CHAPTER 8 SELECTION OF OPTIMUM EXPANSION PLAN

8.1 SELECTION PROCEDURES

In the beginning of this Survey, eight alternatives of the expansion plans were taken into account. In choosing them, the results of the feasibility study conducted in 1995 by Lahmeyer/ Worley under IDA finance were referred to, and a new left bank tunnel plan was additionally considered. In order to select the optimum plan, initial screening was performed to choose three or four prospective alternatives to subsequently execute detailed comparison within the limited time. The initial screening was made during the inception stage of this Survey by means of engineering assessment without quantitative comparison.

In the next step, the prospective alternatives were compared in detail by analyzing power generation efficiency, designing the powerhouse expansion layout, and estimating construction cost of respective alternatives. Final selection of the optimum expansion plan was made on the basis of economic and financial assessment of the alternatives. The procedure for the optimum plan selection is illustrated in Figure 8.1.1.

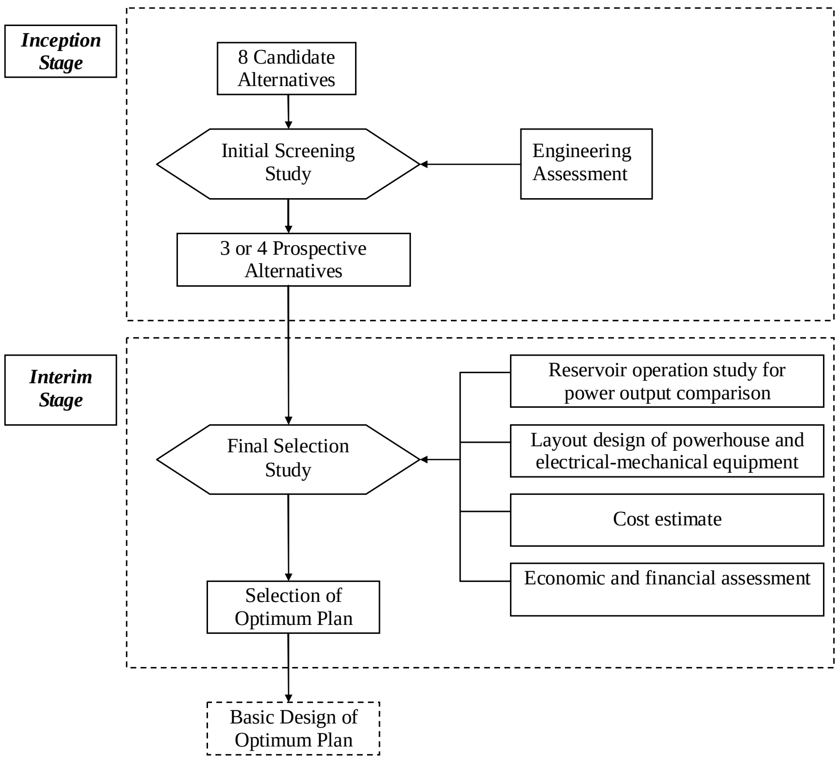

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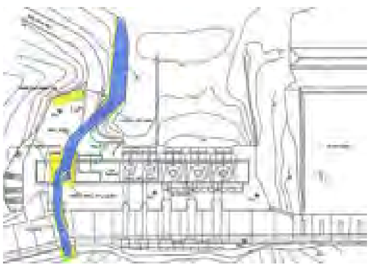
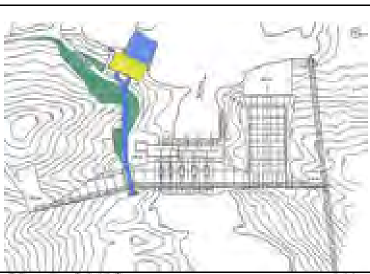
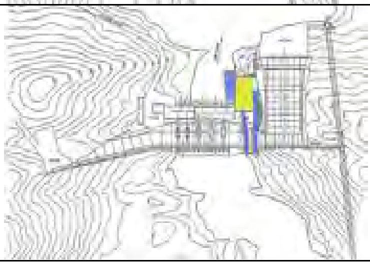
Figure 8.1.1 Flow Chart for Selection of Optimum Plan

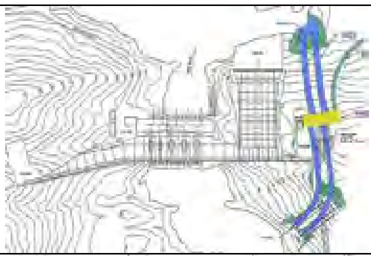
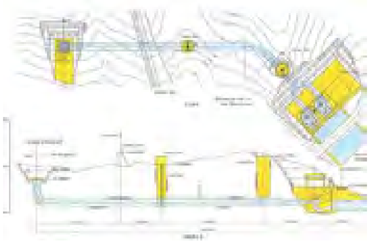
8.2 INITIAL SCREENING OF EXPANSION ALTERNATIVES

8.2.1 CANDIDATE ALTERNATIVES

Eight candidates for the expansion alternatives elaborated at the beginning of Study are shown in the table below. These alternatives were chosen from the results of the feasibility study conducted in 1995 by Lahmeyer/Worley. A left bank tunnel plan (Alternative E) was added as a new candidate.

Table 8.2.1 NN1 Expansion Alternative Plans for Initial Screening

Alternative	Layout	Design Outline	Nos. of Unit	Installed Capacity	Remarks
A1- A3		An additional unit block is arranged between the spillway and the existing powerhouse. A penstock is built in a horizontal hole excavated through the existing concrete dam and an intake entrance is fixed on upstream face of the dam.	1	40MW to 80MW	Layout finally selected in the F/S（40MW） A1:40MW A2:60MW A3:80MW
A4		An additional unit block is arranged outside the southern end of the existing control building. Penstock and intake arrangement for the additional unit is similar to that in Alternatives A1-A2. Turbined water of the additional unit is discharged to the tail bay through a culvert or tunnel.	1	40MW & 60MW	One of the alternative layouts in the F/S
B1		A new powerhouse building is arranged on the left bank of the existing tail bay and set perpendicular to the existing powerhouse. Although the penstock and intake arrangement is similar to that in Alternative A4, the length of the penstock is longer than in Alternative A4.	2	80MW	One of the alternative layouts in the F/S
B2		A new powerhouse building is arranged on the left bank downstream of the existing tail bay. Although the penstock and intake arrangement is similar to that in Alternative B1, the length of penstock is longer.	2	80MW	One of the alternative layouts in the F/S
C		A new powerhouse building to accommodate 2 additional units is arranged in the space between the spillway and tail bay. Two sets of intake tower and penstock are built, each similar to that in Alternative A1.	2	80MW	One of the alternative layouts in the F/S

Alternative	Layout	Design Outline	Nos. of Unit	Installed Capacity	Remarks
D1		A new underground powerhouse is arranged in the right abutment hill. The originally constructed diversion tunnel is intended to be utilized as one of two headrace tunnels. New intake structures are independent from the existing dam	2or 3	80MW & 120MW	One of the alternative layouts in the F/S
D2		A new surface type powerhouse is arranged on the right bank of the spillway plunge pool. Similar to D1, the diversion tunnel is intended to be utilized as one of two headrace tunnels. New intake structures are independent from the existing dam.	2or 3	80MW & 120MW	One of the alternative layouts in the F/S
E		An independent intake tower is built in the reservoir upstream of the left bank dam. A headrace tunnel crossing the dam foundation is extended from the intake to a new powerhouse located downstream of the ridge similar to Alternative B2.	2 or 3	80MW & 120MW	New additional alternative

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The specific names (or numbers) of the alternatives came from the designations in the 1995 FS report except for the replaced new Alternative E. The expansion capacity considered is 40 MW to 120 MW. Capacities smaller than 40 MW were discarded since it was suggested in the 1995 FS report that the interested additional capacities would be in the range of 40-80 MW. A 120 MW capacity was additionally taken up for the study in view of the expected increase of dry season inflow owing to the water storage effect in the NN2 reservoir to be completed in 2011. Capacities greater than 120 MW were not included in the study because it was predicted that energy production would not increase largely in proportion to the installed capacity, since the total inflow available for generation would not change.

