6. Design of Optimum Power Plant

6. Design of Optimum Power Plant

6.1. General Design Concept of Sihanoukville Power Project

The Sihanoukville Power Plant will be designed on the basis of the following design concept:

- Plant Capacity and Expansion Plan

The Plant has a capacity of 180 MW but could be expanded to 270 MW capacity in future. However 180 MW plant would be constructed dividing into two stages at an interval of several years in consideration of so large amount of investment for 180 MW plant and a relatively small increase rate of electricity demand in Cambodia. The time of expansion from 180 MW to 270 MW is expected not in near future but one decade or so after the completion of 180 MW plant.

Then a definition of plant capacity and construction stages are set as follows:

Plant nominal capacity: 180 MW
Definition of construction stages and these capacities:

The works of first 90 MW capacity plant	;	Stage 1
The works of second 90 MW capacity plant	;	Stage 2
The works of last 90 MW expansion plant	;	Stage 3

In this report, the detailed studies including required specifications of equipment, plant layout, construction cost, construction schedule, economic analysis, etc. will be discussed for the first two stages, Stage 1 and Stage 2. However any specific study will not be carried out for Stage 3 except for the issues of environmental impact study and required area space for the final plant.

- Utilities

Main utilities required for operation and maintenance of gas turbine combined cycle power plant are fuel(s), electricity, cooling water, plant make-up water, fire-fighting water, miscellaneous chemicals, lubricants, etc.

(i) Fuel(s)

Natural gas is used as main fuel and diesel oil is used as back up fuel. The availability of natural gas is now under study, but the pipeline of gas is expected to come to the plant from the west edge of the plant boundary. Diesel oil will be supplied from Sokimex Oil Terminal through the oil pipeline, which will run along the railway and reach to the north-west edge of the plant boundary.
The gas pipeline will have a capacity for all three stages.

(ii) Electricity

The electric power necessary for normal start-up and normal shutdown operation of the plant will be supplied via step-down transformer from 220 kV transmission line. While, the electric power for normal continuous operation will be fed via step-down transformer from output circuit of the associated generators.

(iii) Cooling Water

The seawater will be used as the cooling medium for the turbine steam condensers. The seawater will be taken from and discharged to the sea in the west of the plant. The cooling water intake and discharged structures will be installed on the seabed of approx. 5 m depth, with enough distance to avoid hot water recirculation. Incoming and outgoing cooling water pipes are located under the seabed and under the ground from the seacoast to the plant with crossing the road and the railroad.

The cooling water system for auxiliary equipment will be of closed circuit using fresh water. The closed circuit cooling water system has heat exchangers to liberate the heat to the seawater.

(iv) Plant Make-Up Water

Plant make-up water used for boiler feed, drinking, washing, irrigation and other miscellaneous use in the plant will be taken from Prey Treng Pond. However the water of Prey Treng Pond is already used by Sokimex Oil Terminal and the near-by residents, in addition, the water flow is not so plenty in dry season. Therefore a raw water storage tank, of which capacity corresponds to a water demand of the plant for one month, will be provided.

(v) Fire Fighting Water

The water of Prey Treng Pond will be used for fire fighting. Two fire fighting water pumps, one is of electric motor-driven and the other is of diesel engine-driven, will be installed in the border of the pond.

(vi) Chemicals and Lubricants

Many kinds of chemicals and lubricants are required for operation and maintenance of gas turbine combined cycle power plant. Chemicals include the chemicals for water treatment, boiler feed & boiler water treatment, wastewater treatment, bio-fouling control of cooling water pipes, chemical analysis, etc. Lubricants include lubricating oil and grease, etc.

In Cambodia, all these chemicals and lubricants are assumed to be imported from other countries. Therefore, storage tanks and facilities for several months will be provided in the plant considering a required period for procurement.

- Power Transmission

The plant will be connected to 220 kV double-circuit transmission line. The transmission line will come from Takeo Substation via Kampot and enter into the plant at the northeast edge of the plant boundary.

The plant will also provide a connection with a high voltage transmission line to the city center of Sihanoukville. This transmission line will run south of the plant.

- Redundancy design philosophy

In general, “N + 1” basis will be applied to the equipment (or system) that is required to be operated continuously for maintaining full-output operation of the plant. Where, “N” is the required numbers of equipment for generating 100 % output of the plant.

For example,

two machines are installed	:	2 × 100 % (one is for spare)
three machines are installed	:	3 × 50 % (one is for spare)

However, “N” basis (i.e.. no spare) will be applied to the equipment categorized below:

- Main, but costly equipment, such as:
  gas turbine, HRSG, steam turbine, steam condenser, cooling water pump, etc.
- Equipment being unlikely to suffer frequent and/or accidental damages, such as: piping system, transformer, circuit breaker, etc.
- Equipment being considered not to be essential for continuous operation of the plant, such as:
  ventilation and air conditioning system, waste water treatment system, storing equipment, maintenance equipment, equipment for emergency use, etc.

For the control and supervising system, the following philosophy will be applied:

- Local instrument and controls will be single.
- Central control systems which is base on microprocessor technologies will be duplicate for main equipment, such as gas turbine, HRSG, steam turbine, etc.
- Data-way system for communication among the above mentioned central control systems will be duplicate.

- Black Start and Emergency Electric Power Source

Emergency diesel generator will be installed for supplying required electric power for start of the plant and operation for the essential equipment without incoming power supply. The diesel generator(s) has a sufficient capacity for starting one (1) gas turbine with supplying the power required for operation of control system and auxiliary equipment which is needed for gas turbine start up. And UPS (Uninterrputible Power Supply) system will also be provided for supplying DC power for emergency control and lighting for safety shutdown of the plant.

- Inspection and Maintenance Philosophy

Workshop and chemical laboratory will be provided in the plant.
The work shop will be equipped with standard machines and tools for normal inspection/maintenance of mechanical and electrical equipment, such as for welding, cutting, bending, surfacing, drilling, calibration, measuring, etc. Normal inspection,

maintenance and repairing will be carried out in situ, however a special maintenance for gas turbine will be carried out by gas turbine manufacturer in their factories.

The laboratory will be equipped with chemical analyzer and measuring tools/devices required for supervising operation condition and environmental management of the plant. The laboratory equipment may include water analyzer, fuel analyzer, contaminant analyzer of waste effluent, air pollutant analyzer, etc.

6.2. Basic Design Conditions of Power Plant

6.2.1. Site Conditions

(1) Topography

Most part of the site area is generally hilly area covered with grass with elevation of EL. 1.0 m ~ 8.0 m, and a slope of approximately 1/70 and 1/50 in west-east direction, and in north-south direction, respectively.

Northern and eastern parts are surrounded by foot of mountains. Prey Treng Pond and swamps are located in the south boundary of the site.

North-south ward coastline forms the west edge of the site area.

(2) Geology

The general attitude of bedding plane of rocks consisting of sandstone and siltstone strikes N50 - 70E, and gentle dipping of 5 - 10 degree NW toward the sea, and more or less conform the trending (NE - SW) of mountain ranges.

The overburden is composed of mostly sand and silty sand with partly interbedded clayey layer having thickness of approximately 4 - 26 m. Rather thick overburden has been found in the area between two canals and swamps on southern boundary of the site. The overburden is thinning northwards.

(3) Meteorology

According to the meteorological data observed at Sihanoukville Meteorological Observation Station, the following meteorological conditions are depicted:

(a) Winds

Frequency of wind direction varies seasonally. In the rainy season, that is from May to October, the wind direction is mainly West and Southwest as shown in Fig.6.2-1. In the dry season, from November to April, that is mainly North and South. Averaged wind speed is approximately 3.0 ~ 6.0

m/ sec throughout a year.

Annual maximum wind speed data is also available at the Sihanoukville Meteorological Observation Station as shown in Table 6.2-1.

Maximum wind speed in a period of 1990 - 1999, is 24 m/sec with direction of W - NW that occurred in 1996.

(b) Ambient Temperature

Average temperature	28.8 ºC
Monthly maximum temperature	33.7 ºC
Monthly minimum temperature	24.5 ºC

(c) Relative Humidity

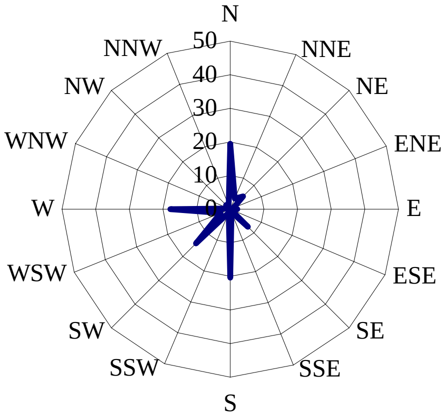
Monthly maximum relative humidity	86%
Monthly minimum relative humidity	76%

(d) Rainfall

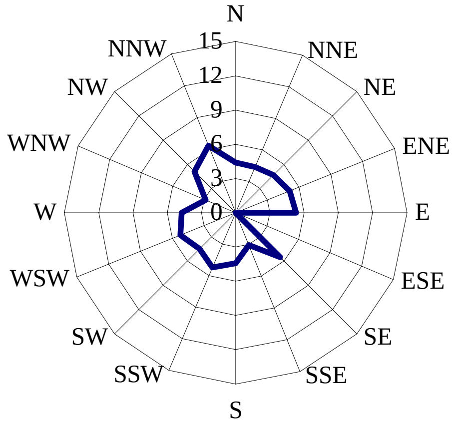
Annual average rainfall (1991 - 1999)	3,200 mm
Maximum monthly rainfall (July, 1991 - 1999)	675 mm

Table 6.2-1 Maximum Wind Speed at Sihanoukville Meteorological Station

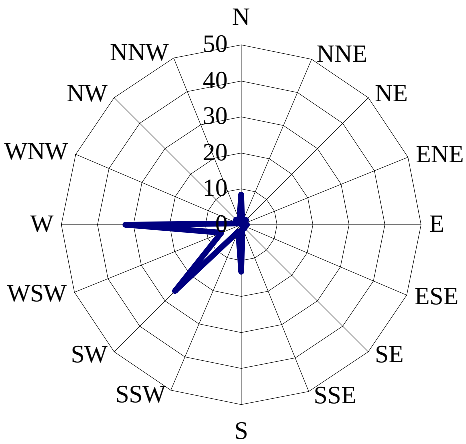
Year	Wind Direction	Annual Maximum Wind Speed (m/sec)
1990	W - NW	18
1991	N - NW	18
1992	NW	19
1993	SW - W - NW	23
1994	W - NW	22
1995	W - NW	18
1996	W - NW	24
1997	N - NW	23
1998	SW - NW	15
1999	N - NW	21



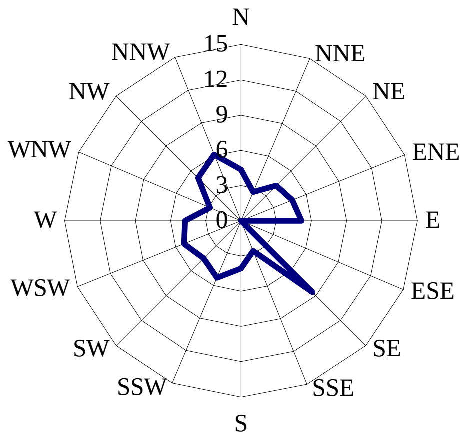
Frequency of Wind Direction in
Year of 1991& 95 ~ 98 [%]



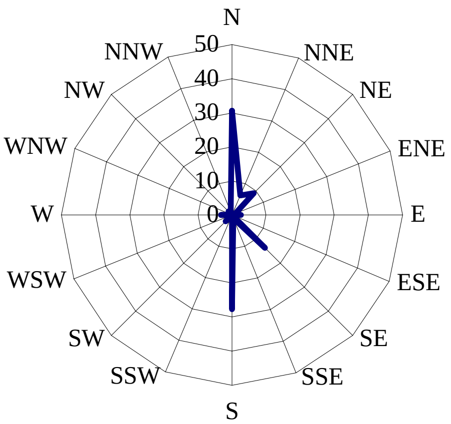
Averaged Wnd Speed In year of
1991&95 ~ 98[m/s]



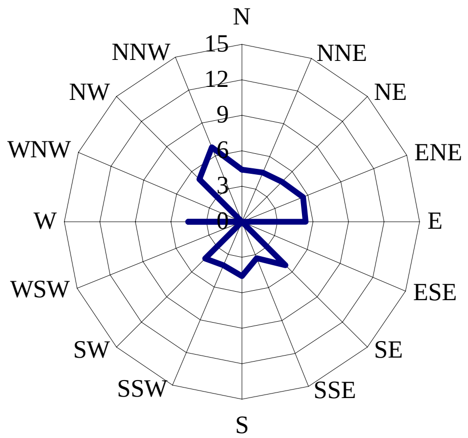
Freqency of Wind Direction In Rainy Season
of Year 1991&95～98[%]



Averaged Wind Speed In Rainy Season of
Year1991&95 ~ 98[m/s]



Freqency of Wind Direction in Dry Season of
Year 1991&95 ~ 98[%]



Averaged Wind Speed in Dry Sesson of
Year 1991&95 ~ 98[m/s]

Fig.6.2-1 Freqency of Wind Direction and Averaged Wind Speed Distribution

Site conditions in item b., c. and d. are based on the data measured in the Sihanoukville Meteorological Observation Station during 1999 - 1999.

