THE DESIGN AND CONSTRUCTION OF A STEAM POWER STATION

BY

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INTRODUCTION

The establishment of a steam power station follows a logical sequence of events, starting with the initial decision to construct such a plant. This decision is not always obvious, and can be made only after a study of the load requirements and the alternative means available for generating electricity.

Depending on the capacity of the plant required the choice of generating plant will lie between Diesel engines, steam turbines or gas turbines. There are other alternative means, such as free-piston gas generators working in conjunction with gas turbine or nuclear plants, but the former type of plant is still in the development stages and, outside the United Kingdom, nuclear power stations are being installed only by well-developed networks on a semi-experimental basis.

The final attainment of the power station generating electricity requires the following processes:

1. A general survey of the network development to establish the required increase in plant capacity and determine the type of prime mover to be installed.

2. An economic survey to determine the scope of the new station, the rating of the machines and (in the case of a steam station) the steam conditions to be adopted.

3. The physical design of the power station.

4. The administration of the work, i.e. arranging finance, conclusion of contracts and supervision of construction.

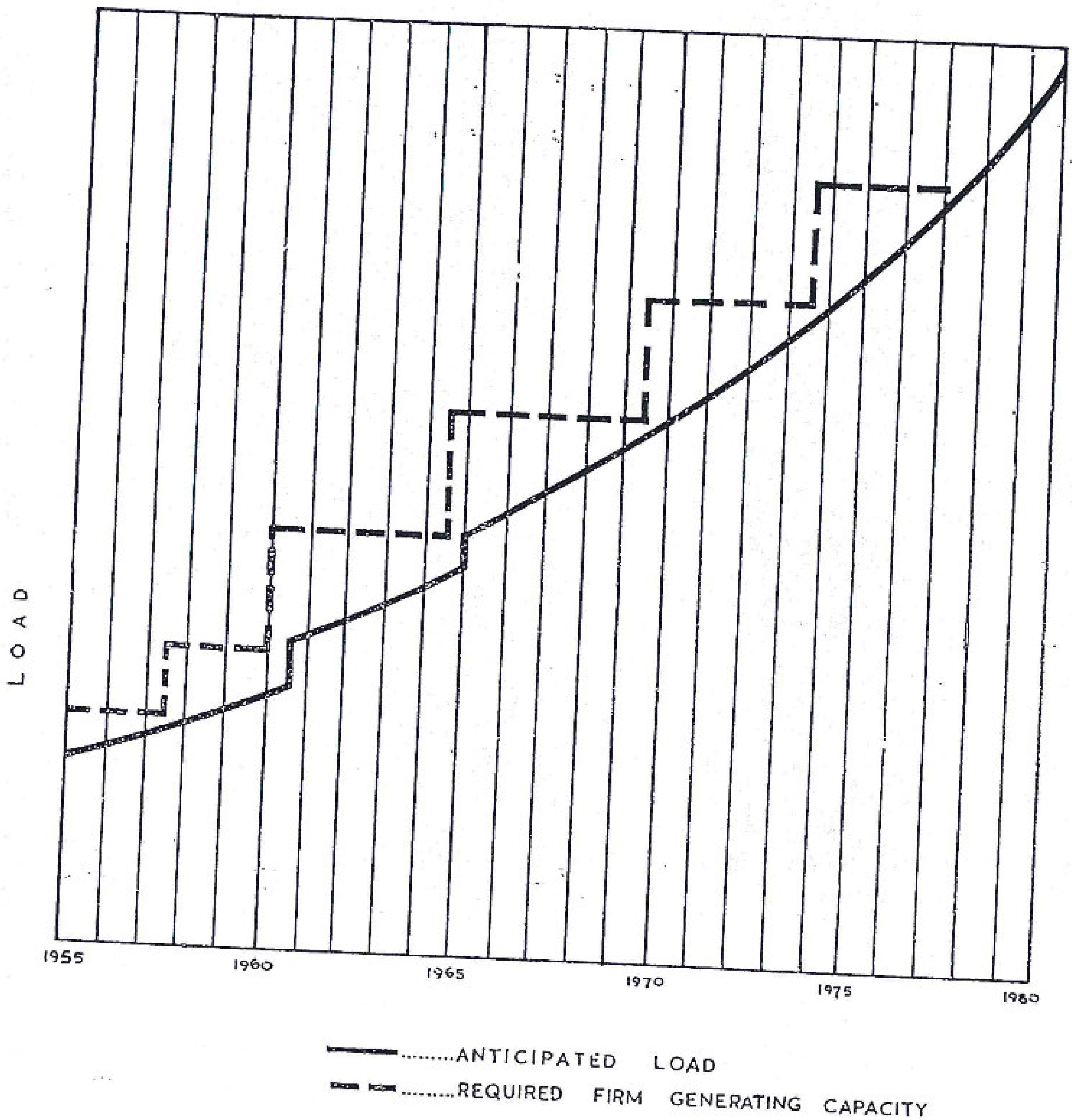


FIG. 1 TYPICAL LOAD GROWTH CURVE

GENERAL SURVEY - PLANT CAPACITY

In order to determine the required increase of capacity for the network under consideration a load growth curve is drawn, a typical specimen of which is shown in Figure 1. The load history of the network up to the time of the survey is plotted and then projected into the future, the resulting curve usually being exponential in shape. From the growth during the preceding years the percentage annual increase can be determined, and this forms a good guide for the projection into the future, providing that the slope is modified to take account of any factors exercising a significant influence. Thus, in a developing country with an intensive programme of industrialisation, this expansion, with the usually-accompanying increased standard of living, may mean increases of demand reaching a very high rate. Whereas, on a network in an already highly industrialised country such as the U.K. the annual growth in demand is of the order of 8%, it is not unknown for the load on a small network to increase at more than twice this rate. Furthermore, in the case of a rapidly developing country individual development projects may introduce block increases of demand of significant size, which can be foreseen. Such step increases are suggested in Figure 1 and show that the general level of the curve is lifted. A typical case in point was the establishment of the new ammonia plant at Point Lisas in Trinidad, which added 20 MW to T.&T.E.C's existing load of about 65 MW.

