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GAS TURBINE INSTALLATIONS IN NUCLEAR POWER PLANTS IN SWEDEN

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ABSTRACT

At each of the four nuclear power stations in Sweden (Ringhals, Forsmark, Oskarshamn, Barsebäck) gas turbine generating sets have been installed. These units are normally used for peak load operation dictated of grid and system requirements but they are also connected to supply the electrical auxiliary load of the nuclear plant as reserve power sources. The gas turbines have automatic start capability under certain abnormal conditions (such as reactor trips, low frequency grid etc) but they can also be started manually from several different locations. Starting time is approximately 2-3 minutes from start up to full load.

RESUME

Des turbines à gaz sont implantées à proximité de tous les quatre centrales nucléaires en Suède (Ringhals, Forsmark, Oskarshamn et Barsebäck). Normalement ces machines sont accouplées pousréprondre aux besoins spécifiques des pointes, mais ils ont aussi une utilisation intermédiaires entre les machines et la centrale nucléaire somme une source de l´énergie de secours.

Les turbines télécommandées (par un arrêt d´urgence d un réacteur on une déviation de fréquence) ou commandées à la main sont capables d atteindre leur plaine charge deux à trois minutes aprés le démarrage.

INTRODUCTION

Sweden has four Nuclear Power Plants located in the southern half of the country, two on the east coast and two on the west coast. Two of the nuclear power plants, Ringhals and Forsmark are owned by the Swedish State Power Board and the two others Oskarshamn and Barsebäck by private companies Oskarshamns Power Group Limited (OKG) and Sydkraft AB. The Swedish 400 KV national grid system connects the four nuclear power plants to each other and to the remaining sources of production, principally hydro power which is situated mostly in the northern part of the country. These are all directed from a central grid control which is located at Vattenfall head office in Råcksta a suburb of Stockholm.

Grid calculations have shown that it is justifiable to install a certain percentage of the total capacity of a large power system, such as ours, in the form of gas turbines which are able to start quickly and provide peak load power. When large production units trip off the grid it is necessary to compensate quickly for this loss of power and drop in frequency. Primarily this increase is done by hydro power but as the hydro power stations are mainly situated in the north of Sweden and heavy consumers in the south, transmission and stability problems can occur. In this application gas turbines are a good alternative due to the short run up time and high peak power availability which in times of low water reserves hydro power cannot give. Under normal circumstances the operating period for gas turbine plants are less than 100 hours per year. System and grid requirements usually dictate that peak load units should be installed adjacent to the load producing centres such as nuclear power plants. The transmission system is usually strong and therefore easier to connect the units to the grid. A harbour is usually situated nearby for ease of fuel transportation. The gas turbines can also be used as stand by power sources for the nuclear power plants in the event of a grid failure and/or turbine house load operation.

The Swedish authorities demand that two installed gas turbine units or at least two halves of two separate units are available before start and during running of the nuclear power plant. The gas turbines are connected to the local 130 KV grid (in Forsmark 70 KV) and can be started without any external supplies.

At each of the four nuclear power stations in Sweden gas turbine generating sets have been installed. The nuclear power plants in Forsmark, Oskarshamn and Barsebäck have similar gas turbine installations and use them in similar ways. Ringhals, however has gas turbines supplied by a different manufacturer and they are also used in a different way. The description has therefore been divided into two parts. One for Ringhals and one for the other three nuclear power stations.

Starting reliability, number of starts and operating hours are all noted in the supplied tables (Table 1).

FORSMARK, OSKARSHAMN, BARSEBÄCK.

General

Situated adjacent to each of the three BWR nuclear power stations is a gas turbine plant. Each of these plants is equipped with 2 "Stal Laval PPD4 Power Pac Duet" gas turbines which are each rated at 40 MW. The units are identical and are used in similar ways with regard to standby power but in the case of peak generation their usage is slightly different. It is for this reason that this description will be more of a general nature outlining their use as standby power sources and also a brief description of the unit itself.

The gas turbines were originally designed for peak load power when grid requirements necessitated this, also for start up and standby power to the nuclear power plant. High fuel prices have governed that only peak load production for operating periods of 20-30 h/year is typical. This is over and above the operating periods demanded by the authorities.

