

BASIC DESIGN OF GAS TURBINES**JGS 210-120-1-69E**

Rev.0 DATE NOV.-30-'95

CONTENTS

	<u>PAGE</u>
1. SCOPE.....	3
2. WORK PROCEDURE.....	3
2.1 Input to the Design.....	3
2.1.1 Process Conditions for electrical Power Generation and Mechanical Drive	3
2.1.2 Input Data.....	4
2.2 Output from the Design.....	7
2.2.1 Basic Design Outputs for Vendor Design.....	7
2.2.2 Follow-up Work by Vendor Design Data	7
2.3 Work Steps.....	7
2.4 Check List	7
2.5 Computer Program.....	8
3. SELECTION PROCEDURE.....	11
3.1 Selection of Type	11
3.1.1 Gas Turbine for Electrical Power Generation	11
3.1.2 Gas Turbine for Mechanical Drive.....	11
3.2 Capacity and Number of Gas Turbines	12
3.3 Design Considerations.....	12
3.3.1 Liquid Fuel Treatment	12
3.3.2 Fuel Gas Quality	15
3.3.3 Start Up of Single Shaft Type Machine for Mechanical Drives.....	16
4. DESIGN.....	16
4.1 Estimation of Gas Turbine Performance	16
4.2 Estimation of Steam Generation in Heat Recovery Steam Generator.....	16
4.2.1 Step-1: To prepare heat recovery diagram.....	16
4.2.2 Step-2: To plot temperature profile of water (steam) side	18
4.2.3 Example of heat recovery steam generator design.....	18
4.3 Gas Turbine Control	25
4.4 Auxiliaries	25
4.4.1 Inlet Air Filter	25
4.4.2 Inlet and Outlet Silencer	26
4.4.3 Exhaust Stack	26
4.4.4 Lubricating Oil System.....	26
4.4.5 Control Oil System.....	26
4.4.6 Cooling Water or Cooling Air System.....	26
4.4.7 Starting System.....	26
4.5 Operation and Maintenance	26
4.5.1 Key Service Factors for Maintenance.....	26
4.5.2 Maintenance Inspections.....	28
4.5.3 Maintenance Intervals.....	28
5. RELATED DOCUMENTS	29
6. DEFINITIONS.....	29
7. ABBREVIATIONS	30
8. REFERENCES.....	30

APPENDIX-1 GAS TURBINE BRAYTON CYCLE AND COMBINED CYCLE.....	31
APPENDIX-2 TYPICAL CONSTRUCTION OF SINGLE-SHAFT HEAVY-DUTY GAS TURBINE.....	32
APPENDIX-3 TYPICAL P&ID OF GAS TURBINE AUXILIARIES	33
APPENDIX-5 POWER FACTOR.....	37

1. SCOPE

- (1) This standard practice provides the guidelines for planning the gas turbines for electrical power generators and mechanical drives, e.g. pumps, compressors, and blowers, in refineries, petrochemical and similar plants.
- (2) Specific instructions given in the Project Specifications take precedence over requirements given in this standard practice.

2. WORK PROCEDURE**2.1 Input to the Design**

The major design inputs (to the computer program for gas turbine system design which is introduced in 4.5) are as follows :

2.1.1 Process Conditions for Electrical Power Generation and Mechanical Drive

Following conditions should be known in advance for selection of gas turbines :

- (1) Ambient air temperature and gas turbine output
 - (a) The gas turbine power output widely varies depending on ambient air temperature, and the possible variation requires special consideration for mechanical drives application. In tropical areas, for example, where ambient temperature ranges from 15 to 35 °C, the power output varies from 100 % to 85 %, and therefore, plant performance may widely vary daily and also seasonally.
One way to use such gas turbine is on a constant power output basis and another is on a maximum available power output basis.
 - (b) On a constant power output basis, the maximum ambient temperature for the gas turbine design is decided and the gas turbine is selected. The selected gas turbine is operated at reduced power for most of the operating period.
 - (c) On a maximum power output basis, heat and material balances for different ambient air temperatures should be prepared to fully utilize the gas turbine's performance. On this basis, the plant performance is evaluated on a cumulative basis considering daily and seasonal variation.
 - (d) To fully utilize the performance of the gas turbine, the plant performance, such as production capacity etc. is occasionally decided based on the selected gas turbine.
 - (e) The power generation plant is classified as a base load plant with constant power output and a peak load plant with variable power output to cope with change in demand. The former is normally operated under the base load output, while the latter is operated under medium range output to peak load output.
- (2) Output at the generator terminal

