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SOME TYPES OF THERMAL ELECTRIC POWER PLANT AND THEIR APPLICATION TO CONDITIONS IN LATIN AMERICA

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Note: This text is subject to editorial revision.

Water power resources are a part of the natural wealth of a country and will always be regarded as a potential source of cheap power. It is, therefore, natural that their efficient utilisation will form the basis of planning for any scheme of electric power development, particularly in countries which lack indigenous supplies of coal or oil as fuels.

Therefore, in considering some types of thermal power plant and their application, the Author has purposely treated them as complementary to hydraulic power rather than just as alternatives.

There are, of course, the usual well known factors which determine the comparative economics, and the timing of hydro-electric power availability with relation to other means.

1. The higher capital cost of hydro-electric construction and which, to be economic, must be on a larger scale than is frequently warranted by the load demand in the early stages of development.
2. The greater time required for hydro-electric construction.
3. Distance from load centres which introduces the cost of transmission.
4. Relative costs of thermal and hydro-electric power as affected by the cost of fuel, imported or indigenous.
5. With imported fuels the continuing drain on foreign exchange resources whereas water is in a sense a renewable commodity.
6. The desirability of minimising dependence for power on imported fuel.

Very commonly today the pattern of development planning is Diesel power to meet immediate small scale demands followed by hydro-electric, but quite frequently Diesel, then steam and hydro-electric.

Before examining the factors determining the choice of the various types of thermal power plant it is proposed to review first the characteristics and present state of development of the main types of conventional prime movers which are available, viz:-

The Diesel engine
Steam plant
The gas turbine

/Consideration of

Consideration of the economies and present prospects for nuclear power has been purposely omitted as it obviously merits treatment as a complete subject in itself. Needless to say, nuclear power is an alternative to both hydroelectric power and other forms of thermal plant which is having increasing consideration as a main source of power for the future.

THE DIESEL ENGINE

The Diesel covers a very wide field of applications, from the largest slow speed marine engine of about 25,000 h.p. or more, to the smallest high speed unit as used for road transport. Within this wide range one is concerned, in the case of electric power generation, normally with units having a rating from a few hundred to about 3,000 horse power.

The range of engines available falls into two types as regards the operating cycle, four-stroke and two-stroke, and into two main speed classifications:

Lower medium speed from 300/500 r.p.m.
Medium speed 600/1000 r.p.m.

In broad terms, the trend of Diesel engine development has naturally been concentrated on:

1. Reducing the cost per horse power.
2. Increasing efficiency and therefore the fuel economy. Already the Diesel engine is probably the most efficient means of converting heat energy into useful electric power at present available to man. Efficiencies of up to about 37 per cent have been obtained on large engines.
3. Increasing the specific output and reducing the weight/power ratio.
4. Maintenance of reliability and availability and at the same time increasing both the periods between overhauls and the life of wearing parts.

Exhaust turbo-charging has become universally adopted and, together with an upward trend in speeds, have been the major factors in the reduction of cost per h.p. and the weight/power ratio. A 50 per cent increase in specific output over the naturally aspirated engine with mean effective

/pressures of

pressures of the order of 10.5 kg. per sq. cm. are quite common today. The trend of mean effective pressures is still upwards with corresponding increase in engine output and reduction of weight/power ratio. With increasing pressure of supercharging the air is delivered to the engine cylinders at an increased temperature and a point is reached where after-cooling becomes desirable. Suitable charge air coolers of small weight and size have been developed, and which require cooling water at about 25°C. The cooling of the air increases its density and enables a larger weight of air to be delivered into the engine cylinders thus allowing more fuel to be burnt, with consequent proportional increase in engine output.

Rotational speeds for a given output have been increased and 600/1000 r.p.m. is quite usual for engines of up to about 2,500 h.p. output. The result has been that quite large power units are available in two main speed classifications - lower medium speed 300/500 r.p.m. and medium speed 600/1000 r.p.m.

Under the stimulus of the requirements of electric traction, the V-form engine with its reduced weight/power ratio has been added to the family of medium power units available for electric power generation. With the V-form engine double the power can be obtained from its 12 or 16 cylinders, by comparison with the corresponding vertical in-line engine of 6 or 8 cylinders, from the same floor space requirements. Various other arrangements have been developed but within the medium power range the V-form engine has proved to be the most favoured.

Whilst the two-stroke cycle engine has been more widely adopted for large slow speed marine engines, particularly of the double acting and opposed piston type, the four-stroke cycle tends to predominate in the medium speed and power range. Theoretically, the two-stroke cycle has an inherent advantage in respect of specific output, but this advantage has not been fully maintained because progress of supercharging on medium power two-stroke cycle engines has been slower, partly due to problems associated with scavenging.

An advanced form of two-stroke engine which departs from the conventional vertical in-line and V-form, is the Napier "Deltic". This is an opposed piston engine with cylinders arranged in three banks to form an inverted

/equilateral triangle

equilateral triangle section with three crank shafts, one at each corner of the triangle. Each crank shaft carries two pistons. The three crank shafts are coupled through a phasing gearing at the drive end of the engine to a single output shaft.