Having drawn the load growth curve and projected it for, say, 10 to 15 years into the future, the requirement for new plant can be estimated by plotting on the same chart the capacity of the existing generating stations. There is no precise mathematical method of arriving at the desirable increase in capacity, and usually by arbitrary decisions must be made to ensure that the new station has a convenient number of generators of such capacity that the system demands will be met for a reasonable period. It has been found that two simple rules often give a close approximation to the best economic solution

(i) A new machine should cover four to five years' load growth.

(ii) A new station should house generating units of approximately double the capacity of the previous largest unit on the network.

SELECTION OF PRIME MOVER

Having established the capacity of the new station, the next step is to determine the type of prime mover to be adopted. The choice is influenced by a number of factors, with cost usually the most important. Typical costs, both capital and annual, for various types of plant are illustrated in Figures 2 and 3. It should be noted that these curves are typical only and that any significant variation in the fuel cost or special site considerations would materially affect the shape of the curves.

Figures 2 and 3 indicate that for loads of up to about 3 MW in a likelihood diesel generators will be the most suitable form of prime move from the cost aspect. Above this range the selection will depend on detaile considerations of cost and on the background history of the network. Thus a network exclusively employing Diesel generation and requiring, say, 1 MW increase might well decide to extend by further Diesel plant rather tha change to the completely different technique of steam.

Leaving aside such special considerations, in the middle load range fron say, 3 to 50 MW, the choice would lie between steam and gas turbines, an the final selection requires a detailed economic survey.

Fuel availability has a considerable influence on the choice of plant Thus, where large supplies of gas are available (by inference at a very lov cost) a much better case can be made for the gas turbine than could be made in a country having plentiful supplies of coal but having to impor distillate oil fuel.

A steam power station requires copious quantities of water for cooling the condensers. Where large supplies are not available, then cooling towers can be adopted, with an accompanying increase in capital cost. Thus, for a unit rating of the order of 20 to 30 MW, the choice which lies between steam and gas turbines would go to the former if plentiful supplies of water, coal or heavy oil were available, but would favour gas turbines in an area possessing a supply of cheap natural gas but suffering from scarcity of water. Again considerations of history and prejudice might operate in favour of one or other type of plant and influence the choice.

ECONOMIC SURVEY

The general survey would have reached a conclusion as to the size of plant increment required and indicated perhaps two alternative prime movers. By this time the site for the extension would be under consideration and the choice might lie between two or three alternative locations. Thus, the economic survey would have to take account of the number of combinations, though this number might be reduced if some of the sites available were obviously suitable for a particular type of plant. Site investigations would have to be made to determine the need for piled foundations, the presence of rock, and other details, which would materially affect the cost of construction. Further alternatives would have to be pursued to determine the most suitable steam cycle in the case of the steam plants.