8.2.2 ASSESSMENT CRITERIA

For the initial screening study of the alternatives, the following assessment criteria were applied for the engineering judgment:

Table 8.2.2 Assessment Criteria in Initial Screening

Items	Assessment Criteria
Topography (land space)	Sufficient land space should be assured at expansion site.
Geology	Foundation at expansion site should be adequately sound to enable economical construction of the powerhouse.
Effect on the dam	Construction of new intake and powerhouse should not at any time threaten the structural safety of the existing NN1 dam
Effect on the powerhouse (P/H)	Construction of new intake and powerhouse should not impede operation of the existing NN1 power plant. Compulsory lowering of reservoir water level for construction purposes should not cause unacceptable reduction of power generation.
Economical approach	Cost and period of construction should be low and short, respectively.
Environmental impact	New powerhouse should not have any serious impact to environment during and after construction.

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8.2.3 RESULT OF INITIAL SCREENING

The initial screening study was carried out in the inception stage to select prospective alternatives (three or four plans) on the basis of the assessment criteria mentioned above. The results of the engineering assessment in the initial screening study are shown in the table below.

Table 8.2.3 Engineering Assessment in Initial Screening of Alternative Plans

O: Selected for further study X: Discarded

Alternative	Engineering Assessment	Judgment
A1-A3	1) Land space is sufficient for expansion up to 60MW but insufficient for 80MW expansion. A1 and A2 can be included in the subjects of further study but A3 cannot be included. 2) There will be permeable rock layer in new tail bay area. Since it is anticipated that, during construction, serious seepage may occur into new powerhouse excavation area from existing unit 5 tail bay, seepage prevention countermeasure is important. This would be solved by grouting in the natural rock barrier between the exiting tail bay and excavation site for new tailrace. 3) Extensive slope stabilization is necessary at steep and high rock slopes excavated below the existing spillway wall. 4) While a large horizontal hole has to be excavated across body of the existing dam to provide a new intake and penstock, such dam piercing work is possible since there are many similar set up in Japan which are worth replicating. 5) There is no other significant problem in civil and electro-mechanical issues.	O
A4	1) Land space for expansion can be ensured by excavating the left bank hill adjacent to the existing control building. 2) Temporary cofferdam for construction of new tailrace outlet structure will partially block the existing Unit 1-2 tailrace channel. It disturbs the operation of Units 1-2. To eliminate such disturbance, a plan of long tailrace tunnel extended 100 m downstream is added to A4. 3) There is no particular geological problem in view of investigation results in the F/S stage. 4) Intake and penstock can be constructed by applying the same dam piecing method as stated for A1 and A2. 5) The existing GIS facility located behind the powerhouse for connecting NN1 with Nam Leuk line has to be relocated before starting intake construction. The Nam Leuk line cannot be used during the relocation. 6) There is no other significant civil and electro-mechanical issues.	O

Alternative	Engineering Assessment	Judgment
B1	1) Land space for the additional powerhouse is very narrow. New tail bay overlaps with the existing tail bay of Units 1-2 at right angle. Both flows discharged from the new and existing powerhouses cross each other in the tail bay. Consequently, significantly turbulent flow in the tail bay will cause rise of tail-water level. This will result in the reduction of effective head for generation of Units 1-2. This problem can be solved by Plan B2. 2) Units 1 & 2 will not be operational during construction of the new tailrace outlet because the existing tailrace is blocked by the cofferdam. 3) As the width of a dam block (between transverse joints) is only 15 m, construction of a large intake for 80MW single penstock in one dam block is not possible because structural safety of dam is threatened. It is necessary to provide two separate intakes of 40MW scale each. 4) The existing GIS facility for connecting NN1 with Nam Leuk line has to be relocated before starting intake construction.	X
B2	1) New powerhouse is located apart from the existing powerhouse. Land space for the new powerhouse is sufficient. 2) Similar to B1, two intakes and penstocks of 40MW scale each are required. 3) Although geological conditions along the new headrace tunnel routes are not confirmed by drilling, no particular geological problem is expected from surface reconnaissance at the site. 4) The existing GIS facility for connecting NN1 with Nam Leuk line has to be relocated before starting intake construction. 5) There is no other significant civil and electro-mechanical issues.	O
C	1) Land space for a new powerhouse is confined by the existing spillway chute and existing tail bay. The land space is obviously not enough for the two 40-MW powerhouse. Alternative C is eliminated from further study.	X
D1	1) There are no obstructive facilities in the expansion site on right bank. Intake and tailrace can be arranged without any land restriction. 2) Rock cover above the top of 40-m high underground powerhouse cavern is 25 to 35 m. This is not thick enough for natural self-stability. Rock around the cavern will be sandstone and weak mudstone layers. Special rock support and rock strengthening will be required to ensure cavern stability. This will result in higher costs for construction in comparison with the surface powerhouse in Plan D2 3) It is necessary to build a new intake tower standing independently in the reservoir. Lowering of the reservoir water level down below the tower base level for intake construction is not realistic because there is no bottom outlet to drain reservoir water. Intake construction without lowering reservoir water level requires underwater works for temporary coffer structures. The coffer structure as high as 32 m or more will have to be built with steel pipe piles which will require longer period of construction. Such independent intake tower is obviously not economical compared with the intakes fixed to the existing dam as applied for Plan A1. 4) The existing diversion tunnel with 6 m diameter is already 40 years old. Use of such old tunnel for future new powerhouse is not suitable. Hence, construction of new tunnel is required. This results in increase of construction cost.	X
D2	1) Similar to D1, there is no restriction in selecting land for intake and powerhouse. 2) As stated in D1 above, independent intake tower standing in deep reservoir is difficult to construct without lowering the water level. It is evident that the intake construction cost becomes much higher than for intake fixed to the existing dam as applied to Plan A1. 3) The powerhouse is surface type which is relatively easy to construct and not	(X) O

Alternative	Engineering Assessment	Judgment
	costly compared with underground type in Plan D1. 4) As stated in D1, use of the existing diversion tunnel for new powerhouse is not suitable. Hence, new tunnels are required. This results in higher construction cost.	
E	1) As the intake is located in reservoir and new powerhouse site, which is apart from the existing powerhouse, there are no land space problems. 2) Similar to D1 and D2, temporary cofferdam for intake construction is costly and requires long construction time. This makes Plan E less economical as compared with the intake fixed to the existing dam as in Plans A1 and A4. 3) A vertical shaft structure is necessary to accommodate intake gate located downstream of the dam. Its construction requires additional cost.	X

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The Survey Team first selected three prospective alternatives, i.e. plans A1-A2, plan A4 and plan B2 for further study in the succeeding stage. The other alternatives either cannot sufficiently be accommodated with the available land space for expansion (plans B1 and C), or are apparently less economical (plans D1, D2 and E).

