corporation Ltd.).

G. B. Gill (Zululand Electrical Utility Co. (Pty.) Ltd.).

Affiliate Members:

N.V. Nederlandsche Kabelfabrieken, Ltd.

The fololwing resignations took place:

Councillor Members:

George Municipality.
Upington Municipality.

Affiliate members:

Pretoria Metal Industries Ltd.
John Brown Land Boilers Africa Ltd.
Sir Alexander Gibb & Partners (Africa).
Morgan Crucible Company (S.A.) (Pty.) Ltd.
Lusaka Electricity Corporation Ltd. (transferred).

Comparative membership figures are as follows:

	1959/60	1960/61
Councillor Members	120	124
Engineer Members	119	118
Honorary Members	12	13
Associate Members	30	29
Associates	9	10
Affiliates	90	85

Finance:

The Income and Expenditure Account for the year under review and the Balance Sheet as at the 28th February, 1961, which are submitted to you call for analysis in view of the fact that an excess of expenditure over income of R569.00 (£285) is reflected therein.

The major increase in cost structure over the previous year, amounting to R624.00

ASSOCIATION OF MUNICIPAL ELECTRICITY

BALANCE SHEET —

1960 R			£		R
9,490	ACCUMULATED FUNDS		4,460		8,920
8,184	Balance at 29th February, 1960	4,745		9,490	
306	*Less*: Excess of Expenditure over Income for the year ended 28th February, 1961	285		570	
	PROVISIONS		179		358
178	Agents' Commission	90		180	
—	Sales Commission	89		178	
1,796	SUNDRY CREDITORS		—		—
—	SUBSCRIPTIONS IN ADVANCE		496		992
—	DEPOSITS ON LIVINGSTONE CONVENTION TRAVELLING EXPENSES		1,851		3,702
—	GRANT RECEIVED IN ADVANCE FOR LIVINGSTONE CONVENTION EXPENSES		250		500
R11,464			£7,236		R14,472

DAVIDSON AND EWING (PTY.) LTD.,
Per R. G. EWING,
Secretaries.

Report of the Auditors to the Members of the Association of Municipal Electricity Undertakings of

We report that we have examined the books, accounts and vouchers of the Association for the received all the information and explanations we required. In our opinion the above Balance Sheet is as at 28th February, 1961, according to the best of our information and the explanations given to us

Johannesburg, 7th March, 1961.

UNDERTAKINGS OF SOUTHERN AFRICA

28th FEBRUARY, 1961

1960 R			£		R
2	PRESIDENTIAL BADGE Nominal Value		1		2
110	FURNITURE AND FITTINGS — at cost less depreciation		49		99
7,930	INVESTMENTS		4,155		8,310
	200 6% Permanent Paid Up Class "B" Shares of R10 each, fully paid	1,000		2,000	
	Fixed Deposit	1,997		3,994	
	Savings Account	1,158		2,316	
1,876	DEBTORS		1,050		2,099
40	PAYMENTS IN ADVANCE		91		182
20	DEPOSIT: Davidson and Ewing (Proprietary) Limited		10		20
1,486	CASH AT BANK		1,880		3,761
R11,464			£7,236		R14,472

R. M. O. SIMPSON,
President.

Southern Africa:

year ended 28th February, 1961; we have satisfied ourselves of the existence of the securities and have properly drawn up so as to exhibit a true and fair view of the state of the affairs of the Association and as shown by the books of the Association.

SAVORY, BRINK, CREMER & CO.,
Chartered Accountants (S.A.)
Auditors.

ASSOCIATION OF MUNICIPAL ELECTRICITY

INCOME AND EXPENDITURE ACCOUNT

1960 R		£	R
38	Audit Fee1960	19	38
2	Bad Debts—Sale of Proceedings	—	—
24	Bank Charges	14	28
2,892	Convention Expenses	1,940	3,881
12	Depreciation—Furniture and Fittings	6	11
592	Executive Council Expenses	363	726
34	Insurance	9	18
174	Postages and Telegrams (General)	69	138
120	Presidential Chain written off	—	—
678	Printing and Stationery	175	350
Cr. 206	Proceedings	39	78
1,800	Secretarial Fees	900	1,800
30	Subscriptions Paid	15	30
116	Sundry Expenses	13	25
70	Telephone	43	87
R6,376		£3,605	R7,210