The output is indicated as an apparent power of kVA (MVA) with a power factor (PF) or active power of kW (MW). Relationship between the active power and the apparent power is as follows :

$$(kW) = (kVA) \times PF \quad (1)$$

$$(MW) = (MVA) \times PF \quad (2)$$

For power factor refer to appendix-5.

- (3) Frequency or rotational speed

System frequency (50Hz or 60 Hz) or rotational speed of the generator is specified. Relationship among frequency (f), rotational speed (N), and number of poles (P) is as follows :

$$f = \frac{P \times N}{120} \text{ (Hz)} \quad (3)$$

The number of poles is always an even number such as 2, 4, 6, ...

Following is a guideline for selection of the number of poles of a generator (except diesel engine driven) :

- When rotating speed of gas turbine exceeded 3,000/3,600 rpm which require speed reducing gear, 4 pole generator is economical.
- When rotating speed of gas turbine can be selected to 3,000/3,600 rpm, 2 pole generator is economical.

Note : In general, rotating speed of small gas turbines (less than 10MW) applied high speed which exceeded 3,000/3,600 rpm, but medium and large gas turbine applied 3,000 or 3,600 rpm.

(4) Waste Heat Recovery

- (a) Waste heat recovery can be provided on the exhaust duct of a gas turbine to recover the waste heat. The waste heat is used for steam generation, heating medium heating, and process gas heating in mechanical drives application.
- (b) The performance of the waste heat recovery varies depending on the operating conditions of gas turbine and ambient air temperature. Therefore, waste heat recovery at reduced gas turbine operation needs to be studied at various ambient air temperatures to decide the design basis of the waste heat recovery system.
- (c) When the waste heat is in deficit, an after-burner system installed in the duct is sometimes provided to meet the heat demand. But such a system is usually costly in investment.

2.1.2 Input Data

Following input data are required :

(1) Process conditions

Refer to section 2.1.1.

(2) Ambient temperature

As gas turbine output varies due to changes in ambient temperature, i.e. output reduction with higher ambient temperature, selection of the temperature largely affects performance of the plant. Refer to section 4.1.

(3) Altitude

Gas turbine output varies due to changes in altitude, i.e. output reduction with higher altitude, so altitude or barometric pressure shall be specified. Refer to section 4.1.

(4) Inlet loss

The loss is mainly caused by an inlet filter and silencer. Generally 100 mmH₂O loss is considered as the inlet loss.

If standard gas turbine package including inlet filter & silencer is applied, no specific data is required.

(5) Exhaust loss

The loss is caused by an exhaust silencer, duct, heat recovery boiler (if applied), and stack. Generally 100 mmH₂O loss for open cycle plant and 250 - 300 mmH₂O loss for combined cycle plant are considered.

Refer to appendix-1 for open cycle and combined cycle plants.

(6) Utility supply conditions

Following utilities are required :

(a) Fuel gas

Table 2.1.2-1^[2] shows fuel gas specification summary for gas turbines.

Table 2.1.2-2^[3] shows fuel gas pressure requirement for gas turbines manufactured by General Electric Company.

For selection of fuel gas, Wobbe index (W.I.) is used. Refer to section 3.3.2 for more detailed consideration.