The following are the main particulars of the "Deltic" 18-cylinder supercharged engine for electric power generation:

Output	2230 Metric H.P. continuous 1537 kW. approximate
Branke M.E.P.	7.1 Kg. per sq. cm.
Crankshaft speed	1600 R.P.M.
Output shaft speed (for electric power generation)	1500 or 1800 R.P.M.
Approximate weight	5490 Kg.
Weight/power ratio	2.46 Kg. per h.p.
Cylinder bore	130.17 mm.
Stroke	184.15 mm. x 2.
Specific fuel consumption	164.6 grams. per H.P. hour.

This engine is in fact of the high speed type as distinct from the two lower speed categories under discussion.

With the higher maximum pressures resulting from increased ratings, super-charging, etc., those parts of the engine affected by cylinder gas loadings have been suitably strengthened. Where higher bearing loadings of modern design give pressures in excess of fatigue strength of white metal, new techniques of bearing construction have been developed.

Thermal loading has naturally increased and this has necessitated special attention to piston and liner conditions from the point of view of heat removal, lubrication and wear.

Solid or direct injection of the fuel has now replaced air blast injection.

What is the measure of this progress? Quite clearly the three most important gains have been in respect of reduction in weight/power ratio,

/cost per

cost per h.p. and improvement in fuel consumption. A consequent effect of the reduced weight/power ratio is the additional saving which has been made possible in respect of building and foundation works. On the other hand, it would be natural to expect a somewhat higher rate of wear and tear with consequent effect on maintenance costs. There does not appear to be any conclusive evidence to indicate that maintenance costs are in fact increased on the higher speed modern engine. Even if the replacement of wearing components has to be made more frequently, the components tend to be cheaper and lighter and labour costs are reduced by the smaller weight and size of the components to be handled.

From recent operating costs examined for one large Diesel station in the Middle East, having some 7 MW. of modern 750 r.p.m. engines and 5 MW. of heavy slower speed engines which had been in service for 10/20 years, maintenance costs for the higher speed engines on one year of operation amounted to about 75 per cent of the costs on the older slower speed engines. At the same time it is agreed that the operating results of one station over one year cannot be taken as conclusive.

An example which brings out very clearly the advance made by the Diesel engine over the last 30 years is a station which commenced its life in 1931 with three 135 KW. Diesel sets running at 143 r.p.m. In 1958 in the same space occupied by two of these engines and in the same width of engine room, two 1,200 KW, sets operating at 750 r.p.m. were commissioned. In a period of nearly 30 years it had become possible to obtain almost ten times the power from the same floor space.

STEAM POWER PLANT

To appreciate more readily the present general pattern of development for steam power plant, a useful starting point is to look at the following summary of Accepted International Standards (International Electro-Technical Commission) for 3,000 r.p.m. 50 cycle turbo-alternator sets at Table I.

/ TABLE I

TABLE I

Accepted International Standards for 3,000 R.P.M. 50 cycle Turbo-Alternator Sets

Continuous Maximum Rating KW	Steam Pressure at Turbine Stop Valve Kg per Sq. Cm. gauge	Steam Temperature at Turbine Stop Valve °C
100,000	105	565
	88	520
60,000	64	485/500
and 50,000	or 88	520
30,000	64	485/500
and 25,000	or 43	450

Exhaust pressure 0.035 (river)
0.065 (cooling tower)

In addition to the above, one further British standard machine is quoted, a number of which have been installed recently or are on order:

120,000 KW	105 Kg per Sq. Cm	540° C. Reheat 540°C

The above range of machines covers the greatest part of today's requirements for 50 cycles but of course above this range there are a number of much larger 3,000 R.P.M. reheat turbo-alternators of from 200 MW. up to 550 MW. which are in operation on, or under manufacture for, large power systems.

Now it will be interesting to take one's mind back some 20, 30, 40 years and look at a few typical pioneer installations during that period. In 1914 a 70 MW. machine was built by Westinghouse and in 1926 a 208 MW. 3-shaft unit by American G.E. The first reheat turbine was a British unit by Metropolitan-Vickers of 20 MW. in 1917 at 33 Kg per Sq. Cm. 340°C., reheat to 260°C. High speeds have been common throughout this period - in 1929 an English Electric 30 MW. set at 3,000 R.P.M. was installed at

/West Ham

West Ham, London, and a Brown-Boveri 36 MW. set in Holland, and both are still in operation. The first machine of any size to operate at 540°C. was a 10 MW. 3,600 R.P.M. unit built in England by B.T.H. for the Detroit Edison Company.

As regards pressure, a topping set of 2.5 MW. at 64 Kg per Sq. Cm. was installed by English Electric at Bradford in 1930 and in 1938 a 54 MW. set operating at 33 Kg. per Sq. Cm. 500°C. by Metropolitan Vickers. The largest set in Europe by 1939 was a 105 MW. set installed at Battersea Power Station, London.