ASSOCIATION OF MUNICIPAL ELECTRICITY UNDERTAKINGS OF SOUTHERN AFRICA

Schedule I

PROCEEDINGS:		
Cost of Printing		1,946
Provision for Sales Commission		178
Provision for Agents Commission 1961	180	
Less: Overprovision for Agents Commission 1960	23	157
		2,281
Less: Advertising (gross)	1,783	
Sales	420	2,203
Net Loss on sale of Proceedings		R 78

UNDERTAKINGS OF SOUTHERN AFRICA

FOR THE YEAR ENDED 28th FEBRUARY, 1961

1960 R		£	R
384	Interest on Fixed Deposits and Savings Account	190	380
2,790	Subscriptions—Affiliates	1,384	2,769
3,506	Subscriptions—Council and Other	1,746	3,492
2	Sundry Revenue	—	—
Cr. 306	Excess of Expenditure over Income transferred to Accumulated Funds	285	569
R6,376		£3,605	R7,210

(£312) included in Convention Expenses represents the increased cost of printing the Papers and Contributions to the Symposium. The increased length of the printed matter circulated prior to the Convention compared with that of the previous year was 52 printed pages. In addition, the large number of blocks incorporated and certain tabulated data increased the printing costs by more than the proportionate increase attributable to the number of pages involved.

I next wish to refer to the loss of R78 (£39) compared with a profit of R206 (£103) in the previous year incurred on the publication of the Proceedings. Certain advertisers who last year contributed to revenue to the extent of R240 (£120), this year found it necessary to prune their advertising allocations and revenue to this extent was thereby lost. However, through the introduction of new advertisers, this reduction in gross advertising revenue was brought down to R134 (£67). Revenue from sales of Proceedings was slgihtly reduced. The increased size of the Proceedings (16 extra pages) together with the cost of Art Work and new Blocks for Papers as well as re-setting of portions of Papers all necessitated by authors' alterations to illustrations and text, resulted in an increase in printing costs of R156 (£78).

Other items of expenditure do not call for any particular comment.

Despite the above factors, the accumulated funds of the Association still stand at the satisfactory figure of R8,920 (£4,460) and it is considered that no radical adjustments in its financial affairs are called for at this stage. Altered conditions over the next year or two may result in a more satisfactory balance between income and expenditure being achieved.

Messrs. Kane and Downey continued to constitute the Finance Committee of the Association during the year under review and once again I thank them sincerely for their assistance. The support of the advertisers in the Proceedings is once again acknowledged with appreciation.

General:

The Regional Branches of the Eastern Cape and Natal continued to function satisfactorily during the year under review.

Johannesburg again acted as hosts for the Mid-year Executive Meeting in 1960, and on behalf of all concerned we convey thanks for the hospitality extended to the Executive Council on this occasion.

To the various members of Sub-Committees of the Association and representatives of other Technical Committees and Organisations we convey the appreciation of the Association for their invaluable work during the year under review.

To you, Mr. President and all Members of the Executive Council I express sincere thanks for the assistance and courtesy extended to us during the past year.

To the Association and all its Members we extend best wishes for 1961/62.

R. G. EWING,

for DAVIDSON & EWING (PTY.) LTD.,

Secretaries.

15th March, 1961.

REPORT ON THE ACTIVITIES OF THE SOUTH AFRICAN BUREAU OF STANDARDS RELATING TO ELECTRICAL ENGINEERING

Mr. President and Gentlemen,

I have much pleasure in presenting the report on the activities of the South African Bureau of Standards during the past year:

CABLES

S.A.B.S. 97—Paper Insulated Cables for General Purposes

The first revision of this specification was approved by the Standards Council on the 5th October, 1959, and this is now available in printed form.

S.A.B.S. 98—Paper Insulated Cables for Heavy Duty

The first meeting of the committee appointed to revise this specification and to bring it into line with the revised S.A.B.S. 97, was held on the 5th April, 1960. The document as amended is being prepared for submission to the Standards Council.

S.A.B.S. 182—Copper Wire and Bar for Electrical Purposes

The committee appointed to draw up this specification was reconstituted and copies of documents together with minutes from previous meetings have been sent out to members of reconstituted committee.

