PEAK LOAD AND EMERGENCY POWER PLANTS

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SUMMARY

A proposal to use existing jet propulsion engines either singly or in multiple to provide hot gases to drive power turbines for electricity generation is considered.

Their maintenance and operation is shown to be reasonable for peak load and emergency duties, and a financial estimate shows that such a scheme for a 20,000 KW winter load set, will produce electricity at a lower cost than a steam plant.

The possibilities of such sets as standby units are discussed, and it is suggested that by designing and manufacturing the power turbine part in advance, in a range of sizes to suit existing important generating sets, and providing strategically-placed pools from which jet engines suitable for driving the power turbines can be despatched as necessary, a large measure of protection against loss of generating capacity by natural hazard and enemy action can be provided, at a very low cost.

INTRODUCTION

At present there is in Canada a considerable shortage of peak load electrical power. New construction is under way to rectify this, but the increasing industrialisation of parts of the country is continually increasing the demand and as defence production gets under way, the situation may be expected to worsen. At the same time, preparedness for defence makes it essential to envisage the possibility of destruction of existing hydro or thermal power stations.

In this report a scheme which, it is believed, was first proposed by Dr. A. A. Griffith, F. R. S., in the United Kingdom, is examined. Dr. Griffith suggested the use of aircraft jet engines, either of current or semiobsolescent types, as gas producers to drive turbines. What a jet engine does is to produce a stream of gas at high speed and may thus be considered as analogous to a steam boiler plant and nozzles which produce a stream of steam at high speed which does work on the runner blades of a turbine.

The possibilities of using existing jet engines to drive turbines are considered and the cost analysis shows that for low utilisation plants the very low capital cost more than makes up for the high fuel consumption and a discussion of other factors brings out many other advantages of the scheme.

THE BASIC PROPOSAL

The basic scheme suggested by the writer to suit Canadian conditions is to use a number of standard jet propulsion engines to supply hot gases to drive a simple turbine which can be directly coupled to an alternator. The number of engines will depend upon the power required, but in all cases, a single stage power turbine would be used.

All jet engines, of any type, provide a stream of hot gas, having a speed between 1600-1900 ft/sec. Different engines pass different mass flows, varying from 50-100 lb/sec. and use more or less fuel. The potential work capacity of those streams is enormous. The kinetic energy of a stream at 1600 ft/sec. is equivalent to 72.5 horsepower per lb/sec. of gas, so that if we can convert 85% of it to useful work, a jet engine of 50 lb/sec., which is a very small jet engine, is capable of yielding some 3070 horsepower.

We could thus imagine a series of power turbines designed to use the gas from any number of such jet engines between 1 and 7, which would provide from 3000 to 21,000 HP.

DATA

In order to permit any analysis, some starting data is necessary.

In this report the Rolls Royce 'Nene' is considered, as the writer has fairly full data, and as it is an engine which is in large scale production in Europe, the U. S. A., and Australia.

It is presumed that the engine will be run at the manufacturers' "unrestricted cruising" rating, thus giving a considerable margin in hand over the "combat" ratings used in aircraft.

Under these conditions, Table I gives the essential performance data, based on a final throwaway velocity of 400 ft/sec., and 87% turbine efficiency.

Ambient Air Temp. °F.	Mass Flow lb/sec.	Jet Velocity ft/sec.	B. H. P.	Fuel Consumption lb/BHP/hr.
60	84.5	1610	5030	0.900
0	93.5	1880	7810	0.725

Table I

Table II expresses this in terms of KW and BTU's/KW hr.

Ambient Air Temp °F.	KW	BTU's/KW hr.
60	3750	22,900
0	5820	18,400

Table II

It will be noted that the heat rate is just about twice that of a fairly modern steam plant. The cost of fuel, using aviation kerosene will be .156 cts. per 1000 BTU's, but there is much experimental evidence that in stationary service a cheaper fuel, costing .115 cts. per 1000 BTU's may be used. When natural gas is available the fuel cost will be much less.

ARRANGEMENT OF A PEAK LOAD UNIT

From Table II, it will be seen that by using four Nene jet engines 23,300 KW will be produced on a cold day, and 15,000 KW on a normal day. This suits the load quite well, since the peak loads will occur in the winter time. For such a unit it is proposed to mount the four engines with their centre lines arranged on the surface of an imaginary cylinder of about 9 feet diameter. The four jet pipes will feed into a sheet metal nozzle box picking up the four circular pipes and feeding the gas into the turbine annulus at a suitable angle of swirl. The simplest turbine runner would be a disc of about 8.5 feet diameter, rotating at 1800 RPM, and having blades about 6" long at its periphery. The turbine will be designed to have very little reaction at the blade roots and since an exhaust diffuser will be used to recover the kinetic energy of discharge, the pressure at the blade roots will be subatmospheric, so that the disc can be air cooled simply, permitting the use of ferritic materials in view of the very low stresses that are involved. With an air cooled disc the blades might reach a maximum temperature of some 550° C., and although lowly stressed, would require austenitic materials. Alternatively it is simple in the larger sizes to provide water cooled disc and blades, in which case all materials would be ferritic.