From a superficial look at this comparison it would appear that modern standards do not constitute any spectacular advance in capacity, pressures or temperatures. These pioneer installations were in a sense a probing forward and today's standards are to a large extent a consolidation of these early developments and experience by gradual progress in metallurgy, particularly in respect of the behaviour of alloy steels at high temperatures, which has made possible the general raising of the level of steam conditions.

During a period of 30 years, blading efficiencies have only increased by some 5-8 per cent and yet overall station thermal efficiencies on a unit sent-out basis have increased from some 17 per cent in 1922 to well over 30 per cent on the most recent modern stations, although 31.5 per cent had been reached on one large plant about 1936.

Progress in overall thermal efficiency has come mainly from improving the power plant cycle efficiency and has been in the following approximate proportions:

Temperature	315 - 565° C	13-17%
Pressure	14 - 105 Kg per Sq. Cm.	12-14%
Feed heating		6-12%
Reheat (where applicable)		2-6%

and from which it will be seen that the raising of initial conditions of pressure and temperature have been the main contributory factors. There is a limit to the extent to which these improvements can be realised, depending on the size of power system and, therefore, the optimum size of generator units at any stage in the development, because the temperatures and pressures

/that can

that can be economically adopted increase with the size of turbine unit. For example, in 1939, before World War II, for conditions obtaining in Great Britain the 30 MW unit at 43 Kg per Sq Cm. and 450°C. was considered as the most economic large unit for central power stations, but for the programme of expansion after 1945 it became the 60 MW. unit at 64 Kg per Sq. Cm. and 480°C, and later the 120 MW. unit, and larger units today. Yet the 30 MW. unit and its steam conditions are still in line with Accepted International Standards as given in Table I and would be appropriate today for a power system requiring generating units of this capacity.

The economic selection of alternative conditions of 64 Kg per Sq. Cm. 485/500°C. or 43 Kg per Sq. Cm. 450°C. would depend on the cost of fuel, its calorific value, load factor and the rate of interest on capital. A high cost of fuel or high load factor would influence the selection in favour of the higher steam conditions as being most economic.

Again depending on the cost of fuel, load factor, etc., the recommended standard conditions for a 10 MW. unit would be 43 Kg per Sq. Cm. 450°C. or 33 Kg per Sq. Cm. 425°C. Certainly 43 Kg per Sq. Cm. constitutes some advance on what would normally have been offered 20 years ago, but is nevertheless, well below the higher levels of present steam conditions which are economic on larger units today.

Over the last 15 years the main factors contributing to this general progress in the evolution of the modern steam plant are as follows:

Increase of Initial Steam Temperature

Maximum steam temperatures have risen from about 480°C. to a normal maximum in common usage today of 565°C. and has been brought about by a greater knowledge of the behaviour of steels at high temperatures and metallurgical research which is producing more suitable materials in the form of ferritic and austenitic steels. On non-reheat machines corresponding advance in pressure is limited by the necessity of maintaining moisture content of the steam in the final low pressure stages within about 12 per cent in order to avoid blade erosion.

/Increase of

Increase of Initial Pressure

Increase of pressure also contributes to increasing the available heat in the steam and therefore, improvement in cycle efficiency, but further advance in pressures as appropriate to the largest modern units can only be made by adopting reheating of the steam after expansion through a part of the turbine, again for the reason of limitation of moisture in the low pressure stages. Reheating also results in a gain in efficiency partly due to reduction of moisture in the steam in the last stages and other advantages such as reduced steam flow, condenser surface area, cooling water quantity, etc. On the other hand, it complicates operation and control, introduces additional pipework and adds to the cost of the boiler plant. In British practice today, the additional complications or gain in efficiency are not considered economically justified for unit ratings below 120 MW, although re-introduction of reheat as a policy in recent years commenced with 60 MW units at 86.5 Kg per Sq. Cm. 440°C reheat 450°C. It is of interest to note that with these steam conditions it was possible to obtain an equivalent heat consumption to that which would have been obtained on the same size of unit without reheating at a temperature of 510°C. thus enabling less costly materials to be used in the high temperature parts of the boiler and turbine.

Higher Speed

3,000 R.P.M. (3,600 R.P.M. for 60 cycles) is now accepted practice for the largest single line turbo-alternator sets so far constructed or projected. A rating of 60 MW had been reached by 1939, but further progress was limited by the size of the alternator with conventional air-cooling. At 3,000 R.P.M. , by comparison with 1,500 R.P.M., the turbine rotor diameter is reduced and this enables increased blade heights to be used in the high pressure stages which contributes to increasing the turbine internal efficiency by reducing the proportion of leakage through the clearance spaces. Greater heat drop through the turbine is provided for by increasing proportionally the number of stages of expansion. A certain point is reached where from considerations

/of efficiency

of efficiency and associated mechanical reasons, it may become desirable to increase the number of cylinders from one to two, or from two to three, as the case may be.