S.A.B.S. 168—Medium Voltage Vulcanized Rubber Insulated Cable and Flexible Cords for Power and Lighting Purposes

Following the decision by the Standards Council on the 9th December, 1957, that this specification and also S.A.B.S. 168 be revised, the committee was reconstructed and a meeting was held on the 23rd March, 1961.

DOMESTIC APPLIANCES AND ELECTRIC INSTALLATIONS

S.A.B.S. SV. 122—Safety Specification for Domestic Radio and Electronic Apparatus

A draft for comment was circulated on the 6th April, 1960. Due to the lack of replies to this notice the closing date for comment was extended and it was then decided to await issue of the revised I.E.C. draft before proceeding with the project. Copies of the I.E.C. revised draft have now been issued to the committee and a meeting was held on the 7th February at which the project was finalized by the committee, bringing it into line with current I.E.C. practice. The final draft is now being prepared for submission to the Standards Council.

S.A.B.S. 151-1958—*Fixed Electric Storage Water Heaters*

A meeting was held on the 28th April, 1960, to discuss a proposed amendment to the specification.

S.A.B.S. 155—*Miniature Circuit-breakers for Lighting, Heating and Domestic Installations*

and

S.A.B.S. 156—*Miniature Circuit-breakers for the Protection of Electric Motors*

Two meetings were held on the 1st April and the 10th November to discuss a draft standard for Moulded Case Circuit-breakers, intended to supersede S.A.B.S. 155 and 156. The committee has finalized the draft specification which has now to be submitted to the Standards Council for approval.

S.A.B.S. 184 — *Electric Heating Pads and Blankets*

This specification was finalized at the 6th meeting of the committee held on the 17th September, 1959. It was approved by the Standards Council on the 4th April, 1960 and is now available in printed form.

S.A.B.S. 185—*Immersion Heaters for Portable Electric Appliances*

The specification for immersion-type heating units for use in portable appliances for heating water and non-corrosive aqueous solutions (viz. kettles, coffee percolators, etc.) was finalized at the second meeting held on the 18th February, 1960. It was approved by the Standards Council on the 4th April, 1960, and has now been published.

S.A.B.S. 186—*Impulsing Energy Regulators for Electric Heating Units*

This specification was finalized at the second meeting on the 5th July, 1960, and was approved by the Standards Council on the 28th November, 1960. The specification is at present with the printers but roneoed copies are available.

DISTRIBUTION

S.A.B.S. 171—*Low Voltage Lightning Arrestors*

This specification was finalized at the third meeting held on the 12th November, 1957, but was brought back to the committee for a further meeting on the 7th August, 1958. The amended document was submitted to the Standards Council on the 9th June, 1960, and has now been published.

S.A.B.S. 177—*Porcelain and Toughened Glass Insulators for Overhead Power Lines* (Previously S.A.B.S. 178)

A meeting was held on the 8th November, 1960, at which the second committee draft was discussed. A draft for comment is under preparation and will be issued shortly.

S.A.B.S. 188—*High and Low Voltage Bushing Insulators*

S.A.B.S. 187—*Standard Bushings for Voltages up to and including 36 kilovolts*

(Previously S.A.B.S. 179 High and Low Voltage Bushings)

Three meetings were held on the 30th June, the 28th July and the 8th December. The committee decided that the specification be divided into the two sections as above, and drafts of the two proposed specifications were discussed. A further meeting will be held before the drafts for comment are issued.

TRANSFORMERS

S.A.B.S. 517—*Distribution Transformers*

Meetings of this committee were held on the 29th April, 21st May, 3rd June and 10th June, 1959. A new committee draft has been prepared for submission to the committee, after which a draft document will be issued for comment.

CODES OF PRACTICE

The Handling, Installation and Operation of Electric Cables

No meetings of this committee were held during the period under review.

Code of Practice for the Testing of Power Transformers

At a meeting held on the 12th April, 1960, it was decided that a project to compile a code of practice for testing power transformers be recommended to the Standards Council for approval.

AMENDMENTS

During the year under review amendments were issued on:

S.A.B.S. 154—*Electric Cooking Plates;* and

S.A.B.S. 185—*Immersion Heaters for Portable Electric Appliances, Apparatus, Connector Type.*

J.C. DOWNEY,
A.M.E.U. Representative to S.A.B.S. Commitees.