The result was presented to DOE/EdL at the first steering committee meeting held at the EdL office in February 2009, and consequently received their concurrence. However, DOE/EdL strongly requested at the meeting to add the Plan D (new powerhouse on right bank) to the prospective alternatives for further study since it would not cause any impact to the existing dam/powerhouse and would result in less land problem for additional transmission lines, if necessary.

The Survey Team accepted the request of DOE/EdL and finally selected four alternatives for further study, i.e., plans A1-A2, plan A4, plan B2, and plan D.

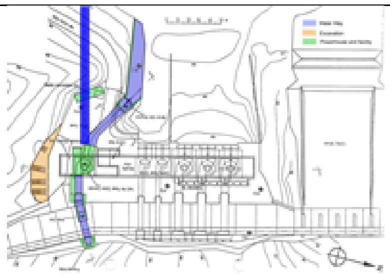
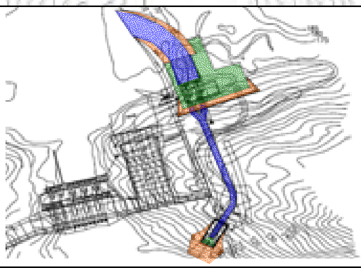
8.3 SELECTION OF OPTIMUM PLAN

8.3.1 LAYOUTS OF ALTERNATIVES

The four alternative layouts selected in the initial screening have major differences in terms of the locations of the powerhouse. In an attempt to select the optimum plan, two or more different installed capacities at each alternative location were considered. A total of 12 comparative plans as listed below were set up for the study.

Table 8.3.1 Alternative Plans for Final Comparison

Alternatives group	Layout	Plan	Installed Capacity	Remarks
A1-A2		A1 A2	40MW x 1 unit 60MW x 1 unit	

Alternatives group	Layout	Plan	Installed Capacity	Remarks
A4		A4-1 A4-2	40MW x 1 unit 60MW x 1 unit	Short tailrace tunnel
		A4-3 A4-4	40MW x 1 unit 60MW x 1 unit	Long tailrace tunnel
B2		B2-1 B2-2	40MW x 2 units = 80MW 60MW x 2 units = 120MW	Separate intake and headrace are provided for each unit
D2		D2-1 D2-2 D2-3 D2-4	40MW x 1 unit 60MW x 1 unit 40MW x 2 units = 80MW 60MW x 2 units = 120MW	Plan D1 (under-ground PH) is abandoned because of high cost.

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Layout of each plan (alternative) was elaborated and the conceptual design was carried out for estimating respective construction costs. Basic conditions for the conceptual design are as follows:

Reservoir WL:	Max. flood WL	EL. 215.0 m
	Normal high WL	EL. 212.0 m
	Minimum operation WL	EL. 196.0 m
Tail WL:	Minimum WL	EL. 164.0 m (Q=0)
	Existing max operation WL	EL. 168.0 m (Q=465m3/s, Units 1 to 5)
Seismic coefficient:	Occurrence probability: 1/145	0.061 (horizontal)
	1/10,000	0.215
	(referred to data provided by the Nam Ngum 2 project design organization)	

Right bank tunnel: In the original plan D, it was foreseen that the existing tunnel (6 m internal diameter) on the right bank can be utilized as one of the waterway tunnels for the expansion plan. However, the tunnel is already 40 years old after it was constructed in 1969 as temporary diversion tunnel for the original dam construction. In order to use it as a waterway for future new powerhouse, large-scale repairs and strengthening of the tunnel will be required. Furthermore, the steel penstock pipe to be laid in the 6 m diameter tunnel is 4.8 m in diameter, or smaller. Such small diameter penstock results in relatively high head loss due to high velocity of flow exceeding 6.5 m/s in the penstock. This is a disadvantage of Plan D. Another disadvantage is that the 6 m diameter tunnel is not enough for larger capacity expansion (60MW or more). Therefore, the original idea of utilizing the existing diversion tunnel was abandoned in this expansion study.

8.3.2 WATERWAY

(1) Intake

For alternative groups A (A1, A2, A4-1, A4-1, A4-3, A4-4) and B (B2-1, B2-2), an intake is constructed after installing temporary steel enclosure on the upstream face of the dam and after the piercing dam. For alternative group D (D1, D2, D3, D4), an intake is constructed after building steel pipe pile cofferdam, which is located in the reservoir near right bank of the dam. Penstock diameter is determined so as to bring the same flow velocity as the existing units 3 to 5. Penstock center level is determined so as to avoid air entrainment into the intake.

Principal features of the intake for existing units 3 to 5 and additional unit (40 - 120MW) are shown in Table 8.3.2.

Table 8.3.2 Principal Features of Intake

Items	Existing Units 3 - 5	Additional Unit Capacity			
	40MW	40MW	60MW	80MW	120MW
Penstock diameter	6.0 m	6.0 m	7.4 m	8.5 m	10.5 m
Penstock center level	EL. 186.0 m	EL. 186.0 m	EL. 184.6 m	EL. 183.25 m	EL. 180.25 m
Max. discharge	118 m^3/s	118 m^3/s	177 m^3/s	236 m^3/s	354 m^3/s

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Although the required penstock diameter is 8.5 m for Alternative B2-1 (80MW) and 10.5 m for Alternative B2-2 (120MW) in case of single unit installation, the width of dam block (No.11) is not sufficiently large as it is only 15 m at dam axis. Therefore, two 40 MW and 60 MW intakes and penstocks are installed in Alternative B2-1 (80MW) and Alternative B2-2 (120MW), respectively, in order to maintain the stability of the dam.

(2) Headrace Tunnel

For alternative groups B and D, pressure headrace tunnels are constructed between the intake and the powerhouse building. Diameter of the headrace tunnels is the same as the intake conduit. Penstock pipe is installed in headrace tunnel where rock cover of the tunnel is thin. Open space around the penstock pipe in the tunnel is filled with concrete. The headrace tunnel is constructed for each unit in Alternatives B2-1 and B2-2.

(3) Tailrace Tunnel

For Alternatives A4-1, A4-2, A4-3, A4-4, a tailrace tunnel is constructed between the powerhouse and the tailrace outlet. For undisturbed operation of the existing NN1 power station, temporary cofferdam is constructed around the site of outlet structure. Diameter of the tailrace tunnel is the same as the headrace tunnel, then lining concrete is placed.

(4) Temporary Enclosure

As temporary enclosure for the piercing dam in alternative groups A and B, a square-shape enclosure is adopted as there are many achievements in Japan, and construction is relatively easy. Inside dimensions of the temporary enclosure are 12 m × 4 m long for 40MW intake, and 13 m × 4 m long for 60MW intake, which can provide the necessary space for intake steel works. In addition, a pedestal concrete is placed as support for the temporary enclosure. After completion, the pedestal concrete is used as a support of the trash rack and stop log. Principal features of the temporary steel enclosure for alternative groups A and B are shown in Table 8.3.3. Horizontal section of the square-shape enclosure is shown in Figure 8.3.1.

For intake construction of the alternative group D, a cofferdam made of steel pipe piles is adopted to resist high water pressure. The steel pipe piles are installed from the platform on the steel piers.