Based on the rainfall intensity data in a period of 1960 - 1970 as shown in Table 6.2-2, probable rainfall in short time is estimated by Gumble method as shown in Table 6.2-3. Applying Mononobe's formula for the relation of rainfall intensity and rainfall period, probable 10 minutes rainfall intensities are estimated as shown in Table 6.2-4.

As a result, a probable rainfall intensity in 10 min. with a return period of 50 years is 45.3 mm.

Table 6.2-2 Rainfall Data in Short Time Period

(mm)

Year	Rainfall in Short Time Period			
	15 min.	30 min.	45 min.	60 min.
1960	18.0	28.8	36.6	39.0
1961	25.2	30.0	36.0	49.7
1962	40.0	65.0	83.0	94.0
1963	28.0	49.0	59.0	64.0
1964	30.0	58.0	80.0	93.4
1965	30.0	49.0	57.0	67.0
1966	53.5	67.0	73.5	83.0
1967	40.0	60.0	85.0	111.0
1968	42.8	52.4	68.5	76.0
1969	35.0	50.0	54.5	63.9
1970	34.0	50.0	73.5	86.5

Table 6.2-3 Probable Rainfall in Short Period by Gumbel Method

(mm)

Return Period (year)	Probable Rainfall in Short Period			
	15 min.	30 min.	45 min.	60 min.
100	63.1	87.8	115.7	138.2
50	58.1	81.4	106.7	127.3
25	53.0	74.9	97.7	116.3
10	46.2	66.2	85.6	101.4
5	40.8	59.3	76.0	89.7
2	32.7	48.9	61.5	71.9

Regression Line:

$y = 0.5772 \bullet x$

$\log_e (r/r_{60}) = k \bullet \log_e (t/60)$

$r = r_{60} (t/60)K$

$k = 0.5772$

t = 10:

$\log_e (10/60) = -1.792$

$\log_e (r_{10}/r_{60}) = -1.034$

$r_{10}/r_{60} = 0.356$

Table 6.2-4 Probable Rainfall in 10 min.

(mm)

Return Period (year)	r_{10} 10 min.
100	49.1
50	45.3
25	41.3
10	36.1
5	31.9
2	25.6

(4) Oceanography

(a) Tide Level

According to the tide level observation in front of the sites and at Sihanoukville Port (1997 - 1999), the following tide level are obtained:

CDL	(Chart Datum Level)	=	- 1.07 m + MSL*
MHWL	(Mean High Water Level)	=	0.37 m + MSL*
MSL	(Mean Sea Level)	=	+ 0.08 m + MSL*
MLWL	(Mean Low Water Level)	=	- 0.17 m + MSL*
HHWL	(Highest High Water Level)	=	+ 1.17 m + MSL*
LLWL	(Lowest Lower Water Level)	=	- 1.06 m + MSL*
Ground Level		=	+ 4.10 m + MSL*

* MSL at Hatien in Vietnam

(b) Wind Wave Height and Period

Wind waves are derived from wind data around the site area. Based on the wind data, probable wind wave is estimated by the SMB method as shown in Table 6.2-5.

Maximum fetch is approximately 43 km in the direction of WNW and averaged water depth is approximately 12 m as shown in Fig.6.2-2.

Probable wind speed is estimated by Gumbel-Chow method. Waves derived here correspond to deep sea waves.

Table 6.2-5 Probable Wave Height and Period

Return Period Year	Probable Wind Speed (m/sec)	Probable Wave	
		$H_{1/3}$ (m)	$T_{1/3}$ (sec)
100	28.8	4.1	6.8
50	27.3	3.8	6.5
25	25.8	3.6	6.4
10	23.7	3.3	6.2
5	22.1	3.0	6.0

(c) Tsunami

As for Tsunami, the area around the site has rare possibility of earthquake and Tsunami. In case of any Tsunami in the Gulf of Thai, that cannot reach to the site due to islands, scattered as shown in Fig.6.2-2, acting as a shield against Tsunami to the site area.

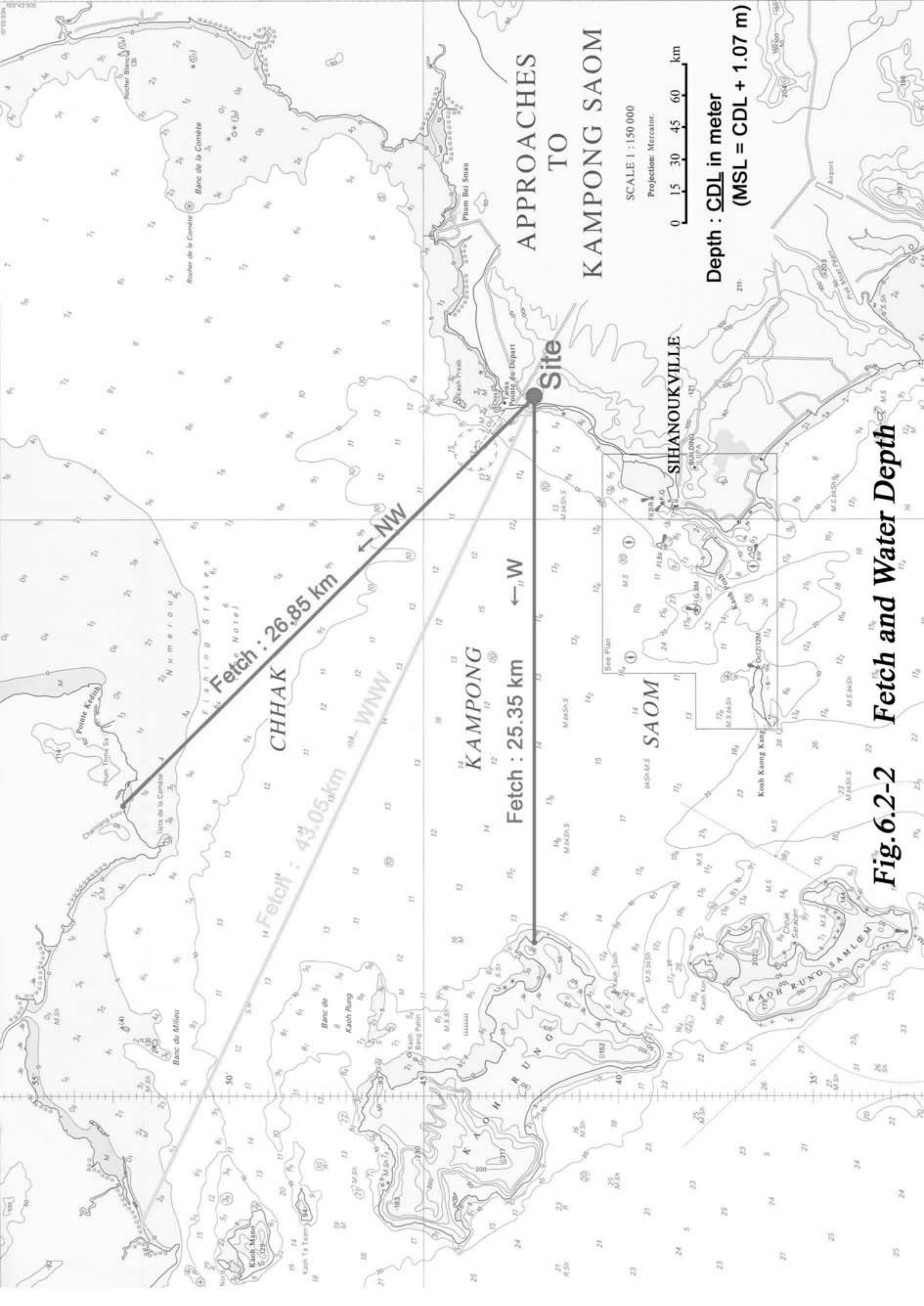


Fig.6.2-2 Fetch and Water Depth

(5) Site Ground Elevation

When the site ground elevation is designed the following items should be considered:

- Balance of soil works including soil/rock excavation and filling based on topography and subsurface geological condition.
- The ground is safe against possible high tide level and waves.
- Optimum arrangement of cooling water circulation pipe system.

(a) Wave Run-up Height

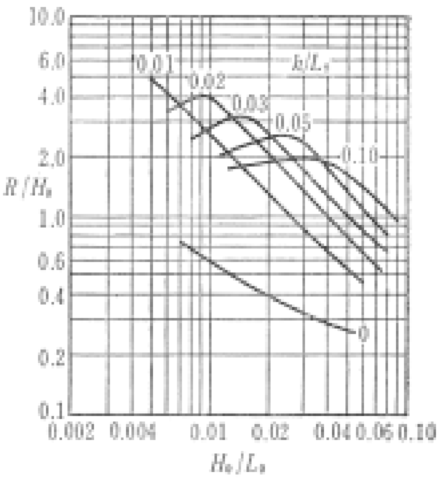
Wave run-up height is estimated based on the hydraulic model test results on wave run-up and incident waves as shown in Fig.6.2-3. The result is for the case of wave breaks occurrence.

Considering that the seabed slope is approximately 1/50 ~ 1/30, for a return period of 50 years, the wave run-up height is estimated as below:

Ho	=	3.8 m
To	=	6.5 sec
Lo	=	$1.56\ To^2 = 65.9$ m
Ho / Lo	=	0.057

When, h = 0.0 ~ 1.0 m

	R/Ho	=	0.25 ~ 0.6
Then	R	=	0.95 ~ 2.28 m



Seabed slope	:	1/30
Seawall slope	:	1/3
R	:	Wave run-up height
Ho	:	Deep sea wave height
Lo	:	Deep sea wave length
h	:	Water depth considered

(Source : JSCE: Hydraulic Formulae, 1976, pp531)

Fig.6.2-3 Relation of Wave Run-up Height and Wave Steepness

(b) Possible Maximum Water Level

As a result, the possible sea water level rise can be estimated as a sum of possible high tide level and wave run-up height:

Possible high water level = 1.17 m + 2.28 m = 3.45 m + MSL

(c) Condenser Limit

The plant ground level is normally set as + 4.0 m ~ 5.0 M + MSL, considering pump trip and siphon effect in arranging the cooling water circulation pipe system.

(d) Balance of Soil Works

For alignment of the power plant site on the topographic map, the area is divided into element of approximately 30 m square as shown in Fig.6.2-4.

After considering the expansion ratio and compaction ratio during soil works, the optimum ground elevation is so calculated as approximately 4.1 m + MSL to minimize the residual soil volume. Total soil excavation volume as normal condition will be approximately 95,000 m^3.

(e) Site Ground Elevation

Considering the above, the site ground elevation is 4.1 m + MSL.