ELECTRICAL WIREMEN CONTRACTORS' BOARD

Mr. President, Ladies and Gentlemen,

There were twelve meetings of the Board during 1960, one of which was a special meeting to again consider possible amendments to the Act. The Examinations Sub-Committee met on four occasions during the year.

393 applications for registration were considered during the period under review and 148 registration certificates were issued, bringing the total number issued since 1940 to 7,702.

Concerning examinations, 527 candidates wrote the sections of Section A and 15.2% became eligible for the practical examination. 277 candidates presented themselves for the practical examination and 51.6% passed. In both sections of the examination the results are poorer than corresponding results in previous years.

The magisterial area of Umzinto and the municipal areas of Bothaville and Winburg were determined during the year bringing the total number of areas determined to 117 at the end of 1960.

Concerning amendments to the Act the Board has recommended alterations to Section 19 of the Act that should remove the anomally concerning the troubles over testing and connecting premises wired by Government or Provincial authorities. In addition a further amendment proposed excludes elevators from inspection by the local authority. Finally a proposal that all contractors be registered in a determined area has been accepted. It is of course not known when the amendments will be effected.

A certain amount of time has been spent by the Board on the question of Native trainees and the licensing of these. It is more than possible that some form of registration of limited scope for use in Native areas only will result.

I am indebted to the Board for permission to submit this report and also to our Members and Executive for proposing me to represent the Association for a further period of office.

R. W. KANE, Representative.

WIRING REGULATION COMMITTEE

During the period under review the Committee has met on four occasions and the main business has been the consideration of proposed amendments to the Regulations concerning auto-transformers, control of signs, underwater lighting, lifts, hazardous situations, mixed loading on circuits, estimated load and the current ratings of p.v.c. cables.

In addition a number of queries concerning interpretations of the Regulations were handled.

Since my last report the Committee has been augmented by representatives from the S.A.R. & H. and by the Electric Cable Manufacturers of South Africa.

Members will be interested to know that at the end of February, 1961 approximately 3,550 copies of the English version and 1,400 copies of the Afrikaans version have been sold. The Afrikaans version has the errata slip inserted that was referred to last May in Durban. It is possible that a few purchasers have not received this and an approach to the South African Institute of Electrical Engineers will be welcomed.

Concerning Regulation 204 on estimated load, all large supply authorities were approached for information concerning their habits and opinions. The Committee is very grateful to those that helped and summarized copies of the replies received have been forwarded to those authorities. Somewhat associated with this investigation was an approach to the five Provincial Ad ministrations for details concerning their procedure on the promulgation or otherwise of the Regulations and which towns or supply authorities have adopted one or other of the editions. At the time of preparing this report only three Administrations had replied. It is, however, obvious that habits differ between provinces, for example, the Electricity Supply Commission apply the latest editions of the Regulations Union wide, certain Transvaal supply authorities also immediately apply the latest edition; a move is afoot in Natal for a similar approach through Provincial Administration channels. South West Africa has promulgated their own Regulations mainly based on the 1955 edition, the majority of supply authorities in the Cape and Orange Free State have adopted the 1955 edition. The balance of the country and certainly some of the Transvaal authorities are apparently still concerned with the First Edition published in 1940.

Arising from the above replies concerning Regulation 204 and the Provincial procedure, your Committee is inclined to the opinion that the requests for amendments of Regulation 204 may not be warranted in so far as it appears that what was considered extremely conservative in the editions up to that of 1955 — namely the estimated loading of socket outlets — has been materially altered in the 1960 edition and it is felt that some further experience must be gained in the application of this latest edition before Regulation 204 is altered if at all.

Another matter of interest concerns the current rating of p.v.c. cables. Because of a loophole in the 1951 and 1955 editions the country has apparently accepted ratings somewhat comparable to those of paper insulated cables. The introduction of the 1960 edition has created (for those who have adopted this edition) a problem since V.R.I. ratings are specified. Considerable discussion has ensued and since to date no authoritative guide can be obtained from either overseas or locally, the Committee has decided to await such an issue before recommending any alterations. The whole problem highlights the necessity for means of universal adoption of the Regulations throughout the country and possibly some approach to the Provincial Administrations may help in this direction.