For a given heat drop the number of expansion stages required varies inversely with the speed and therefore, at 3,600 R.P.M. the number of stages are usually fewer and the machine shorter in length.

Hydrogen Cooling of Alternators

The introduction of hydrogen cooling of 3,000 R.P.M. machines from about 60 MW transformed the situation and made possible a rapid advance in the specific output of alternators. This has been due to the better cooling properties of hydrogen in respect of thermal conductivity and heat transfer coefficient. The output from a given amount of active material in a design can be increased by raising the pressure of the hydrogen.

A further advantage of hydrogen cooling is the reduced windage losses due to its low density. For this reason, in the U.S.A. on 3,600 R.P.M. alternators hydrogen cooling is used on units from about 20 MW capacity.

Boiler Availability

The story of the development of boiler design from the point of view of availability and the progress in the last 20 years or so towards improved availability is a long and complex one, and much has been recorded on the subject before technical societies. Briefly, it would appear that whilst the importance of boiler availability has always been appreciated, in earlier days as unit capacities increased and steam conditions advanced, compromise in design was perhaps naturally towards reduction in first cost by adopting higher ratings of combustion chambers and heat transfer surfaces. The effect on availability was to some extent marked by the provision of standby capacity and very frequently at least two boilers were used per turbine. Later, with the development of larger interconnected systems, considerations of reserve capacity caused more attention to be focussed upon the disparity between the availability of boiler and steam turbine plant. Also, a high order of availability is demanded by the modern unit arrangement.

/Accordingly, in

Accordingly, in the past 20 years great progress has been made in boiler availability and on the basis of continuous service between annual outage for survey and maintenance the boiler approaches closely that of the steam turbine.

The greatest problem with the steam boiler arises from the fouling and corrosion caused by the products of combustion of the fuel, coal being the worst offender. Design for high availability is centred around the combustion chamber and the combustion process and is concerned primarily with the suppression of volatilisation of those constituents in the fuel with corrosive or deposit forming characteristics; minimising the formation of deposits on the heating surfaces; and provision for their easy removal by cleaning when the boiler is on load.

Volatilisation of the harmful constituents can be controlled by the method of firing, the conditions with spreader stokers, pulverised fuel and the cyclone furnaces being more favourable than with the chain or travelling grate stoker.

The problem of deposits has been dealt with by re-disposition of the heating surfaces. The combustion chamber has been increased in volume and radiant heat absorbing surface in the form of water walls provided to reduce the gas leaving temperature to below the fusion and softening temperature of the ash, with corresponding reduction in the amount of convection surface. Convection tube and superheater tube surface is also spaced across the gas flow so as to prevent bridging by deposits. In fact today, convection heating surface as such has disappeared from modern designs of boiler units for such as 60 MW capacity and upwards.

The foregoing remarks refer particularly to conditions arising from coal firing, but the oil fired boiler is not entirely free from these problems having regard to the possible presence of vanadium, relatively high sulphur and other harmful constituents. In general however, a very much higher combustion chamber heat release is possible on oil fired units and this will be evident from comparison of the size and particularly the height of oil and coal fired units.

/The demand

The demand for high boiler availability has had to be met by a more liberal design but with increased first cost.

Unit Boiler and Turbine

There is general acceptance today of the unit boiler turbine arrangement up to the largest capacities. It is lowest in first cost, as it involves fewer and larger boilers than previously, and there is a saving in piping and valves. The unit arrangement is simpler to operate but presupposes a boiler availability equivalent to that of the turbine plant.

Whereas for large systems supplied by several power stations reserve capacity is vested in the system as a whole, for small systems dependent on one power station only, a fully interconnected arrangement of plant is preferred in order to give adequate operating flexibility during overhaul of a boiler or under emergency conditions, and with such arrangements any combination of turbines, boilers and boiler feed pumps can be operated together.

Standardisation

There has been a move towards greater standardisation in size of power units and steam conditions which for obvious reasons ultimately benefits the operator as well as the manufacturer.

General

For unit capacities below 60 MW there appear to have been few major changes in the pattern of development. The average level of steam conditions has tended to rise towards the appropriate economic level according to the size of unit, and also the final feed water temperature by increased use of regenerative or bled steam feed water heating.

THE GAS TURBINE

In many fields of application and in respect of low maintenance costs and competitive installed cost, the gas turbine has become established as a proved prime mover.

/Unfortunately, in

Unfortunately, in its simplest form as an open cycle machine comprising a compressor, combustion chamber and turbine, the cycle efficiency is still low by comparison with Diesel or large steam plant with advanced steam conditions, and as a practical proposition for continuous operation the open cycle machine is dependent on the use of a clean fuel.

More highly advanced cycles, of which there are a great number of variations possible, can be adopted using regeneration or recuperation by exhaust heat recovery, compounding, intercooling, reheat, etc., and by so doing efficiencies of up to about 34 per cent have been approached and are therefore comparable with Diesel or steam power. However, the advantage of simplicity, saving in space and low first cost, associated with the simple open cycle is thereby lost.