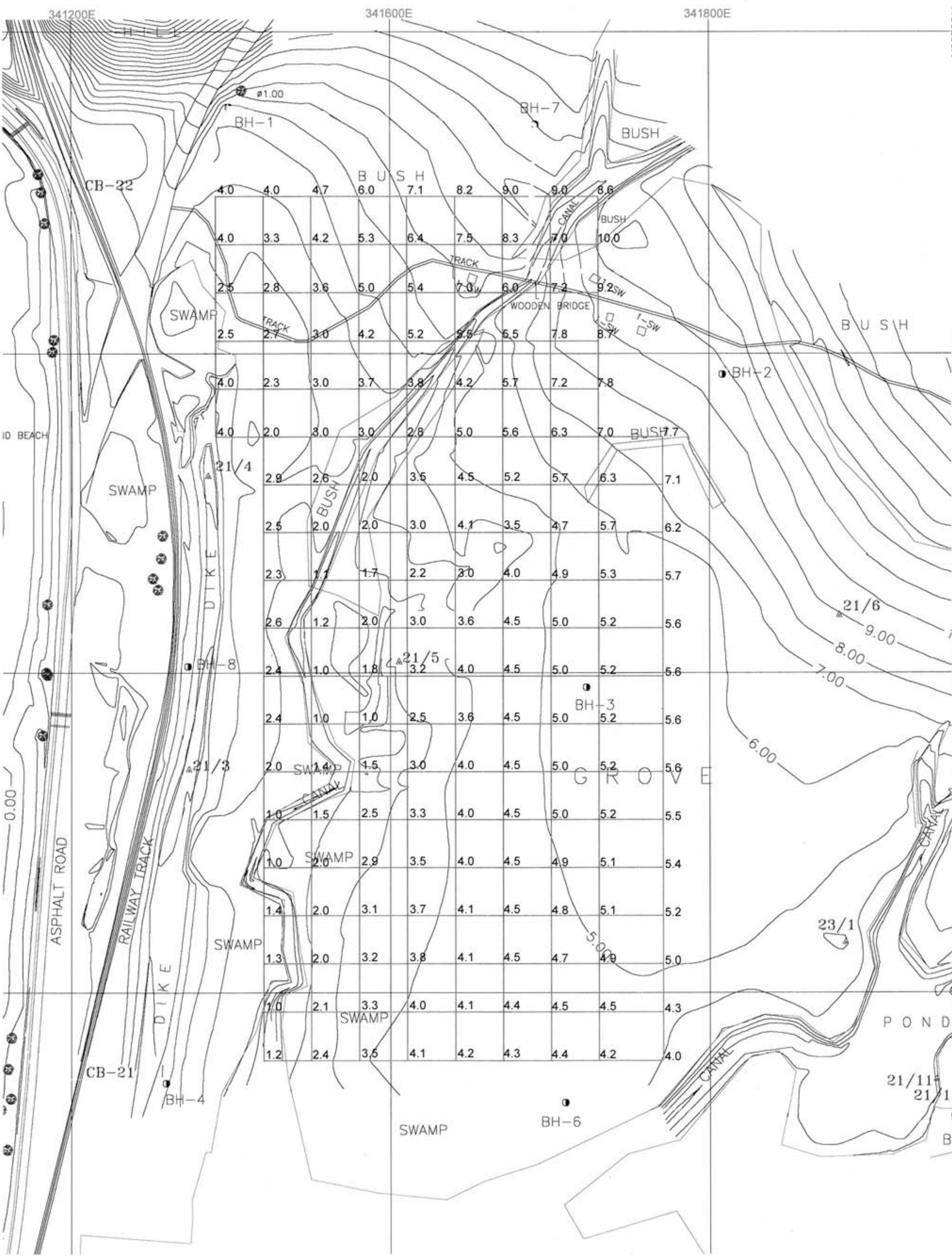


Fig.6.2-4 Ground Elevation of Grid Node in the Plant Area

6.2.2. Fuels

(1) Kind of Fuels

Sihanoukville gas turbine combined cycle project will use natural gas as main fuel and diesel oil as standby fuel. However, at present in Cambodia diesel oil is available but natural gas is under development. Refer to Section 3.1 regarding availability of fuels.

(2) Natural Gas Properties

The anticipated chemical composition and heating value based on typical natural gas are shown in Table 6.2-6. Pressure at the outside of the plant boundary perimeter fence is expected to be 25 - 30 kg/cm^{2}g.

Table 6.2-6 Properties of Typical Natural Gas

Components	Unit	
CO_2	vol. %	1.65
N_2	vol. %	1.92
CH_4	vol. %	95.49
C_2H_6	vol. %	0.72
C_3H_8	vol. %	0.07
C_4H_{10}	vol. %	0.02
C_5H_{12}	vol. %	0.10
High Heating Value	kJ/Nm^3	38,700
Low Heating Value	kJ/Nm^3	34,920

(3) Diesel Oil Properties

The anticipated chemical composition and heating value are shown in Table 6.2-7.

Table 6.2-7 Properties of Diesel Oil

Components	Unit	
Carbon	wt. %	86.22
Hydrogen	wt. %	13.10
Oxygen	wt. %	0.10
Nitrogen	wt. %	0.08
Sulfur	wt. %	0.20
Water & Sediment	wt. %	0.00
Ash	wt. %	0.00
High Heating Value	kJ/kg	44,430
Low Heating Value	kJ/kg	41,470

6.2.3. Cooling Water

(1) Quality

Sea Water

(2) Temperature

Condenser Design Temperature	29°C
Permissible Temperature Rise	7°C

The temperature of seawater as cooling water was measured from October 28, 2000 to January 9, 2001 (dry season). According to the measured data, the maximum and minimum temperature is approx. 30°C and approx. 27.5°C, respectively. The average temperature is approx. 29°C. Therefore the average temperature of 29°C during dry season is applied to condenser design temperature.

(3) Water Levels

See Section 6.2.1.(4).

6.2.4. Raw Water

(1) Source

Prey Treng Pond is the most likely fresh water source for the power plant.

(2) Quantity

In dry season, fresh water discharge observed at Prey Treng Pond is approx. 17 lit/sec in the end of February 2001. The quantity of fresh water is enough for the power plants. However, the 1-month reservoirs will be installed against water shortage during dry season considering increase of future fresh water demand for other consumers.

Variation of rainfall in dry season (from November to March) through 1991 to 2001 is shown in Fig.6.2-5.

Return period of rainfall in dry season of 2001 is calculated as 1.4 year based on the above variation as shown in Table 6.2-9. As a result, the raw water quantity is expected to be supplied mainly from the Prey Treng Pond.

(3) Water Quality

Water analysis of Prey Treng Pond is shown in the Table 6.2-8. The water quality was analyzed by UAE Lab. in Thailand.

In this report, the fresh water is planned to obtain from Prey Treng Pond. However this conclusion comes from only one-year measurement of water flow from Prey Treng Pond and Hun Sen Dam, and water flow in dry season is very limited. Therefore, to finalize water source, additional measurement of water flow and analysis of water characteristics for several years are recommended to be continued.

Table 6.2-8 Non-Excess Probability Dry Season Rainfall at Sihanoukville

Return Period (year)	Probability (%)	Rd (mm)
20	5.00	23.51
10	10.00	88.74
5	20.00	167.69
3	33.33	241.46
2	50.00	318.75
1.5	66.67	396.04
1.2	83.33	492.83
1.1	90.91	558.42

RD : Rainfall in Dry Season (November - March)
Dry year : Probability 10% occurrence of Rd less than 88.74 mm.

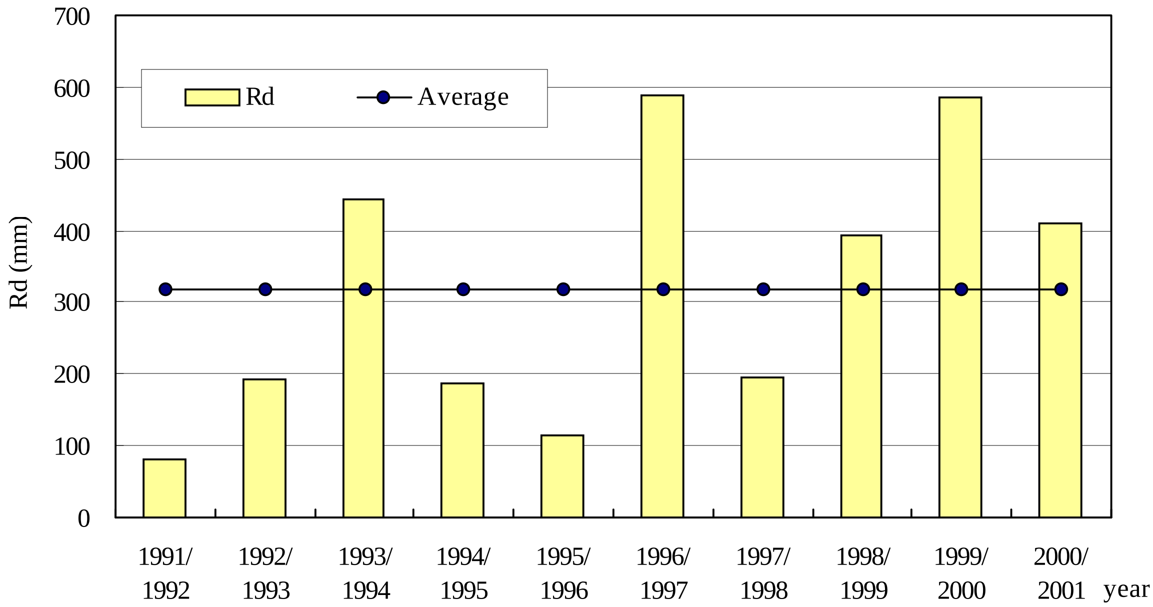


Fig.6.2-5 Variation of Rainfall in Dry Season

Table 6.2-9 Quality of Fresh Water

Parameter	Unit	Dry Season	Rainy Season
Color	-	Yellowish	Yellowish
Odor	-	No	No
pH	-	9.0	6.9
Salinity	ppt	0	0
Transparency	m	1.3	2.2
Dissolved Oxygen	mg/l	5.3	6.8
Turbidity	NTU	3.2	2.2
Total Hardness	mg/l as $CaCO_3$	12.0	8.1
Total Suspended Solids	mg/l	1.0	2.0
Total Solids	mg/l	65.0	36.0
Carbon Dioxide	mg/l	2.11	2.07
Cations			
Sodium	mg/l as Na	3.142	2.60
Potassium	mg/l as K	0.809	0.315
Calcium	mg/l as Ca	ND	ND
Magnesium	mg/l as Mg	2.92	1.96
Manganese	mg/l as Mn	Limit of Quantitation	ND
Iron	mg/l as Fe	0.918	0.731
Ammonia Nitrogen	mg/l as NH_3-N	0.185	0.14
Anions			
Chloride	mg/l as Cl	4.76	5.82
Bicarbonate Alkalinity	mg/l as $CaCO_3$	12.0	2.07
Sulfate	mg/l as SO_4^{2-}	3.1	2.1
Silica	mg/l as SiO_2	28.0 *	4.06
COD	mg/l	35.93	37.85
Oil and Grease	mg/l	ND	ND

* should be checked by further analysis

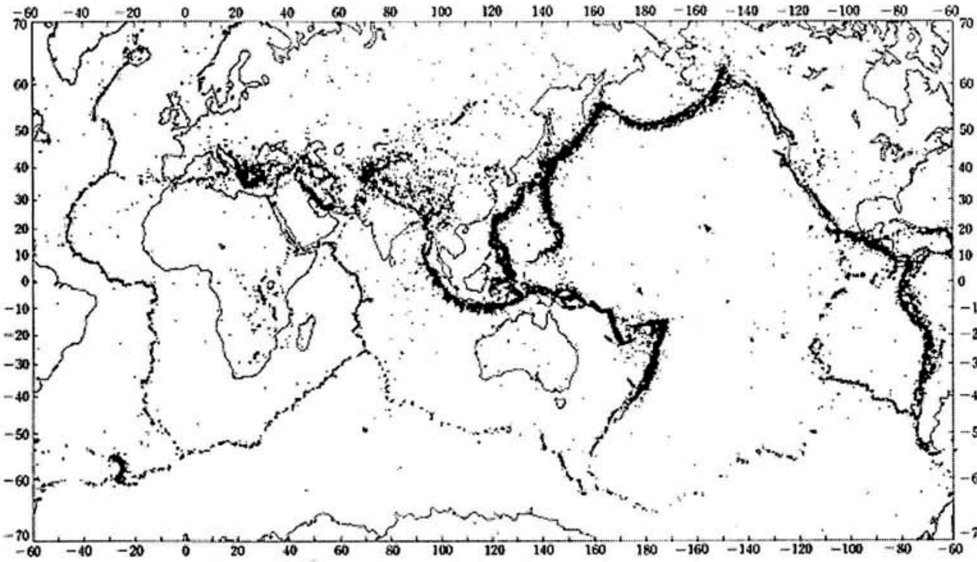
6.2.5. Seismic Design Condition

Earthquake distribution in the world (1970 - 1985) is shown in Fig.6.2-6. No earthquake has been found in Cambodia. While a seismic hazard map is presented in USGS H.P. as shown in Fig.6.2-7.