Peak load power

When the grid requires more electrical power production the gas turbines can be started manually and syncronized to the grid in about 2 minutes. Three operating modes can be used. "Peak power" mode means that after a manually initiated start the unit automatically runs up and syncronizes and leads up to a desired load following a loading curve which can be selected from a range of different loading curves. "Operating double" means that both ends of the unit start and syncronize. The loading must be done manually. "Operating single" means that only one end of the unit starts and syncronizes. Loading must be done manually. All starts for peak load power are initiated by request from the central controlroom in Stockholm. The actual start is carried out from the remote controlroom in the nuclear power station or from the local controlroom at the gas turbine plant. In Forsmark the start is automatically initiated from a low frequency relay (about 5 seconds time delay). If one of the units should be in operation when something occurs requiring standby power, then the unit can be disconnected from the grid and transferred to the standby power system without having to be stopped and then restarted. This means that the unit must be capable of full-load rejection without tripping due to overspeed.

Starting power

The nuclear power plant is not allowed to operate without both 400 KV and 130 KV (Forsmark 70 KV) grid in service. Gas turbines cannot in this case provide the required starting power.

The authorities demand further more that one gas turbine unit or two halves of two separate units are available before starting the nuclear process.

Standby power

The operational safety of a nuclear power plant depends to a great extent on the constant availability of the electrical supplies. An electrical failure within the station can cause tripping of the generator from the external grid and transferring over to house load operation. In some circumstances this can be unsuccessful due to disturbances in the various control systems being unable to cope with such transients resulting in a turbine trip and reactor scram. In circumstances such as these essential site supplies are battery or diesel generator secured but in the event of 6 KV supply failure in conjunction with a major pipe failure in the reactor the water level in the reactor would start to fall eventually exposing the reactor core. Calculations have shown that feed water or core cooling must be supplying water to the reactor within two minutes to avoid core exposure. With an electrical system backed up with gas turbines, supplies can be made available to the essential components quickly thus avoiding the risk of core exposure.

The electrical auxiliaries in the nuclear station are fed from two separate, fully segregated systems. Furthermore all electrical components essential for the safety of the plant are duplicated, half being fed from one system the other half being fed from the other. These are in turn each "backed up" with a gas turbine set, electrically and mechanically independent of each other which can deliver half or full load into these essential supply boards (20 and 40 MW respectively).

The gas turbines have two operating modes which are:

1) Automatic emergency start. This initiates when certain trip sequences occur in the nuclear power plant. These safety related trip functions are initiated from various monitoring instruments within the station which monitor various parameters both during operation as well as shut down. When any of these emergency functions occur the gas turbine units start automatically and run in standby mode until they are required. If the normal 130 KV grid fails and the 6 KV network voltage falls below 65 % the gas turbine breakers close and the units supply power to the nuclear plant.

2) Manual start. If for some reason the auto start is unsuccessful or there is a risk that the 130 KV grid should fail the gas turbines can be started manually. This can be done from several different locations, these being central controlroom, diesel-controlroom and local controlroom.

The gas turbine units with their auxiliary equipment are tested once per year after the overhaul period. Testing of the gas turbines only is carried out every month.

BRIEF DESCRIPTION OF STAL-LAVAL GAS TURBINE PPD4

General

The PPD4 gas turbine unit is a standard Power Pac Duetpower plant, consisting of two gas generators, two power turbines, one alternator, governing, control and axuiliary systems, and prefabricated soundinsulated buildings (figure 1). Essential items in the governing, control, and auxiliary systems have been duplicated further to increase the starting and operating reliability, and free-wheel couplings between the power turbines and the alternator are included as standard. At maximum load the PPD4 can deliver 43 MW.

Gas generators

The gas generators are reconditioned Pratt & Whitney JT4A-11 aircraft jet motors which have been modified for stationary service. One of these modifications is the provision of smoke reducing burner cans, which permits the use of diesel fuel and reduces the emission.

Power turbines

The power turbines are three-stage axial turbines mechanically separate from their gas generators. The power transmission between the gas generators and the power turbines is performed by the gas flow from the gas generators. There are thus no gears between the rapidly rotating parts in the gas generators and the alternator drive shafts.

