

Feasibility study of tidal power from Loughs Strangford and Carlingford with pumped storage at Rostrevor

by

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The Chairman (Mr F. H. Allen) said that the Author had made no reference to the rivers flowing into Strangford and Carlingford Loughs. These might not perhaps be of great significance, but as there was a fairly mountainous area to be drained he would have thought that they might carry quite a high discharge from time to time. Perhaps the Author would comment on the river-flow regime and whether the flood-water aspect was of any significance in relation to the proposed tidal barrages. Had he considered the possible risks of silting-up at or near the barrage sites as a result of the changes the schemes would impose on the tidal flow and tidal currents?

Mr B. T. Seddon (Messrs Binnie and Partners) said that his remarks would be confined to the pumped storage aspects of the scheme. He had not had the opportunity of visiting the site but had seen Ordnance sheets and Admiralty charts of the area.

74. While he agreed with the Author's general conclusion that there appeared to be a good case for pumped storage in the Northern Ireland electricity supply system, he thought the Author had greatly under-estimated the cost of construction of the Rostrevor scheme. In Appendix 2 the cost had been estimated as £28·4/kW for a 300 MW installation, including transmission. It was possible that with a very favourable site and an installed capacity of 1200 MW or more, a pumped storage scheme could be constructed for £30/kW, but construction costs rose appreciably for lower installed capacities and Rostrevor Bay could not be classed as a very favourable site. The gross civil costs quoted were about £12·2 per kW, which compared with £21·5 per kW quoted for a 400 MW installation at Cruachan. The gross head at Rostrevor would be 1450 ft as compared with 1200 ft at Cruachan and this would lead to a smaller power station and reduced tunnel diameter. On the other hand, as the shafts would probably require steel lining where the internal pressure exceeded 1000 ft, the weight of steel would be appreciably increased. The tailrace tunnel at Rostrevor would also be about 1200 ft longer than in the Scottish scheme.

75. The use of the sea as the lower storage raised a number of problems. The chief one at Rostrevor would probably be the prevention of pollution of fresh water by seepage from the upper reservoir. Several streams rose on the hillside immediately below the proposed reservoir site and flowed into the Rostrevor river, and to prevent pollution of these streams by small quantities of salt water could add considerably to the cost of the scheme.

76. It was proposed that the lower intake/outfall should be in Rostrevor Bay. The foreshore here was sandy and the depth of water at Low Water Mean Springs was 7 ft at 500 ft from the shore, increasing to 10 ft 4000 ft offshore. The maximum pump discharge would be about 4000 cusecs. The construction of an intake to draw this flow across a sandy foreshore with a 7-ft minimum depth of water, and to exclude

sand from the tunnel, would be costly. If the tidal barrage were constructed, the minimum depth of water would be 15 ft and this condition would be improved.

77. He considered that the gross construction cost of a 300 MW pumped storage scheme at Rostrevor was likely to be of the order of £48 per kW, including transmission. However, even if the annual costs in Table 10 were adjusted upwards by this amount, the nett annual saving with pumped storage in 1980 would still be at least £2 500 000 if the Author's other figures were accepted. In Table 9 the Author charged 25% of the estimated 400 MW cost when the first set was installed. Surely this figure should be at least 50%, as 70% of the civil costs and 25% of the plant costs would have been incurred at this stage.

78. The construction of the Rostrevor scheme would probably take about five years: nine months for roads and access tunnel, two years to complete the power station to the stage when draft tube erection could commence, and 2½ years for plant. The Author appeared to have assumed a 3½-year period of construction, but even this would not explain the low interest during construction, amounting to 6% of gross construction costs. Perhaps the Author would explain how he arrived at this figure.

Mr E. M. Gosschalk (Senior Engineer, Sir Wm Halcrow & Partners) said that it was refreshing to have offered for discussion a Paper which represented an early diagnosis compared with the leisurely autopsies to which they were more accustomed. It was with some diffidence that he wished to question two points.

80. He wondered if the influence of 'value engineering' was responsible for the approach to design which was described. If so, this would be unexceptionable but for the suspicion that it had resulted in preoccupation with the turbo-generators, which produced the monetary return, at the expense of the back-up facilities and basic barrage. The adoption of unconventional cheap and simple solutions at a preliminary stage could lead to severe underestimation of the difficulties and cost. The barrage under construction by the Dutch at Haringvliet¹² was an impressive example of the meticulous and sophisticated designs which could prove necessary for tidal structures. At the Rance barrage the French had abandoned caisson construction in favour of conventional cofferdamming. The Author's comments on this decision relative to his proposals would be of interest. Were the Author's proposals sufficiently conservative to avoid inhibitive escalation at some stage?

81. The total annual costs given in Appendices 1 and 2 for tidal power and pumped storage seemed to postulate that perpetual loans for the projects could be obtained. Was there any likelihood that money could be borrowed for a project of this kind on such terms? If the loans had to be liquidated over, say, 20 years, the annual costs would be increased by some 40% during that period. On the other hand, it was very important in evaluating such projects as these to find some means of taking credit for the reduction in annual costs which occurred after the loan had been repaid and which often continued long thereafter.

Mr A. W. Pedder (Messrs Merz and McLellan) said that papers which contained a large element of creative or imaginative thinking deserved respect. At the same time, fundamental shortcomings must not be overlooked. He had two small points to make, both of them relating to the general economics of the scheme.

83. First, it ought to be stated explicitly that the calculations and estimates presented in the Paper showed this particular application of tidal power to be quite uneconomic. This followed from comparison of the figures in Table 10, from which the costs for a system with pumped storage alone were seen to be cheaper in both capital and annual costs than the scheme having pumped storage plus tidal power. Indeed, the conclusion that the tidal power component of the scheme was uneconomic could have been deduced directly from Table 1, which showed the cost of tidal energy to be about 1d/kWh, which was very expensive for off-peak energy and considerably higher than thermal power.

84. His second point related to pumped storage alone. His colleagues and he had for years been enthusiastic about pumped storage in situations where it could be shown to be justified, and they were proud to have had some connexion with the Cruachan scheme. However, the cause of pumped storage was not served by overstatement of its advantages, which he strongly suspected had occurred here.

85. He supported the remarks of Mr Seddon that the capital costs of the pumped storage scheme were probably too low, but his own contribution related to the annual costs.