Finally there is a matter of interest regarding the use of mineral insulated cables for space heating purposes. The Regulations and particularly Table 12 only treat these cables as normal conductors. It stands to reason that when used for space heating or heating elements a considerably higher current is necessary and acceptable. This value is usually about twice that of the tables.

J. C. DOWNEY, Representative.

REPORT OF THE RECOMMENDATIONS COMMITTEE FOR NEW ELECTRICAL COMMODITIES

Mr. President, Gentlemen,

A brief summary of how this Committee is constituted and its functions will not be out of place.

1. REPRESENTATIVES.

(1) A.M.E.U. — J. L. v.d. Walt — Chairman, J. C. Downey.

(2) Mr. R. W. Kane.

(3) South African Bureau of Standards— Mr. A. A. Middlecote, Mr. D. I. Jones.

(4) S.A.I.E.E. Wiring Regulations Committee — Mr. J. C. Fraser, Mr. A. Dannenbaum.

(5) Electricity Supply Commission—Mr. J. W. Barnard, Mr. W. Steen-Stenerson.

(6) Electrical Engineering and Allied Industries Association — Mr. J. Morrison.

(7) Electrical Contractors Association of South Africa — Mr. F. B. Gibson, Mr. J. M. Fraser.

(8) Secretaries — Messrs. Davidson and Ewing (Pty.) Ltd.

2. FUNCTION.

The function of this committee is to investigate new electrical commodities *for which no standard specification exists*, and then, after considering test reports, practical installations, etc., only *recommend* to its members that the commodity was found suitable for use. The S.A.B.S. acts as testing authority, only upon requests of the Committee, after an application has been received. Applicants must therefore submit their applications and samples to the Secretaries as well as samples for testing purposes to the S.A.B.S.

It is the responsibility of the applicants to submit the test reports to the Committee.

The Committee may also request the S.A.B.S. to subject the sample to certain tests.

VERSLAG VAN DIE AANBEVELINGSKOMITEE VIR NUWE ELEKTRIESE WARE.

Meneer die President, Menere,

Dit sal paslik wees om 'n kort uiteensetting van die samestelling en funksies van hierdie komitee te gee.

1. VERTEENWOORDIGING.

(1) V.M.E.O. — J. L. v.d. Walt—Voorsitter, J. C. Downey.

(2) Mnr. R. W. Kane.

(3) S.A.B.S. — Mnr. A. A. Middlecote, Mnr. D. I. Jones.

(4) S.A.I.E.I. Komitee vir Bedradingsregulasies — Mnr. J. C. Fraser, Mnr. A. Dannenbaum.

(5) Elektrisiteitsvoorsieningskommissie — Mnr. J. W. Barnard, Mnr. W. Steen-Stenerson.

(6) Elektriese Ingenieurswese en Geallieërde Indutrieë Vereniging — Mnr. J. Morrison.

(7) Elektriese Kontrakteurs Vereniging van S.A. — Mnr. F. B. Gibson, Mnr. J. M. Fraser.

(8) Sekretarisse — Mnre. Davidson en Ewing (Edms.) Bpk.

2. FUNKSIE.

Die funksie van hierdie komitee is om aansoeke vir die gebruik van nuwe elektriese ware *waarvoor daar geen standaard spesifikasie bestaan nie* te ondersoek en nadat toetsverslae, praktiese installasies, ens., besigtig is, *slegs aan lede aan te beveel* of so 'n ware geskik vir gebruik is, al dan nie. Die S.A.B.S. doen die toetswerk alleen op versoek van die komitee nadat 'n aansoek ontvang is. Applikante moet dus hulle aansoeke en monsters aan die Sekretaris stuur, asook monsters aan die S.A.B.S. vir toetsdoeleindes.

Dit is die verantwoordelikheid van die applikant om die toetsuitslae aan die komitee te stuur. Die komitee mag ook die S.A.B.S. versoek om sekere toetse uit te voer.

It must be noted that the Committee does not consider commodities for which a standard specification exists. It is the responsibility of the Engineer to satisfy himself that the commodity offered does conform with the standard specification.

During the year two meetings were held and members were advised of the decisions of these meetings through the usual news bulletins. Members are advised to record these recommendations and thus obviate unnecessary enquiries.