Free-wheel couplings

Between each power turbine and the alternator is a free-wheel coupling. The SSS (Synchro-Self-Shifting) coupling automatically disconnects the drive if the speed of the power turbine drops below the speed of the alternator. In this way the two halves of the unit can be run independently of each other. The alternator can also be used for synchronous condenser operation. If a fault occurs in the one half of the unit during operation, the speed of this power turbine will drop and the free-wheel coupling will automatically disengage, but operation will continue without interruption with the other power turbine and gas generator still driving, although the output will, of course, be reduced to half.

Alternator

The alternator is a three-phase two-pole machine, arranged for direct air cooling through filters.

Auxiliaries

Black start (when isolated from the external grid) is ensured by air starting and the units own batteries. During starting, the electric energy for ignition and other auxiliaries are taken from the starting batteries. When the gas generator has reached idling speed the starting equipment is disconnected. The PPD4 is completely independent of external power supplies for starting and running.

Turbine governing

Fuel flow to the gas generators is regulated by a hydraulic control unit which receives electrical signals from the electronic turbine governing equipment and operates an electro-hydraulic servo.
The following governing modes are used in the operation of the PPD4:
Freguency governing.
Acceleration governing of the power turbine.
Load limiting.
Load sharing.
Stator current limiting.
The gas generators are thus controlled by these five governing functions together with the fuel control belonging to each gas generator. The final control signal derived from the turbine governor operates an electro-hydraulic converter which provides hydraulic operation of the fuel valves.

RINGHALS / LAHALL

General

The Lahall gas turbine station is situated approximately 5 km from the Ringhals nuclear power plant. The gas turbine plant comprises of 4 English Electric-AEI(GEC) Quad AVON (DEA2)machines. These units are installed for peak load operation but two of them, Lahall 1 and 2 are also connected to supply the electrical auxiliary load of the nuclear power plant Ringhals 1 (BWR 750 MW).

Peak load power

When more power is required in the electrical system the gas turbines can be started up and synchronized automatically. This is initiated when the frequency falls below 49,7 Hz for more than 0.5 sek in the case of unit 1 and 2, and for unit 3 and 4 49.5 Hz without any time delay. The gas turbines can also be started from a remote control centre in Stockholm or from the controlroom in Ringhals 1. After a start has been initiated the unit is automatically synchronized and run up to full power (60 MW). Starting can also be initiated from the local controlroom for each unit in Lahall. Generator output can be varied between peak load (60 MW), intermediate load (53 MW), and base load (45 MW). The units can also run with only one turbine at 30 MW and operate as synchronous condensers. Manual start of the units can be initiated from the control centre in Stockholm, from the central controlroom in Ringhals unit 1 or local in Lahall itself.

Starting power

The nuclear power plants are not allowed to start operating before both the 400 and 130 KV grids are available. The authorities also demand that one gas turbine unit (unit 1 or 2) or two separate halves of two gas turbine units are available before start and during running of the nuclear power plant.

Standby power

The gas turbines in Lahall were built for peak load operation only. During the period when the nuclear power unit 1 (BWR) in Ringhals was being comissioned the designers observed a special operating case. Ringhals is unique in so much as the auxiliary feed water and core injection pumps are turbine driven. These pumps are provided to supply water to the reactor in the event of the normal condensate and feed water pumps being out of service. The system comprises of one turbine driven high pressure auxiliary feed water pump and two high pressure core injection pumps. In the suction line of core injection pumps a low pressure pump is positioned. Preceding a reactor trip in conjunction with faults in both the 400 KV and 130 KV grid the auxiliary feed water pump would start to supplement the reactor water level. If the level in the reactor falls below a certain level the HP core injection pump would start. In the unlikely case where both the 400 KV and 130 KV supplies are disrupted together with the two HP core injection pumps being out of service and a pipe break with a leakage rate of 40 kg/s, which is the capacity of the HP auxiliary feed water pump, the water level can only be maintained above the core for 30 minutes through the auxiliary feed water pump. During that time the normal 6 KV supplies must have been reinstated so that the normal duty condensate and feed pumps can be restarted to maintain reactor level.

Lahall units 1 and 2 have an installed emergency manual start for delivering power to Ringhals 1 so that if such an eventuality should occur the 6 KV net can be secured and the normal condensate and feed system pumps started within the 30 minutes mentioned. This emergency start is tested every year after the annual outage before the plant is allowed to operate.