Table 2.1.2-1 Fuel Gas Specification Summary
Standard machine

	Specifications
Contaminants	
Solids	• 30 ppm maximum, 10 micron maximum
Water	• 0.25% above saturation maximum
"Dry" Gas	• 0.1 gallon vapor per 1000 ft ³ maximum (13.4 liters per 1000 m ³ maximum)
Hydrocarbons	• No condensation upon 20°F (6.7°C) drop
Heating value	
Range	• 300 - 5,000 Btu/scf (2,670 - 44,500 kcal/Nm ³)
Change	• ± 10% nominal
Flammability limits	• Upper to lower flammability ratio = 2.2 : 1 minimum
Composition	
Sulfur	• Exhaust heat recovery units only.
Alkali metal and sulfur	• 5 ppm equivalent alkali metal sulfates maximum

Table 2.1.2-2 Minimum and Maximum Standard Fuel Gas Supply Requirement

MINIMUM AND MAXIMUM STANDARD FUEL GAS SUPPLY REQUIREMENTS					
Model Series	SUPPLY PRESSURES - PSIG (kg/cm ²) (*1)				Maximum Allowable
	Required Minimum				
	Std. (*2) @59°F (15°C)	Std. @0°F (-17.8°C)	DLN 1 (*3) @59°F (15°C)	DLN 1 @0°F (-17.8°C)	
3002 J	115 (8.1)	130 (9.1)	-	-	205 (14.4)
5001 P	200 (14.1)	235 (16.5)	-	-	275 (19.3)
5001 R	145 (10.2)	160 (11.3)	-	-	225 (15.8)
5002 A	175 (12.3)	175 (12.3)	-	-	225 (15.8)
5002 B	225 (15.8)	225 (15.8)	-	-	275 (19.3)
6001 B	240 (16.9)	270 (19.0)	285 (20.0)	300 (21.1)	350 (24.6)
7001 EA	260 (18.3)	305 (21.4)	290 (20.4)	310 (21.8)	350 (24.6)
7001 F	300 (21.1)	330 (22.2)	330 (23.2)	345 (24.3)	450 (31.6)
7001 FA	310 (21.8)	345 (24.3)	350 (24.6)	370 (26.0)	450 (31.6)
9001 E, 7 valve	275 (19.3)	320 (22.5)	325 (22.9)	350 (24.6)	450 (31.6)
9001 E, 9 valve	250 (17.6)	305 (21.4)	300 (21.1)	325 (22.8)	450 (31.6)
9001 F	300 (21.1)	330 (23.2)	330 (23.2)	345 (24.3)	450 (31.6)
9001 FA	315 (22.2)	355 (25.0)	350 (24.6)	370 (26.0)	450 (31.6)
LM 2500	375 (26.4)	-	N/A	N/A	450 (31.6)
LM 5000	635 (44.3)	-	N/A	N/A	700 (49.2)
STIG	690 (48.5)	-	N/A	N/A	750 (52.7)
LM 6000	655 (46.1)	655 (46.1)	-	-	695 (48.9)

Note (*1) at GT fuel strainer inlet
 (*2) Standard Combustor
 (*3) Dry Low NOx Combustor (GE's Type-1)

(b) Fuel oil

Gas turbine liquid fuels have a wide range of properties, but for gas turbine applications they may be classified into two broad classes; true distillates and ash-forming oils. Table 2.1.2-3^[2] shows properties of liquid fuels. The most common true distillates are the lighter oils such as naphtha, kerosene. The ash-forming oils are normally the heavier oils such as blends, crude, and residual oils.

Table 2.1.2-4^[4] shows limits of the trace metals in fuel oil for burning the turbine.

Refer to section 3.3 for the fuel oil treatment system.

Filterable dirt is of concern in the fuel pump, flow divider, and fuel nozzle. Reasonably fine filtration (generally 5 micron) ahead of the turbine is recommended.

(c) Cooling water for lube oil cooling and generator cooling. Air cooling type is also available.

(d) Control power

(e) Electric power (AC or DC), compressed air, or high pressure gas.