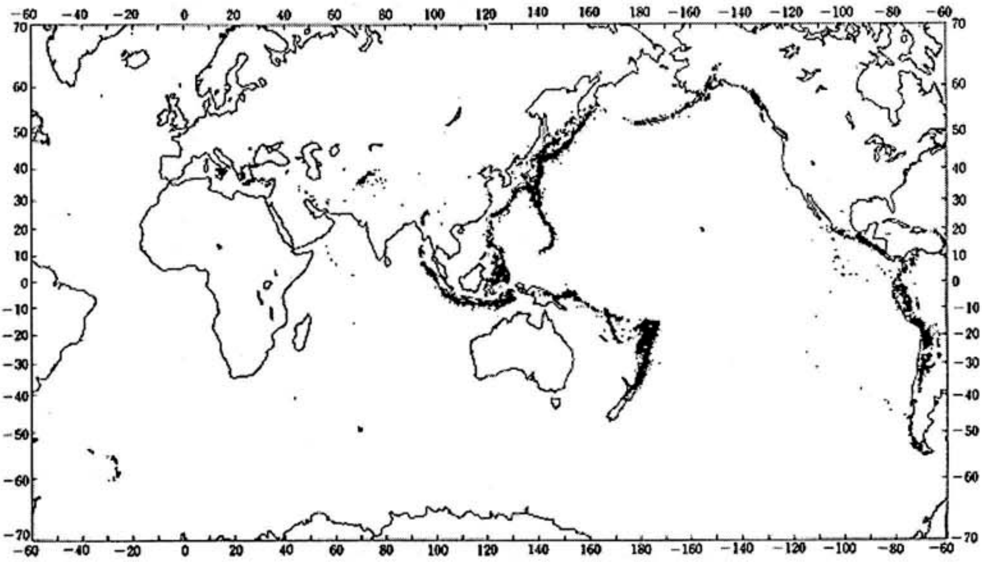
Value of PGA (Peak Ground Acceleration) is corresponding to value with a 10% chance of exceedance in 50 years and the site classification is rock.

This implies the event with a recurrence period of approximately 500 years. That will be adequate for the designing the important facilities of the project.

In Cambodia, the PGA value is 20 - 40 gal. As a result, the seismic coefficient defined as “the fraction of a weight to be used as a horizontal force in a quasistatic analysis” could be set as 0.05.

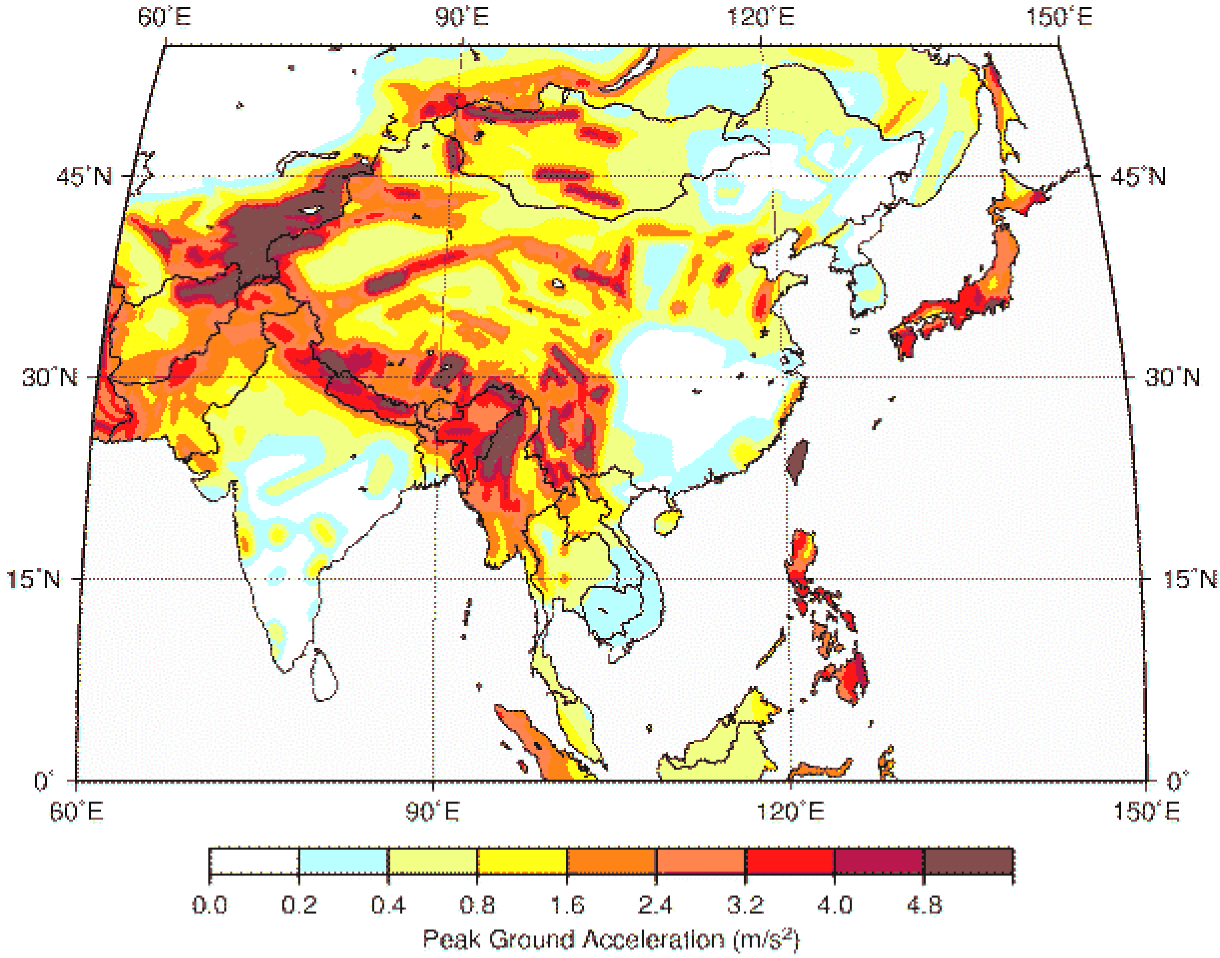


World Earthquake Distribution
(M > 4.0, Depth < 100 km, 1970-1985)



World Earthquake Distribution
(M > 4.0, Depth > 100 km, 1970-1985)

Fig.6.2-6 World Earthquake Distribution (1970-1985)



Depicting PGA, with a 10% chance of exceedance in 50 years. The site classification is rock

(Source : http://seismo.ethz.ch/GSMAP/eastasia/eastajia.html)

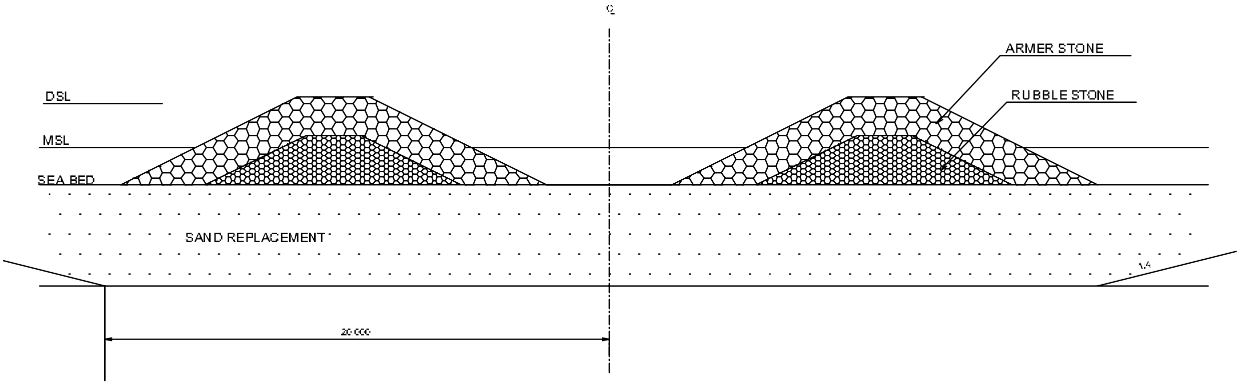
Fig.6.2-7 Seismic Hazard Map

6.2.6. Selection of Intake and Discharge Facility Types

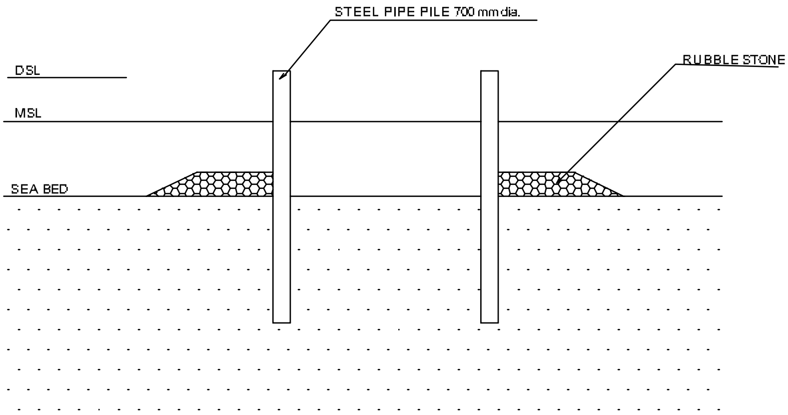
For selecting the type of intake and discharge facility, estimation of construction cost and features of each type are compared between 1) Rubble stone type, 2) Steel pipe pile type and 3) Buried pipe type as shown in Fig.6.2-8.

Rubble stone type and steel pipe pile type are both to make open channel to connect between intake/discharge pit and inlet/outlet, respectively. Buried pipe type is to set pipe under sea bed to connect intake/discharge pit to inlet/outlet, respectively.

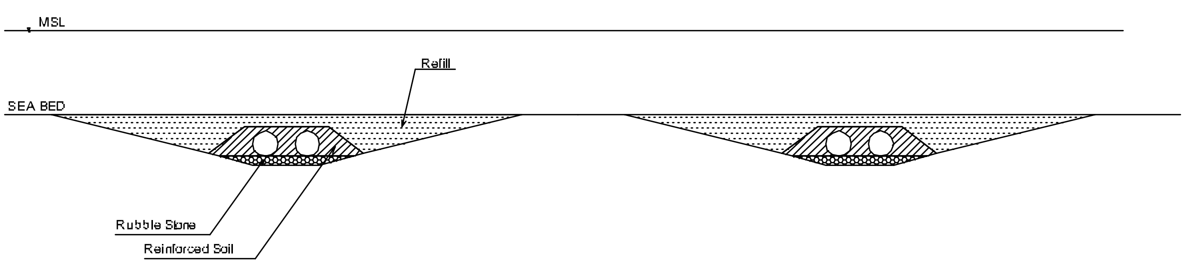
Approximate cost and features of each type are summarized in Table 6.2-10.
Considering less environmental impact in addition to construction cost, the buried pi-pe type is most prosperous.



(a) RUBBLE STONE CHANNEL TYPE



(b) STEEL PIPE PILE CHANNEL TYPE



(c) BURIED PIPE TYPE

Fig.6.2-8 Comparison of Intake/Discharge Facility Type

Table 6.2-10 Comparison of Intake and Discharge Facility Type

Item		Rubble Stone Type	Steel Pipe Pile Type	Buried Pipe Type
Length	Intake	300 m	300 m	300 m
	Discharge	300 m	300 m	300 m
Seawall		1,000 m	1,000 m	None
Construction Cost		10.1 Mil.$ (3 stages)	6.8 Mil.$ (3 stages)	3.8 Mil.$ (2 stages) 5.8 Mil.$ (3 stages)
Feature	Dispersion of Warm Water	Larger heated water area		Smaller heated water area
	Affect to Landscape	Bad	Bad	Good
	Affect to Beach	Local scoring due to off-shore structure expected	Local scoring due to off-shore structure expected	Less wave effect
	Affect to navigation	Obstructive to navigation	Obstructive to navigation	Limited obstruction to navigation
	Sedimentation	Sedimentation in the channel expected	Sedimentation in the channel expected	Less sedimentation expected
	Construction	Easy	Not difficult	Not difficult
Priority		3	2	1

6.3. <u>Configuration of Combined Cycle Power Plant</u>

6.3.1. Outline of Power Plant

Outline of power plant is as follows,

• Plant capacity	180 MW Stage 1 : 1 × 90 MW Stage 2 : 1 × 90 MW
• Type of power plants	Gas turbine combined cycle
• Plant site	OP-4 site in Sihanoukville (Approx. 2 km south of Sokimex Oil Terminal)
• Mode of operation	Base load operation
• Fuel	Natural gas and Diesel oil
• Cooling water	Seawater
• Fresh water	Prey Treng Pond next to the site and the water reservoir will be installed in the site for shortage of water during dry season

6.3.2. Type of Combined Cycle Power Plant

Gas turbine combined cycle power plant is composed of gas turbines, HRSGs and steam turbines. On the gas turbine combined cycle power plant, generally, one and more gas turbine(s) and correspondent number of steam turbine(s) are equipped to have necessary plant capacity. The number of HRSGs is the same as that of gas turbines and the waste heat in the gas turbine exhaust gases is converted to steam by the HRSGs to be utilized for steam turbines.