The power turbine consists simply of the disc and blades, overhung on a suitable shaft, a sheet metal nozzle box and sheet metal exhaust ducting. Other than the disc and blades, no difficult castings or forgings would be involved.

OPERATION OF THE UNIT

Apart from the jet propulsion engines, the only accessories would be a lubrication system for the turbine bearings, and the air or water cooling system. The whole power plant (excluding the electrical side) could easily be driven by one man, and could be started up and put under load in a matter of minutes. When generating, the engine throttles would be controlled by the governor on the power turbine shaft to hold constant frequency. For part load conditions, if required, one or more of the jet engines can be shut down, running the power turbine under partial admission, although the possibility of blade vibration must be taken into account in the design. In the event of a failure of one of the jet engines under load, it may be shut down and replaced by a spare engine without shutting down the turbine. The installation could and should be designed to permit an engine change in less than 15 minutes so that the only effect of failure would be a 25% loss of power for this time.

RELIABILITY OF JET ENGINES

At present the so-called service life of good jet engines varies between 300 and 600 hours. At the end of this period they are dismantled, inspected and reassembled with repaired and replacement parts as necessary. An engine operating in an aircraft was a much more severe life than one operating at steady power. It is proposed to limit the engine to a turbine inlet temperature lower than that used in aircraft for take off or combat, which means a very considerable reduction in creep, while the fact that the power plant will not be called upon to accelerate and decelerate in rapid succession is a further factor conducive to long life. Finally many turbine troubles arise as an effect of the pressures at low altitude. There is every reason to believe that an engine used for a power plant should have overhaul periods considerably greater than found in military service. In the cost analysis that follows, however, no such improvement in service life has been assumed.

ECONOMICS OF PEAK LOAD PLANT

To illustrate the possibilities of the scheme, the following is a preliminary rough analysis of some of the costs of a peak load plant using four 'Nene' jet engines and a power turbine, in a 22,500 KW power plant. This is compared with a steam power plant of the same capacity.

The cost of a European-built 'Nene', F.O.B. Montreal, is about £7500, so that four will cost $90,000. A generous allowance for the power turbine is $10,000 and to be on the safe side we allow for an additional $20,000 for engine mounts, fuel system and control instruments, making a total cost of the turbine parts $120,000 or $5.34/KW.

We can now construct Table III, giving itemised costs, compared with those of the steam plant.

Item	Steam Turbine $/KW	Proposed Gas Turbine $/KW
Land	------	------
Buildings	51.0	15.0
Condenser Water Supply	3.66	
Coal Handling	4.38	
Ground Improvements	2.92	0.5
Boilers, Economisers, etc.	24.4	
Piping	13.1	
Other Boiler Equipment	12.4	
Turbine	13.7	5.34
Generator	13.7	13.7
Condenser	6.9	
Foundations	3.6	1.0
Electrical Equipment	19.5	19.5
Transformers	6.55	6.55
Miscellaneous	1.45	.25
	175.90	61.84

Table III

No price has been given for the land. The fact that the gas turbine plant needs no water may make its land less expensive, and may save on transmission line costs and losses by permitting location of the plant near the load.

The capital outlay for 22,500 KW is thus $\$3.96 \times 10^6$ and $\$1.39 \times 10^6$ respectively for the steam and gas turbine plants.

In considering the financing arrangements there are many variables, but for simple illustrative purposes it is assumed that all items other than the gas turbine will have a scrap value of 5% of their initial cost after 20 years, while the gas turbine is assumed to have no scrap value after 6000 hours running or 20 years, whichever is sooner. Interest is assumed to be 5% and the annual charges cover this together with sinking fund payments, with 5% interest, to retire the debt. We can thus construct table IV, giving the fixed charges for the two cases.

Hours run per year	Steam plant Annual Charges $	Gas Turbine plant annual charges		
		For Gas Turbine $	For rest of plant - $	Total $
100	334,000	10,100	107,000	117,100
200	334,000	10,100	107,000	117,100
300	334,000	10,100	107,000	117,100
400	334,000	12,700	107,000	119,700
500	334,000	15,000	107,000	122,000
600	334,000	18,420	107,000	125,420
800	334,000	25,500	107,000	132,500
1000	334,000	33,000	107,000	140,000

Table IV

For estimation of running costs we will assume that both the steam and gas turbine power plants average an 18,000 KW output. This, of course, is rather high. It should be borne in mind that since we have multiple gas producers, the gas turbine can be run at part loads with very nearly the same efficiency as full load so that the heat rate of the gas turbine will not fall very much. It is assumed that the average heat rate of the gas turbine is 20,000 BTU's/KW hr., and for the steam plant 14,000 BTU's/KW hr. For the gas turbine fuel costs .115 cts. per 1000 BTU's and coal for the steam plant .0525 cts. per 1000 BTU's. Table V then gives running costs in cts. per KW hr. No allowance is made for the cost of ash removal in the steam plant.