(f) DC power for emergency lube oil pump and turning device

Table 2.1.2-3 Typical Properties, Liquid Fuels

Fuel Type	True Distillates		Ash-Forming Fuels	
	Kerosene	No.2 Distillate	Blended Residuals and Crudes	Heavy Residuals
Specific Gravity, 100°F (38°C)	0.78 / 0.83	0.82 / 0.88	0.80 / 0.92	0.92 / 1.05
Viscosity, cSt, 100°F (38°C)	1.4 / 2.2	2.0 / 4.0	2 / 100	100 / 1800
Flash Point, °F	130 / 160	150 / 200	50 / 200	175 / 265
Flash Point, °C	55 / 70	55 / 95	10 / 95	80 / 130
Pour Point, °F	-50	-10 / 30	15 / 110	15 / 95
Pour Point, °C	-45	-20 / 0	-10 / 45	-10 / 35
Gross Heating Value, kcal/kg	10,700 / 10,950	10,500 / 10,950	10,500 / 10,900	10,150 / 10,500
Gross Heating Value, Btu/b	19,300 / 19,700	19,000 / 19,600	19,000 / 19,400	18,300 / 18,900
Filterable Dirt, % max.	0.002	0.005	0.05	0.2
Carbon Residue (100% Sample), %	-	-	0.3 / 3	2 / 10
Sulfur, %	0.01 / 0.1	0.1 / 0.8	0.2 / 3	0.5 / 4
Nitrogen, %	0.002 / 0.01	0.005 / 0.06	0.06 / 0.2	0.05 / 0.9
Hydrogen, %	12.8 / 14.5	12.2 / 13.2	12.0 / 13.2	10.0 / 12.5
Ash (Fuel as Delivered), ppm	1 / 5	2 / 50	25 / 200	100 / 1000
Ash (Inhibited), ppm	-	-	25 / 250	100 / 7000
Trace Metal Contaminants (untreated)				
Sodium plus Potassium, ppm	0 / 0.5	0 / 1	1 / 100	1 / 350
Vanadium, ppm	0 / 0.1	0 / 0.1	0.1 / 80	5 / 400
Lead, ppm	0 / 0.5	0 / 1	0 / 1	0 / 25
Calcium, ppm	0 / 1	0 / 2	0 / 10	0 / 50

Table 2.1.2-4 Trace Metal Effects

Trace metal	Limits in raw fuel	Effect on turbine	Type of treatment
Sodium plus Potassium	150 ppm	High temperature corrosion	Fuel washing
Calcium	10 ppm	Fouling deposits	Fuel washing to a limited extent
Lead	1 ppm	High temperature corrosion	None
Vanadium	Legal**	High temperature corrosion	Inhibited by magnesium
Magnesium	None	Inhibits vanadium/forms deposits	Use to inhibit vanadium

** Vanadium levels less than 0.5 ppm do not require inhibition. Maximum vanadium levels may be dictated by local codes regarding stack particulate emissions and the user's acceptable costs to inhibit.

2.2 Output from the Design

2.2.1 Basic Design Outputs for Vendor Design

The major design outputs are listed as below:

- (1) Basic preparation of gas turbine data sheet
 - Number of sets
 - Type of gas turbine*
 - (2) Basic preparation of fuel treatment system data sheet, if required
 - Type of fuel treatment system including fuel pressure boost-up
 - (3) Basic preparation of exhaust gas heat recovery system data sheet, if required
 - Type of exhaust gas heat recovery system based on the estimated exhaust gas flow rate*, temperature*, and composition*
- * GT performance with the following associated information can be estimated by the computer program of "GT PRO" and "GT MASTER" described in section 2.5:
- System summary
 - Plant efficiencies
 - Steam cycle performance
 - Plant auxiliaries power consumption
 - Graphic output of heat recovery diagram
 - Graphic output of cycle flow schematic
 - Estimated major equipment costs

2.2.2 Follow-up Work by Vendor Design Data

- (1) Review of gas turbine performance and reflection to basic design including the heat recovery system data sheet.
- (2) Review of fuel qualities & pressure requirements, and reflection to the fuel treatment data sheet if necessary.
- (3) Review of NO_x, SO_x, and particulate values in exhaust gas, and necessary countermeasure should be considered.
- (4) Incorporation of auxiliary piping to JGC P&ID
- (5) Incorporation of utilities consumption to utility summary

2.3 Work Steps

Refer to Fig.2.3-1 for work step (design procedure flow) schematic and Table 2.3-1 for design parameters table.