Table 8.3.3 Principal Features of Steel Enclosure

Items		40 MW Unit		60 MW Unit	
		Dam Block No. 11	Dam Block No. 20	Dam Block No. 11	Dam Block No. 20
Type		Square type		Square type	
Inside dimensions	Width	12 m		13 m	
	Length	4 m		4 m	
	Height	32 m		32.7 m	
Weight of steel enclosure		820 t	870 t	930 t	980 t
Volume of pedestal concrete		1,050 m^3	1,300 m^3	1,250 m^3	1,630 m^3

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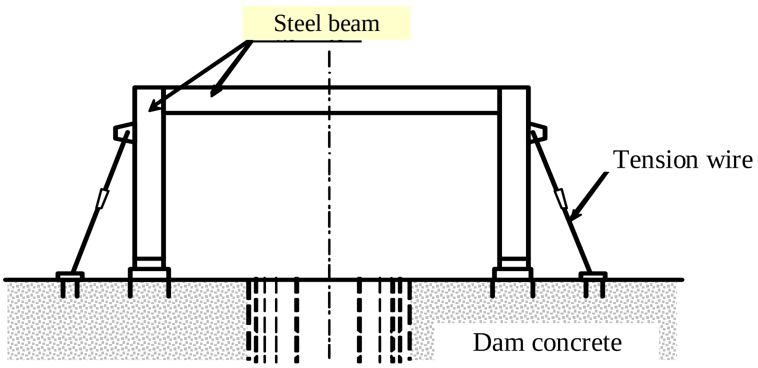

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Figure 8.3.1 Concept of Steel Enclosure (Square-type)

(5) Piercing Dam

Diameter of hole excavated by piercing dam is 7.2 m for the 40MW expansion, and 8.6 m for the 60MW expansion. Clearance between the penstock pipe and the excavated face in the dam body is set to be 0.6 m as a necessary space for installing the penstock pipe. This was determined from similar precedents of installing penstock. Examination was made on the condition that the dam body is pierced using Slot-Drilling method. Principal features of piercing dam are shown in Table 8.3.4.

Table 8.3.4 Principal Features of Piercing Dam

Items	40MW Unit		60MW Unit	
	Dam Block No. 11	Dam Block No. 20	Dam Block No. 11	Dam Block No. 20
Penstock diameter	6.0 m		7.4 m	
Piercing diameter	7.2 m		8.6 m	
Piercing length	21.8 m		22.8 m	
Intake center elevation	EL. 186.0 m		EL. 184.6 m	

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(6) Dam Stability

Dam stability including stress in the foundation rock are checked. Dam blocks No.11 and No.20 are the sections to be examined. Self-weight, water pressure, hydrodynamic pressure, silt pressure, inertia force of dam due to seismic action, and uplift pressure are considered as loads. Changes in load conditions due to the dam piercing or temporary enclosure are considered. Principal features of steel enclosure and piercing dam are shown in Table 8.3.3 and Table 8.3.4, respectively. Conditions of dam to be analyzed for stability, shown in Figure 8.3.2, include the current condition, during-construction and, after-completion. Load conditions to be applied are the usual, unusual (Flood, Earthquake k=0.061) and extreme (Earthquake k=0.215) cases. Properties of materials are based on those shown in the final report on Nam Ngum Dam (1972).

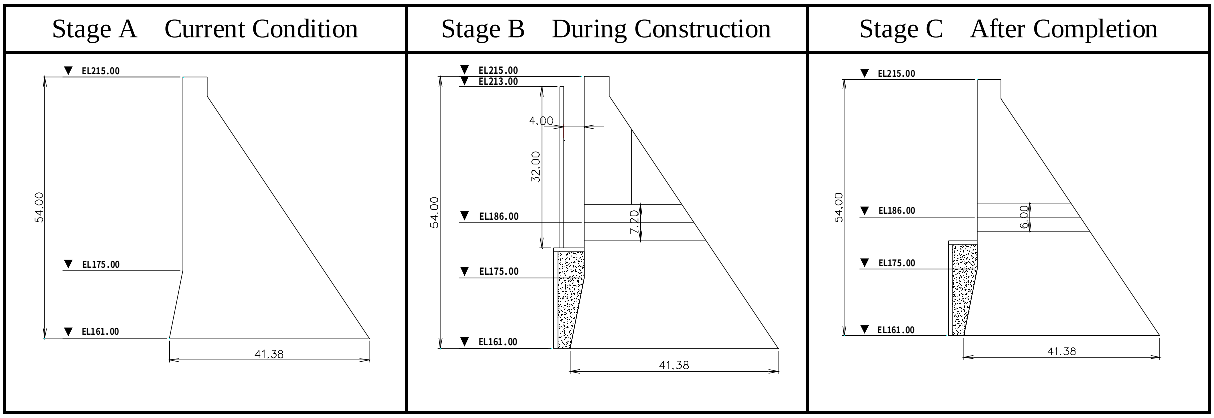

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Figure 8.3.2 Conditions of Dam to be Analyzed for Stability (Example of No. 20 Block)

Based on the conditions mentioned above, overturning, sliding and stress in the foundation rock are checked using the Lao Electric Power Technical Standards. In checking the extreme case, the manual of US Army Corps of Engineers is used as reference. Criteria for judging stability are shown below.

a) Overturning

Under usual operation, the acting point of the resultant force of the expected external forces and the self-weight shall be within the center one-third (the middle third) of the horizontal section of the dam body. In case of earthquake or flood conditions, it shall be within the center one-half (the middle half) of the horizontal section of the dam body. In case of extreme load condition, it shall be within the horizontal section of the dam body.

b) Sliding

The safety factor shall be 3.0 or more under usual conditions. It shall be 2.0 or more in case of earthquake or flood conditions. It shall be 1.3 or more, in case of extreme load condition.

c) Stress in the foundation rock

The compressive stress in the foundation rock at the bottom downstream end shall not exceed the basic allowable stress. It shall be lower than 1.33 times the allowable stress, in case of the extreme load condition.

The calculation details of the stability analysis for the dam block Nos. 11 and 20 having an intake for 40 MW or 60 MW plan are shown in Appendix F. The results of stability analysis (other than foundation stress) are summarized in the following Table 8.3.5 and Table 8.3.6.

Table 8.3.5 Results of Dam Stability Analysis (40MW Case)

Case	Block No.	Load Conditions	Stability check on	During construction		After completion	
Case 1.1 40MW	11	Usual	Overturning resultant	within middle 1/3	ok	within middle 1/3	ok
			Sliding safety factor	8.4	ok	8.3	ok
		Flood	Overturning resultant	-		within middle 1/2	ok
			Sliding safety factor	-		7.9	ok
		Earthquake (extreme)	Overturning resultant	-		within base	ok
			Sliding safety factor	-		4.8	ok
Case 1.2 40MW	20	Usual	Overturning resultant	within middle 1/3	ok	within middle 1/3	ok
			Sliding safety factor	7.1	ok	7.0	ok
		Flood	Overturning resultant	-		within middle 1/2	ok
			Sliding safety factor	-		6.8	ok
		Earthquake (extreme)	Overturning resultant	-		within base	ok
			Sliding safety factor	-		4.1	ok

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Table 8.3.6 Results of Dam Stability Analysis (60MW Case)

Case	Block No.	Load Conditions	Stability check on	During construction		After completion	
Case 1.3 60MW	11	Usual	Overturning resultant	within middle 1/3	ok	within middle 1/3	ok
			Sliding safety factor	8.4	ok	8.3	ok
		Flood	Overturning resultant	-		within middle 1/2	ok
			Sliding safety factor	-		7.8	ok
		Earthquake (extreme)	Overturning resultant	-		within base	ok
			Sliding safety factor	-		4.9	ok
Case 1.4 60MW	20	Usual	Overturning resultant	within middle 1/3	ok	within middle 1/3	ok
			Sliding safety factor	7.0	ok	6.9	ok
		Flood	Overturning resultant	-		within middle 1/2	ok
			Sliding safety factor	-		6.8	ok
		Earthquake (extreme)	Overturning resultant	-		within base	ok
			Sliding safety factor	-		4.1	ok

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8.3.3 POWER HOUSE AND TAILRACE

As presented in Section 8.3.1, there are 12 alternative plans determined based on the location of power stations and the installed capacity.