There are two types for gas turbine combined cycle power plant. One is single shaft type and the other is multiple shaft type. Table 6.3-1 shows the characteristics of both types.

As for plant efficiency, multiple shaft type is better than single shaft type at full and high loads because the steam turbine for multiple shaft type has higher efficiency. However, single shaft type is better than multiple shaft type at a low load. The steam turbine's efficiency of multiple shaft type lowers with load drop and as a result the plant efficiency lowers, but single shaft type can recover the plant efficiency up to the same level as that at a full load by stopping one by one with load drop.

Judging from Cambodian power situation and better efficiency of combined cycle plants, it is expected that the plant will be used for base load service and operated at a high load. Therefore, for this Project multiple shaft type is better because the efficiency is higher at full and high loads. Furthermore, multiple shaft type has flexibility for space of installation and the area of multiple shaft type is smaller than that of single shaft type.

Table 6.3-1 Comparison between Single Shaft and Multiple Shaft Configurations

	Single Shaft	Multiple Shaft
Capital Cost	Base	Same
Efficiency	Base	Better at higher load Worse at lower load
Availability	Base	Same
Operability	Base	Worse
Required Area	Base	Smaller

6.3.3. Capacity of Gas Turbines

One and more gas turbines are combined with a steam turbine to have necessary plant capacity for multiple shaft type gas turbine combined cycle plant.

Regarding the combination of gas turbine and steam turbine, it is better that the number of gas turbines to a steam turbine is reduced by applying larger gas turbines from the economical point of view. However, it is necessary to decrease an influence of forced outage of the equipment on power system by applying many smaller gas turbines judging from the power system stability point.

For power system in Cambodia, the maximum permissible capacity drop is approx. 30 MW in case of stop of one (1) gas turbine judging from the power system stability point as described in item 2.3 of this report. Therefore, the maximum capacity of gas turbine is approx. 20 MW and the number of gas turbines is 3 sets for each stage of 90 MW.

6.3.4. Steam Condition

Selection of steam temperature depends on the level of exhaust gas temperature of gas turbine. It is generally applied that gas temperature drop from gas turbine outlet to HRSG inlet is 1°C and temperature difference between exhaust gas temperature and steam temperature of steam turbine is 20°C.

Selection of steam pressure depends on a limit of moisture content in the steam leaving steam turbine. The maximum pressure is selected for steam temperature to make exit-moisture content of steam turbine not more than 10%.

Steam condition at steam turbine inlet is as follows,

At natural gas firing

- Steam pressure 5.4 MPa
- Steam temperature 493°C

At diesel oil firing

- Steam pressure 5.5 MPa
- Steam temperature 497 °C

6.3.5. Condenser Vacuum

Condenser vacuum of steam turbine depends on inlet temperature of cooling water, temperature rise across condenser and terminal temperature difference (between saturation temperature of exhaust steam and outlet temperature of cooling water). It is generally applied that temperature rise across condenser is 7°C and terminal temperature difference is 4°C.

For the Project, inlet temperature of cooling water is 29°C, outlet inlet temperature of cooling water is 36°C (29+7) and saturation temperature is 40°C (36+4). Therefore, condenser vacuum is 7.38 kPa which is equivalent to the saturation pressure of 40°C.

6.4. Particulars of Main Equipment

6.4.1. Gas Turbine

(1) Major Specifications of Gas Turbine

The major specifications of gas turbines are as follows.

(a)	Capacity	20 MW class
(b)	Type	Indoor
(c)	Fuel	Natural gas and diesel oil
(d)	Number	3 sets per stage

(2) Candidate Gas Turbines

Main manufacturers of 20 MW class gas turbine are GE, ANSALDO, ABB and MHI. Tables 6.4-1 shows the performance of gas turbines supplied by these manufacturers.

Table 6.4-1 Performance of Typical Gas Turbines (Natural Gas, ISO Base)

Manufacturer	GE	ANSALDO	ABB	MHI
Model	LM2500-PE	AGT25000	GT10B	MFT8
ISO Base Rating (kW)	22,800	26,180	24,770	25,420
Heat Rate (kJ/kWh)	9,785	10,057	10,534	9,755
Exhaust Temperature (°C)	523	465	543	466

(Source : Gas Turbine World Handbook)

(3) Performance at Site Conditions

Table 6.4-1 shows the performance of gas turbine at ISO condition of 15°C, 1,013 hPa and 60% relative humidity and on natural gas fuel. However, fuel type, atmospheric pressure, ambient temperature, relative humidity, etc will change the performance of gas turbine.

Natural gas and diesel oil will be used as fuels for the Project and regarding atmospheric condition atmospheric pressure is 1,013 hPa, ambient temperature is 28.8°C and relative humidity is 81% in Sihanoukville. Table 6.4-2 (natural gas firing) and Table 6.4-3 (diesel oil firing) show the performance of gas turbine at the above-mentioned site condition.

Table 6.4-2 Performance of Typical Gas Turbines with N.G. at Site Conditions

Manufacturer	GE	ANSALDO	ABB	MHI
Model	LM2500-PE	AGT25000	GT10B	MFT8
Capacity (kW)	19,670	23,480	22,220	22,610
Heat Rate (kJ/kWh)	10,216	10,513	11,015	10,262
Exhaust Temperature (°C)	538	479	557	482

Table 6.4-3 Performance of Typical Gas Turbines with D.O. at Site Conditions

Manufacturer	GE	ANSALDO	ABB	MHI
Model	LM2500-PE	AGT25000	GT10B	MFT8
Capacity (kW)	19,640	22,680	21,460	21,830
Heat Rate (kJ/kWh)	10,295	10,605	11,112	10,350
Exhaust Temperature (°C)	547	481	559	484

(4) Standard Gas Turbine

As mentioned in the above items (2) and (3), each manufacturer has its peculiar model of gas turbine and a gas turbine made by one manufacturer has different performance and capacity compared to gas turbines made by other manufacturers. Therefore, we image the gas turbine (called the standard gas turbine hereafter) which has average performance of the gas turbines made by manufacturers so that we carry out the future feasibility study.

The performance of the standard gas turbine at site condition is as follows,

(a) Natural Gas Firing

- Capacity 20,600 kW
- Heat Rate 10,500 kJ/kWh (2,508 kcal/kWh)
- Exhaust Temperature 514°C

(b) Diesel oil Firing

- Capacity 20,000 kW
- Heat Rate 10,593 kJ/kWh (2,530 kcal/kWh)
- Exhaust Temperature 518°C

(5) Start of Gas Turbine

(a) Normal Start

A gas turbine is first started from a barring condition using a starting device energized from an outside power source or a diesel-driven starting device. The starting procedure will be single-button operation to accelerate to the rated speed.

Synchronization of the generator to the system and initial load after reaching rated speed will be automated.

(b) Black Start

Since the Sihanoukville combined cycle power project is the largest key power station in the Cambodian system, it is recommended that at least one or more gas turbine generators in the Sihanoukville power station is preferred to have a black start capability. This is required in the event of a serious system disturbance or total loss of power generation when the whole plant shuts down.

(6) Main Components of Gas Turbine

A gas turbine is composed of air filtration system, compressor, combustion system, turbine, exhaust gas system, lubricating oil system and starting system.

A gas turbine is connected to the generator through a reduction gear or directly.

These components shall be of proven type suitable for continuous use as the prime mover for the generation of electrical energy.

Regarding the turbine, first stage blade will be coated for long term service, if applied.

For natural gas firing it is preferable that the burners are of the proven dry low NOx type.

The gas turbines are required to be housed within an acoustic enclosure equipped with a forced ventilation system. All natural gas control valves will be installed within the enclosure.

(7) Maintenance Schedule

Periodical maintenance is required for gas turbines to keep high efficiency and ensure reliability. The details of maintenance work will be submitted by each manufacturer. Generally combustor inspection takes place at intervals of 12,000 equivalent operation hours and hot gas path inspection takes place every 24,000 equivalent operation hours, i.e. after 1.5 years and 3 years respectively. Major inspection generally occurs every 48,000 equivalent operation hours (6 years).

6.4.2. Heat Recovery Steam Generator (HRSG)

(1) Type of HRSG

HRSG is installed to utilize heat of exhaust gas from gas turbine in order to produce steam for steam turbine. There are several types of HRSG as shown in Table 6.4-4. Suitable type is selected according to the steam condition and available installation area or standard design of manufacturer.

Table 6.4-4 Type of HRSG

stage of steam pressure	circulation of boiler water	gas flow direction
single-pressure	natural circulation	horizontal
multi-pressure	forced circulation	vertical

(2) Stages of Steam Pressure

There are two types of HRSG in relation to number of stages of steam pressure. Single pressure type has only one pressure stage. Multi-pressure type has two or more pressure stages and there is advanced one with reheat cycle. Single pressure HRSG has a simpler water-steam system because of only one pressure stage. Though multi-pressure HRSG has rather complicated system, it has a higher heat recovery rate and improves efficiency of power plant. It is preferable to select multi-pressure HRSG for the Project to improve efficiency.

(3) Circulation System of Boiler Water

There are two types of boiler water circulation system, i.e. natural circulation and forced circulation. Natural circulation utilizes the difference of densities of water and water/vapour mixture within the circulation system. Forced circulation circulates the boiler water by using boiler circulation pump. For horizontal gas flow type HRSG, natural circulation is always applied, but for vertical gas flow type HRSG either natural or forced circulation is applied. Gas flow direction of HRSG is discussed in the following section. Table 6.4-5 shows comparison of characteristics of these two circulation types. Each circulation type has its own superior and inferior points. The selection may be based on standard design of manufacturer unless any trouble in operation has been reported.

(4) Gas Flow Direction

There are two types of HRSG in relation to gas flow direction, i.e. horizontal gas flow type and vertical gas flow type. Horizontal gas flow type HRSG has vertically arranged self-supported heat exchanger tubes, and gas flows horizontally through the HRSG. Vertical gas flow type HRSG has horizontally arranged hanger-supported heat exchanger tubes and gas flows vertically through the HRSG. Table 6.4-6 shows comparison of these two types.

(5) Component of HRSG

(a) Heat Exchanger

Kinds of heat exchanger used for dual pressure type are as follows:

- High pressure superheater
- High pressure evaporator
- High pressure economizer
- Low pressure super heater
- Low pressure evaporator
- Low pressure economizer

Fig.6.4-1 shows an example of arrangement of heat exchangers applied to the vertical gas flow type HRSG. All tube banks normally consist of finned tubes in order to recover the heat efficiently and minimize the physical volume of boiler.

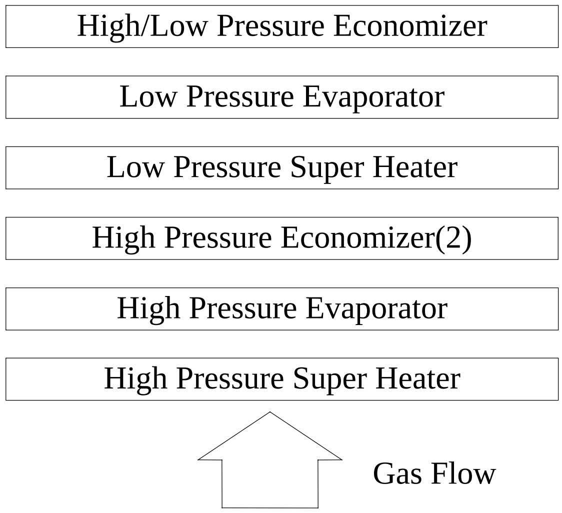


Fig.6.4-1 Arrangement of Heat Exchanger

(b) Boiler Casing

Boiler casing envelops all heat exchangers. Heat insulation material is fitted inside or outside of boiler casing and minimizes the heat liberation to the outside. Boiler casing is reinforced by steel.