2.4 Check List

As gas turbine performance varies with changes in site conditions (ambient temperature, barometric pressure), following outputs should be re-checked.

- (1) Frame (50 Hz machine or 60 Hz machine, for electrical power generator drive without speed reduction gear)
- (2) Power output (ISO or site)
- (3) Heat rate (ISO or site)
- (4) Environmental limitation of SO_x and NO_x :

As no output data for SO_x and NO_x levels of the flue gas are available from the computer program, those should be derived by consultation with specific gas turbine manufacturer.

2.5 Computer Program

GTPRO : The computer program [GT PRO] is used for gas turbine power & co-generation/combined cycle system design. The program has a gas turbine data file for the system design. 90 gas turbines of different types and manufacturers are stored in the data file.

Besides calculation of open cycle performance of gas turbine, combined cycle performance of steam cycle balance including waste heat boiler (with or without auxiliary firing) and steam turbine (with extraction / condensing) can be also calculated. Based on the calculation results and estimated major equipment cost, investment analysis can be done using the program.

GTMMASTER : The other program [GT MASTER] is used for off-design performance calculation based on the data calculated by GTPRO.

Fig. 2.3-1 Work Step Schematic Flow

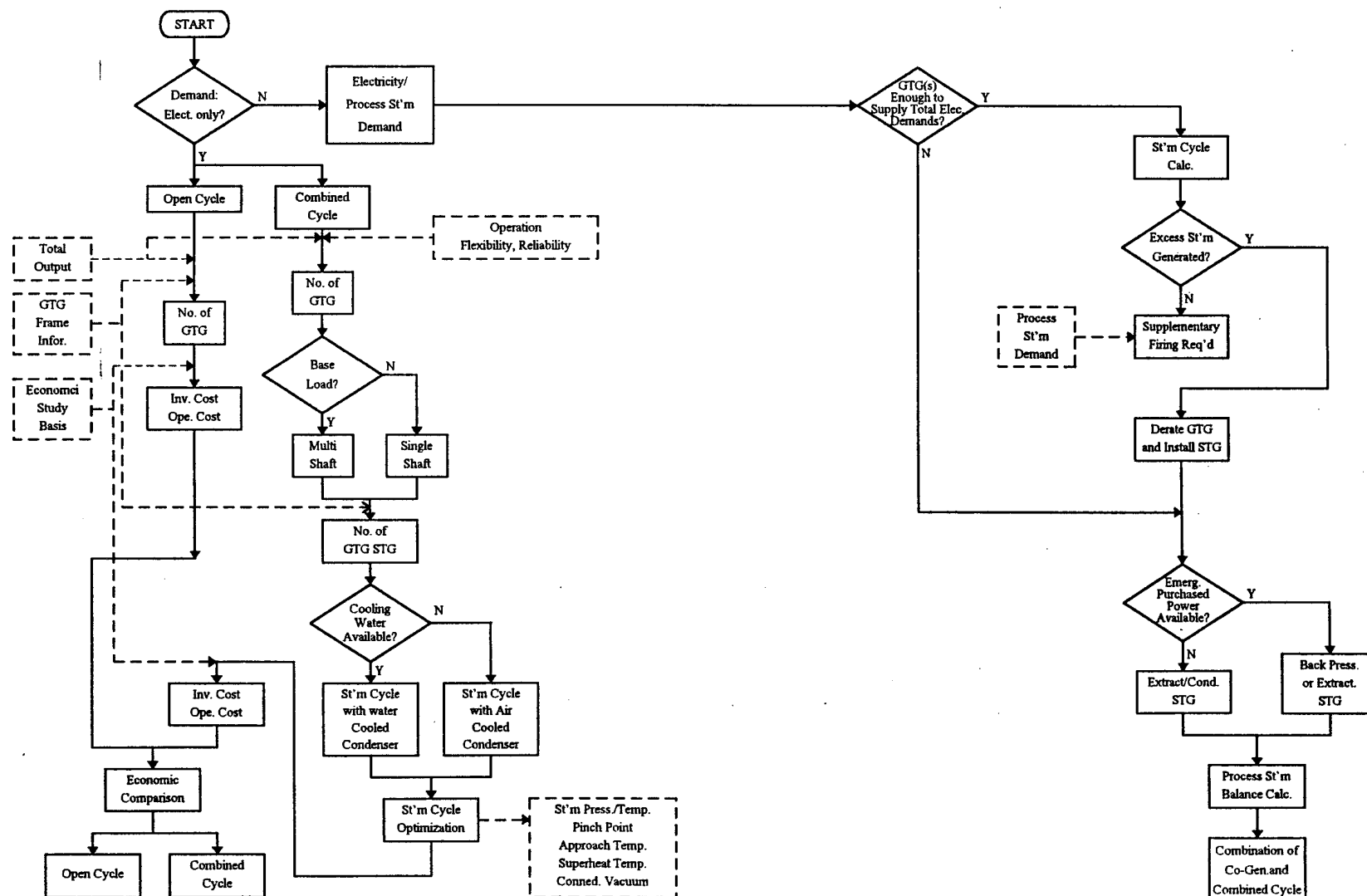


Table 2.3-1 Design Parameters Table

ITEM \ DESIGN STAGE	BASIC CONFIGURATION	GAS TURBINE GENERATOR	HEAT RECOVERY STEAM GENERATOR	STEAM SYSTEM	ELECTRICAL	EVALUATION