Major features of such alternatives are summarized below.

Table 8.3.7 Major Features of Powerhouse and Tailrace for Each Alternative Plan

No.	Alternative Plans	Major Features	
1	A1 (40MWx1 unit)	Powerhouse	• Above ground powerhouse is extended adjacent to the existing powerhouse and spillway. • No turbine inlet valve is installed. • No additional overhead traveling (OHT) crane is installed.
		Tailrace	• Tailrace type is open channel. • The existing tailrace gate & gantry crane are used.
2	A2 (60MW x 1 unit)	Powerhouse	• Above ground powerhouse is extended adjacent to the existing powerhouse and spillway. • No turbine inlet valve is installed. • New OHT crane (250 tons) is installed.
		Tailrace	• Tailrace type is open channel. • New tailrace gate (80 tons) & gantry crane is installed.
3	A4-1 (40MW x 1 unit)	Powerhouse	• Above ground powerhouse is independently constructed adjacent to the existing control room. • No turbine inlet valve is installed. • New OHT crane (170 tons) is installed.
		Tailrace	• Tailrace type is short tunnel with 6.0 m dia. and approximately 40 m length. • New tailrace gate (56 tons) & gantry crane is installed.
4	A4-2 (60MW x 1 unit)	Powerhouse	• Above ground powerhouse is independently constructed adjacent to the existing control room. • No turbine inlet valve is installed. • New OHT crane (250 tons) is installed.
		Tailrace	• Tailrace type is short tunnel with 7.4m diameter and approximately 40 m length. • New tailrace gate (80 tons) & gantry crane is installed.
5	A4-3 (40MW x 1 unit)	Powerhouse	• Above ground powerhouse is independently constructed adjacent to the existing control room. • No turbine inlet valve is installed. • New OHT crane (170 tons) is installed.
		Tailrace	• Tailrace type is long tunnel with 6.0 m diameter and approximately 100 m length. • New tailrace gate (56 tons) & gantry crane is installed.
6	A4-4 (60MW x 1 unit)	Powerhouse	• Above ground powerhouse is independently constructed adjacent to the existing control room. • No turbine inlet valve is installed. • New OHT crane (250 tons) is installed.
		Tailrace	• Tailrace type is long tunnel with 7.4 m diameter and approximately 100 m length. • New tailrace gate (56 tons) & gantry crane is installed.
7	B2-1 (40MW x 2 units = 80MW)	Powerhouse	• Above ground powerhouse is independently constructed at left bank of approx. 160 m downstream from the existing power station. • No turbine inlet valve is installed. • New OHT crane (170 tons) is installed.
		Tailrace	• Tailrace type is open channel. • New tailrace gate (56 tons) & gantry crane is installed.

No.	Alternative Plans	Major Features	
8	B2-2 (60MW x 2 units = 120MW)	Powerhouse	• Above ground powerhouse is independently constructed at left bank of approximately 160 m downstream from the existing power station. • No turbine inlet valve is installed. • New OHT crane (250 tons) is installed.
		Tailrace	• Tailrace type is open channel. • New tailrace gate (80 tons) & gantry crane is installed.
9	D2-1 (40MW x 1 unit)	Powerhouse	• Above ground powerhouse is independently constructed at right bank of the existing spillway stilling basin. • No turbine inlet valve is installed. • New OHT crane (170 tons) is installed.
		Tailrace	• Tailrace type is open channel. • New tailrace gate (56 tons) & gantry crane is installed.
10	D2-2 (60MW x 1 unit)	Powerhouse	• Above ground powerhouse is independently constructed at right bank of the existing spillway stilling basin. • No turbine inlet valve is installed. • New OHT crane (250 tons) is installed.
		Tailrace	• Tailrace type is open channel. • New tailrace gate (80 tons) & gantry crane is installed.
11	D2-3 (40MW x 2 units = 80MW)	Powerhouse	• Above ground powerhouse is independently constructed at right bank of the existing spillway stilling basin. • New turbine inlet valve (2 sets) is installed. • New OHT crane (170 tons) is installed.
		Tailrace	• Tailrace type is open channel. • New tailrace gate (56 tons) & gantry crane is installed.
12	D2-4 (60MW x 2 units = 120MW)	Powerhouse	• Above ground powerhouse is independently constructed at right bank of the existing spillway stilling basin. • New turbine inlet valve (2 sets) is installed. • New OHT crane (250 tons) is installed.
		Tailrace	• Tailrace type is open channel. • New tailrace gate (80 tons) & gantry crane is installed.

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The drawings of plan, profile and sections for plans A1 (40 MW), A2 (60 MW), A4-1 (40 MW), A4-2 (60 MW), A4-3 (40 MW), B2-1 (80 MW), D2-1 (40 MW), D2-3 (80 MW) are attached in Appendix E-1.

8.3.4 ELECTROMECHANICAL EQUIPMENT

In preparation for the expansion plans, a site survey was conducted to check the types, ratings, layouts and present operating status of the existing electromechanical equipment. The survey results are outlined as follows:

(1) Principal Features of Existing Electromechanical Equipment

a) Turbines (Unit 3, 4, 5)

The existing turbine for each unit consists of vertical-shaft, Francis turbine and has no inlet valve. The existing cooling water supply system for each unit is arranged for closed-circuit water circulation system with water-to-water heat exchangers.

The exiting turbines for units 3, 4, and 5 are rated as follows:

1) Rated head: 37.0 m
2) Rated unit discharge: 117.1 m^3/s
3) Rated output: 40,000 kW
4) Rated rotational speed: 136.4 rpm
5) Turbine centerline elevation: EL. 161.0 m

b) Generators (Units 3 to 5)

The existing generator for each unit is of three-phase, vertical-shaft synchronous alternator with umbrella-type construction. Each generator for units 3 to 5 is arranged for a special construction to support the thrust bearing from the turbine head cover. Each generator is provided with a water spray-type firefighting system.

The existing generators for units 3 to 5 are rated as follows:

1) Rated output: 50,000 kVA
2) Rated voltage: 11 kV
3) Rated frequency: 50 Hz
4) Rated rotational speed: 136.4 rpm
5) Rated power factor: 0.8

c) Main Transformers (Unit 3 to 5)

The existing main transformer for each unit consists of three single-phase transformers. The method of cooling is through the natural-oil-circulation forced-air-cooling (ONAF). Each single-phase transformer is provided with independent water mist-type firefighting system. One single-phase transformer is provided as a spare for common use to the main transformers for units 3 to 5.