Efficiency

The amount of heat which can be converted into useful power output, and therefore the cycle efficiency, is determined fundamentally by the range of temperature of the working medium between inlet to the turbine and the temperature at which the exhaust heat is rejected. The upper limit of temperature, sometimes referred to as T.max. is ultimately dependent upon the availability of suitable steels which can be stressed at high temperatures without excessive creep. The actual design maximum varies with operating conditions to be met, and the required "running life" before blade replacement becomes necessary, is influenced by the time effect of creep of the steel at high temperatures. The permissible T. max. is also influenced by the detailed design of a particular machine and the provision made for internal cooling. The normal range of T. max., which varies according to the conditions affecting the selection of design temperature, is from 600 to 800°C. for "long life" turbines for power generation. The exhaust or lower limit of temperature on the simple open cycle is fixed by atmospheric conditions and percentage of loading.

At present the maximum overall efficiency practicable on the simple open cycle machine is about 22 per cent. Although unfavourable comparisons

/are frequently

are frequently made with steam plant, it must be remembered that this level of efficiency is about the same as is quite common with small steam power plants, even of modern design, particularly where cooling water temperatures are relatively high.

Although the available heat for conversion into power is limited by temperature conditions the main reason for the present low efficiency of the gas turbine by comparison with steam or Diesel is the high proportion of available heat required for the work of compression. The rapid advance of the gas turbine in recent years has largely resulted from improvements in compressor design and efficiency, combined of course with the availability of suitable high temperature materials.

Regeneration

To lower the exhaust temperature further it is possible to return some of the exhaust heat normally rejected, to the cycle with gain in thermal efficiency. This is done by means of a heat exchanger to transfer exhaust heat to the combustion air after the compressor, the process being known as regeneration or recuperation. This is the first step in the direction of the more complex but efficient cycle, and as shown at Fig. 2 ... The maximum efficiency which has been obtained on a regenerative cycle is of the order of 27/28 per cent.

Two-shaft Arrangement with Separate Power Turbine

The alternator is driven by a separate power turbine at constant speed. The compressor turbine can be run at varying speeds according to the load with consequent improvement in partial load efficiency. This arrangement also gives more freedom of choice of compressor speed.

Compounding

Efficiency is also dependent on compression pressure ratio but above a certain ratio, about 6:1, for mechanical and aerodynamic reasons it becomes necessary to compound the compressor. Compounding is only likely to be economic for units with larger outputs operating at higher load factors.

/Intercooling

Intercooling

With compounded compression, cooling of the air by water cooler between the first and second compressor stages reduces the volume of air to be compressed in the second stage and consequently the power for compression. Alternatively, it makes possible a greater mass flow of air which, with the combustion of additional fuel, gives increased output with some saving in first cost.

Closed Cycle Turbine

In its simplest form the closed cycle gas turbine consists of an air heater in which the heat of combustion is transferred to air as the working medium circulating on a closed system through the compressor, air heather and turbine. It has been developed for use on fuels such as pulverised coal, peat and agricultural waste, which would foul the turbine in an open cycle system.

Advantages of the Gas Turbine and Limitations

The principal advantages of the gas turbine can be summarised as follows:

Simple mechanically.
Simplicity of layout particularly in the case of the open cycle machine with or without regeneration.
Small space requirement per unit of output with consequent saving in building costs.
Relatively simple foundations.
Low first cost of complete installation.
Operating staff requirements are appreciably less than for steam plant and would tend to be less on larger power capacities than for Diesel plant.
Quick starting time from cold. The gas turbine unit can be started and put on load within 15/30 minutes, according to size.
Simple maintenance and low maintenance costs.

/From operating

From operating experience it has been established that maintenance costs are lower than for steam plant and appreciably so by comparison with Diesels. Out-of-service time for planned maintenance and overhaul is low, resulting in high availability.

The arrangement of operating cycle can be selected so that no cooling water is required. Where pre-cooling of air is adopted or on compound cycles with inter-cooling, water requirements are relatively small.

Auxiliary power requirements are small, of the order of 1 per cent by comparison with 5 per cent or more for steam plant.

The limitations to the application of the gas turbine at the present stage of its development are imposed by considerations of:

Efficiency and specific fuel consumption. Fuel consumption is higher than for the Diesel engine, but with a simple recuperative cycle it will not necessarily be very different from that obtained on the less efficient small steam plant.

Except in special circumstances, where cheaper heavy fuels can be treated with additives or it is practicable to arrange for routine internal cleaning or washing, the operation of the open cycle gas turbine is restricted to clean liquid or gaseous fuels.

The mass of air which can be handled by the compressor is proportional to the density of the air. Consequently, the open cycle gas turbine has to be derated as the altitude above sea level increases and also for high ambient air temperatures. The effect of derating is normally to increase the installed cost per KW. In climates where there is a higher electrical demand in the cold season, the limitation in output imposed by seasonal high temperatures may be of less importance.