The emergency start is initiated from the control room for Ringhals 1. Both gas turbine units 1 and 2 start up, one of the units delivers power to Ringhals 1 electrical net whilst the other runs in standby mode. If for some reason the first gas turbine trips then the other will take over the load.

Units 1 and 2 at Lahall are test run once per month whilst units 3 and 4 are tested only every 3rd month. The units are operationally checked once per year after the overhaul period.

BRIEF DESCRIPTION OF GAS TURBINE UNITS DEA2 IN LAHALL.

General

The English Electric-AEI DEA2 60 MW unit utilizes four gas generators and two power turbines - the power turbines being coupled through clutches to opposite ends of a common ac generator. With this latter arrangement it is possible to operate at half load on maximum efficiency using either of the duplicate gas turbines. Either end can be used to run the generator up to speed when synchronous condenser operation is required.

The considerable experience to date with the DEA2 has been on peak-load generation. This paper covers typical plant - detailed information will be provided for specific requirements of duty cycles, ambient conditions and extent of equipment required.

Gas generators

The gas generators selected for these units is the Rolls Royce Avon engine which, in addition to its proven reliability as an aero-engine, has now amassed extensive industrial experience in both base-load and peak-load applications. It is a simple open-cycle single-shaft engine with a seventeen-stage axial-flow compressor, tube-annular combustion chambers and a three-stage axial-flow turbine.

The Avon is operated on light distillate fuel. Comprehensive protection devices are included to ensure safe operation. The generator mountings incorporate service connections designed for quick engine replacement. Starting is by a 110 volt d.c. starter motor.

Power turbine

The power turbine casing is so supported as to allow complete freedom from loading due to thermal expansion. The two-stage rotor comprising separate discs, is overhung from the shaft which is supported in plain bearings completely separated from the gas path. Cooling air, bled from the gas generator compressors, is fed to the stator and rotor assemblies to limit thermal stresses during all conditions of operation. The power turbine and the gas generators are connected by a separate transition duct.

Generator and Free-wheel couplings

The English Electric-AEI a.c. generator is of the cylindrical shaft turbo-type driven directly from the power turbine shaft through a flexible gear-type coupling. Machines are air-cooled using closed-air-circuit water coolers. The bearings are lubricated by oil pumped from the power turbine system. An automatic-clutch is incorporated to allow the generator to be used as a synchronous compensator for control of power factor or transmission line stability.