The main transformers are rated as follows:

a) Rated power: 50,000 kVA for three-phase connection
b) Rated voltage ratio: 115/11 kV
c) Transformer connection: YNd1
d) Short-circuit impedance: 8.5 % for three-phase connection

d) Powerhouse Overhead Traveling Cranes

There are two overhead traveling cranes in the existing powerhouse; one is a 100-ton crane and the other is 80-ton crane. The two cranes will be used for handling the generator rotor for units 3 to 5 by synchronizing their tandem operations. The overhead traveling cranes are designed for the following conditions:

a) Lifting capacity (main hoist/auxiliary hoist)
  · No. 1 crane: 100/20 tons
  · No. 2 crane: 80/10 tons
b) Span of runway crane rails: 16.2 m
c) Boundary to powerhouse structure
  · Upper space over crane rail: 3.8 m
  · Side space: 0.6 m
d) Lifting beam for tandem operation
  · Rated load: 170 ton

· Lifting beam own weight: 9.9 ton

e) 115 kV Outdoor Switchyard

The existing outdoor switchyard is of conventional, outdoor open type bus-and-switch arrangement for 115 kV switchgear, and is located on the roof of the powerhouse. The 115 kV switchyard is connected to five generating units and five 115 kV transmission line feeders. The electric power generated by the five generating units is supplied to the C1 area through the five transmission line feeders. The existing outdoor switchyard and 115 kV switchgear are designed as follows:

1) Bus arrangement: Main and transfer bus scheme in which a transfer bus is added to the single-bus scheme
2) Bus conductors
   · Main bus for No. 1 TL side: ACSR 240 mm^2
   (ACSR: Aluminium Conductor Steel Reinforced)
   · Transfer bus for No. 1 TL side: ACSR 240 mm^2
   · Common bus for Units 1 and 2: HDCC 150 mm^2
   (HDCC: Hard-drawn Copper Stranded Conductor)
   · Main bus for Units 3 to 5: HDCC 325 mm^2
   · Transfer bus for Units 3 to 5: HDCC 200 mm^2
3) Insulator strings
   · Type and color of insulator disc: Porcelain, brown color
   · Number of insulator discs: Nine pieces/string
4) 115 kV circuit breakers for Units 3 to 5
   · Operating method: Stored energy operation with motor charged spring
   · Rated voltage: 123 kV
   · Rated normal current: 3,150 A
   · Rated short-circuit breaking current: 40 kA
5) 115 kV disconnectors for Units 3 to 5
   · Operating method: Manual operating
   · Rated voltage: 121 kV
   · Rated normal current: 800 A
   · Rated short-time withstand current: 26 kA for 4 s
6) 115 kV current transformers for Units 3 to 5
   · Rated voltage : 121 kV
   · Rated current ratio : 500-250//5/5 A
   · Rated short-time withstand current： 26 kA for 1 s

f) 115 kV GIS (Gas Insulated Switchgear)

The 115 kV GIS is installed for interconnection between the NN1 Hydropower Station and the Nam Leuk Hydropower Station. For this purpose, the 115 kV GIS is connected to the conventional outdoor switchyard by two circuits of 115 kV, 400 mm^2 XLPE power cable, each of which has a current carrying capacity of 450 A or a power transmission capacity of 90 MVA. Recently, the 115 kV GIS was extended for one circuit to connect an additional 115 kV transmission line between the NN1 Hydropower Station and the Thalat Substation.

The 115 kV GIS is designed as follows:

1) Bus arrangement : Main and transfer bus scheme in which a transfer bus is added to the single-bus scheme
2) Number of circuits
   · Nam Leuk line feeder: 1 circuit
   · Thalat line feeder: 1 circuit
   · Nam Ngum 1 switchyard main bus: 1 circuit
   · Nam Ngum 1 switchyard transfer bus: 1 circuit
3) Rated voltage: 123 kV
4) Rated normal current: 1250 A
5) Rated short-time withstand current: 25 kA for 1 s

g) AC Station-Service Power Supply Equipment

An AC power supply to the auxiliary equipment for all the five units and the station's common facilities is generated by two station-service transformers. One of these transformers is connected to the generator bus for either unit 1 or unit 2, while the other is connected to the 115/22 kV transformer through a 22 kV cubicle. The two station-service transformers are arranged for normal/standby operation duty, so that either transformer is normally used for supplying power to the whole power station. Judging from its actual load current, each station-service transformer has sufficient extra capacity to serve for additional equipment/facilities.

Based on the above, it was reported that the station-service power supply from the 22 kV circuit is often unstable because the 115/22 kV transformer is also connected to the 22 kV distribution lines for supplying power to local consumers living in the vicinity.

On the other hand, the existing low voltage switchgear has no spare circuit breakers for supplying power to additional equipment/facilities. Judging from the circuit configurations and cable connections, it seems difficult to make modifications for installing additional circuit breaker to the existing low voltage switchgear. The existing station-service power supply system is designed for the following:

1) Nominal AC voltage: 380 - 220 V AC for three-phase and four-wire system
2) Rated frequency: 50 Hz
3) No. 1 station-service transformer (power source: unit 1 generator or unit 2 generator)
   · Rated power: 1,000 kVA
   · Rated voltage ratio: 11/0.38 kV
4) No. 2 station-service transformer (Power source: 22 kV bus)
   · Rated power: 1,000 kVA
   · Rated voltage ratio: 22/0.38 kV

h) DC Power Supply Equipment

The existing DC power supply system consists of two sets of stationary batteries and battery chargers. In normal operation, one set is used for DC power to supply unit 1, unit 2 and station-common loads while the other set is used for DC power to supply units 3, 4, 5. However, each set of DC equipment has sufficient capacity to supply DC power to the whole power station, in case of emergency.

The DC distribution panels for units 1 and 2 have a few spare circuit breakers for additional equipment/facilities. However, no spare circuit breakers will be available in the DC distribution panels for units 3, 4 and 5. The DC power supply equipment is designed as follows:

1) Normal DC voltage:	110 V DC
2) Stationary batteries	
· Quantity:	2 sets
· Type:	Valve regulated type lead acid batteries
· Capacity:	300 AH at 10-hour discharge rate
· Number of cells:	53 cells/set
3) Battery charger	
· Quantity:	2 sets
· AC input voltage:	380 V AC, three-phase, 50 Hz
· DC output current:	60 A DC
· Floating charge voltage:	114 - 122 V DC

i) Control and Protection Equipment

The control and relay boards for units 1 and 2 are all arranged in the control room. These were refurbished in 2004 under the Project for Rehabilitation of the NN1 Hydro Power Station through Japan's Grant Aid Scheme, and are still operating in good condition.

Concerning units 3, 4 and 5, their local control and relay boards are arranged in a relay room located at the side of the machine bay for each unit. In addition, their remote control boards are arranged in the control room, aligned with the local control boards for units 1 and 2. The existing control room has space remaining for the installation of just one duplex-type control board for the additional units.

It is noted that the control and relay boards for unit 5 were just refurbished in July 2009. However, the control and relay boards for units 3 and 4 are still being used since 1978 even if these have already deteriorated due to aging. Therefore, EdL plans to refurbish the control and relay boards for units 3 and 4 in the near future.

EdL is also planning to construct a central hydropower station control center in the NN1 Power Station, which is aiming at effective use of the NN1 Hydropower Station.

j) 115 kV Transmission Line

A total of five 115 kV transmission line feeders are connected to the NN1 Hydropower Station. Three feeders are connected directly to the outdoor switchyard, but the remaining two feeders are connected to the outdoor switchyard through the 115 kV GIS.

Each conductor of the 115 kV transmission lines is made up of ACSR 240 mm^2 which has current carrying capacity of 590 A at continuous allowable temperature of 90 °C, and could possibly carry electric power of 117 MVA.

The 115 kV transmission line systems around the NN1 Hydropower Station are shown in Figure 8.3.3.