86. For example, if the figures for 1980 in Table 10 were considered, it could readily be deduced that the effect of replacing 480 MW of thermal plant by 400 MW of pumped storage was to save £2.2 million per annum in thermal operating costs. In this case the fuel component of the operating costs was likely to be either negative (an extra cost in the pumped storage case owing to losses) or negligible, so that most of the £2.2 million must be for operating costs other than fuel, i.e. salaries, wages, etc. At nearly £5 per kW per annum this seemed to be far too high.

87. The whole calculation was very sensitive to quite minor changes in the curves of Fig. 10, and he would like to know more about their basis. However, whatever the cause, he felt that the pumped storage scheme was credited with suspiciously high annual savings, in the year 1980, for example, by something like £1½ million too much.

Mr M. Braikевич (Hydro-electric Department, English Electric Co. Ltd) said that he thought a brief description of the machinery would be of interest. When large quantities of water had to be dealt with under a low head, almost all this head had to be converted into velocity to pass the discharge through the propeller runner. There was a pressure drop across the wheel, resulting in high suction on the downstream side of the vanes. The velocity had then to be converted back into head in a diffuser so that the water could be discharged into the tailrace. The most efficient form of diffuser was a long, straight, conical pipe: this meant that a horizontal setting was indicated if excavation was to be kept down.

89. As the water velocities were high the path through the turbine should be direct, and since pressure was easily converted into velocity a bellmouth at the turbine inlet was all that was necessary. The resulting hydraulic solution was the tube turbine (Fig. 11(a)). This turbine had to drive a generator: the conventional solution was to locate this in a large bulb upstream of the runner. The generator could be either direct-driven (Fig. 11(b)), which gave a bulb which was shorter but larger in diameter, or driven through epicyclic gearing (Fig. 11(c)) resulting in a longer bulb but one of smaller diameter. In either case, length was added upstream of the runner which was hydraulically useless. Attempts had been made to put the generator bulb in the draught tube but this had interfered with the efficiency of the diffuser and complicated the layout.

90. Another scheme was to put a bend in the draught tube and use this to get the shaft to the generator (Fig. 11(d)). This also interfered with the diffuser, the axis of the unit was included and the foundations were deepened. It should be noted that all the alternatives had the same runner diameter and were therefore exactly comparable in respect of overall size of unit.

91. The attractive solution was to mount the generator rotor round the runner using the turbine wheel as the spider (Fig. 11(a)). This arrangement was first suggested by the well-known U.S.A. consulting engineers, Messrs Harza, and was developed independently and actually used by Arno Fischer in Germany during the last war. Both designs relied on seals pressing against the flanks of the rotor to prevent water reaching the windings. The Germans found the seals very troublesome and had some failures. The generator became wet because of both faulty seals and condensation, though Mr Braikевич believed the plants were finally made workable and were operating. It was certainly a difficult seal and there could be failure, but whatever the seal the generator had to be able to withstand water.

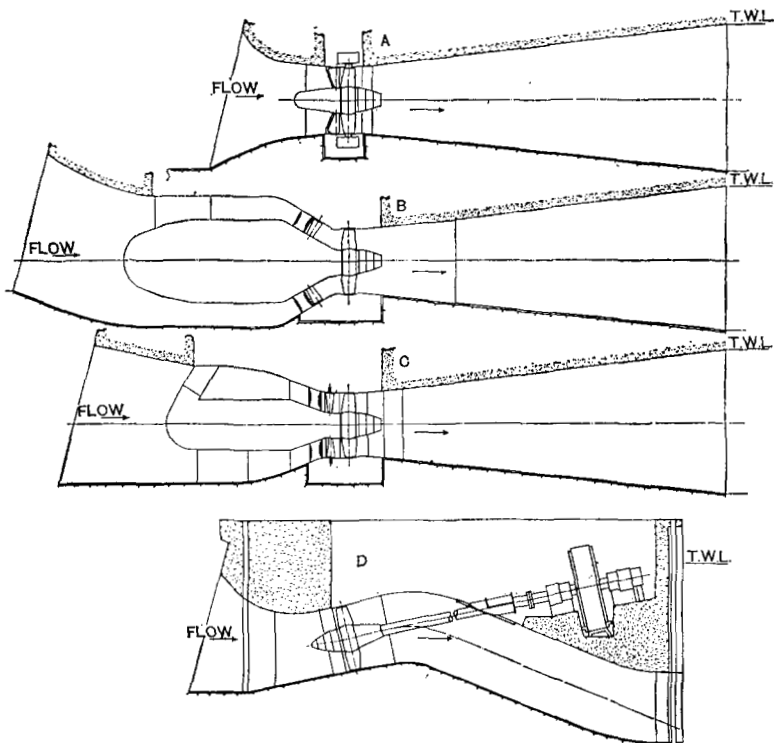


FIG. 11: COMPARISON OF TUBULAR TURBINES

92. The question then arose, whether it would not be simpler to design the generator rotor to run in water and suppress the seals. This had been proposed and was shown in Fig. 12. The rim was bolted to the vanes, the runner being of the fixed vane type. The coils were encapsulated in resin and the whole sheathed in stainless steel. The inside of the rotor was protected by a rubber or plastic liner, the two static seals sealing against this continuous surface. A separate exciter was used, the current passing through an access fin to the nacelle, from there through slip rings to the turbine shaft; then through the discharge, the rubber hub and the vanes, to the rotor. The stator was completely isolated from the water. The main turbine bearing was located as close as possible to the centre of gravity of the rotor generator/turbine runner and there was a thrust and journal bearing at the upstream end of the shaft. Guide vanes controlled the discharge and were coupled to an outside regulating ring. The guide vanes could close off the flow completely.

93. It was known that the generator rim rotating in water would cause a loss due to drag, but this would not be serious, and the exact value could be obtained from model tests. When the wetted perimeter of the rotor was less, some of this loss would persist even with seals. The unit lent itself to installation in a reinforced concrete cell, and kept this cell as short as possible, using the available length effectively to get a good draught tube. With tidal power, almost half the cost was in plant, so it was essential to reduce this. The tube units proposed were a step in the right direction.