(c) Steam Drums

Circulation type boiler, not one-through type, is usually applied to HRSG of combined cycle because of relatively low steam pressure. Circulation type boiler has horizontally arranged drum. Feedwater is converted to vapour/ water-mixture in evaporator tube and flows into drum. Mixture is separated into steam and water at drums and the steam is induced to steam turbine through the super heater. Separated water goes down to evaporator again.

Because of relatively low pressure of steam, significant level fluctuation of drum water would frequently happen during start-up due to sudden introduction of a lot of heat from GT. This level fluctuation is called swelling phenomenon. To minimize the fluctuation of water level, drum size should be selected properly and drum water blow down system should be installed to control the water level.

(6) Estimated Main Spec. of HRSG

Item	Unit	Natural Gas		Diesel Oil	
		HP	LP	HP	LP
Evaporation	t/h	85.8*	20.6*	84.9*	20.2*
Steam pressure	MPa	5.7	0.74	5.8	0.74
Steam temperature	°C	496	235	500	235
Feedwater temperature	°C	60		135	
Number of installation		One for each GT (Three for each stage of 90 MW)			

* Total evaporation of three HRSGs for 90 MW

(7) Stacks

A common stack will be provided for three HRSGs to help disperse the flue gas into the atmosphere.

The height will be 50 m and the diameter will be 3.9 m.

Table 6.4-5 Comparison between Natural Circulation and Forced Circulation Type of HRSG

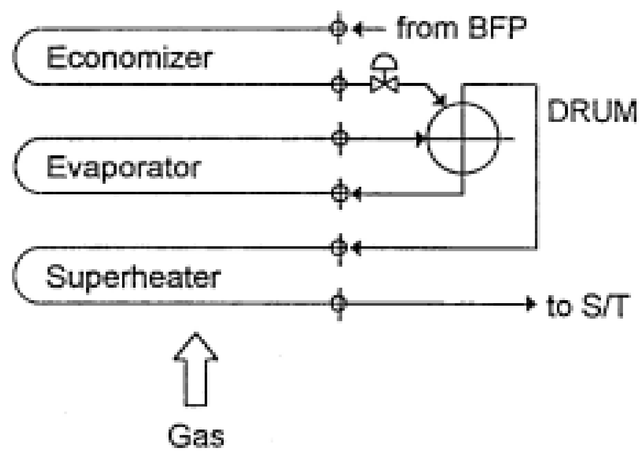
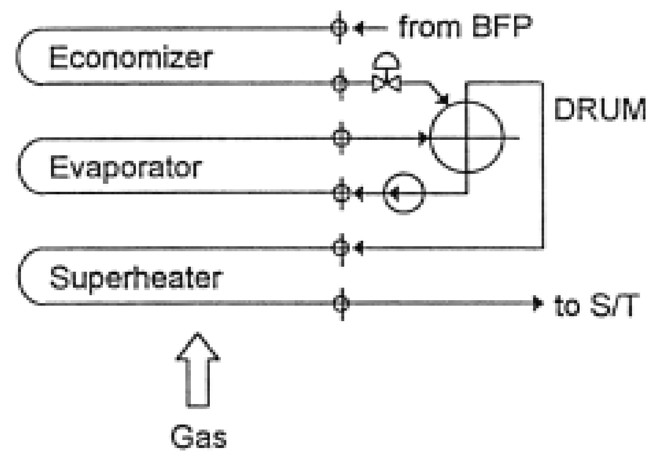
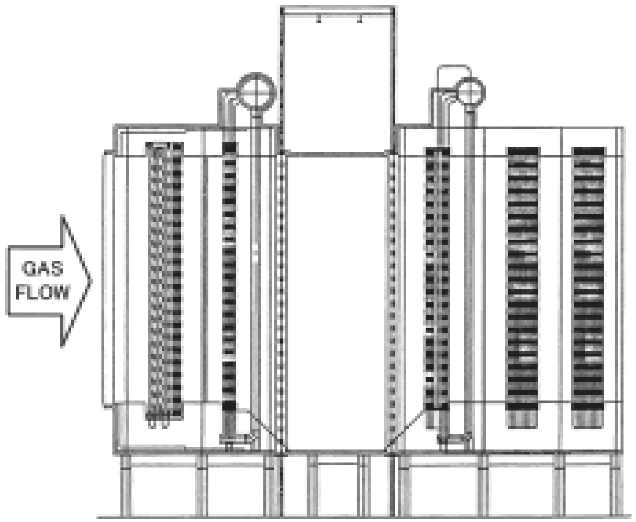
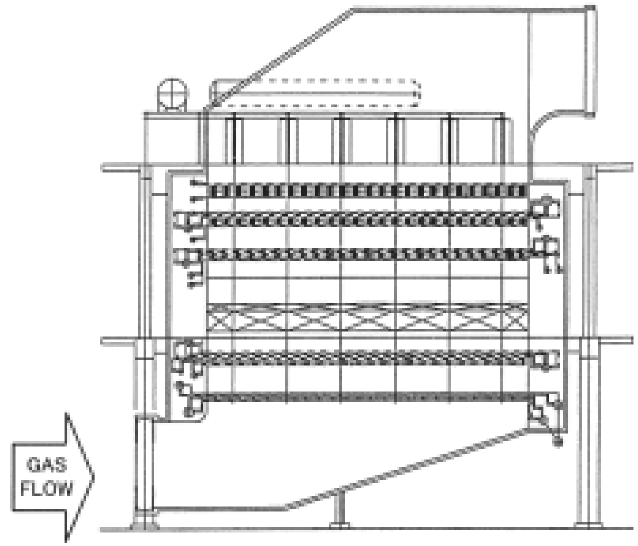
			natural circulation	forced circulation
Schematic system				
Applicable Range	Circulation Ratio		14 ~ 6	~ 4
	Pressure		below 17.7 MPa	below 19.6 MPa
Startup Time			Base	Shorter
Reliability	Stability of Water Circulation		Base	Better
	Possibility of Trouble		Base Circulation system is simple.	Higher Circulation system is rather complicated.
Size	Height		Base	Same
	Required space		Base	Same
Cost	Weight	Pressure parts	Base (100%)	Lighter (90%)
		Non-pressure parts	Base (100%)	Same
		Steel structure	Base (100%)	Same
	Auxiliary Power Consumption		Base (100%)	Larger (120%)
	Maintenance		Base	Maintenance cost of BCPs increase.
	Construction cost		Base	Same

Table 6.4-6 Comparison of Type of HRSG

			Horizontal Gas Flow Type	Vertical Gas Flow Type
Features of HRSG				
Features	Heat Exchange Area		Base	Same
	Pressure Drop of Exhaust Gas		Base	Same
	Startup Time&Load Variation		Base	Same
Size	Height		Base	Same
	Required space		Base (100%)	Smaller(98%)
Cost	Weight	Heat Exchange Tube	Base	Same
		Header	Base	Same
		Non-pressurized Parts	Base (100%)	Lighter (83%)
		Steel Frame	Base (100%)	Heavier (133%)
	Ease of Construction	Number of Welding	Base (100%)	Smaller (67%)
		Number of Module	2Modules	1Module
	Ease of Maintenance and Inspection		Base (Scaffolding is required.)	Easier (Scaffolding is not required.)
	Construction Cost		Base	Same

6.4.3. Steam Turbine

(1) Type

There are two types of steam turbines that are used for gas turbine combined cycle plant by exhaust flow direction. One is axial exhaust turbine and the other is down exhaust turbine.

The axial exhaust turbine has higher efficiency because of lower exhaust loss and it is possible to reduce the construction cost of foundation and building of steam turbine because of lower required level of installation. Therefore, the axial exhaust turbine has an advantage over down exhaust turbine.

However, the axial exhaust turbine is not applicable to large capacity steam turbines because they have multiple exhausts. The capacity of steam turbine that single exhaust can be applied to is not more than 200 to 250 MW and down exhaust is applied to the steam turbine with larger capacity.

The axial exhaust turbine will be applied to the Project because the capacity of the steam turbine is approx. 28 MW.

(2) Major Specification

The major specification of the steam turbine for the Project is as follows.

• Type	Axial exhaust turbine		
• Rated output	28,200 kW		
• Rated speed of turbine	3,000 rpm		
• Steam condition	Steam pressure	(HP/LP) :	5.4 MPa / 0.7 MPa
	Steam temperature	(HP/LP) :	493°C / 234°C
• Condenser vacuum	7.38 kPa		
• Number of installation	One for each stage of 90 MW		

(3) Main Components of Steam Turbine

A steam turbine is composed of cylinder, blading, rotor, bearing, valves, control oil system, lubricating oil system and barring system.

A steam turbine is connected to the generator through a reduction gear or directly.

These components shall be of proven type suitable for continuous use as the prime mover for the generation of electrical energy.

A condenser will be installed to condense the exhaust steam from a steam turbine by cooling water. The condenser will be of single or two pass surface type. An automatic on-load condenser tube cleaning system will be equipped to keep the condenser clean.

(4) Operation of Steam Turbine

Start-up, rotating speed acceleration, synchronizing, loading and shut down will be carried out automatically from the central control room.

The steam turbine generator will be operated with gas turbine and HRSG follow mode at any load except at the stage of start and stop procedure.

Since steam flow generated in the HRSG depends on the load of the gas turbines, the steam turbine will be operated in a slide pressure mode in order to be able to achieve the optimum operating efficiency.

The steam turbine is provided with bypass facilities to allow the steam turbine to start up with minimizing thermal stress caused by temperature difference.

6.4.4. Generator

(1) Design Concept

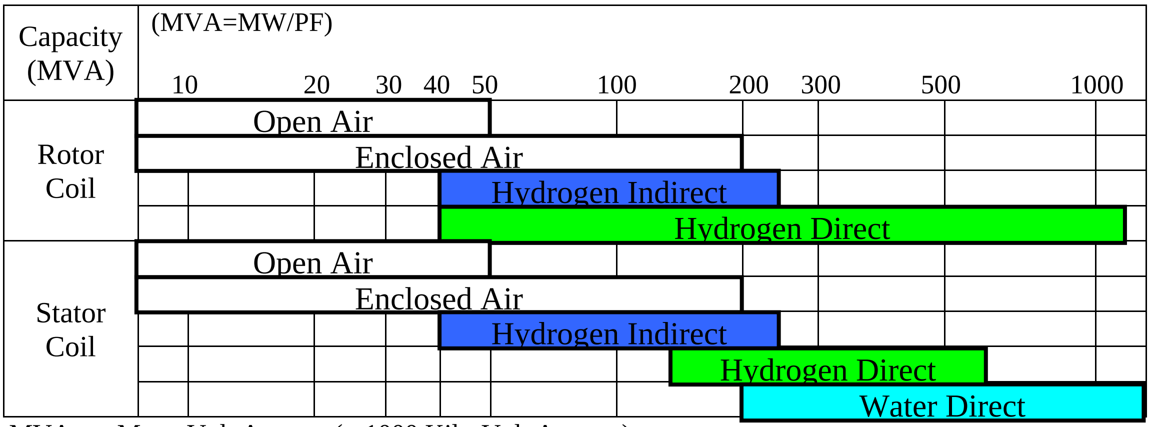
Design technology, manufacturing technology and material technology for generator have been remarkably advanced especially in electro-magnetic analysis, cooling method, insulation material, excitation system and etc. and, therefore, high reliability has been reached for wide range of unit capacity.

Design technologies associated with electrical and mechanical characteristics and performances depends mainly on experiences and know-how of each manufacturer and customer can select most suitable specifications to meet the requirements from the network power system and to satisfy his own operation and maintenance requirements for cooling method, power factor, short circuit ratio and excitation system.