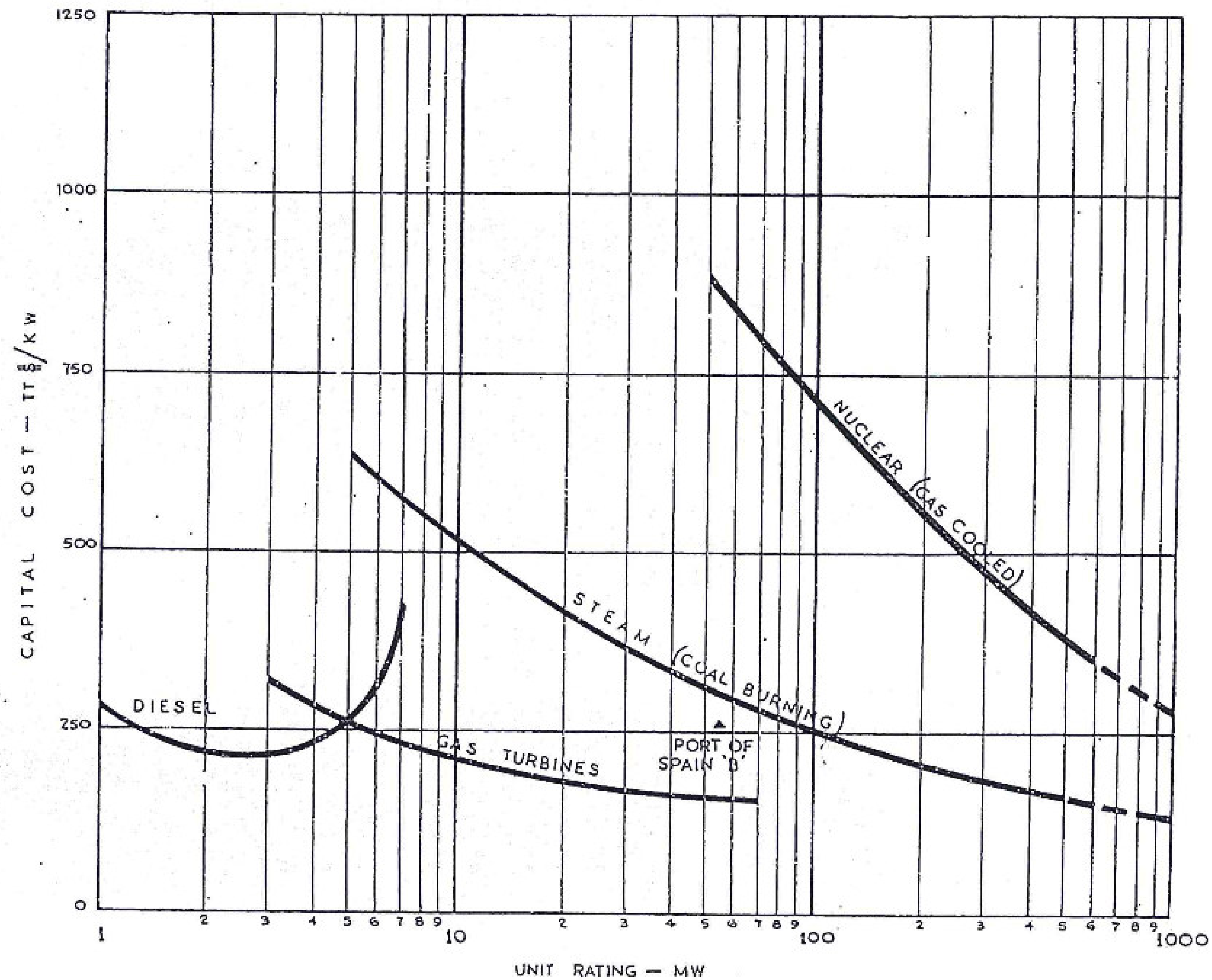


FIG. 2 COMPARATIVE CAPITAL COSTS OF THERMAL GENERATING PLANT

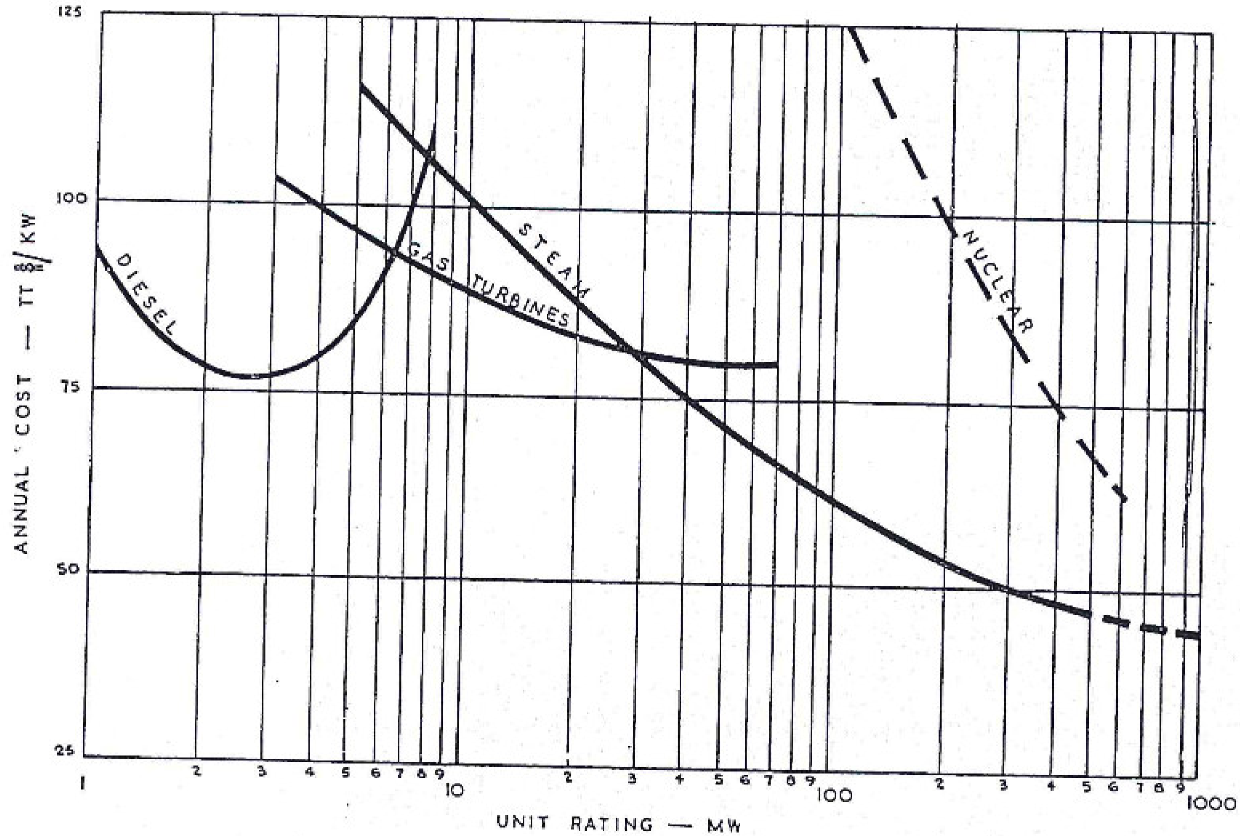


FIG 3. COMPARATIVE ANNUAL COSTS

VALUES USED .... FUEL COST 80¢ / MILLION Btu

INTEREST 6 %

LIFE 25 YEARS STEAM
20 " DIESEL AND GAS TURBINE

OVERHEADS 15% FUEL COST STEAM
45% " " DIESEL & GAS TURBINES

LOAD FACTOR 50 %

The economic survey would be based on tentative cost estimates for the various alternatives, these costs including extraneous items such as establishment of access to the site, any extra transmission facilities, arrangements for bringing the fuel to the site, e.g. the establishment of a pipeline or rail connection. With this information the initial cost of the power station can be calculated and the estimate so reached should be within 10% of the final cost. At this stage the method of financing the construction has to be considered, for the economic assessment will be influenced by the terms of a loan.

Whilst the capital cost of the plant is important, it is most usual to make comparisons on the basis of the total annual cost, this being made up as follows:

(i) Fixed charges, i.e. interest on capital loan plus depreciation. It is now quite usual to amortize steam plant over $27\frac{1}{2}$ years, but Diesel plant and gas turbines are more prudently written off over 20 years.

(ii) Fuel cost.

(iii) Maintenance charges. This is an important item when considering Diesel and gas turbine plant where the maintenance costs may be of the order of three times that of steam plant.

(iv) General overheads, i.e. supervision, operating staff and administration.

Where finance is available at reasonable cost the annual cost method gives the most economical choice of the alternatives, but in certain circumstances, e.g. where capital is very difficult to obtain, the first cost of the plant may be of over-riding importance. This may result in having to buy plant of low efficiency and the higher total annual cost resulting from the heavier fuel consumption must be accepted.

PHYSICAL DESIGN

For the economic survey tentative designs for the alternatives will have been made, and once the course to be adopted is decided work on the station design starts in earnest, based on the tentative design used in the economic survey. For the purpose of this paper it is assumed that steam plant has been selected.

At this stage the designer will have the following information available: The location of the station; the type of fuel; the steam cycle; the size of generating unit and the total number of units to be accommodated.

The site layout will already have been tentatively drawn up in preparing the estimates for the economic survey. This may be dictated by physical features, e.g. the relation of the site to the source of cooling water or railway access, and the shape of the site may determine the arrangement of the ancillary buildings. Individual opinion plays a great part in the layout of the buildings; thus, the office and administration block may be in a separate building from the main machinery, or more usually it is placed as an annexe at one end of the main turbine hall. Due to the very restricted nature of the site for Port of Spain 'B' the office block was placed along the length of the turbine hall over the transformer bays, and whilst this arrangement is convenient for operation it brought some difficulties in the design of services.