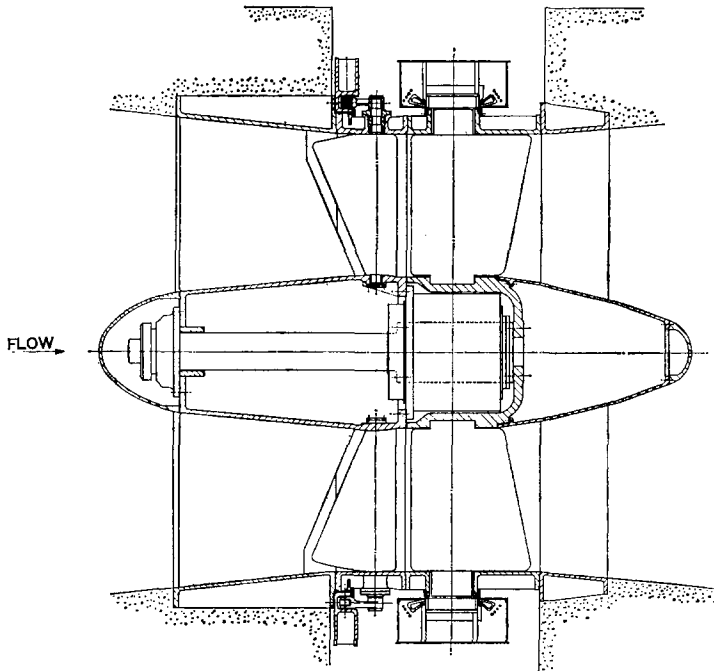


FIG. 12: SECTION THROUGH TUBULAR UNIT

94. Modern insulating techniques allowed the rotor to be immersed safely; in fact this was being done more and more in industry. An interesting example was that of a boiler feed pump where the complete driving motor, including the stator, was immersed in water at 2000 lb/sq. in. because it was too difficult and inefficient to construct a seal between the pump (which helped to force the water through the boiler tubes and so had high boiler pressure on both suction and delivery) and the motor.

95. Knowing that electrical engineers generally disapproved of water a tube turbine was developed with a magnetic drive to the generator rotor so that no windings were immersed. However, after careful study the electrical engineers preferred immersion.

Mr C. D. Crosthwaite (Messrs Freeman, Fox and Partners) said that it would appear that there was not a very great deal to be said for adding tidal power to pumped storage; but, to be fair, this must have been very obvious to the Author from his own figures. One point he had made was that there was a saving on imported energy, and this must be an important consideration for a country such as Northern Ireland, with very limited power resources of its own.

97. With regard to the criticisms of the Author's cost figures, with which he was inclined to agree, it must be borne in mind that this was, after all, a feasibility study, and the object was to establish whether a particular project was worthy of further consideration. It did not pretend to be exhaustive in every respect and he was sure the Author did not intend it to be.

98. Studies of this sort on a much bigger scale were needed, as there was a tendency in this country to dismiss schemes as uneconomical without sufficient consideration.

Mr W. E. Blackmore (Sir William Halcrow & Partners) said that the Author had not been convincing in his reasons why a scheme for pumped storage had to be tacked on to a scheme for tidal power.

100. A tidal power scheme produced non-firm power which could be firmed by various devices in an integrated electrical system. A pumped storage installation was one of several such devices. But just as the economics of producing power by the tidal scheme had to be compared with other means of producing power, the economics of firming the power by pumped storage had to be compared with other means of firming; to lump the two schemes together obscured what should be two separate comparisons.

101. Furthermore, joining together the two installations geographically, because of the fortuitous circumstance that a site suitable for the pumped storage installation happened to exist near the site of the tidal power scheme, tended to obscure the fact that from the point of view of transmission costs they need not be together, and the pumped storage installation could be anywhere between the source of power and the load centre; this was because about as much power had to be transported from the pumped storage installation to the load centre at peak times as from the tidal scheme to the pumped storage installation at off-peak times.

Mr J. T. Fulton (Down County Council) said that there had been a public demand for a road connexion between the two sites.

103. The Down County Council had considered the suggestion that a barrage should be placed so as to provide a road connexion, the idea being that advantages, such as the generation of tidal electricity, might also accrue and thus help to spread the cost. This had fallen down not on engineering but on social grounds, as there had been a tremendous public outcry against the idea of closing off salt water from the area.

104. The Chairman had already enquired about the fresh water flow in the area. Mr Fulton estimated the catchment area to be about 400 sq. miles. The figure for maximum storm run-off given by the drainage authority in the area was about 30 cusec/sq. mile. If these figures were correct the fresh water flow would never come to more than 10% of the flows the Author had considered.

105. One question which came to mind was whether the quantity of fresh water would ultimately reduce the salinity of the present salt water and as a result have any effect on the surrounding prevailing conditions. The main river flowing into Strangford was the Quoile, which was controlled by flood gates only opening two hours before and after low water. This might have to be considered and might add to the expense.

106. He presumed that the siting of the Strangford barrage was fixed purely from the point of view of the generation of tidal power, but a credit of £2½ million against the cost of a possible bridge was included in the figure. It would appear that traffic in the area did not warrant a bridge so that it was probably unfair to consider the £2½ million in the figures. Would it alter the Author's figures very much if the road were moved to a more suitable position from the traffic point of view, at the other end of the Strangford narrows, even though the water was deeper? How did the cost of the rubble portion of the barrier compare with the concrete works? Would the increase in depth have an appreciable effect on the overall cost?

107. Mr Fulton, in answer to an intervention by the Chairman as to why the local inhabitants should worry whether the loughs were more or less salt, said that they were concerned with agricultural aspects, the main point being that the farmers round about claimed that the flow of salt water in and out allowed them to have

vegetable crops earlier in the year than elsewhere. If this flow were reduced no doubt they would still have the same complaints.

Mr J. D. Humphreys (Messrs Balfour, Beatty & Co. Ltd) emphasized Mr Crosthwaite's comment that the Paper was, after all, only a study of feasibility.

109. If reference were made to sea defence works and tidal or other similar barrages constructed in the past in attempting to select a reasonable cross section for a feasibility study, it would be seen that they were many and varied, and that there was inevitably a certain arbitrary element in the selection of the design. In fact, in studying some of the more sophisticated examples it was difficult to tell whether the cross section itself was complicated because the design problem was difficult or whether the selection of a complicated cross section had rendered the design of the embankment more difficult than it need have been. In particular it should be borne in mind, when comparing a tidal power barrage with a sea defence work (as had been suggested by an earlier speaker) that whereas sea defences often had to be impermeable, this was of relatively small importance in a tidal barrage. It was perfectly reasonable, therefore, for the Author to have assumed a fairly simple section for his feasibility study.