(2) Cooling Method

Cooling methods being technically applicable to the generator are open air cooling, totally enclosed air cooling, totally enclosed hydrogen indirect cooling, totally enclosed hydrogen direct cooling and water cooling. These cooling methods can be applied generally as shown in Fig.6.4-2 in relation to generator unit capacity while each manufacturer has his own standard application criteria.
General application and features of each cooling method are as mentioned below.
For this project, considering generator unit capacity, availability of cooling water and economics, following application will be suitable;

Gas turbine generator	:	Totally enclosed air cooled. Open air cooled type may be applied only when gas turbine generator unit will be installed and started to operate as simple cycle system before combined cycle plant is completed, and no cooling water will be available.
Steam turbine generator	:	Totally enclosed air cooled.



MVA : Mega-Volt Ampere (= 1000 Kilo-Volt Ampere)
MW : Mega-Watt (= 1000 Kilo-Watt),
PF : Power Factor

Fig. 6.4-2 Cooling Method of Generator

Open air cooling is applied in case that generator capacity is small, cooling water is not available, ambient air is relatively clean and causes less insulation deterioration and/or rapid start-up is needed for emergency or peak-load cut service. In this cooling method, the generator offers easy operation but is subject to insulation deterioration due to ambient atmosphere and lower efficiency than other cooling methods.

Totally enclosed air cooling is applied for low capacity and middle capacity class generator and has advantages of easy operation and maintenance since no hydrogen gas supply and no hydrogen gas sealing system are needed and, therefore, system is simple, comparing to totally enclosed hydrogen cooling. This method makes insulation deterioration due to ambient atmosphere less than open air cooling, and has higher efficiency than open air cooling and lower efficiency than totally enclosed hydrogen cooling.

Totally enclosed hydrogen indirect cooling is applied mainly to middle capacity class generator and has higher efficiency than air cooling. This cooling method, however, needs hydrogen gas supply and sealing systems and, therefore, operation and maintenance are more complicated than air cooling.

Totally enclosed hydrogen direct cooling is applied to middle capacity and large capacity class generator and has no major difference from totally enclosed hydrogen indirect cooling for operation and maintenance, while both methods are different in view point of winding conductor cooling construction.

Water cooling is applied to the large capacity generator above the application range of totally enclosed hydrogen cooling. Stator winding conductor is cooled directly by cooling water flowing inside core path of winding conductor to get higher cooling effect. Cooling water control and supply system is required to be provided. The rotor windings and others are cooled by the same manner as hydrogen cooling and therefore, hydrogen gas supply system and sealing system are needed.

General features of each cooling type of the generator are outlined below.

Open air cooled generator	Stator and rotor are cooled by the ambient air. Stator casing has an inlet opening to take the cooling air from the outside and an outlet opening to discharge heated air. Cooling air is driven by fans mounted on the rotator shaft to circulate through paths in the generator.
Totally enclosed air cooled generator	Stator and rotor are totally enclosed in the stator casing and cooled by the enclosed air inside the casing. This enclosed air is cooled by the air coolers (air to water heat exchanger) which are mounted inside or outside the stator casing. Cooling air is driven by fans mounted on the rotator shaft to circulate through paths in the generator. External cooling water is required.
Hydrogen indirect cooled generator	Stator and rotor are totally enclosed in the stator casing and cooled by the enclosed hydrogen gas inside the casing. Stator winding conductors and rotor winding conductors are cooled through the insulation by the cooling gas. Hydrogen gas is cooled by hydrogen gas to water heat exchangers which are mounted inside the stator casing and is driven by the fans mounted on the rotor shaft to circulate through the paths inside the generator. External cooling water is required. In order to prevent hydrogen gas from

leaking, rotor bearings are sealed by the sealing oil which is supplied from external sea oil supply system.

Hydrogen direct cooled generator .... Stator and rotor are totally enclosed in the stator casing and cooled by the enclosed hydrogen gas inside the casing. Stator winding conductors and rotor winding conductors are cooled directly by the cooling gas. Hydrogen gas flows inside the core path of stator and rotor winding conductor to get higher cooling effect. Hydrogen gas is cooled by hydrogen gas to water heat exchangers which are mounted inside the stator casing and is driven by the fans mounted on the rotor shaft to circulate through the paths inside the generator. External cooling water is required.

Water cooled generator ...... Stator winding conductors are cooled directly by the cooling water flowing inside the core path of the conductor. Cooling water is cooled and monitored by the external cooling water supply system. Rotor and others are cooled by the same manner as hydrogen cooled generator.

(3) Electrical and Mechanical Characteristics and Performances

Characteristics and performances are decided from the following points of view:

- To be based on the considerations of the requirements such as load characteristics and operation requirements of the network system
- To be based on the considerations of the requirements of the applied regulations and standards
- To be based on the technical and economical conditions in the design and manufacturing of each manufacturer

(a) Rated Output

Rated output is selected to be capable of operating rated output of the driving gas turbine or steam turbine at the rated power factor and the specified ambient conditions

(b) Rated Power Factor

Generally, either one of lagging power factor 0.8, 0.85 or 0.9 is applied. Rated power factor is to be selected economically in consideration of load power factor (reactive power demand) and power factor regulation capability of the total network. Usually, 0.9 lag is applied to middle capacity class and large capacity class for utility service and, for others such as air-cooled type, 0.8 or 0.85 lag is applied. Therefor, 0.8 or 0.85 lag is applied to generators of the Sihanoukville power station.

Almost all of generated power of the Sihanoukville power station is intended to be sent to Phnom Penh to feed the load around there. Higher power factor of transmitted power results in lower transmission line loss and the higher rated power factor of the generator gives better economy than lower rated power factor. It is recommended that the power factor of the load in Phnom Penh network system is improved by some power factor control equipment such as Static Var Controller (SVC) in main substations so that generators of the Sihanoukville power station can adopt higher power factor, 0.85 lag. In this connection, according to the past records by the load dispatching center of EDC in Phnom Penh, power factor of the total load of power station IPP1, C2, C3, C5 and C6 is as mentioned below. These values can be understood to be typical average power factor values of the network load in Phnom Penh.

	Dry season (Feb. 19, 1999)	Rainy season (Sept. 5, 2000)
Highest	0.92 (Around AM 2:00)	0.91 (Around AM 0:00)
Lowest	0.8 (Around PM 7:00)	0.78 (Around PM 7:00)
Average	0.868	0.863

(c) Rated Voltage

For utility service, generator rated voltage is decided as most suitable technically and most economical, based on the manufacturer’s optimum standard design without considering voltage of any external network since generated voltage is stepped up to the transmission line voltage for utility service by the main transformer (generator transformer). Generally, rated voltage is selected in the range of 11 kV to 15 kV for the range of 25 MVA to 100 MVA.

(d) Short Circuit Ratio (SCR)

Short circuit ratio (SCR) is decided, taking into consideration stability of the associated network system and response of the excitation system. Large short circuit ratio gives better contribution to the stability of the network system. However, too large SCR means that the generator is, what is called, iron machine and relatively large in the frame size and, therefore, uneconomical. It is not always most suitable design. Usually, 0.4 to 0.45 is applied.

(f) Insulation Class and Permissible Temperature Rise

Usually, class B or F insulation material is applied and permissible temperature rise values are applied for design as specified for each class in the applied standards. Sometimes in case that severe or critical operation is expected, one rank lower value than specified one for applied insulation material is applied as design purpose. For instance, permissible temperature rise values for class B are applied to the class F insulation material.
For this project, it is preferable that class F insulation materials will be applied and permissible temperature rise will be based on class B insulation.

(4) Excitation System

Generally, applicable excitation systems are either brushless excitation system and static excitation system. Some manufacturers may have similar excitation systems to those as their standard systems.

General features of typical brushless excitation system and static excitation system are as follows.

(a) Brushless Excitation System

This system consists mainly of AC excitation generator, rotating rectifier assembly which rectify output of the AC excitation generator and feed DC excitation current to the excitation circuit of main generator, permanent magnetic generator which supply excitation power to the AC excitation generator. AC excitation generator, rotating rectifier assembly and permanent magnetic generator are all mounted on the rotating shaft directly connected to the main generator rotor shaft. It has following specific features:

(i) Inspection and replacement of brushes are not needed since it has no brush and no slip-ring

(ii) Total length of the rotating shaft of the generator and exciter is longer than one in case of static excitation system

Fig.6.4-3 shows outlined system configuration of brushless excitation system.

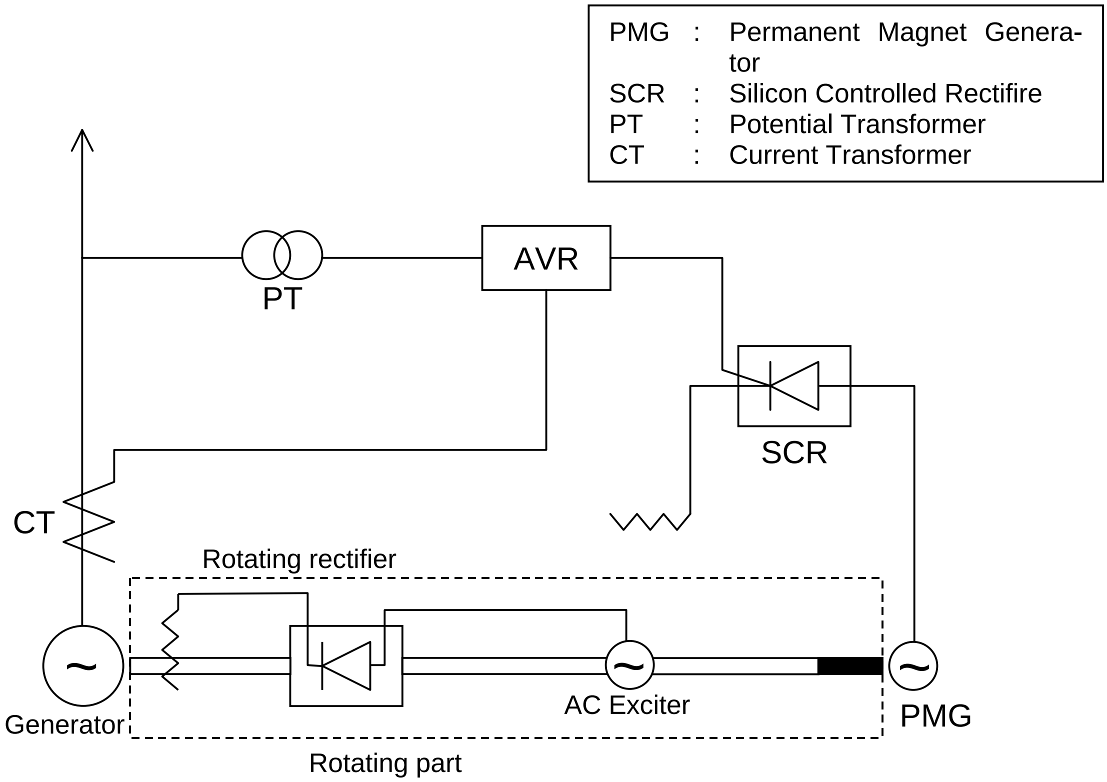


Fig.6.4-3 Brushless Excitation System

(b) Static Excitation System

Excitation power is derived directly from generator output via excitation transformer and rectified by thyrister rectifying circuit. Then, rectified DC is fed to excitation circuit of main generator through slip-ring on generator rotating shaft.

It has the following specific features:

(i) Inspection of brush and slip-ring and replacement of brush are needed

(ii) Total length of the rotating shaft of the generator is shorter than one in case of brushless excitation system. On the other hand, installation area for excitation transformer and thyrister rectifier is needed.