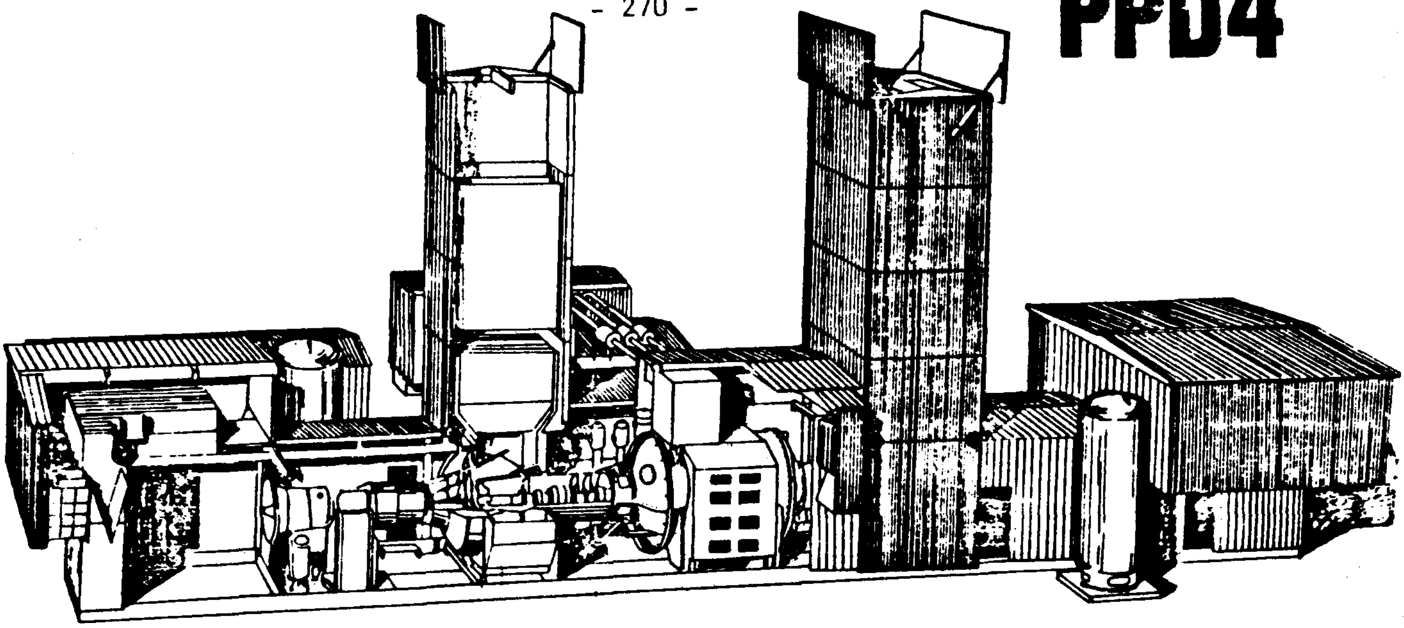
Control system

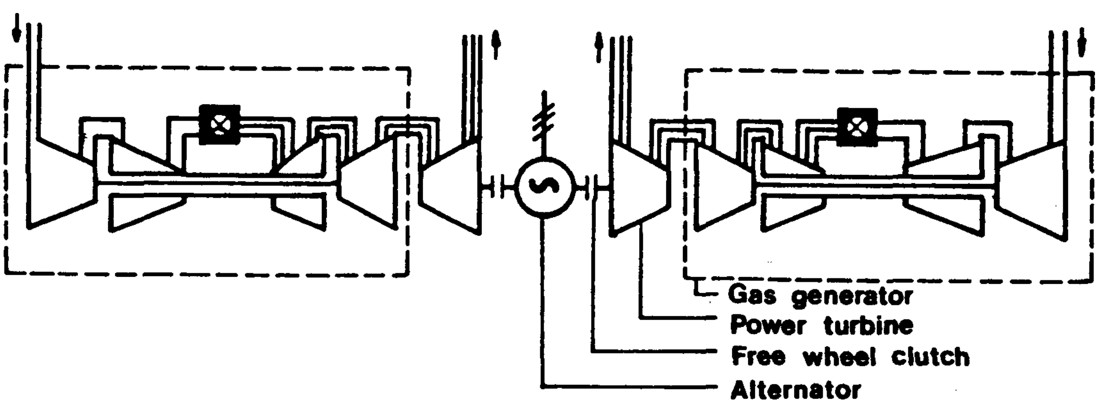
The control system provides for automatic push button starting and includes a local control and instrument panel, governor, synchronizer, automatic voltage regulator and alarm system. The plant requires a d.c. supply during the initial start-up period and for emergency shut-down condition, made independent of external supplies for "dead" station starting by the provision of batteries.