The design of the station may be influenced by considerations of the period envisaged for its development. Thus, on a very large network a new station which may be only one of a group meeting the increasing load requirements would be established as an entity, with succeeding machines following as rapidly as feasible so that the whole construction would be complete within six or seven years. With smaller networks this is not usually either desirable or practicable financially, and a new station is established with either one or two machines with further units following as required by the system expansion so that complete development of the station may take ten to fifteen years. The pattern of development will influence the detailed design, since for a station with a long period of development it must be recognised that to install initially some items of basic plant, such as water treatment equipment, of the capacity required for the final growth of the station would be uneconomic. It must be borne in mind also that whilst the general lines of development must be fixed, some scope must be left for variations in design or even in the size of the units which may prove desirable in the future.

The basic internal layout of the station can be established readily from experience of past designs. The two main alternatives open to the designer are to arrange the turbo- alternators either longitudinally or transversely in the station, and this choice depends on the width of the boiler relative to the length of the turbine. In earlier times when it was either not practicable to build a boiler whose output matched the steam requirements of the turbine or, as a reflection of the general lower availability of the boiler compared with the turbine, it was considered preferable to have a greater number of boiler units than turbines, the usual arrangement was to place the turbines longitudinally. Following improvements in boiler design and, in particular, the universal adoption of pulverised fuel firing for large coal-burning units, it was found feasible to adopt the single boiler/turbine unit, and up to about 150 MW the most economical arrangements occurs with the turbines located transversely. The two alternative arrangements are shown in Figure 4.

For the very large units of 200- 500 MW now under construction in U.K. it has been found that the boiler width has increased to the point where it is convenient to arrange the turbines longitudinally. With this size of unit factors other than the sheer cost of space call for consideration, particularly the installation of the overhead crane in the turbine room, which has to be able to handle heavy weights at large spans, and the longitudinal arrangement undoubtedly simplifies this problem.

Assuming that the size of the unit to be adopted is such that the transverse arrangement is preferable, then a design on the lines of that shown in Figure 5 might be developed. In this it will be seen that the boilers, turbines and any necessary step-up transformers are accommodated on common centre lines and ideally the building would be so orientated on the site that the switchgear controlling the power outlet is placed close to the transformers.

The preliminary layout of the main building is quite straightforward and the main dimensions can be set out on the basis of past experience. Thus, if a 50 MW machine is being specified then the probable length of the machine can be estimated to within about 3 feet, and similarly the centre line spacing can be set out from a knowledge of the probable boiler dimensions. The height of the building is established from the probable height of the turbine condenser, which allows a good estimate to be made of the height of the operating floor. The height of the crane rail is determined by the need to lift a machine stator over another machine, and after that the roof level can be determined from the probable dimensions of the crane. These dimensions may be modified slightly as the design progresses when the various dimensions are more accurately known, but at Port of Spain 'B' the only modification found desirable was to lower the operating floor (and consequently the crane rail level) by 1 foot, which enabled some economies to be made in structure cost.

At this stage a decision is usually made on the chimney arrangement, which can have a considerable influence on the station layout. The decision is influenced by questions of cost and by statutory requirements for air pollution. The latter was decisive in the construction of the 650' high chimney now being constructed at Eggborough Power Station in U.K., and in the interest of economy only one chimney is being built for the four 500 MW units. At the other end of the scale, at Port of Spain 'B' the siting and prevailing winds, plus the use of natural gas, permit the much more moderate height of 175', and for simplicity, individual chimneys were adopted for each boiler.

In many ways the arrival at the main dimensions and features of the station is the easiest part, and sometimes considerable ingenuity has to be used in laying out the ancillary plant, the most important items of which consist of some or all of the following:

1. Fuel Storage and Firing Arrangement - A 200 MW station operating at 50% load factor would require about 700 tons of oil or 1200 tons of coal each day. In addition to the equipment for handling this flow it is prudent to allow at least one month's reserve storage, which would mean providing accommodation and simple access to 21,000 tons of oil or 36,000 tons of coal.

2. Ash Handling - In the case of a 200 MW coal-burning station there would probably be about 150 tons of ash for disposal each day, usually in very finely divided form, which is handled either dry or as a wet slurry.

3. Cooling Water - The same station would require up to 120,000 g.p.m. of water circulated through the turbine condensers, and if a straight-through system is used, means must be provided to draw and return this amount to

the source. Where such large quantities are not available then coolin towers must be provided. These occupy a good deal of space and must b sited conveniently relative to the turbine hall to permit easy connectio Screening plant is required to prevent the entry of debris which woul choke the condensers.

4. Make-up Water - A 200 MW station would require up to 100,000 gallon per day of water to act as make-up to the feed system. This may b acquired from wells, town mains, rivers or other convenient sources o fresh water. Depending on the constitution of the water, then it may b processed by softening, evaporation, demineralization, or a combinatio of these.

5. Auxiliary Power System - Depending on the type of fuel burnt and th source of cooling water a 200 MW station may use from 3½% to 7½% o its power out-put for auxiliary plant, i.e. provision must be made in th station to handle between 7 and 15 MW of power. Usually, in a station o this size there would be two levels of voltage used, 3.3 kV for the majo motors and 415V for the smaller supplies. A typical layout of the statio electrical system is shown in Figure 7.