Status of Progress

In 1954 it was recorded that over 100 gas turbines were in service or under construction by makers in U.S.A., Switzerland and Great Britain. Appreciable progress has been made since then and it is known that several makers in these countries have built well over 100 gas turbines each. Over

/the last

the last 20 years many thousands of hours operating experience has been accumulated. Most of the machines in service or projected are of the simple open cycle type, with or without regeneration. A number of closed cycle plants for operating on pulverised coal or other solid fuels have been completed or are on order.

There is, e.g., a typical British open cycle machine having an output of approximately 2,000 KW when operating on a simple cycle at 15°C. It is of the two-shaft type with separate power turbine, with a heat exchanger for operation on a regenerative cycle.

The largest units which have been made by the same firm are two of 20 MW. capacity each. These machines are of the open cycle four-shaft compound type with intercooling but without regeneration. Their primary duty is to supply power at variable frequency for driving blowers for a wind tunnel at the Royal Aircraft Establishment, Bedford, England. When not required for this purpose these gas turbines are available for peak load service on the electricity supply system.

FACTORS AFFECTING THE SELECTION OF TYPE OF THERMAL ELECTRIC PLANT

From consideration of the various features and characteristics of some of the types of modern thermal prime movers reviewed, suitability for, or limitations with regard to certain applications, will have already suggested themselves without necessity of much further elaboration. It therefore, remains to refer briefly to some of the factors which may determine the appropriate type of plant in particular circumstances or to meet special requirements.

Diesel Plant

For electrical load demands up to 10 MW in the early stages of development the Diesel has a number of special merits. It can be put into commission more quickly than steam plant, and within its range of capacity is lower in first cost than an equivalent small steam station and higher in thermal efficiency. The comparative installed costs of such capacity plant would be of the order of 140/170 U.S. dollars for Diesel and 190/220 dollars for steam.

Where development has commenced with Diesel plant, experience indicates that the optimum point for changing over to steam is when steam units of a minimum capacity of about 10 MW. can be economically justified, and similarly for initial development where the demand to be made approaches 10 MW. This proposition is made for general guidance, although there are examples where steam development commencing with 5 MW. units has been economically justified.

A further advantage of the modern Diesel for such initial development is its mobility because of its low weight/power ratio and compactness, which facilitates its transfer to other developing areas. Of particular application to such requirements are special mobile units mounted on rigid skid type under bases. The power units of up to about 1,000 KW, capacity are largely self-contained and complete with starting equipment, air blast radiator cooling and switchgear. Such a power unit requires only a light concrete raft, good hard ground or a packed gravel bed for a foundation and a simple type of light weight prefabricated building. Frequently the Diesel plant will be retained in care and preservation for emergency or peak load service after power has become available from larger scale developments of steam or hydro-electric.

Thus it will be clear that there is a field where the Diesel is pre-eminently suitable. Its thermal efficiency is only to a small extent affected by size and speed, within the range being considered for power generation and is comparable with that of the most modern steam plant and a good deal higher than the average. Therefore, in the early stages of a development it makes possible the production of power at rates which compare favourably with the cheapest electric supply.

With the trend today towards power planning by a national or other large supply organisation, naturally one hopes that there will not be a repetition of the indiscriminate growth of small and scattered Diesel plants by a multiplicity of small operators, which has been so much a characteristic of the past. Today, these often present a problem when the needs of larger development arise because of the lack of standardisation, unsuitability for retention, and the cost of writing-off units with a high percentage of useful life remaining.

There is a ten 12-cylinder charged air cooled supercharged V-form Diesel alternator sets operating at 750 R.P.M. in an electric supply station in Bangkok, Thailand, the total installed capacity being 10.6 MW.

Combined Thermal and Hydro-electric Generation

In countries possessing both water power resources and supplies of indigenous fuels such as coal and oil, whilst hydro-electric will form the basis of planning, the magnitude, form and the phasing of such development will be related economically to the cost of thermal generation, and the effect of particular conditions on overall cost and the best use of investment resources. It can be said that no country, even with large water power potential supplemented by fuel resources, has developed hydro-electric power to the exclusion of thermal. Even in Switzerland, where water power is plentiful and cheap, about 6 per cent of capacity is provided by thermal plant, and with imported fuel.

Dry periods or freezing of watersheds in abnormally severe winters which cannot be foreseen from statistical records can prejudice the reliability of hydro-electric power.

/By virtue

By virtue of the different characteristics of the two types of generation, thermal plant can fulfil to some extent a complementary function to the development and operation of hydro-electric power with the following being some of the advantages from a combined system:

Increased reliability of the system as a whole. The availability of interconnected thermal plant does give some measure of insurance against the hazards of Nature and the vulnerability of long transmission lines.

Economy of the combined system by improvement of the operating efficiency of thermal plant and reduction in transmission losses. Thermal plant can be located close to the load areas, which is not normally possible with hydro-electric plant. In some circumstances it may even be economic to plan such a thermal plant to be operated on peak load in order to reduce the investment in the transmission lines from considerations of uneconomic load factor. In association with a low cost run of the river plant, thermal power can make up the deficiency between availability of water power and load demand, thereby permitting maximum water utilisation, and increasing firm output of the system. In this way thermal plant fulfils an analogous function to the storage plant.