Mr D. L. Walker (C.E.G.B. Planning Dept) said that he would like to add briefly to Mr Pedder's suggestion that the operating costs for thermal power stations shown in Fig. 10 of the Paper appeared too high. The Author had stated in § 58 that the shape of this curve was based on Fig. 7 of the Mackenzie Report concerning electricity in Scotland, which showed the variation of load factor with operating costs for a large number of power stations in one particular year (1960). However, for an individual power station operating at a decreasing load factor in future years the shape of the curve would be quite different and similar to Fig. 9 of the Mackenzie Report. From 80% load factor to 50% load factor, operating costs would not increase by very much, and at lower load factors they would increase by a smaller proportion than that shown in Fig. 10 of the Paper.

111. The average operating cost for Coolkeeragh and Ballylumford A power stations published in the Annual Report of the Electricity Board for Northern Ireland for 1964 was about 0.62 d/kWh. The costs shown in Fig. 10 of the Paper, weighted according to the published load factors for those two stations, gave an average operating cost of 0.78 d/kWh. This test seemed to confirm that the operating costs for thermal power stations used in the economic assessment were too high. If this was accepted then pumped storage would appear rather less favourable and tidal power rather more unfavourable than had been suggested in the Paper.

Mr J. D. Steel (Essex River Authority) said that no doubt many members of the audience had come across the fact that in detailed design one could rarely evolve a machine, or any part thereof, to perform two functions. Morris in his earlier cars fitted a 'Dynamotor' to start the engine and charge the battery—a clumsy machine that failed to turn the engine in cold weather.

113. In the same way, he felt that in attempting to turn a turbine into a pump the result would be much the same: it would not do the job properly. Thinking in terms of pumped storage, surely it would be better to accept the fundamental premise that there would have to be a separate machine to do the pumping?

The following contributions were received in writing:

Professor A. H. Naylor (Ahmadu Bello University, Zaria) wrote that tidal power schemes were severely handicapped when compared with any other source of power except possibly wind. The Severn Barrage scheme of 1932 was rendered uneconomic by the cost of the complimentary pumped-storage scheme in the Wye valley which was then necessary. The scheme of 1943, though freed from this charge, had to bear,

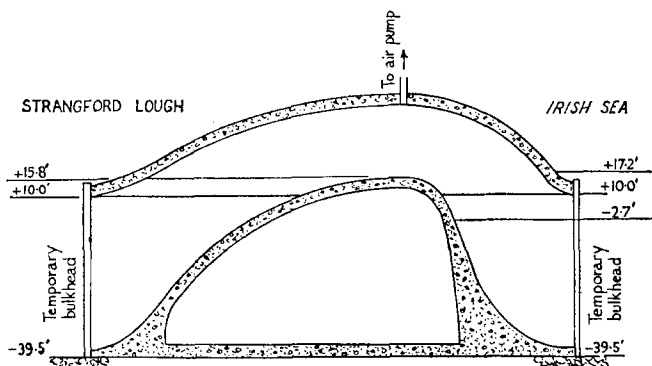


FIG. 13: SECTION OF SIPHON SLUICWAY

in spite of the grid, and quite wrongly in the writer's opinion, the cost of high-tension transmission to London. This rendered it only marginally economic. Proposals for an investigation into the potentialities of a scheme at Strangford Lough were made about 1950 but dismissed by the Northern Ireland Advisory Committee on Fuel and Power, of which Professor Naylor was Chairman, as having no chance of success. The reasoning was that the Severn Barrage had a tidal range at Springs of 46 ft compared with 14 ft 6 in. at Strangford and for basins of the same area the power would be ninefold. With construction costs of the same order of magnitude, even allowing for the greater area of Strangford, it appeared to be a non-starter.

115. There had been advances in construction techniques since then and circumstances generally were changed, so that a review was proper and timely. Mr Wilson had rendered a signal service to Northern Ireland by his investigation.

116. The Author rightly ignored the permeability of the rubble dam. In the Johore Causeway, Malaya,¹³ a rubble embankment, checking the tidal flow and producing heads up to 4 ft 2 in., effectively limited the leakage as was evidenced by the anchoring of the current node to within a few hundred feet of the causeway in spite of a voids ratio of 40% in the rubble bank. Moreover, in such cases marine growth progressively clogged the interstices.

117. The Author referred to the advantages of using floating caisson turbine units which lay in speed of construction as well as cost. In the same discussion to which he referred,² Professor Naylor had advocated a siphon sluiceway, primed and shut down by air pumps as offering a great economy in prime cost and maintenance over any form of sluice gate. Fig. 13 indicated a typical section. Because of its Venturi action it could provide a greater discharge per unit length than a Tainter gate. Such reinforced concrete siphons could, too, be prefabricated in units, and with the upstream and downstream faces sealed by temporary bulkheads, floated out into position.

118. As the case for a road bridge at Portaferry had not been accepted, it would be unrealistic to credit the power scheme with even half the cost. The long controversy over the alternative scheme for a half-tide barrage put forward by the county surveyor had shown that impounding the waters of the lough would not be entirely beneficial.

119. The Author's figures showed conclusively that neither of the tidal power schemes as economically viable compared with even conventional thermal schemes. When there was also the probability of a break-through in the cost of nuclear power they must therefore be ruled out.

120. Whilst the Rostrevor pumped storage scheme would be necessary with a tidal scheme, pumped storage was in any case accepted as desirable. Schemes had already been worked out at Glenariff and, in anticipation of nuclear power, in the Silent Valley. The Rostrevor scheme would have to be compared with these. The Author had made a clear case for pumped storage, and as any source of power whatsoever would benefit thereby, there seemed no justification for delay.

Mr B. Severn (Balfour, Beatty and Co. Ltd) wrote that a recent surface examination of the Rostrevor site described in the Paper had not indicated any particular difficulties, and the Author should be congratulated on finding so promising a location. It appeared that a pumped storage scheme could be developed there very economically, and studies were continuing into the manner in which this might best be done. An arrangement having a surface powerhouse at the shore of the lough had also been considered, but a preliminary comparison suggested that the extra cost for much more steel lining would probably outweigh any savings. From the amenity point of view underground works would be more readily acceptable.

122. Another comparable site existed to the east of Slieve Donard. Because of the lesser head available there, the cost would probably be rather less favourable although a larger capacity plant could be installed.

123. The economics of pumped-storage projects were a popular subject for slide-rule exercises, usually on the basis that such plants would generate whenever the cost of peaking energy from available thermal plants would be greater than off-peak energy *via* pumped storage. However, it had been made plain¹⁴ that in the case of Ffestiniog the planned economical peak lopping amounted to only about one-seventh of the forecasted annual energy generated at the station. The remainder arose from standby and reserve duty.