Members are reminded of the fact that these news bulletins are private and confidential and not for publication. The Committee will appreciate it if members treat it as such.

During the year a number of applications were received for the installation of various makes of apparatus for boiling water, usually of the quick boiling type. The Committee could not consider these as a specification exists for water heaters and members must satisfy themselves that the articles comply.

The Committee continues to provide a useful service to its members which is borne out by the number of applications received.

J. L. VAN DER WALT, *Chairman.*

Daar moet op gelet word dat die komitee nie aansoeke oorweeg waar daar reeds 'n standaard-spesifikasie vir die ware bestaan nie. Dit is die verantwoordelikheid van die ingenieurslid om toe te sien dat sulke ware wel aan die standaard-spesifikasie voldoen.

Gedurende die jaar was twee vergaderings gehou en lede was deur die gewone nuusbriewe van die bevindings verwittig. Lede word aanbeveel om hierdie bevindings te bewaar en sodoende onnodige navrae uit te skakel.

Lede word ook daarop gewys dat hierdie aanbevelings privaat en vertroulik en nie vir publikasie is nie. Die komitee sal dit waardeer indien lede hierdie aanbevelings as sulks sal beskou.

Gedurende die jaar was 'n aantal aansoeke vir waterverwarmers (van die vinnige soort) ontvang. Die komitee het hierdie aansoeke nie oorweeg nie, aangesien standaard spesifikasies reeds bestaan en lede moet toesien dat die produkte daaraan voldoen.

Die komitee gaan voort om 'n nuttige diens aan lede te lewer wat uit die aantal aansoeke wat ontvang word blyk.

J. L. VAN DER WALT, *Voorsitter.*

REPORT ON ELECTRICAL WORK PLANNED OR IN PROGRESS IN THE NATIVE AREAS

At the 34th Convention it was suggested that this report should be kept up-to-date. The members who had submitted information upon which the 1960 report was based were requested to submit details of any work completed during the past year and copies of the questionnaire were sent to additional members who were thought to have carried out work in their Native Areas. Four new returns were received and these are shown on Schedule A which is in the same form as the returns submitted to the 34th Convention.

Schedule B shows the replies received from authorities who have carried out work during the past 12 months.

G. MASSON.

ASSOCIATION OF MUNICIPAL ELECTRICITY UNDERTAKINGS OF SOUTHERN AFRICA

ELECTRICITY FOR DOMESTIC PURPOSES BY AFRICAN NATIVE FAMILIES.

SCHEDULE "A"

	GRAHAMSTOWN	QUEENSTOWN	SOMERSET EAST	WALMER
A. General				
No. of towns'ps or settled com.	1	1	1	1
No. of dwelling units	—	1,094	329	—
How many dwellings:				
Lighting only	—	—	None	160
Lighting and Cooking	—	99	None	Nil
Average family income		£6-£12	+-£11	
Where no supply available..	—	R12 to R24	+-R22	£12
Lighting supply only	—	—	—	£24
Lighting and other purposes	—	£20 40	—	
Who is responsible for payment for electricity consumed	—	Consumer	—	—
B. Town Planning Details				
Any difficulty due to Town Planner's design	Yes	Not unduly	No	No
Are street corners splayed ..	Yes	Yes	No	No
Do curved streets make erection of O/H mains difficult	Yes	No	No	No
What size sites are provided for load centres..	—	—	None	25' x 25'
C. Financing of Schemes				
Work financed out of the Natives Services Levy	—	—	—	—
Work financed out of the National Housing Loans	Street lighting	Reticulation & Street lighting	—	—
Work financed out of the Local Authorities' own funds	—	Wiring & Sub-Stations	Street lighting ex Beer Hall A/c	Reticulation
Work financed out of Other sources..	—	—	—	—
D. Design Details				
Are E.H.T. mains O/H or U/G	O/H U/G	U/G	O/H	U/G
Are L.T. mains O/H or U/G ..	O/H	O/H	O/H	O/H
Where are poles planted	Near kerb	Near kerb	Near build. line	Near kerb
Do you operate with M.E.N. ..	No	No	No	Yes
Conductor configuration	Vertical	Old-Horizon New-Verti.	Vertical	Vertical
D. Design Details—Continued				
Conductor materials	Copper	Copper	Copper	Copper
Type of Load centre	Brick kiosks	Brick kiosks	Pole transf.	Pole transfr.
Capacity of Load centres	30 K.V.A.	500 KVA.	25 KVA.	100 KVA.
E.H.T. protection of transformer	Fuse	O.C.B.	Dropout fuse	Fuse
Street lighting fittings:				
Wattage	60 w.	60 & 100 w.	200 w.	150 w.
Spacing..	450'	240'	300'	500'
Type	Tungsten	Tungsten	Tungsten	Tungsten
Flourescent street light fittings:				
Type of Starter	—	—	—	—
Do multitube fittings have separate ballasts ..	—	—	—	—
Are they high p.f. type ..	—	—	—	—
No. of tubes per fitting ..	—	—	—	—
Length of tube	—	—	—	—
Are street lights provided in every street	No	New sec. Yes Old sec. No	No	Yes
Approx. cost of street lighting fittings	£4	£3 1s. 11d.	£3 0s. 0d.	£3 10s. 0d.
Approx. cost of street lighting	R8	R6.19	R6	R7
wire guards	—	—	—	—
House S/C Type of insulation O/H services	—	O/H P.V.C.	—	O/H P.V.C.
House S/C Type of insulation U/G services	—	—	—	—
House S/C Size of conductor ..	—	7/.044 7/.052	O/H —	10 S.W.G.
House S/C Size of meter/amperes	—	5, 10 & 20amp.	—	—
E. Tariff.				
For Bulk supply to townships ..	—	Cost	Standard	Cost