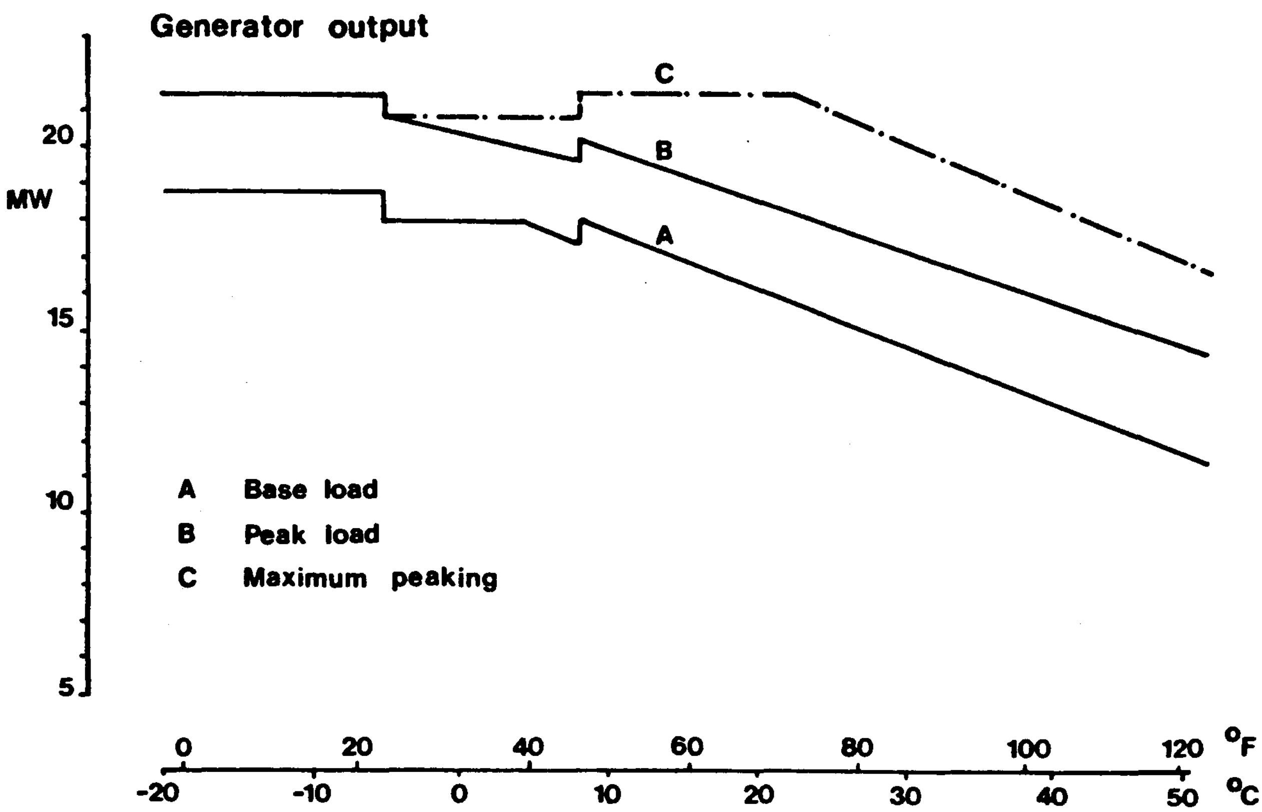
Average/year/unit	Ringhals (Lahall)	Forsmark	Oskarshamn	Barsebäck
Starting reliability	90	95	99	98
Number of starts Peak load operation	5	2	1	2
Number of starts Stand by operation	0	3	1	2
Number of starts total	25	35	35	35
Operating hours total	20	30	25	30