DESIGN BASIS	DESIRED DESIGN OUTPUT RELIABILITY GRADE DEMAND FORECASTING - AVERAGE - SEASONAL - DAILY SITE CONDITIONS ECONOMIC STUDY BASIS - UTILITY PRICE - DEPRECIATION	ALTITUDE OF SITE AIR TEMPERATURE AIR HUMIDITY FUEL CHARACTERISTICS	QUICK START REQUIREMENT	COOLING WATER TEMPERATURE (IN CASE OF WATER COOLING) AIR TEMPERATURE (IN CASE OF AIR COOLING)	SITE CONDITIONS VOLTAGE SYSTEM GROUNDING SYSTEM	ECONOMIC STUDY BASIS
MAJOR DESIGN FACTORS	NO. OF TRAINS CAPACITY PER EACH TRAIN NO. OF GTG FRAME SELECTION, OF GTG SINGLE SHAFT OR MULTI-SHAFT	FUEL TREATING SYSTEM	SINGLE PRESSURE OR DUAL PRESSURE STEAM CONDITIONS - PRESSURE - TEMPERATURE SUPPLEMENTARY FIRING - PROVIDED OR NOT TYPE OF HRSG - VERTICAL OR HORIZONTAL PRESSURE DROP ACROSS HRSG PINCH POINT APPROACH TEMPERATURE LOW TEMPERATURE CORROSION	STEAM TURBINE DESIGN - QUICK LOAD CHANGE - DUAL STEAM - ADMISSON - SLIDING PRESSURE CONDENSER DESIGN - BACK PRESSURE - TYPE - SIZE	ELECTRICAL DISTRIBUTION SYSTEM START-UP OR EMERGENCY POWER SYSTEM CONTROL AND INSTRUMENTATION POWER SYSTEM	OPTIMIZATION OPERABILITY
CALCULATION	ROUGH ECONOMIC AND OPERATION EVALUATION - RELIABILITY ANALYSIS - ECONOMIC STUDY - OPERATION - FLEXIBILITY	GTG PERFORMANCE CALCULATION - POWER OUTPUT - HEAT RATE - TEG FLOW RATE - TEG TEMPERATURE - TEG COMPOSITION UTILITY REQUIREMENT	HRSG HEAT BALANCE CALCULATION HRSG RATING HRSG PRESSURE BALANCE DEW POINT ESTIMATION UTILITY REQUIREMENT	STEAM BALANCE CALCULATION STEAM TURBINE OUTPUT UTILITY REQUIREMENT CONDENSER RATING	SHORT CIRCUIT ELECTRICAL POWER CONSUMPTION (AUXILIARY LOSS) STABILITY STUDY (IF NECESSARY) - STATIC STABILITY - DYNAMIC STABILITY	COST ESTIMATION - INSTALLATION - OPERATING - MAINTENANCE OPERABILITY STUDY - PART LOAD - START-UP - SHUT DOWN - EMERGENCY
DATA FILE	GAS TURBINE FRAME INFORMATION COST DATA	GTG PERFORMANCE DATA FUEL PHYSICAL PROPERTIES	FLUE GAS PHYSICAL PROPERTIES STEAM PHYSICAL PROPERTIES DEW POINT ESTIMATION CURVE	STEAM TURBINE PERFORMANCE STEAM PHYSICAL PROPERTIES		COST DATA