	GRAHAMSTOWN	QUEENSTOWN	SOMERSET EAST	WALMER
For consumers	—	Standard Block	—	3d. (2½c) per unit
Is sup. available 24 hours per day	—	Yes	—	Yes
Are current limiters used	—	No	—	Yes
Do you levy a fixed charge:				
Lighting only	—	—	—	—
Unrestricted use	—	—	—	—
Have you a special tariff for African township	—	No	No	—
F. Metering				
Do you meter individual consu.	—	Yes	—	Church and Business
Are prepayment meters used	—	Yes	—	No
Any problems with prepayment meters	—	No	—	Yes
G. Consumption and Demand				
Annual consumption. Fixed tariff — Lighting only	—	—	—	—
Annual consumption. Fixed tariff — Unrestricted	—	—	—	—
Annual consumption. Metered—Lighting only	—	—	—	—
Annual consumption. Metered—Unrestricted use	—	—	—	—
After diversity demand — Fixed tariff Lighting	—	—	—	—
After diversity demand — Fixed tariff unrestricted	—	—	—	—
After diversity demand—Metered lighting	—	—	—	—
After diversity demand—Metered unrestricted	—	—	—	—
How are accounts collected — payable at	—	Payable at office	—	—
H. Reticulation costs				
(a) **Street lighting reticulation scheme.**				
No. of stands in town'p con.	1,030	464	329	364
Size of stand	40' x 70'	40' x 60' 70' x 80'	55' x 65'	50' x 50'
Cost per stand, street lighting	£1 10s. 0d. R3	£5 R10	£1 15s. 0d. R3.50	—
Cost per street lamp erected	£33 7s. 0d. R66.70	£58 R116	± £40 R80	—
(b) **Street lighting and domes. power**				
No. of stands in township	—	538	—	—
Size of stands	—	40' x 60' 70' x 80'	50' x 100'	—
A.d.m.d. catered for	—	—	—	—