Table 1

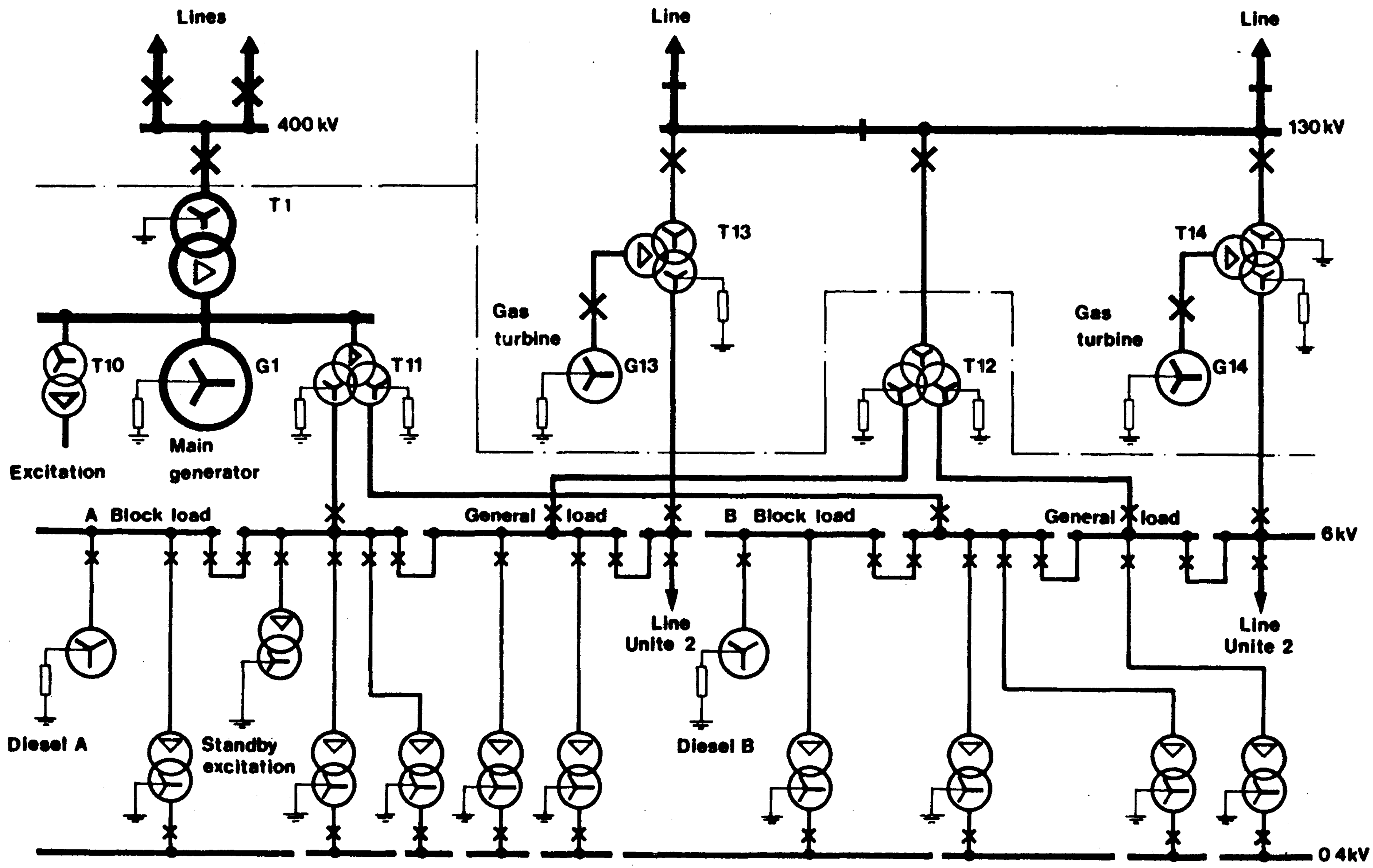
PPD4

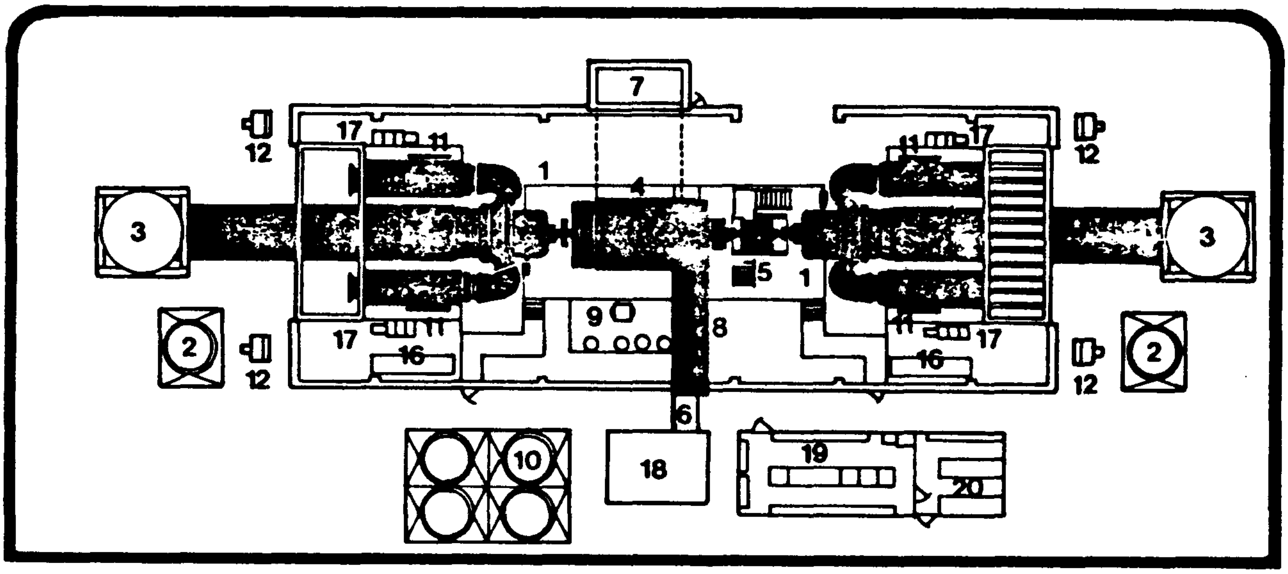


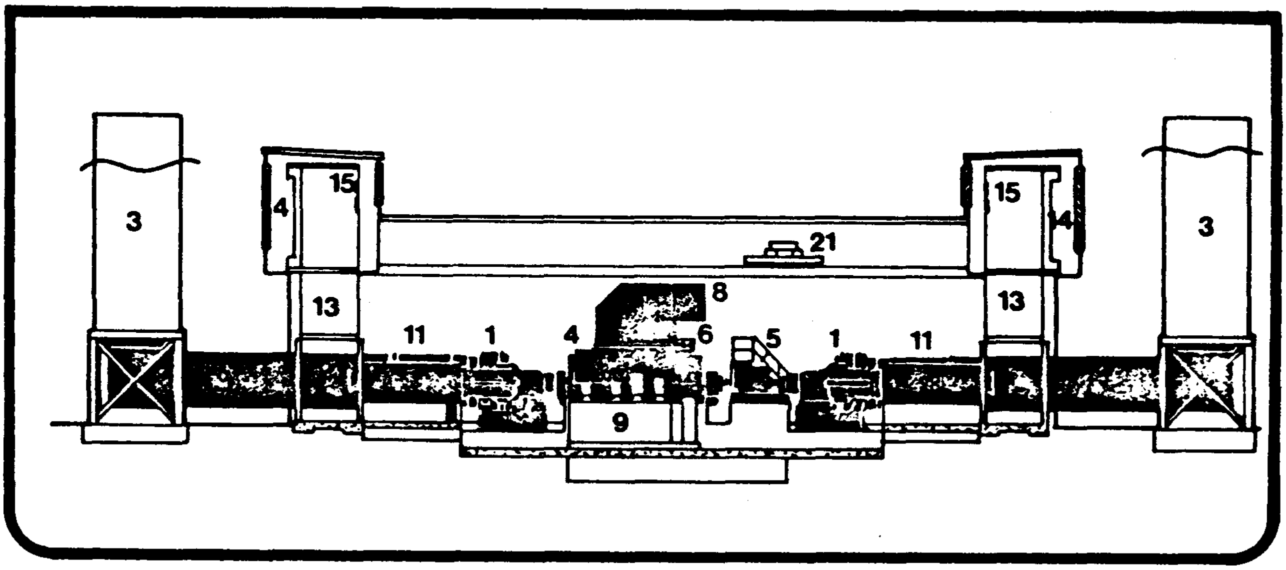

Gas generator
Power turbine
Free wheel clutch
Alternator


Generator output
MW
20
15
10
5
C
B
A
A Base load
B Peak load
C Maximum peaking
0
20
40
60
80
100
120
°F
-20
-10
0
10
20
30
40
50
°C

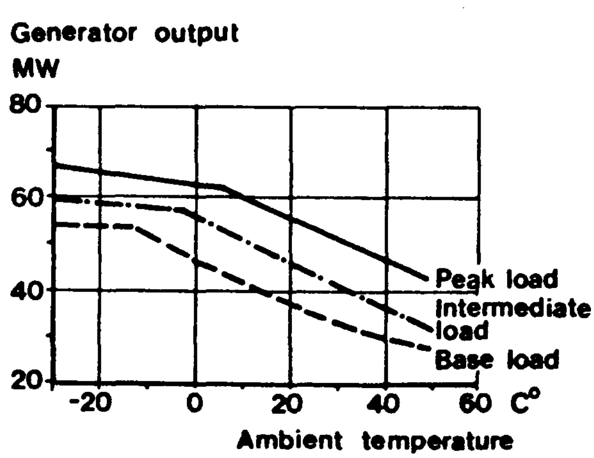
Schematic electrical diagram Barsebäck







1 **Power turbine**
2 Turbine air-blast air-cooler
3 Exhaust stack and silencer
4 **A.C. generator**
5 Exciter
6 Generator connections
7 Generator cooling-air intake and filter
8 Generator cooling-air exhaust and silencer
9 Lubricating oil package
10 Lubricating oil air-blast cooler
11 **Avon gas generator**
12 Lubricating oil air-blast cooler
13 Air intake silencer
14 Air intake filter
15 By-pass doors
16 Liquid/gas fuel supply cubicle
17 Liquid/gas fuel control cubicle
18 **Switchgear cabin**
19 **Control cabin**
20 Battery room
21 **5 ton crane**



Schematic electrical diagram Ringhals