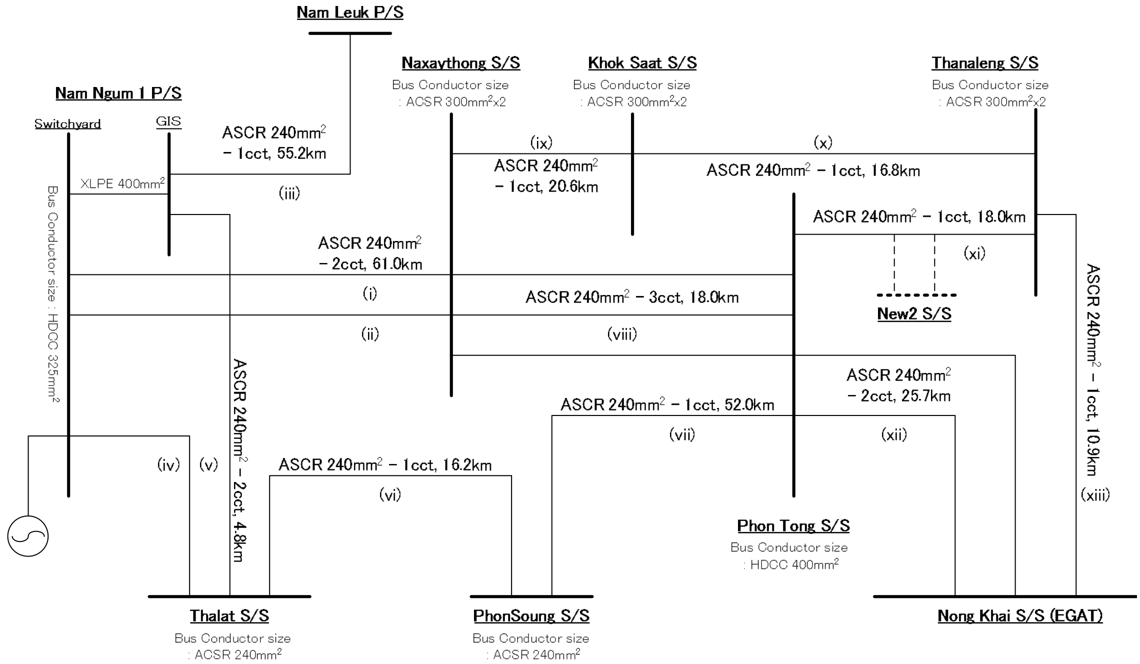

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Figure 8.3.3 115 kV Transmission Line Connection Diagram for NN1

k) 115 kV Thalat Substation

The Thalat Substation is located at a distance of about 4.8 km from the NN1 Hydropower Station. Therefore, there is a concern that the expansion project will affect the current carrying capacity of the 115 kV bus. The Thalat Substation is designed as follows:

1) Bus arrangement: Main and transfer bus scheme in which a transfer bus is added to the single-bus scheme
2) Bus conductors:
   - · Main bus: ACSR 240 mm^2
   - · Transfer bus: ACSR 240 mm^2
3) Number of circuits
   - · Transmission line feeders: 5 circuits
   - · Transformer: 1 circuit
   - · Bus coupler: 1 circuit

(2) Study Items for Electrical and Electromechanical Equipment for Expansion Plans

a) Net Head for Additional Turbine

Each of the existing turbine units 1 to 5 is designed for a rated net head of 37 m.

After completion of the NN2 Hydropower Station, which is now under construction, inflow to the NN1 reservoir will be regulated by the operation of NN2. As a result, it is expected that yearly average water level of the NN1 reservoir will increase considerably due to the regulated inflow from NN2. On the other hand, after completion of this NN1 Expansion Project, the water level at the NN1 tailrace will also increase due to the additional turbine discharge from the additional unit. Therefore, it is required to review the rated net head for the additional turbine.

The turbine rated net head will be determined through further study at the basic design stage. For the purpose of comparative studies of alternative plans, however, the turbine rated net head was tentatively assumed at 38.0 m, on the assumption that the rated net head will increase by at least 1.0 m from the present condition.

b) Turbine Output

For convenience of comparative studies, the unit output for each alternative plan was considered as 40 MW or 60 MW at the generator terminal. Accordingly, taking the generator efficiency into consideration, the turbine rated output for each alternative plan was determined at 40.9 MW or 61.3 MW.

c) Type of Turbine

Referring to the existing turbines for units 3 to 5, Francis turbine was selected as the type of turbine for each alternative plan.

d) Turbine Rotational Speed

The turbine rotational speed was selected referring to the specific speed which is calculated by the following equation:

$$Ns = N \times \sqrt{Pt}/Hn^{1.25}$$

where,
- Ns: Specific speed (m-kW)
- N: Rotational speed (rpm)
- Pt: Turbine output (kW)
- Hn: Net head (m)

In case of the Francis turbine with a net head of lower than 40 m and a turbine output of higher than 40 MW, the specific speed will become very high. If the specific speed exceeds 300 m-kW, it is expected that the operating performance of Francis turbine will worsen remarkably. Therefore, in the selection of the turbine rotational speed, the specific speed for Francis turbine is practically limited to 300 m-kW. Relationship between the applicable turbine speed and calculated specific speed is shown in Table 8.3.8 below:

Table 8.3.8 Selection in Turbine Speed for Alternative Plans

Turbine Output Pt	Net Head Hn	Speed N	Specific Speed; Ns	Ns Upper Limit	Judgment
(kW)	(m)	(rpm)	(m-kW)	(m-kW)	
40,900	38.0	125.0	267.9	300	○
		136.4	292.4		◎
		142.9	306.3		×
61,300	38.0	107.1	281.1	300	○
		111.1	291.6		◎
		115.4	302.8		×
Existing Units 3 to 5 (for reference)					
40,000	37.0	136.4	298.9	-	-

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The higher the turbine speed, the smaller the machine size required. This will consequently be economical. Therefore, the turbine speed was chosen at 136.4 rpm for the 40.9 MW turbine and 111.1 rpm for the 61.3 MW turbine, which are the maximum values within the upper limit of specific speed.

e) Inlet Valve

For all the alternative plans, except for D3 (40 MW x 2) and D4 (60 MW x 2), each turbine was designed to directly connect with an individual steel penstock without an inlet valve, in the same manner as the existing turbines for units 1 to 5.

For the alternative plans D3 and D4, one steel penstock was arranged for common use of two units of turbines. In this arrangement, each turbine was provided with an inlet valve for convenience of operation and maintenance. Each inlet valve was designed for through-flow type butterfly valve and its internal diameter was estimated at 5.0 m for alternative plan D3 and 6.0 m for alternative plan D4.

f) Generator Output

The rated power factor of each generator was selected as 0.8, which is the same as the existing generator units 3, 4 and 5, and the rated generator output was determined as either 50 MVA (40 MW) or 75 MVA (60 MW).

g) Type of Generator

Each generator was designed for three-phase, vertical-shaft, synchronous alternator with umbrella-type construction, which is the same as the existing generators for units 3, 4 and 5.

h) Powerhouse Overhead Traveling Crane for Additional Units

The rotor weights for the generators with rated output of 50 MVA (40 MW) and 75 MVA (60 MW) were estimated at 164 ton and 246 ton respectively.

1) Alternative plan A1 (40 MW x 1)

   Two (2) existing overhead traveling cranes (100 ton and 80 ton) can be used as they are.