3. SELECTION PROCEDURE

3.1 Selection of Type

- (1) There are two types of gas turbines, i.e. heavy-duty industrial gas turbine and aero-derivative gas turbine. In general, heavy-duty industrial gas turbine is preferred to the aero-derivative gas turbine which requires premium gas and liquid fuels. The heavy-duty industrial gas turbine can fire crude oil, residual oils, and very lean gas which are widely used in refineries and petrochemical industries.
- (2) However, aero-derivative gas turbine should be considered if the same has advantages of operating and maintenance costs, space limitation, etc.
- (3) Single-shaft and dual- or more -shaft gas turbines are available in the industrial gas turbines. Single-shaft gas turbine is so constructed that rotational components such as axial air compressor, expander turbine, and driven machine are mounted on one shaft. Fig. 3.1-1 shows a schematic of single-shaft gas turbine.
Dual-shaft gas turbine is so constructed that the turbine is splitted into two parts each of which rotational components are mounted on the independent shaft. Fig. 3.1-2 and Fig. 3.1-3 show schematics of dual-shaft gas turbine.
Multi-shaft gas turbine is so constructed that the turbine is splitted into three or more parts each of which rotational components are mounted on the independent shaft. Fig. 3.1-4 shows a schematic of three-shaft gas turbine.

3.1.1 Gas Turbine for Electrical Power Generation

- (1) Single shaft or dual shaft (split) type
A single shaft machine is preferred, as the larger inertia can give greater frequency stability than dual shaft type.
Application of the dual shaft type requires careful consideration of matching governor and generator characteristics from the viewpoint of frequency stability.

3.1.2 Gas Turbine for Mechanical Drive

- (1) Dual or more shaft type machine
In general, dual or more shaft type gas turbines, which can drive driven machine at variable speed without sacrificing efficiency and also can provide high torque even in a lower rotating speed range, are selected for the mechanical drives, because mechanical drives require :
 - (a) variable rotating speed to operate driven machine's at required performance, such as adjusting throughput or discharge pressure of centrifugal compressors, and
 - (b) high torque in low rotating speed range, for example, start-up operation of centrifugal compressors.
These features are the same as steam turbine which can drive driven machines at variable speed and high torque even in a lower rotating speed range, as opposed to electric motor which only drives rotating machines at constant speed.
- (2) Single shaft type machine
As mentioned above, dual or more shaft type machines are generally selected for mechanical drives, however, single shaft type machines, widely used for power generation and of course regarded as proven machines, are now beginning to be used for mechanical drives.
The reasons for using such single shaft type machines, which are not flexible enough for mechanical drives, are :
 - (a) maximum capacity of proven dual or more shaft machines is limited to about 20 MW at site rating, and
 - (b) for larger than 20 MW mechanical drives, steam turbines were the only proven driver, but for the refrigerant compression in LNG liquefaction and pipeline gas compression etc., larger capacity gas turbine drivers have become increasingly attractive from the economical viewpoint.
The application of single shaft machines for mechanical drives requires some additional countermeasures to supplement their lesser flexibility for mechanical drives. The countermeasures are discussed in section 3.3.3 "Start Up of Single Shaft Type Machine for Mechanical Drives".