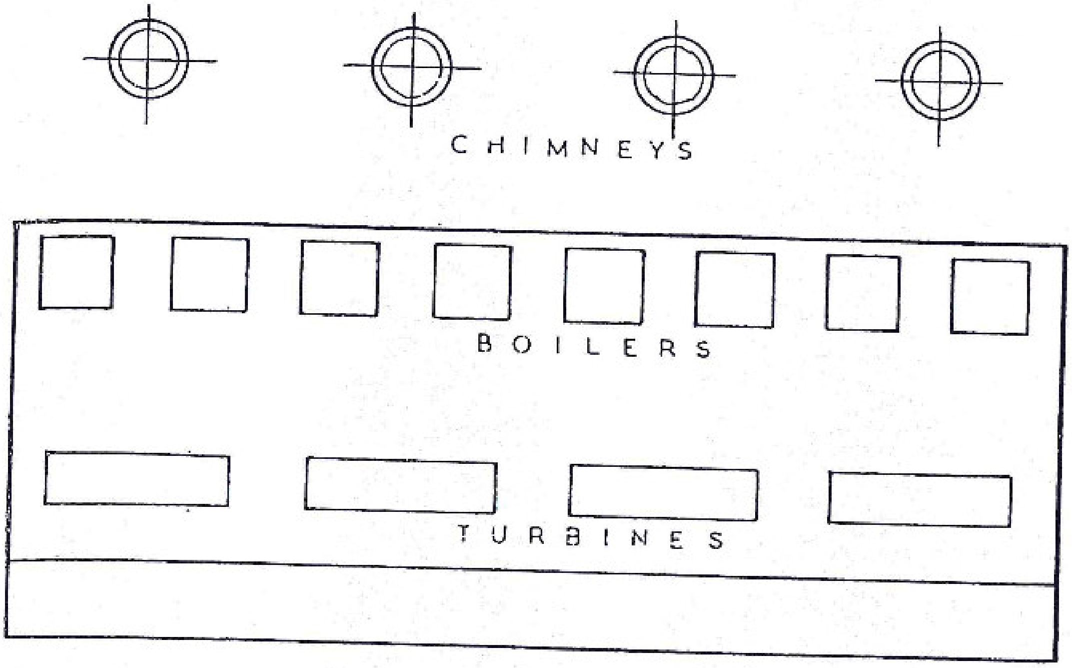
6. Control Arrangement - It is now usual practice to establish control centres handling two boiler/turbine units, and these are usually placed at a convenient point central to the plant controlled. The electrical control may be placed in a variety of positions, ranging from a separate building outside the main plant housing to right in the centre of the station, as at Port of Spain 'B'.

ADMINISTRATION - PREPARATION OF CONTRACTS

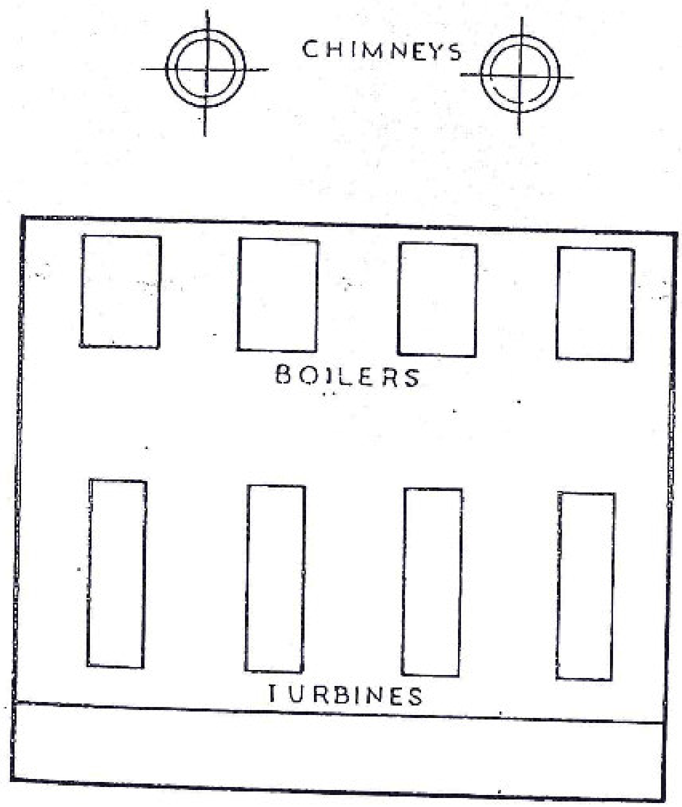
Parallel with the progress of the design the specification is prepared describing the requirements for the plant. This specification must contain sufficient indication to allow tenderers to quote a realistic price, and failure to prepare an adequate specification can result in considerable difficulty. A vague, loosely worded document may result in the omission of essential equipment or the provision of a standard lower than necessary, or a conscientious contractor may quote an over-high price through being unnecessarily prudent in covering the omissions of the specification.

The engineer writing the specification must also bear in mind the method of calling for contracts. Thus, if tenders are to be called on a worldwide basis the tender must be much more comprehensive and explicit than would be necessary if an enquiry were being directed to a particular manufacturer.

The tenders, when received, are scrutinised, and a further economic assessment made on the basis of the cost and performances quoted by the