124. Operating regimes were therefore difficult to forecast with accuracy—particularly if there were to be two or more pumped storage plants in a system. The usefulness of Ffestiniog had exceeded expectations, and operational experience with this and the immediately succeeding pumped storage stations should be most valuable. Much benefit should ensue if the experience now being gained could be carefully recorded and published so that the actual demands made on these plants, and their practical capabilities and limitations, might be more fully understood.

Mr C. M. Stoupe (Electricity Board for Northern Ireland) wished to correct any misunderstanding that might arise from the statement in § 6 which might be construed as a firm proposal by the Electricity Board. This doubt should be removed since the conclusions drawn by Mr Wilson after a very detailed study only confirmed the more tentative views held by the Board that tidal energy, even in the most favourable conditions, was difficult to justify and the conditions in Northern Ireland, with a much lower tidal range than the adjacent west coasts of England, Wales, and Scotland, were not likely to be the best situations for an initial exploitation of new techniques in this field.

126. The diagram in Fig. 3 was extremely interesting but the precise mode of operation in practice would require very careful assessment. It would be interesting to know whether the operational sequence would be controlled by manual means either remotely or locally, or whether it could reasonably be operated by the tide level itself. It was also interesting to speculate on the reliability of the sluices, since inadvertent retention in the open or part-open condition would reduce generation to near zero.

127. On the question of availability, it might be appropriate at this point to refer to § 36 where it was stated that while the power produced was inconvenient for direct use 'it is precisely predictable'. On this point, Mr Stoupe wished to comment that while the potential tide level was predictable it did not necessarily follow that the availability of the plant, which was essential for the conversion of this energy to use,

was equally predictable. In this context he noted in § 28 that the proposed plant was still under development, in itself not a good augury for maximum reliability, and although reference was made in § 50 to the higher availability of 'hydro plant' for which credit was taken he wished to remind the Author that the medium discussed in the Paper, both for tidal and pumped storage purposes, was sea water, with all its attendant corrosive and erosive properties. This point also had a bearing on the life assumed for the turbines which, in these conditions, might well be considered too high at 40 years. All these factors had a significant bearing on the final economic analysis not only of the tidal scheme but of the pumped storage scheme which could be an economic possibility for plant extensions in Northern Ireland in its own right.

128. In this connexion it was important to ensure that the most economic scheme was adopted, i.e. even if a tidal scheme could be made economic by combining it with a pumped storage installation it would be wrong to proceed with this if the pumped storage scheme without tidal energy yielded even greater economies. The information in § 40 had some relevance here. This appeared to assume that pumped storage facilities were abundantly available for development for use with the thermal plant. If this was true then the above remarks might be discounted.

129. Also in § 40, certain costs were given for Coolkeeragh, the source of the cheapest generated unit on the Northern Ireland system, and Belfast East, the most expensive. Mr Stoupe believed these figures purported to be the running cost components only; if so, he would suggest that the figure for Coolkeeragh was too high for the year in question, and that this figure should be 0.55*d*. The figure for Belfast East was more or less correct for the load factor quoted.

130. With regard to § 41, he suggested that it was misleading to adopt the simple treatment which the Author applied here to justify the use of pumped storage in preference to Belfast East in the year 1962. The cost comparison should be made between the total system costs of (a) all-thermal plant, and (b) thermal plant plus pumped storage plant, and the calculation would therefore be more properly based on a comparison between the effect of adding new thermal plant to meet increased load against adding new pumped storage plant to meet the same load. The advantages of the lower capital cost of pumped storage plant could then be properly assessed. The Author of course had done precisely this in the Appendices to the Paper but did not justify the use of pumped storage plant until 1975, some thirteen years later than 1962.

131. Concerning savings which had been obtained by the introduction of pumped storage or pumped storage plus tidal power into the system, time permitted only an assessment of those obtained for 1977. The operating costs per kWh given by Mr Wilson for thermal plant in Fig. 10 were too high and the curves shown in Fig. 14 were based on actual costs for the stations quoted together with an estimated curve for Ballylumford B. It could be seen that the costs were not only lower than those used by Mr Wilson but rose less steeply with decreasing load factor, and in consequence had a very significant effect on the economic assessment of pumped storage.

TABLE 11: NET SAVING RELATIVE TO ALL THERMAL SYSTEM

	Saving from 'Table 10 comparative system'	Saving based on lower operating costs of Fig. 14
Thermal + pumped storage Alt. (1)	£2 290 000	£960 000
Thermal + pumped storage + tidal power Alt (2) .	£2 090 000	£320 000

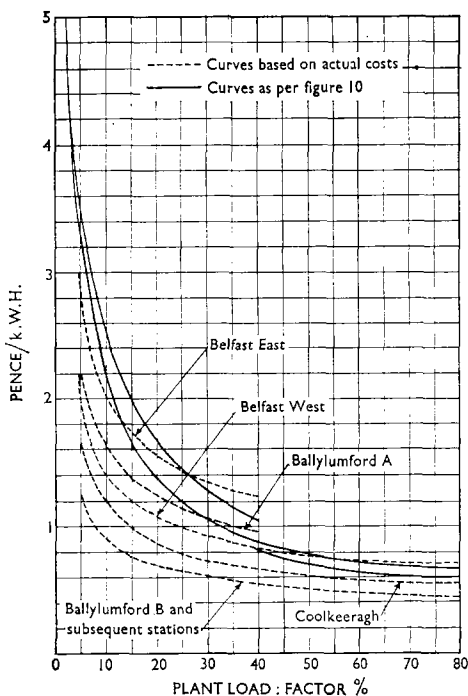


FIG. 14: OPERATING COSTS PER kWh SENT OUT AT VARIOUS LOAD FACTORS

132. Using these lower operating costs for the year 1977 and Mr Wilson's capital cost estimates, the savings shown by the introduction of pumped storage and pumped storage plus tidal power were as given in Table 11.

133. It should be noted that Mr Wilson showed an additional capacity for the all-thermal system of 80 MW over the thermal plus hydro system from 1976 onwards. Accepting that there could be some reduction in the 12% cover as a result of the introduction of the pumped storage plant there was still an excess of about 50 MW for the all-thermal plant over the thermal plus hydro scheme. This resulted in additional capital charges for the all-thermal system of the order of £150 000, which reduced the savings shown in the table for the year 1977 to £810 000 and £170 000 for alternatives 1 and 2 respectively. The saving of £170 000 in the case of tidal power was, of course, marginal and well within the accuracy of the estimates, and as mentioned later raised the question of spending large amounts of optional capital for a very doubtful small saving.