Fig.6.4-4 shows outlined system configuration of static excitation system

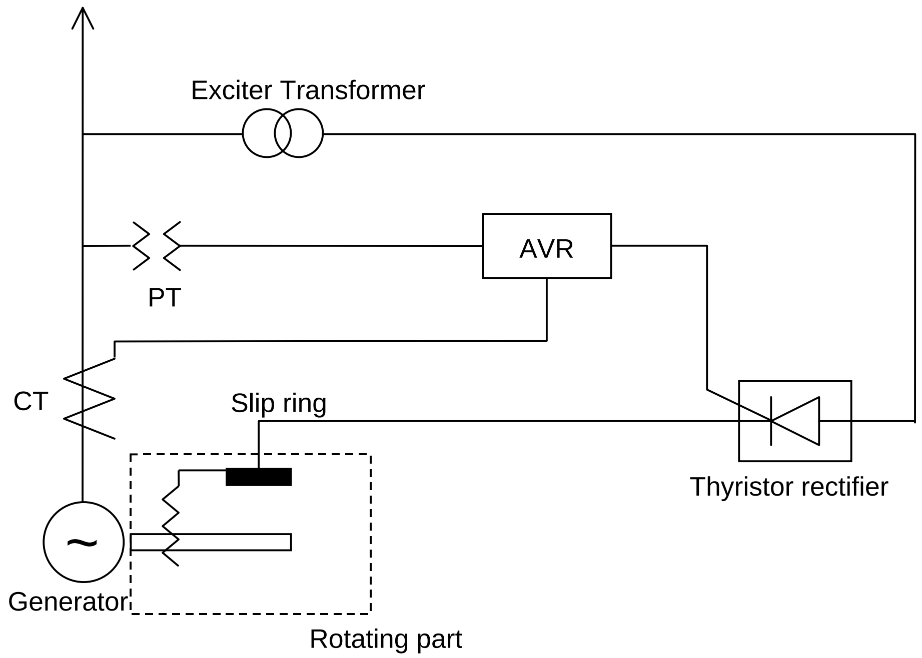


Fig.6.4-4 Static Excitation System

6.5. Scope of Works

6.5.1. Outline

The power plant for the Project will be furnished on full turnkey basis including all works such as erection work, civil work, etc.

The equipment and works for the Project are as follows,

(1) Civil Works

Land surveying

Boring

Excavation

Grading and site preparation

Foundations

Intake pipes and cooling water pump pit

Discharge pipes

Concrete tanks

Road in the premises

Gardening

Parking lots

Perimeter wall fence

Fresh water pump pit at Prey Treng Pond

Temporary and reinforcement works of the existing roads and bridges

Temporary and reinforcement works of the existing railway

Border protection works for Prey Treng Pond

(2) Architectural Works

Powerhouse including gas turbine room, steam turbine room, central control room, electrical room, emergency diesel generator room, etc.

Administration building including chemical laboratory

Work shop

Warehouse

Canteen Building

Guardhouse and fire station

Water treatment house and storeroom of chemicals

Ventilation and air conditioning system

Diesel oil receiving house (next to Sokimex Oil Terminal)

Fresh water pump house at Prey Treng Pond

(3) Mechanical Equipment

Gas turbines and their ancillary equipment

HRSGs and their ancillary equipment

Stacks

Steam turbines and their ancillary equipment

Deaerators

Condensers

Steam and water system

Cooling water pumps, screening plants and condenser cooling water system

Closed circuit cooling water system

Fuel gas treatment and supply system

Diesel oil receiving system (next to Sokimex Oil Terminal) and oil transfer pipeline

Oil storage tanks and oil supply system

Fresh water transfer system

Water treatment and demineralization plant

Potable water system and general water service system

Waste water treatment system

Compressed air system

Cranes and lifts

Fire prevention and fighting system

Machine tool

Instruments for chemical analysis

(4) Control and Instrumentation System

Overall plant supervisory control system

Gas turbine generator supervisory control system

HRSG supervisory control system

Steam turbine generator supervisory control system

Data acquisition system

Common facilities supervisory control system

Uninterruptible power supply system (UPS) for C & I system

Telecommunication equipment to/from load dispatching center

(5) Electrical Equipment

Generators and main circuit equipment

Transformers

High voltage and low voltage station electrical system

DC system

Emergency diesel generator set

Operational instruction system

Grounding system

Lighting system

Lightning protection system

In-plant substation

Supervisory, operational and protective system for electrical equipment

In-house communication system

6.5.2. Terminal Point

The terminal points for the Project are as follows;

(1) Fuel

Natural Gas	Inlet of natural gas receiving system at site boundary
Diesel Oil	Inlet of diesel oil receiving system next to Sokimex Oil Terminal

(2) Cooling Water

Intake	Inlet of intake mouth
Discharge	Outlet of discharge pipes

(3) Fresh Water

Inlet of transfer pumps located on the border of Prey Treng Pond

(4) Effluent

Outlet of cooling water discharge canal or storm water run off

(5) Flue Gas

Outlet of stack

(6) Access

Connection point with the existing road leading to the Sokimex Oil Terminal from Sihanoukville City

(7) Control and Instrumentation System

Connection point within the power plant for receiving load dispatching instruction from load dispatching center and sending the information and data of power generation on the telecommunication system

(8) Electrical Equipment

Outlet of feeders for transmission line in the in-plant substation

6.5.3. Philosophy of Expansion from 90 MW to 180 MW

The Sihanoukville power plant will be implemented in three stages (i.e., Stages 1, 2 and 3). Each 90 MW plant will be constructed in each stage. However, common works such as site preparation, etc. have to be done in Stage 1.

The philosophy of expansion from Stage 1 (90 MW) to Stage 2 (total 180 MW) is as follows.

Note : The term "All works" means all works necessary for the whole plant of Stage 1, Stage 2 and Stage 3.

	Stage 1 (90 MW)	Stage 2 (Total 180 MW)
Civil Works		
Excavation	All works	None
Leveling and site preparation	All works	None
Soil disposal	All works	None
Foundations	Works related to 1st 90 MW	Works related to 2nd 90 MW
Intake pipes and discharge pipes	Works related to 1st 90 MW	Works related to 2nd 90 MW
Cooling water pump pit	Works related to 1st 90 MW and 2nd 90 MW	None
Bridge and culvert construction work of cooling water lines for crossing the existing provincial road/railway	All works	None
Road in the premises	All works	None
Tree planting and garden	All works	None
Parking lots	All works	None
Fence	All works	None
Fresh water pump pit	Works related to 1st 90 MW and 2nd 90 MW	None
RC raw water reservoirs	Works related to 1st 90 MW	Works related to 2nd 90 MW
RC filtered water storage tanks	Works related to 1st 90 MW and 2nd 90 MW (common use)	None
RC tanks for wastewater treatment plant	Works related to 1st 90 MW and 2nd 90 MW	None
Architectural Works		
Administration building	All works	None
Gas turbine rooms	Works related to 1st 90 MW	Works related to 2nd 90 MW
Steam turbine rooms	Works related to 1st 90 MW	Works related to 2nd 90 MW
Central control room	Works related to 1st 90 MW and 2nd 90 MW	None
Electrical room	Works related to 1st 90 MW	Works related to 2nd 90 MW
Emergency diesel generator room	Works related to 1st 90 MW and 2nd 90 MW	None
Pump rooms	Works related to 1st 90 MW	Works related to 2nd 90 MW
Canteen building	All works	None
Work shop	Works related to 1st 90 MW and 2nd 90 MW	None
Warehouse	Works related to 1st 90 MW and 2nd 90 MW	None

	Stage 1 (90 MW)	Stage 2 (Total 180 MW)
Water treatment house	Works related to 1st 90 MW and 2nd 90 MW	None
Guardhouse	All works	None
Ventilation and air conditioning system	Works related to 1st 90 MW	Works related to 2nd 90 MW
Diesel oil receiving house	Works related to 1st 90 MW and 2nd 90 MW	None
Fresh water pump house	Works related to 1st 90 MW and 2nd 90 MW	None
Mechanical Equipment		
Gas turbine sets	Works related to 1st 90 MW (3 gas turbines)	Works related to 2nd 90 MW (3 gas turbines)
HRSG sets and stacks	Works related to 1st 90 MW (3 HRSGs)	Works related to 2nd 90 MW (3 HRSGs)
Steam turbine sets	Works related to 1st 90 MW (1 steam turbine)	Works related to 2nd 90 MW (1 steam turbine)
Deaerators	Works related to 1st 90 MW (3 deaerators)	Works related to 2nd 90 MW (3 deaerators)
Condensers	Works related to 1st 90 MW (1 condenser)	Works related to 2nd 90 MW (1 condenser)
Steam and water system	Works related to 1st 90 MW	Works related to 2nd 90 MW
Main cooling water system	Works related to 1st 90 MW	Works related to 2nd 90 MW
Closed circuit cooling water system	Works related to 1st 90 MW	Works related to 2nd 90 MW
Fuel gas treatment, supply system	Works related to 1st 90 MW	Works related to 2nd 90 MW
Diesel oil receiving system	Works related to 1st 90 MW and facilitated for link with 2nd 90 MW	Works related to 2nd 90 MW
Oil storage tanks	Works related to 1st 90 MW (1 oil storage tank)	Works related to 2nd 90 MW (1 oil storage tank)
Diesel oil supply pumps	2 × 100% pumps (1 normal operation and 1 common standby for 1st 90 MW and 2nd 90 MW)	1 × 100% pump
Diesel oil supply system	Works related to 1st 90 MW and facilitated for link with 2nd 90 MW	Works related to 2nd 90 MW
Pumps for water treatment system	2 × 100% pumps (1 normal operation and 1 common standby for 1st 90 MW and 2nd 90 MW)	1 × 100% pump
Pre-treatment system	2 × 100% trains (1 normal operation and 1 common standby for 1st 90 MW and 2nd 90 MW)	1 × 100% train
Fresh water transfer line	Works related to 1st 90 MW and facilitated for link with 2nd 90 MW	Works related to 2nd 90 MW
Demineralization plant	2 × 100% trains and 1x100% regeneration equipment	1 × 100% train
Demineralized water storage tanks	Works related to 1st 90 MW	Works related to 2nd 90 MW
Demineralized water transfer line	Works related to 1st 90 MW and facilitated for link with 2nd 90 MW	Works related to 2nd 90 MW
Potable water system	Works related to 1st 90 MW and facilitated for link with 2nd 90 MW	Works related to 2nd 90 MW
Wastewater treatment system	Works related to 1st 90 MW	Works related to 2nd 90 MW
Air compressors	2 × 100% compressors (1 normal operation and 1 common standby for 1st 90 MW and 2nd 90 MW)	1 × 100% compressor

	Stage 1 (90 MW)	Stage 2 (Total 180 MW)
Compressed air distribution system	Works related to 1st 90 MW and facilitated for link with 2nd 90 MW	Works related to 2nd 90 MW
Cranes and Lifts	Works related to 1st 90 MW (Overhead crane for gas turbine building is of common use)	Works related to 2nd 90 MW
Fire prevention and fighting system	All pumps and works related to 1st 90 MW for hydrant system and facilitated for link with 2nd 90 MW / Fire fighting system for 1st 90 MW equipment	Fire fighting system for 2nd 90 MW equipment
Control and Instrumentation System		
Overall plant supervisory control system	Works related to 1st 90 MW	Works related to 2nd 90 MW
Gas turbine generator supervisory control system	Works related to 1st 90 MW	Works related to 2nd 90 MW
HRSG supervisory control system	Works related to 1st 90 MW	Works related to 2nd 90 MW
Steam turbine generator supervisory control system	Works related to 1st 90 MW	Works related to 2nd 90 MW
Data acquisition system	Works related to 1st 90 MW	Works related to 2nd 90 MW
Common facilities supervisory control system	Works related to 1st 90 MW	Works related to 2nd 90 MW
Uninterruptible power supply for C & I system	Works related to 1st 90 MW	Works related to 2nd 90 MW
Telecommunication equipment to/from load dispatching center	Works related to 1st 90 MW and expandable hardware capability for 2nd 90 MW	Works related to 2nd 90 MW
Electrical Equipment		
Generators and main circuit equipment	Works related to 1st 90 MW	Works related to 2nd 90 MW
Transformers	Works related to 1st 90 MW	Works related to 2nd 90 MW
High voltage and low voltage station electrical system	Works related to 1st 90 MW	Works related to 2nd 90 MW
DC system	Works related to 1st 90 MW	Works related to 2nd 90 MW
Emergency diesel generator set	Works related to 1st 90 MW and 2nd 90 MW (common use)	None
Operational instruction system	Works related to 1st 90 MW	Works related to 2nd 90 MW
Grounding system	Works related to 1st 90 MW	Works related to 2nd 90 MW
Lighting system	Works related to 1st 90 MW	Works related to 2nd 90 MW
Lightning system	Works related to 1st 90 MW	Works related to 2nd 90 MW
In-plant substation	Works related to 1st 90 MW	Works related to 2nd 90 MW
Supervisory, operational and protective system for electrical equipment	Works related to 1st 90 MW	Works related to 2nd 90 MW
In-house communication system	Works related to 1st 90 MW and facilitated for link with 2nd 90 MW	Works related to 2nd 90 MW