	GRAHAMSTOWN	QUEENSTOWN	SOMERSET EAST	WALMER
Average cost per stand including street lighting	—	£15 5s. 0d. R30.50	—	—
I. Wiring.				
No. of houses wired	—	—	—	—
Size of service cable	—	—	—	—
Cost of service cable	—	—	—	£15 R30
Cost of meter	—	—	—	—
Cost of limiter, fuses or m.c.b.	—	—	—	—
Cost of house wiring (L— light S— socket)	—	—	—	—
Cost of house wiring	—	—	—	—
Cost of house wiring	—	—	—	—
Cost of house wiring	—	—	—	—
No. of sockets per house	—	—	—	2
Type and rating of socket outlets	—	—	—	—
Are cooker control units provided	—			—
Wiring system used	—	—	—	Conduit
Are lights mounted in centre of rooms	—	—	—	Yes
Are lighting switches grouped in one position	—	—	—	No
Are ceiling switches used	—	—	—	—
J. Special Features				
Have communal kitch. been used	—	No	—	—
Any special service layouts	—	No	—	—
Any special design features	—	No	—	—
K. Maintenance				
Who is resp. for wiring mainten.	—	Consumer	—	Council
L. Bantu artisans and contrac.				
Do native wiremen carry out installation work	—	—	—	No
Do native wiremen carry out maintenance work	—	—	—	No
Are native contractors permitted	—	—	—	—
How many nat. cont. in your area	—	—	—	—
Are connection fees charged for individual dwellings	—	£7 10s. 0d. R15	—	—
Other connection fees	—	£10 0s. d. R20	—	—
Wages paid to electrical trainees 1st Year	—	—	—	—
2nd Year	—	—	—	—
3rd Year	—	—	—	—
4th Year	—	—	—	—
5th Year	—	—	—	—
C = C.O.L.A.				
Wages paid to qual. nat. artisans	—	—	—	—

SCHEDULE B.

WORK DONE DURING THE YEAR 1960.

	Bloemfontein	Bulawayo	Benoni	Cape Town	Durban	East London	Johannesburg	Port Elizabeth	Salisbury	Sasolburg
HOUSES										
Number wired during 1960 ...	Nil	592	Nil	Nil	Nil	2900	—	Nil	842	70
Average consumption (Per annum kWh)	1200	3588	360	1440	—	—	350 to 650	1260	960 to 1620	348 to 420
After diversity maximum demand kVA	—	1·0	0·27	0·40	—	—	0·2 to 0·4	—	0·34 to 0·59	0·50 to 0·75
Type of service connection ...	—	overhead	underground	—	—	—	underground	underground	—	—
BUSINESS PREMISES										
Average consumption kWh. ...	3000	—	—	—	—	—	100 to 5000	—	—	—
After diversity maximum demand kVA.	—	—	—	—	—	—	1 to 10	—	—	—
HOSTELS.										
Total accomodation for **Males**	—	—	—	14238	—	1136	24000	—	35000	576
Females	—	—	—	—	Nil	—	117	Nil	165	—
Wiring carried out during the past year for the housing of:— Males	—	—	—	Nil	4000	—	Nil	74 housing blocks.	620	—
Wiring carried out during the past year for the housing of:— Females	—	—	—	Nil	Nil	—	Nil	—	—	—
Average consumption per capita per annum Males	—	—	—	144·20 kWh	39 kWh	53 kWh	·022	—	336 to 687	54 kWh
Average consumption per capita per annum Female	—	—	—	—	—	—	·022	—	72 to 644	—
A.D.M.D. kVA per capita Male	—	—	—	0·345	0·042	0·045	·05	—	0·06 to 0·162	0·03
A.D.M.D. kVA per capita Female	—	—	—	—	—	—	—	—	0·33	—
Is electric lighting provided ...	Yes	—	—	Yes	Yes	Yes	Yes	Yes	Yes	—
Is provision made for electric cooking?...	No	—	—	Plugs provided for 1328 persons	1–15A plug — 4 men	—	No	—	Yes	—
Is provision made for electric water heating?	No	—	—	—	—	—	1 hostel — Yes	—	Yes	—
Is provision made for electric Ironing	No	—	—	—	—	—	No	—	·Yes	—
Is full lighting provided? ...	Yes	—	—	—	Yes	—	Yes	—	Yes	Yes
Tariff	1d. per unit	—	—	1d. per unit	1·58d. per unit	1·5d. per unit	—	1·076 per unit	—	—
TOWNSHIP RETICULATION.										
Cable laid EHT.	—	—	Nil	—	6·5 miles	—	3	—	—	—
Cable laid LT.	—	—	Nil	—	6·5 miles	—	—	—	—	—
LT. street light mains	—	—	Nil	—	15 miles	—	10	—	—	—
No. of additional street lights	—	—	Nil	—	515	—	220	125	—	—
Transformer kiosks	2	—	Nil	—	7	—	5	1	—	—

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