134. On the more detailed aspects of the civil construction Mr Stoupe wished to ask the Author to what extent were some of his proposals entirely novel, e.g. the sinking of the caisson units which were to contain the turbo units at the time of the sinking. The Veerschegat closure was referred to in § 13, but did this include the use of tide operated turbines? How were the turbines to be maintained once sunk and concreted in place?

135. In § 11 mention was made of the stabilizing of the rock rubble fill by asphaltic concrete. In view of the long financial life of 80 years allocated in the economic assessment, it was important to know if the stability of such a structure could be

guaranteed for such a period or if high maintenance costs or future remedial work would be necessary. If so, had these been duly assessed in the overall economic appraisal?

136. On the question of amenity value, it might be one thing to state that the estimated cost of £2 500 000 for a road bridge had been taken as a credit towards the tidal energy costs, but if the public, in the form of the Government, did not value a bridge as highly as that, then the credit could only be considered excessive. After all, if the value of a bridge was as high as £2 500 000 then why was it not yet built? Secondly on amenity it was indicated that the permanent mean level of the lough would be some 6 ft higher than the present mean level, and therefore improve navigation. This might be true but there could be repercussions from loughside interests who might consider that the present washlands yielded them some income by the fact that they were washlands and if these were to be permanently flooded compensation might be claimed.

137. On the financial side it should be noted that tidal energy was capital intensive; indeed almost all the cost was capital. No mention was made of the fact that if extra, i.e. optional capital was spent, one would normally expect a quicker return on this capital. In fact the return was spread over 80 years and it was impossible to tell what the cost of energy might be in that period from more advanced thermal/nuclear techniques. Also the interest rates quoted ranged from 5%–6%, all below the current rates for borrowing.

138. Mr Wilson was to be congratulated, however, on a most interesting and detailed Paper in which the vision of cheap energy from the tide, so long sought by mankind, became a more practical proposition, and might in the long run be an economic reality.

Mr E. J. K. Chapman (Senior Partner, James Williamson & Partners) wrote that the proposed method of constructing the tidal barrages was of great interest, and if technically sound would remove one of the chief economic disadvantages of tidal barrages, namely the construction of two costly temporary dams to achieve one permanent structure.

140. The main doubt in the writer's mind was whether the loss of water through the pervious rockfill embankment could in fact be kept within acceptable limits. He had in recent years experience of a form of tidal embankment in connexion with two large steam power stations in Scotland. Each of these involved rockfill embankments up to 2 miles in length enclosing lagoons for the disposal of the fly-ash from the stations. These were constructed along the foreshore approximately on the low tide mark, and in both cases the embankments had a top width of about 25 ft and a height of the same order.

141. The lagoons acted as holding ponds for the mixture of fly-ash and water, and the water was drawn off as the fly-ash settled out. As the fly-ash would seal any leaks in due course, it was not considered necessary to provide impervious embankments, and one was constructed wholly of rockfill, while the other consisted of rockfill with a backing of blaes (colliery waste).

142. Observation showed that the bulk of the flow through these embankments, before any sealing was done, was accounted for by individual leaks or runs of a turbulent character, and this fact, in conjunction with a study of records of water levels, suggested that the leakage did not follow Darcy's Law ($V=Ci$) but was more likely to be of the form $V=C\sqrt{i}$ where i is the hydraulic gradient. The maximum leakage through a 3000 yard length of the embankment with blaes backing, amounted to about $\frac{1}{2}$ cusec/lin. yd, whereas the much higher rate of 2 cusec/lin. yd was noted from a 1000 yd length of the all-rockfill embankment.

143. While Mr Chapman realized the difficulties of applying these rough and ready observations to the Author's proposals, he found it difficult to resist the temptation to do so. If it could be assumed that the all-rockfill embankment was analogous

to the proposed Strangford barrage and the embankment backed with blaes more in line with the Carlingford proposals, and allowance was made for the different hydraulic gradients and tidal cycles involved, then he would suggest that the loss of potential output due to leakage was unlikely to be less than 5% in each case. In the circumstances this might be acceptable if the leakage could be kept within this figure and he would be very interested to know if the Author had any figures based on observation to support his contention that leakage was of little practical importance.

144. Turning to the pumped storage proposals, Mr Chapman remarked that the pumped storage plant at Rostrevor, apparently originally conceived as an auxiliary to the tidal schemes, was in the end shown to be more economically attractive on its own.

145. It seemed however that the storage requirements of the scheme had been seriously underestimated. If the suggested 400 MW installation was complete, it would represent about 20% of the whole Northern Ireland system capacity. While he himself was convinced that a thermal system could with advantage absorb this percentage of pumped storage, it did require to be backed up with a good margin of storage.

146. The storage proposed for Rostrevor was only 5 hours, which was in line with similar schemes in England and Wales intended to operate on a daily cycle. This was satisfactory for schemes which formed only a very small proportion of the total system capacity but he felt that Rostrevor was more in line with the Scottish system where future pumped storage schemes would form a much higher proportion of the system capacity and were likely to operate on a weekly cycle requiring at least double this amount of storage. This made no allowance for storing the energy from tidal plant, and if this was built in addition, it would increase still further the demand on storage at Rostrevor. In either event it would seem that the capital estimates should be increased to allow for extra storage.

The Author, in reply, said that the Chairman had raised the point about inflow of rivers into the Loughs. The discharge of any of the rivers entering the impounded reservoirs was very small in relation to the quantities of water being exchanged between reservoirs and sea. Even at times of high flood there seemed no prospect of this being greater than about 5% of the barrage discharge and it had been ignored in the calculations. It was, however, a bonus in energy and would marginally improve matters.

148. So far as silting up of areas inside and outside the barrage was concerned, this was something which clearly would require a detailed investigation in any barrage scheme. He did not think it would be a major problem in the case of Strangford since so much of the original channel would be used for turbine discharge, but changes would take place at Carlingford and model tests would be needed to indicate the best position of the power station relative to the navigation channels.

149. Mr Gosschalk was mistaken in thinking that perpetual loans were envisaged for the projects. Appendices 1 and 2 both used conventional sinking funds to provide the initial costs of particular parts of the projects in specified numbers of years. His comment about Dutch practice was interesting and the Author concurred in his views of the excellence of their engineering. The Author had been present during the positioning and sinking of one of the closing caissons at Veerschegat in 1961 and had been impressed with the essential simplicity of the idea. Only later, after seeing the construction of the Rance cofferdam had the idea of eliminating cofferdams altogether by fitting the turbines into floating caissons been worked up for the actual schemes under discussion. It was hardly true to say that the French had abandoned caisson construction. At the time La Rance was started there had been no estuary closure by this method.