Overall saving in invesment, particularly by limiting thermal power development.

Where steam plant is used on a combined system, for maximum economy it is normally operated on base load at a high load factor under steady load conditions. It will be appreciated that steam plant is less well suited to operation on peak load characterised by low load factor, and because of standby losses from banking of boilers to keep the plant in a state of readiness.

On smaller systems or where thermal capacity required at a particular point is of the order of 10 MW or less, Diesel plant is to be preferred and is more flexible in that it is quite well suited to peak load operation by reason of higher efficiency and quick starting.

/For conditions

For conditions where thermal plant is required only for peak load or emergency purposes, the simple cycle gas turbine has a strong claim as the most suitable thermal prime mover, by reason of its advantages already enumerated. With not a very high utilisation factor when applied to peak load or emergency service its main disadvantage of fuel consumption assumes less importance.

An interesting example is the recent Port Mann Station of the British Columbia Electric Company, which is understood to be the world's largest gas turbine station and is of 100 MW capacity comprising four - 25 MW simple open cycle gas turbine units. The normal plant on the system is exclusively hydro-electric with widely separated power stations and long transmission lines. The gas turbine plant is situated near Vancouver and is for emergency service as a safeguard against water shortage or transmission failures. Gas turbine plant was selected by reason of capital cost, minimum operating personnel, the simple cycle facilitating remote control which is effected from the load despatching centre in Vancouver, and rapid readiness for load (within 30 minutes). With a low utilisation factor, efficiency was considered of less importance. The fuel to be used is natural gas, with provision for operation on crude oil.

The design and planning of operation of a combined thermal and hydro-electric system is a complex one if optimum overall results are to be achieved, and will be appreciated by engineers who have been concerned with such developments.

The Dry Cooled Condensing System for Steam Power Plant

A new development in cooling towers makes it possible to extend the application of steam power plant to areas where the scarcity of water has previously made this impossible, even to the extent of supplying only the small percentage of make-up required for the evaporative cooling tower, or where such scarcity imposes limitation on extension of existing plant.

The air cooled or (as it has become known in England) the "dry" cooled condensing system, was first envisaged by Professor L. Heller and Mr. L. Forgo, of Budapest, and outlined by them at the 1956 World Power Conference in Vienna.

/The System

The System Arrangement

The main features of the system can be summarized as follows:- The turbine exhaust steam is condensed in a direct contact or jet condenser by the circulating water after it has been cooled in the air coolers. The mixed cooling water and condensate are drawn from the condenser by the circulating water extraction pump at the discharge from which the boiler feed water is drawn off. The circulating water passes through the cooler circuit and thence to the condenser sprays. The system is entirely closed and therefore, no make-up water is required as with the conventional evaporative cooling tower.

On such a system it is important that there should be no air leakage into the closed system because of the effect on vacuum and the problem of detection of leaks. This requirement is met by operating the system so as to maintain the pressure at all points beyond the extraction circulating pump on the circulating water system slightly above atmospheric pressure. This pressure condition is reconciled with condenser pressure by interposing a water turbine which is coupled to the circulating water pump to absorb the surplus pressure before the sprays.

Coolers

The Heller cooler - which is of patented design - is of special interest since it is on this unit that the successful development of the "dry" cooling tower system largely depend. The cooler is made entirely of aluminium, is simple, effective and not expensive to construct, and is built up from standard elements.

The cooling element in the Heller cooler [illegible] is specially designed and constructed to ensure a high rate of heat transfer. The cooling fins are in the form of slotted aluminium strips, the purpose of the slots being to prevent the thickening up of the boundary layer of air which would form with air flow over an equivalent flat surface. In this way heat transfer is improved without excessive air pressure drop.

The arrangement is such that [illegible] the air flow is induced by natural draught through the cooler columns mounted around the base of a conventional chimney type tower. Alternatively, the tower can be of the mechanical induced draught type with a fan in the diffuser outlet. The main factors affecting the economic choice of natural or mechanical draught are the size of plant, rate of interest on capital and fuel cost. For maintenance purpuses, and where necessary as a safeguard against freezing, the coolers are divided into sections, each of which can be gravity drained into a tank situated within the basement area of the cooling tower. With the mechanical draught type of tower the fan can be driven by a multi-speed motor and the fan run at a reduced speed during periods of partial load, or low air temperature.