3.2 Capacity and Number of Gas Turbines

Capacity and number of gas turbine set(s) are determined based on the following factors:

- (a) Operating range (Maximum & minimum capacity of plant)
- (b) Plant reliability (No spare, n+1, or n+2 sparing philosophy)

No spare	Lowest reliability and flexibility, while the most economical, and maintenance of the gas turbine is required during periods of low plant capacity
n + 1	Higher reliability and flexibility with relatively higher capital expenditure (capex), maintenance of the gas turbine at any time, but preferably during periods of low plant capacity
n + 2	Highest reliability & flexibility, while the highest capex, maintenance of the gas turbine can be done at any time

The GTW Handbook [5] shows the latest gas turbines available world-wide.

3.3 Design Considerations

3.3.1 Liquid Fuel Treatment

- (1) In the case of true light distillate oil, treatment is required primarily to capture dirt and shipment contaminants that have not been removed by the storage tank settling system arrangement.
- (2) Filters are the most commonly used device, although centrifuges and electrostatic desalters may also be required to remove sodium if present as a result of sea water contamination.
- (3) Treatment and conditioning systems for the ash-forming fuels are more complex because of the processing steps required to remove or control their trace metal contaminants. Particular attention must be paid to sodium and vanadium. Complete fuel treatment includes :
 - (a) Washing the fuel to remove the water-soluble trace metals such as sodium, potassium, and certain calcium compounds.

The fuel washing involves mixing heated fuel with 5 - 10% of potable water along with a small amount (0.02 %) of an emulsion-breaking fluid to aid in separation. The process is a two- or three-stage extraction procedure with the extraction water flowing counter-current to the fuel.

Either centrifuges or electrostatic desalters are used for this separation process. Fig.3.3.1-1 and Fig.3.3.1-2 show the typical centrifuge and electrostatic processes, respectively. Table 3.3.1-1 shows a comparison of centrifuge and electrostatic processes.

Table 3.3.1-1 Comparison of Centrifuge / Electrostatic Features

Parameter	Electrostatic	Centrifuge
1 Type of mechanism	Static	Dynamic
2 Control system	Manual	Automatic complete
3 Time to reach start-up stability	4 hours (per stage), 12 hours total	20 minutes total
4 Reliability	Good	Good
5 Maintenance	Low	Low
6 Solid removal	Fair - additional filtration needed	Excellent
7 Desludging	By water effluent but can accumulate in vessels. Approximately once a year vessels should be cleaned.	By water effluent and by automatic bowl opening
8 Amount of heating required for fuel treatment	260 - 280°F	210°F
9 Performance in Na + K removal	Meets specifications if fuel is within system design specification.	Exceeds specification even if raw fuel exceeds design specification.
10 Oil content in water effluent	500 - 2,000 ppm typical 50,000 ppm maximum	50 ppm typical 500 ppm maximum
11 Response time to correct fuel not meeting washed fuel specification	Long (hours)	Short (minimum)
12 Fuel required to change system (cannot be used)	Approximately 500,000 gallons	50 - 100 gallons
13 Flexibility - servicing while operating	System cannot be partially shut down.	Centrifuges can be removed from service while continuing to operate.
14 Space required	Large area	Limited area
15 Cost	- Small systems - Large systems	Lower Higher