150. Mr Seddon had said that the cost of the pumped storage scheme at Rostrevor

had been greatly under-estimated. The estimates had been re-examined and allowances increased where any doubts existed. The effect was not very great.

151. He had re-examined the Admiralty chart in the light of Mr Seddon's remarks and admitted that he had been mistaken in his answer at the meeting when the Paper was presented. The coast was rocky and the foreshore covered densely with boulders with almost no sand visible, but the water depth was not as great as he had said. The best site for the intake/outfall would be slightly to the south of that shown in Fig. 2. There the depth at LWS was $10\frac{1}{2}$ ft about 1400 ft from the high water shoreline at present and would be not less than 17 ft if the tidal barrage was constructed. Moving the tunnel line slightly in this way would make the tunnel about 400 ft or 6% longer than originally estimated.

152. The maximum pump discharge would be about 3000 cusecs, not 4000, and so inflow velocities should not exceed 3-4 ft/sec. at the $10\frac{1}{2}$ -ft depth even on the rare cases of pumping coinciding with extreme low water. This was not excessive.

153. The view now taken in the light of these revisions was that the estimates of Appendix 2 should be increased to give a total capital cost of £9.11 m. or £30.4 per kW installed. Transmission costs had been allowed for.

154. For interest during construction a 6% rate was assumed and a four-year construction period, with 10, 30, 60, and 90% of total cost paid out at the end of each of the four years.

155. On the question of salt pollution from the reservoir into streams arising on neighbouring hillsides, the Author pointed out that obviously steps would be taken to minimize this and the estimates included a lining to the reservoir. There was no arable land on the hydraulic gradient between reservoir and sea, nor was there any principal water supply so far as he could find out, so that even if saline seepage occurred, it did not seem to be a major problem.

156. Mr Seddon had made the further point that in Table 9 the 25% cost of the 400 MW installation charged against pumped storage after installation of the first set was inadequate. He would agree this might be on the low side but it depended on how the scheme was designed. If designed as a two-stage scheme, something more of the order of 35% might be appropriate.

157. Mr Pedder seemed to have misunderstood the purpose of the Paper. This was an exploration into new possibilities, not a case for the explicit statement of any view of the Author's without qualification.

158. Mr Pedder found it odd that in 1980, £2.2 million per annum could be saved by replacing 480 MW of thermal plant by 400 MW of pumped storage. Perhaps he had not considered the advantages to the system of the elimination of spinning reserve and boiler banking by the 400 MW of pumped storage? These had been estimated by the C.E.G.B. at £10/kW.¹⁵ In the circumstances a saving of £5/kW did not appear unreasonable. In any case a simple comparison of two alternative increments of the system could not be justified. The saving was made on all the plant in the system. The Author agreed about the sensitivity of the calculation to minor changes in the curves of Fig. 10 and more importantly perhaps to the hypothetical load factors ascribed to each station in the system.

159. Mr Braikevitch's contribution was authoritative and informative and was most welcome. The cell design proposed had been developed with his help and advice, to take advantage of the tube turbine with peripheral generator.

160. Mr Fulton had made an interesting contribution and the Author had to admit that he had not considered the question of the Quoile drainage. If the mean level of Strangford Lough was raised as was proposed, then the discharge of the Quoile would either have to be pumped occasionally or a certain amount of land bordering the river flooded. Either way this was a disadvantage which had not been foreseen.

161. The barrage had been sited for minimum cost at a relatively shallow part of the narrows, but deep enough to accept easily the necessary number of turbine cells.

Moving it to deeper water must increase the cost, and to move it to Strangford village would increase it substantially, since the volume of rock rubble needed would be twice or three times as much. This might increase the overall cost by some 10%. Crediting the barrage with bridge value had been questioned. This had been done only where a strong, some might say vociferous, demand existed. If this benefit of the barrage was not credited, there would be a revenue from toll charges which the Author had balked at trying to assess. It seemed simpler to credit the minimum cost of a bridge towards which the Government of Northern Ireland had said publicly it would contribute.

162. Mr Walker and Mr Stoupe had criticized the curves of Fig. 10 and Mr Stoupe had provided, in Fig. 14, the correct curves. The Author hoped that he would not take it amiss if it was pointed out that this was precisely the information he had requested two years ago when the studies were being done. The information with regard to Ballylumford B and future stations in Fig. 10 had been supplied, apparently erroneously, by the E.B.N.I. and the two other curves taken with minor adjustment from the Mackenzie Report. It was certainly true that the revised curves would make Alternatives 2 and 3 a good deal less profitable than they appeared in the analysis in the Appendices and the Author had no hesitation in accepting the revised figures of Mr Stoupe's Table 11.

163. He did not, however, accept that it was fair to deduct the capital charges of the excess 50 MW, in the all-thermal alternative, from the nett savings of Table 11. One of the advantages of pumped storage as proposed was the introduction of another size of unit into a system such as that of Northern Ireland since it enabled supply to be kept more nearly to the curve of rising demand. The E.B.N.I. would hardly contemplate introducing a 70 MW thermal set in 1977.

164. It was true that the pumped storage alternative did not begin to show savings until 1975, but this was because of the existing and ordered thermal stations. In the Author's view a pumped storage component should be considered before the second half of Ballylumford B. This meant starting construction in 1968 and having the first set running by 1972. The date by which the overall system first started to show a saving compared with a (by that time) hypothetical alternative was irrelevant. In any case as Mr Severn had indicated, Mr Stoupe could probably find uses for pumped storage which had not been included in the hypothetical programmes postulated.

165. Dealing with the remainder of Mr Stoupe's contribution, all of which was very welcome and highly relevant, the Author felt that the operation of the tidal power station would be controlled locally very much as most hydroelectric schemes were. The tide level could not be allowed to control operation since maximum economic advantage could be obtained by moving the periods of tidal generation within appreciable, though narrow, limits. The sluices would be as reliable as any hydraulically operated turbine ring, since they were the guide vanes on the turbines. The auxiliary refilling sluices proposed would be as reliable as any Tainter gate operation. The Author would have thought that this was at least as good as a boiler or steam turbine.