LONGITUDINAL ARRANGEMENT



TRANSVERSE ARRANGEMENT

FIG 4. ALTERNATIVE STATION ARRANGEMENTS

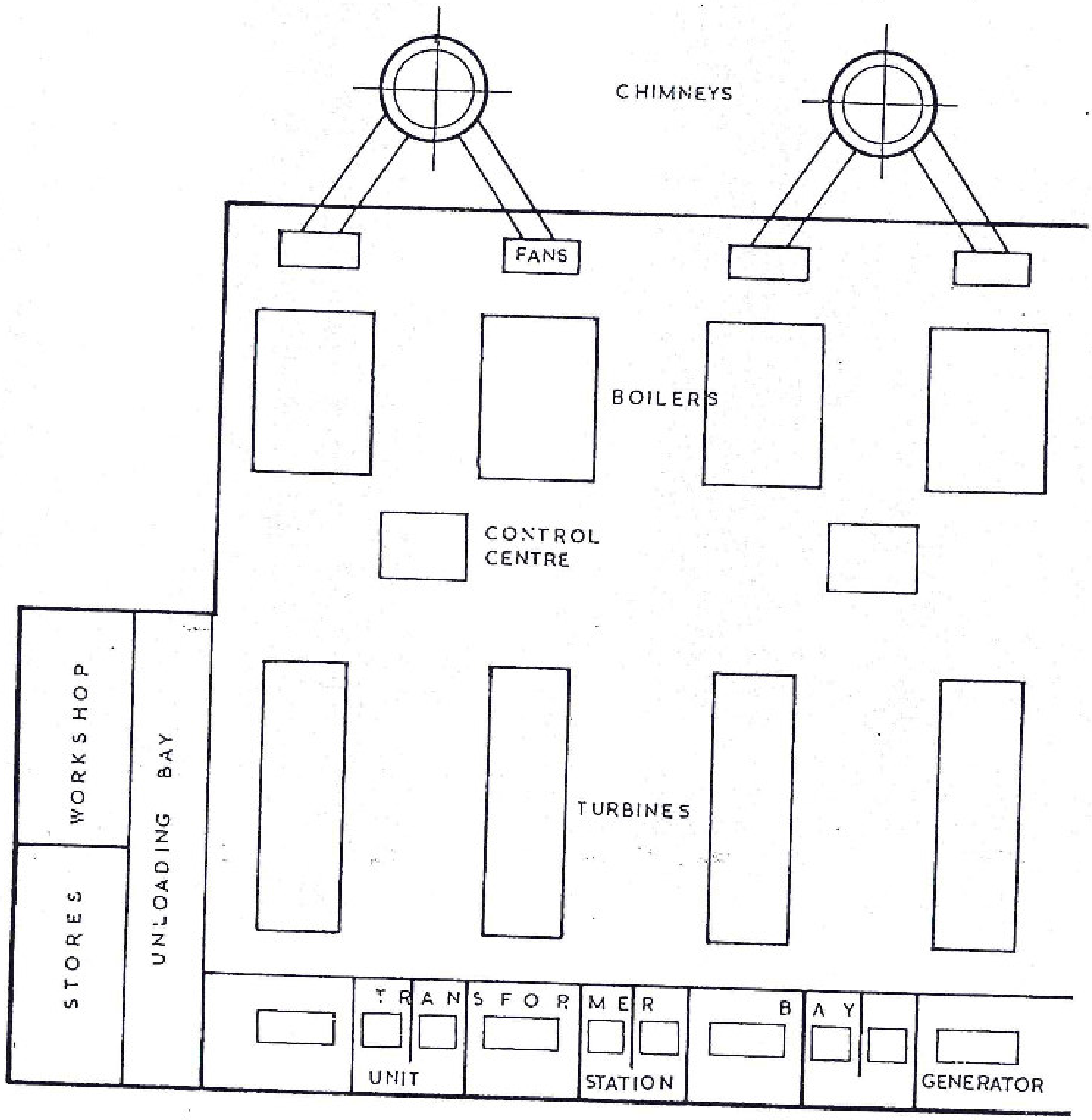


FIG.5 · TYPICAL 4 – UNIT STATION LAYOUT

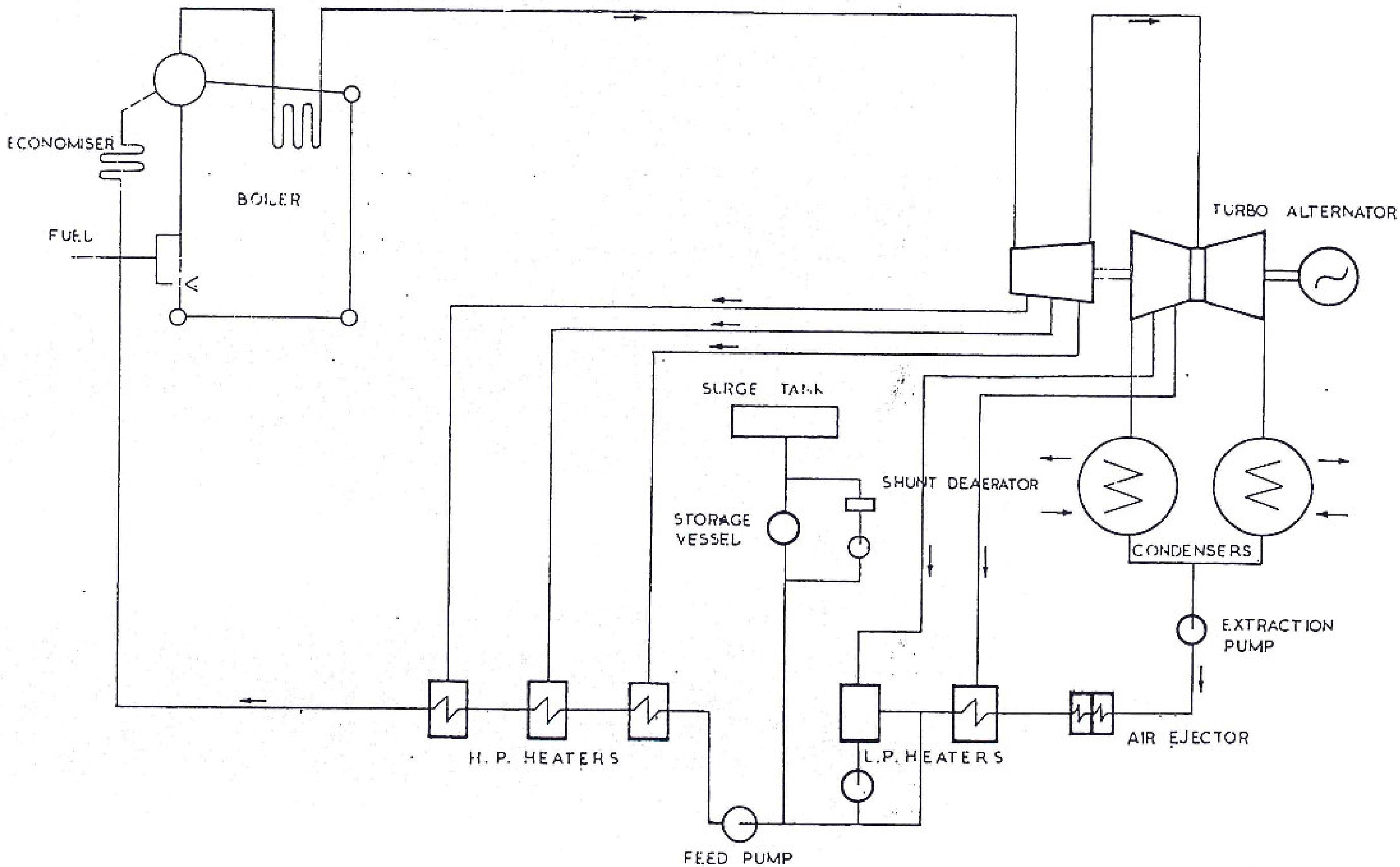


FIG. 6. SIMPLIFIED STEAM AND FEED SYSTEM

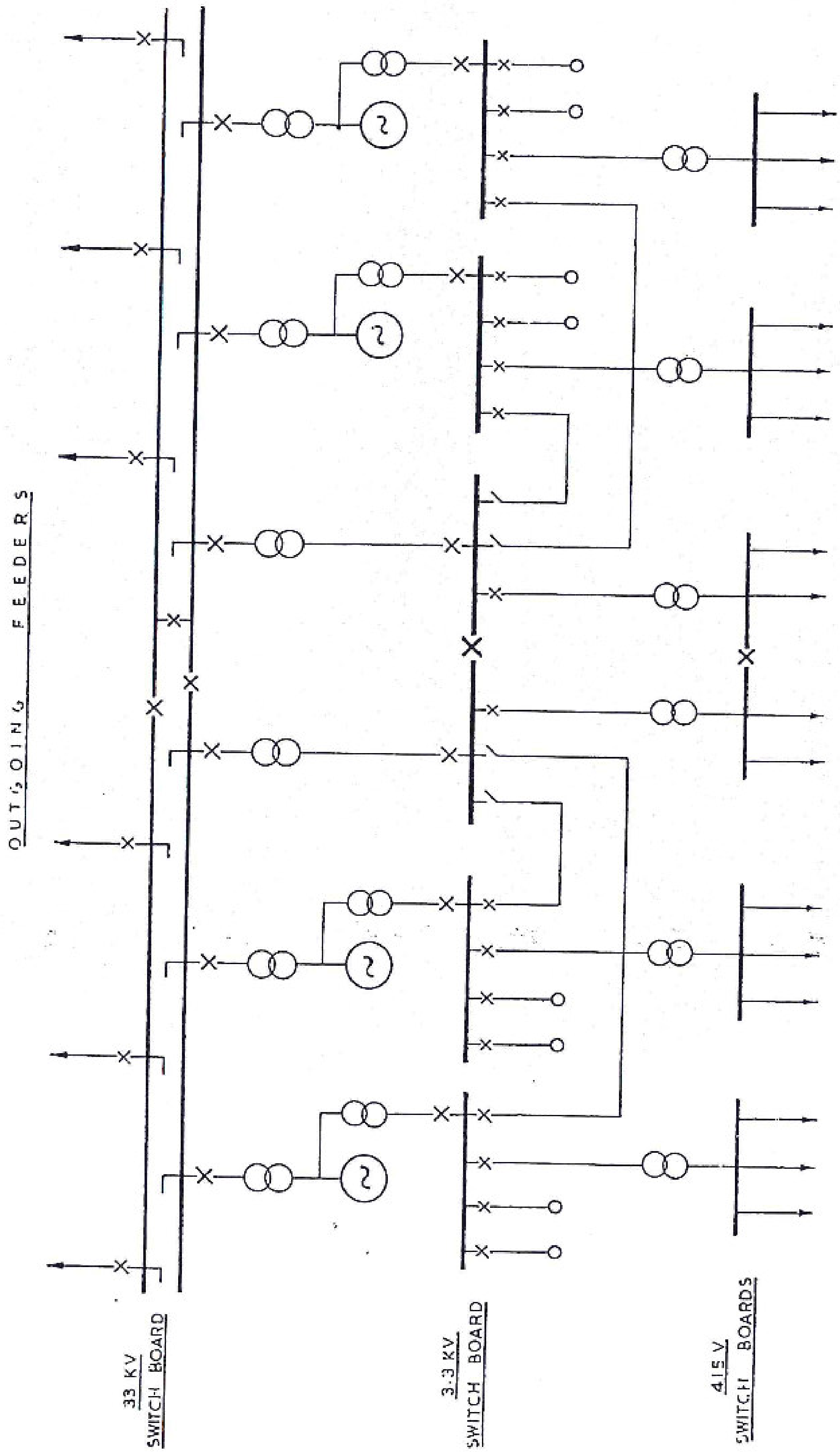


FIG. 7. TYPICAL ELECTRICAL SYSTEM FOR 600MW STATION

various tenderers. This analysis enables the suppliers of the plant to be decided. The contracts are usually awarded to the offers showing the lowest annual cost (which is not necessarily the lowest price). It is important to check tenders in order that obvious errors may be investigated, and it will often be found that a tender which is very much lower than the general order of prices should be treated with caution, since in its composition mistakes may have occurred or the tenderer been over-optimistic with regard to costs, which may lead to trouble during the execution of the contract.

Following the award of the contracts, the delivery dates are known and a date for the commissioning of the station can be set. The design of the station must be scrutinised and modifications made to take account of the particular type of equipment accepted. This may entail alterations to dimensions and certainly a good deal of work in completing the design details. This final detailing is done in collaboration with the manufacturers, the process continuing even during the manufacture of the plant, and commonly progress of portions of the design forces modifications to other sections.

PLANT MANUFACTURE

After the contracts are let it is essential that close contact be maintained between the Purchaser (or the Consulting Engineer representing his interests) and the Contractor to ensure that the plant comes up to the standards specified. This is particularly important if the specification has been based on British standards and the contractor is, say, from a European country normally working to a different set of standards. Through the progress of the manufacture agreement on the design, details must be reached and deviations from the specification permitted where these are reasonable and can be justified on the grounds of either economics or technical improvement.

CONSTRUCTION ON SITE

Usually at least a year elapses from the award of the contracts to the appearance of the first plant items on site, but this time is fully occupied in civil works construction. The general civil design will have been done during the preparation of the specification, but this may need to be modified in detail depending on the accepted contract. In order to ensure that the site is in a satisfactory condition for the reception of the first item of the plant (usually the boiler) civil works should start 9 to 12 months in advance of this date.

Timing is of great importance on the site if the construction programme is to proceed without hindrances, delays and extra costs. Thus, the turbine contractor can do very little work if the foundation block and overhead crane are not available at the date scheduled for construction to start. A typical construction programme is shown in Figure 8.

Before work can start on the site a considerable amount of preparation of facilities is needed. The 200 MW station previously quoted as an example may need a labour force of up to 600 men, and facilities for sanitation and messing are required. An area of at least two acres is needed for storage of material in process of erection. The power requirements for construction equipment such as pumps, compressors, welding machines, cranes and lighting may rise to 300 kW, and adequate provision for supply to the contractors must be made.