	Steam Plant ¢/KW hr.	Gas Turbine Plant ¢/KW hr.
Fuel	.735	2.300
Lubricating Oil	.005	.005
Maintenance	.014	.028
Operating Staff	.060	.012
Total	.814	2.345

Table V

In constructing Table V no allowance has been made in either case for operating crew for the electrical side. The maintenance figure for the steam turbine plant probably should increase at very low utilisations, since boiler and condensers will probably deteriorate more under intermittent service than at steady conditions.

If we now convert the figures for capital charges in Table IV to cts. per KW hr. we can draw up Table VI showing both the fixed charges and operating costs.

Hours Run per Year	Steam Plant			Gas Turbine Plant		
	Fixed Charges	Running Costs	Total ¢/KW hr.	Fixed Charges	Running Costs	Total ¢/KW hr.
100	18.55	0.814	19.36	6.50	2.35	8.85
200	9.27	0.814	10.08	3.25	2.35	5.60
300	6.18	0.814	6.99	2.17	2.35	4.52
400	4.63	0.814	5.44	1.66	2.35	4.01
500	3.71	0.814	4.52	1.36	2.35	3.71
600	3.09	0.814	3.90	1.16	2.35	3.51
800	2.31	0.814	3.12	0.92	2.35	3.27
1000	1.86	0.814	2.67	0.78	2.35	3.13

Table VI

Thus considered as a peak load or standby plant, the proposed gas turbine plant produces power more cheaply than the steam plant up to a utilisation of 700 hours/year. Of course, variations in fuel price, or in interest charges, and a more complete and detailed study will change the utilisation at which the costs are equal. Apart from the direct costs there are two other factors to be considered. The first is that provided the alternator and switch gear were available, the time for construction of such a plant would be a matter of months rather than years as with a steam plant. The second factor is that if such a plant were erected at the existing steam station, a large fraction of the waste heat can be utilised for feed water heating, thus permitting the steam normally bled for this purpose to expand fully in the steam turbine. There is an excellent precedent for this in Oklahoma where a gas turbine with feed water heater using the exhaust gas has markedly improved the overall turbine heat rate.

EMERGENCY PLANTS

So far we have been considering the possibilities of power plants for use by either utility companies, or a large consumer, with a view to producing peak load or standly power cheaply and quickly.

From the defence viewpoint the factors are rather different. Failure of a power plant may have serious repercussions on industry. In the event of air raids, stations are obviously one of the prime targets and the consequences of stations being put out of action, for both domestic and industrial considerations, are very serious. The provision of cheap standby sets, which can easily and fairly cheaply, be placed underground may well recommend itself.

Another consideration is the provision of alternative power sources for existing generator units. It seems probable that in the event of a raid on a steam station, serious damage is more likely to occur to the boilers, condensers and turbines than the alternator, while in a hydro system, a lucky hit on a dam or penstocks may completely prevent generation for a relatively long period. It might be well worth while designing a suitable gas turbine to suit the alternators at all stations where a forced outage would be serious.

In the case of steam stations, where relatively high speed generators are used, this presents no problem and probably very few standard designs would be required. The cost would be very low, and there is no necessity to provide enough jet engines for all the stations. Instead a central pool would be held so that they could be despatched as necessary.

For the big hydraulic turbines, the problem is rather more difficult. A unit of 45,000 EHP or 33,500 KW would require say eight Nene jet engines, which is no problem, but the alternator will be designed to run at about 100-120 RPM. A direct gas turbine drive would require a large unit with many stages, alternatively a single stage could be used, together with a gear box. However in considering either of these possibilities, and bearing in mind that many hydraulic turbine generators are vertical, with the drive from underneath, it would appear that the cheapest and best scheme is to provide a new alternator at 1800 RPM which can be installed in a suitably sheltered spot some little distance from the main station. It would then be available for peak load as well as emergency purpose. A more detailed investigation is necessary to decide the best solution.

CONCLUSIONS

(1) It is shown that a gas turbine power unit can be easily and cheaply constructed, in large sizes suitable for electricity generation, using existing jet engines.

(2) The technical and production resources required are small, and no great development problems can be seen.

(3) A preliminary study of the costs shows, that for low annual utilisation times, such as are met with in peak load service, the low first cost of the gas turbine as compared with a steam plant more than compensates for higher fuel costs, permitting cheaper power generation.

(4) Such units might well be considered for emergency or stand by plants to guarantee continuity of power supply in emergencies.