166. So far as plant was concerned he appreciated the point about operation in sea water. The plant manufacturers did not view this with special concern. The turbo-generators would be installed after the sinking and stabilizing of the caisson cells. Stop logs would be available for the isolation and dewatering of any cell and the maintenance and/or replacement of a complete plant unit.

167. The use of asphaltic concrete placed under water was a new technique developed by the Dutch on the construction of the new IJmuiden breakwater. There was no reason to believe that it would not be long lasting and effective in its function of preventing scour removal of the rubble bank.

168. Tidal schemes were capital intensive. The idea that such schemes should show a quicker return was common but questionable. Society invested about as much in coal mines, rail tracks, harbour facilities, ships and thermal power stations

to produce thermal energy as it did in a tidal power station with pumped storage, for the same effect. Electrical engineers tended to start counting investment when the coal arrived at the boilers. The average costs of borrowing by the C.E.G.B. for the last 5 years to 1964 were respectively 5.34, 6.07, 6.53, 5.75, and 5.26%. The Author was surprised that the E.B.N.I. should be paying more.

169. Professor Naylor's and Mr Chapman's contributions were particularly welcome. The former's, because of his interest in tidal schemes and the ingenuity of his suggestions, and the latter's because all students of pumped storage schemes knew his work as essential reading. By coincidence they had both dealt with the permeability of the rock rubble bank which was one of the Paper's more controversial points. The Author had no figures based on observations and was the more grateful, therefore, for those given. The only real risk of leakage was under the caissons. Where embankment was proposed the centre section would be pumped sand fill and so virtual watertightness would result, as evidenced by Dutch experience. The Americans had conducted extensive model tests on the Passamaquoddy dumped rock closure proposals and apparently concluded that adequate impermeability could be assured with depths of up to 300 ft by mixing fines with the rock fill. This was a matter for further discussion and collection of evidence. Professor Naylor's suggestion of floatable siphon units was most interesting and would be pursued.

170. Mr Chapman's remarks about the storage required were apt. The Author was aware of the storage problem and indeed had attempted to find a solution to part of it, in another study.¹⁶

171. To show his approach to it, and to answer Mr Crosthwaite and Mr Blackmore's view that there was little to be said for adding tidal power to pumped storage, he would conclude his reply by repeating some of his introductory remarks to the Paper when it was presented.

172. Tidal energy could not be used as a replacement for energy from conventional power stations unless it was stored, one way or another. (La Rance combined the storage system in the main generation scheme.) If a conventional pumped storage scheme was used, then the question could be asked, why not simply use off-peak conventional energy? This could be done, at a cost of extra fuel only, efficiency losses and some increased maintenance and operation, i.e. the 'incremental energy' cost. However, as the quantity of off-peak energy rose, these costs increased, as less efficient stations were brought into operation to provide it. Once the quantity became substantial, the 'incremental energy' cost ceased to be applicable.

173. Suppose the curve of weekly demand on the system was as shown in Fig. 15 and the blocks of tidal energy occurring were used to meet all the energy above the horizontal line either directly (shaded portion) or through pumped storage and regeneration. Then, when the tidal energy contribution was large enough, the conventional power stations were able to operate at higher load factors throughout their lives with less frequent starting and stopping, and a flexible and efficient means of covering peak loads was provided. The storage necessary to achieve any particular position of the horizontal line was calculable. Similar analyses could be made for combined use of tidal energy, hydro spill units or off peak conventional energy. The storage estimated for in the Paper was adequate for the Strangford energy balance, but additional storage would be desirable as the system expanded. This was why additional possibilities were shown on Fig. 2.

174. The criterion was, of course, cost, but if the quantity of energy was large, in relation to the total, there would be the benefit of lower cost per kW of pumped storage construction and the replacement of the energy that would be provided off-peak by less efficient stations. Given the right sites, such combined use of tidal energy and pumped storage might lead to a lower overall system cost than any alternative.

175. The Author had set out to ascertain whether barrage sites with comparative low tidal ranges could yield energy economically if new techniques were used. The

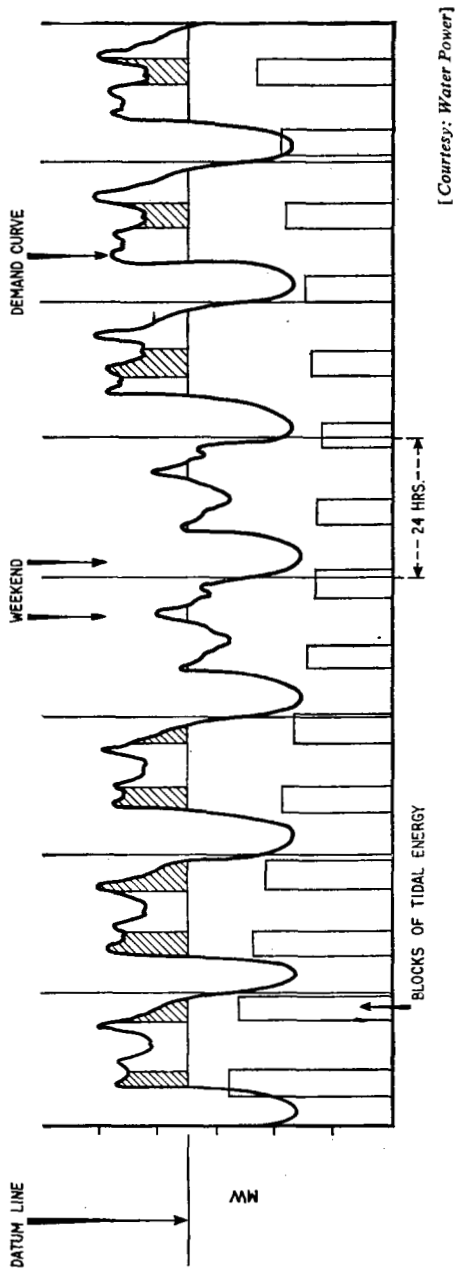


FIG. 15: GRAPHICAL ILLUSTRATION OF INTEGRATION PROGRAMME

only way to prove this was to postulate actual cases and to do all the resulting work on schemes and estimates and to try to integrate the energy into the electrical system. This was why Northern Ireland had been chosen. It had both sites and a system small enough for an outsider to make reasonable guesses. While his imperfect analysis had shown that tidal energy was uneconomic in the context considered, the Author hoped the ideas in the Paper, and their discussion, might be of practical value elsewhere. He was indebted to all the contributors to the discussion for the interest shown in his work.

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