TRAINING OF OPERATING STAFF

The new station will require an operating staff trained to handle it and this usually requires a fair amount of planning. Ideally, the Superintendent of the new station should be appointed and present on site at least nine months before the proposed commissioning date so that he will be thoroughly familiar with all aspects of the new station. Similarly, the operators, who should already have had previous experience of steam stations and preferably of similar plants, should arrive on site at least three months before the expected commissioning date, so that they too can familiarize themselves with the plant. This practical familiarization should be supplemented by classroom work to ensure that the men are of the technical standard required.

COMMISSIONING

As the commissioning date approaches the co-ordination of the various contracts becomes even more important. Thus, the turbine requires steam approximately one month before the anticipated date for first synchronising, and the boiler in turn will require power and treated water supplies about one month before this.

The commissioning starts when the first switchboards are made alive, most probably with the object of commissioning the water treatment plant to provide suitable water for the boilers. It is unlikely that by this stage the main high voltage switchboards will be available, and it may be necessary to provide temporary supplies from the site substation. Once water is available and power to drive the fans the boiler can be boiled out to remove mill scale and grease, this process usually taking about three days at progressively higher pressures. Following the boil-out the water is drained and the boiler examined internally for satisfactory cleanliness. On completion of fitting the drum internals the boiler is then ready for safety valve floating, after which it is a steaming unit. Before steam can be applied to the turbine then the intervening steam lines must be cleared of mill scale, dirt and foreign matter left by erectors, and to this end temporary extensions to atmosphere are made and the lines blown through at reduced pressure, usually with spectacular results.

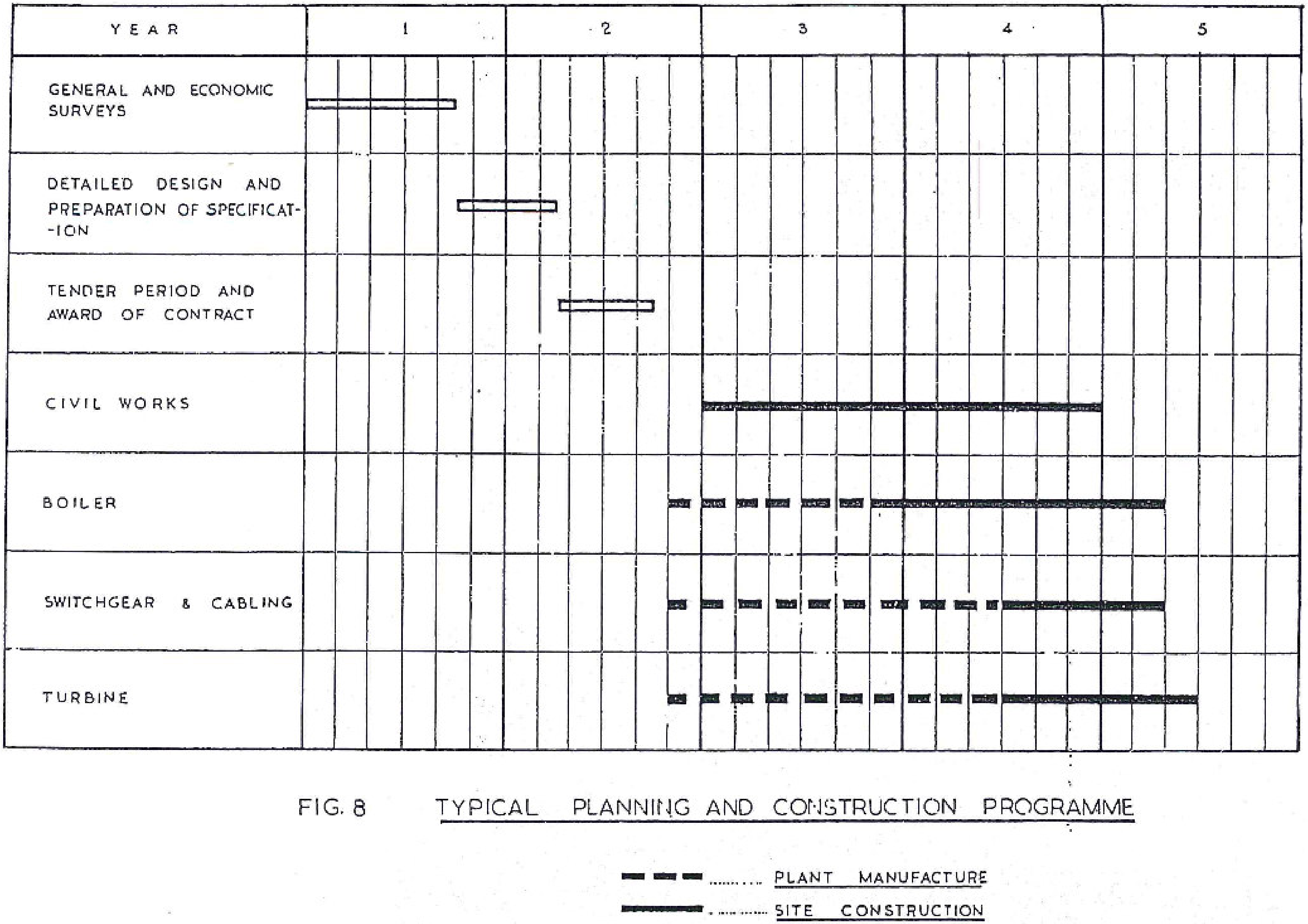


FIG. 8 TYPICAL PLANNING AND CONSTRUCTION PROGRAMME

Steam is now available for the turbine. During the preceding few week the water system of the turbine has been washed out to remove dirty and for eign bodies. Similarly, the lubricating oil system, which may hold up to 4,00(gallons of oil, has been flushed through followed by manual cleaning to ensur(that as much dirt as possible is removed before the machine is run. When stean is available the machine can receive its first run which, if successful, is usually of only a few minutes duration, following which the machine is shut down and all bearings examined.

This examination done, the machine is again brought up to speed and run with the generator short-circuited to dry out the winding, this process usually taking about three days, during which the alternator is operated at very close to its maximum permissible winding temperature. At the conclusion of the dry-out the machine is shut down, the windings pressure tested and the permanent connections made off. In the case of a hydrogen-cooled machine the gas system can now be tested and filled, following which the machine is ready for service. The great day arrives when the machine is synchronised with the network for the first time, the culmination of perhaps five years' work by a large number of people.

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