Applications

The "dry" cooled condensing system is particularly applicable to circumstances where there is a problem as to the availability of an adequate cooling water supply, or the cost of providing a supply is high. It also makes possible the siting of a station simply by consideration of the most economic location with relation to fuel supplies and the load areas to be served. Its performance is entirely independent of atmospheric humidity, whereas the evaporative cooler increases in size and cost with high humidity, which is of particular significance in hot climates. The question of whether or not to instal a "dry" cooler is mainly one of economics. The British Central Electricity Generating Board recognising the potentialities of the scheme caused investigations to be made, as a result of which an order has been placed for a 120 MW turbo alternator set using the system, with the object of gaining experience on an installation of present day commercial standards as to capacity and steam conditions. This set, which is served by a natural draught tower, is being erected alongside four sets having the same output and steam conditions but each working with a natural draught tower of the conventional evaporative type.

The Gas Turbine

The gas turbine is quite rapidly establishing itself in three main fields of application where its advantages outweigh considerations of thermal efficiency. They are as follows:

/Where cheap

Where cheap and clean fuels are available.

The most common of such fuels are natural gas, oil refinery tail gas and sewage gas. The oil fields of the Middle East and Venezuela and the natural gas fields of Canada are examples of where a large number of open cycle gas turbines have been installed for various purposes. In addition to the use for normal power generation, gas turbines are being used for direct drive for pumping and boosting on natural gas and oil transmission pipelines. Under desert conditions independence of water supplies has been a main factor determining the selection of the gas turbine.

Peak load and emergency service on electrical power system.

A typical installation of this type in British Columbia has already been mentioned. The value of the gas turbine for this duty is being increasingly recognised in the U.S.A. Efficiency, even with high cost distillate fuels, is of less importance because of the low utilisation factor.

Integration with Industrial processes.

There is considerable scope for the economic integration of the open cycle gas turbine with various manufacturing processes, particularly in the steel and chemical industries, and oil refining. The gas turbine is able to use waste gases and at the same time supply where necessary useable heat from the exhaust gas for process work, compressed air and mechanical power. In this way, a high overall cycle efficiency can be obtained making the gas turbine an attractive investment.

A number of such integrated gas turbine installations have been adopted in the steel industry, notably in France. The turbine operates on blast furnace gas and regenaration is provided. Arrangements can also be provided for air to be taken from the turbine compressor to supply air for blast furnace blowing. For example, there is what is in effect a process installation associated with sewage disposal in the Northern Outfall Works of the London County Council. The plant operates on sewage gas of about 70 per cent methane

/content. Three

content. Three of the sets, each of 750 KW., are used for power generation and the remaining five, each of 960 BHP, drive blowers for supplying air for activation of the sewage sludge. The gas turbines are of the open cycle two-shaft type and incorporate regeneration. Exhaust heat is also used for provision of hot water for the sludge digestion tanks. It is estimated that waste heat recovery improves the overall thermal efficiency of the plant to about 50 per cent.

Operation on Residual Fuels

As yet, there is no final solution to the problem of burning cheaper residual fuels, which problem arises particularly from the deposit forming and corrosive properties of vanadium, sodium and other salts at temperatures above about 650°C. Above this temperature hard scales are formed which are not amenable to any form of removal by washing and the vanadium pentoxide produced causes the corrosion. At temperatures lower than about 600/650°C. vanadium corrosion does not normally occur and the deposits are water soluble.

There are some installations designed for, or in operation on, residual fuels, but these are relatively few. Additives to the fuel are also being used on some installations, the most common one being magnesium sulphate, and these have the effect of modifying the reaction of the vanadium and sodium salts so as to render them innocuous.

The use of residual fuels with additives requires in effect an additional process to be provided with the power plant for the preparation and treatment of the fuel. This involves considerable extra equipment, such as treated and untreated fuel storage tanks, heat exchangers, centrifuges, settling tanks, etc. It remains to be proved from operating experience how far the use of additives will be an economic solution. In other cases where residual fuels are used without additives, there are usually special conditions making their application practicable, for example:

> Operation at a low T. max., where the resulting lower efficiency can be accepted.

/Availability of

Availability of residual or clean crude oils with low ash and vanadium content which is below harmful proportions.

Where plant operating schedules are such that machines can be taken out of service as a regular routine for internal cleaning, or where water washing is practicable during operation.

CONCLUSION

As an alternative or complementary to hydro-electric power, thermal plant will always have an important part to play in any scheme of electrical power development. The historic position of steam and its suitability for the largest scale power generation is too well known to have needed elaboration. The Author has therefore sought to direct attention to some marginal fields in which the Diesel engine, particularly in the early stages of a development, and the gas turbine have inherent advantages and special claims to consideration.

Whilst the trend of overall thermal efficiency is towards 40 per cent for the very large steam power units now going into service or projected, using high steam temperatures and pressures with reheat, no such spectacular advance can be expected for the smaller steam plant. The overall thermal efficiencies economically obtainable with conventional regenerative cycles will continue to be limited by the more moderate steam conditions as appropriate to the unit capacity.

The gas turbine will no doubt make progress in many fields of application in the future. What is happening on gas turbine development and application today is perhaps analogous to that of the steam plant in the period between 40 and 20 years ago.

It is hoped that the brief and general review of the present stage of development of the Diesel engine, steam power unit and the gas turbine will have been helpful in suggesting their suitability in various appropriate fields of application.

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