2) Alternative plan A2 (60 MW x 1)

   The existing overhead traveling cranes cannot be utilized for lifting the 75 MVA generator because its rotor weight exceeds the total lifting capacity (180 tons) of said cranes. Moreover, the required crane rail span is wider than the existing one.

   Therefore, other than the existing cranes, one new 250-ton crane is required for handling the additional generator.

3) Other Alternative Plans

   The existing overhead traveling cranes cannot be utilized for the other alternative plans either.

   Therefore, one new overhead traveling crane is required in the additional building for each alternative plan. The required lifting capacity of the new crane is estimated at 170 ton for the 50 MVA generator, and 250 ton for the 75 MVA generator.

i) Main Transformer Rated Power

The rated power of the main transformer selected is either 50 MVA or 75 MVA, which is equal to the generator rated output.

j) Type of Main Transformer

The main transformer is the heaviest item during shipping and transportation. Due to transporting restrictions on the access roads, it is preferable that the shipping weight be limited to 30 tons. However, the shipping weight of a 50 MVA three-phase transformer will be no less than 50 tons. In order to reduce the shipping weight, single-phase type or special three-phase type was applied to the main transformer as described below:

1) The existing main transformers for units 3 to 5 are rated for 50 MVA each and of single-phase type. One spare single-phase transformer is provided for common use to units 3 to 5.

   In case of the alternative plans A1 and A4-1, a new 50 MVA main transformer was arranged near the existing powerhouse, similar to the existing main transformers. Therefore, a single-phase type transformer was selected for the alternative plans A1 and A4-1 along with the design policy for the existing main transformers for units 3 to 5.

2) Special-three phase type was selected for the main transformer to be installed at a place far from the existing powerhouse or have rated power other than 50 MVA. This was adopted since the special three-phase type transformer will have a practical advantage not only for a required installation place but also for connection with the generator main bus.

k) Relocation of Existing 115 kV GIS

The existing 115 kV GIS is located in the area to be excavated under alternative plans A4-1 (40 MW x 1), A4-2 (60 MW x 1), B-1 (40 MW x 2) and B-2 (60 MW x 2). In case of these alternative plans, it is required to relocate the existing 115 kV GIS to another place where it is convenient for connecting with the existing 115 kV transmission lines. The candidate site for this relocation is the left bank of the dam, which is about 150 m away from the present location. This relocation work includes disassembling and reassembling of the existing GIS, construction of a new GIS building, replacement of two 115 kV transmission towers, replacement of 115 kV power cables between the 115 kV GIS and the outdoor switchyard.

l) Connection of Additional Units to 115 kV Transmission Lines

The existing 115 kV outdoor switchyard is located on the roof of the powerhouse and are connected with five 115 kV transmission line feeders as shown in Figure 8.3.3. Referring to the results of power flow analysis, the five 115 kV transmission lines have a total power-carrying capacity of not less than 382 MVA at normal condition and 332 MVA at one-circuit faulty condition.

Since the total output of the existing generators is 190 MVA (155 MW), the existing 115 kV transmission lines still have an extra power-carrying capacity of more than 100 MVA. Therefore, in case the additional output is 100 MVA (80 MW) or less, it is practical to connect the additional units to the existing 115 kV transmission lines through the existing outdoor switchyard.

On the other hand, in case the additional output is 150 MVA (120 MW), the total output of the NN1 is 340 MVA, which exceeds the allowable current carrying capacity of the existing 115 kV transmission lines. In this case, construction of a new 115 kV transmission line is required to connect the additional units to the 115 kV network system. Taking these conditions into consideration, connection of the additional units to the 115 kV transmission line was planned as follows:

1) Alternative Plans A1 (40 MW x 1) and A2 (60 MW x 1)

   The existing outdoor switchyard should be extended to the roof of the additional powerhouse building to connect the additional unit to the existing 115 kV bus.

2) Alternative Plans "A4-1" (40 MW x 1) and "A4-2" (60 MW x 1)

   Since there are three circuits of the existing 115 kV transmission lines over the planned construction site for the additional powerhouse building, new 115 kV switchgear for the additional unit cannot be installed on the roof, in similar way to the existing outdoor switchyard. No sufficient space for installation of new 115 kV switchgear is available either in the expansion area. Therefore, it was planned to connect the additional unit to the existing outdoor switchyard through the 115 kV GIS to be relocated under Sub-Paragraph 11 above. The new main transformer for the additional unit should be connected to the relocated 115 kV GIS by 115 kV XLPE power cables. This will require extension of the 115 kV GIS for one more circuit for the 115 kV power cable connection to the new main transformer.

3) Alternative Plan B2-1 (40 MW x 2)

   It is difficult to arrange a route for direct cable connections between the additional powerhouse and the existing outdoor switchyard. Therefore, there seems to be no choice but to connect the additional units to the existing outdoor switchyard through the 115 kV GIS to be relocated under Sub-Paragraph 11 above, in the same manner as the Alternative Plan A4-1. The new main transformers for the additional units should be connected to the relocated 115 kV GIS by 115 kV XLPE power cables. This will require extension of the 115 kV GIS for two more circuits for 115 kV power cable connections to the new main transformers.

4) Alternative Plans D2-1 (40 MW x 1) and D2-2 (60 MW x 1)

   In order to connect the additional unit to the existing 115 kV bus, it is necessary to construct one 115 kV single-circuit overhead line between the additional main transformer and the existing outdoor switchyard. On the roof of the existing powerhouse, there is sufficient space to extend the existing outdoor switchyard to the right side. The new 115 kV switchgear for the additional unit will be installed in the extension area of the existing outdoor switchyard.

5) Alternative Plan D2-3 (40 MW x 2)

   In order to connect the additional unit to the existing 115 kV bus, it is necessary to construct one 115 kV double-circuit overhead line between the additional main transformer and the existing outdoor switchyard. The new 115 kV switchgear for the additional units will be installed in the extension area of the existing outdoor switchyard.

6) Alternative Plans "B2-2" (60 MW x 2) and "D2-4" (60 MW x 2)

   The existing 115 kV transmission lines have no sufficient capacity to carry the additional output of 150 MVA (120 MW) without overloading. Therefore, the additional units for these alternative plans cannot be connected to the existing outdoor switchyard. As a result, construction of a new 115 kV double-circuit transmission line is required to connect the additional units to the 115 kV network system. For this purpose, it is necessary to construct a new 115 kV outdoor switchyard near the additional powerhouse. The new outdoor switchyard will be of conventional, outdoor open type with a conventional type 115 kV switchgear. The 115 kV bus will be arranged for the main and transfer bus scheme in the same manner as the existing outdoor switchyard.

The existing Thalat Substation and Phon Soung Substation, which are the nearest substations from the NN1 Hydropower Station, do not have sufficient space for the necessary extension to introduce additional 115 kV double-circuit transmission lines. Therefore, the new 115 kV double-circuit transmission line was planned to be connected to the existing Naxaythong Substation at a distance of 61 km from the NN1, or to the Hin Heup Substation at a distance of 54 km.

m) Conductor Size of 115 kV Bus for Existing Outdoor Switchyard

Each conductor of the existing 115 kV main bus is HDCC 325 mm^2 of which the continuous current carrying capacity is 875 A at the maximum allowable temperature of 90 °C. The required conductor size of the 115 kV main bus for each alternative plan was examined under the following conditions and assumptions:

1) All the generators, including additional units, are operated with their rated outputs.
2) The outdoor switchyard is receiving incoming power of as much as 20 MVA from the Nam Leuk Hydropower Station.
3) The kind of conductor for the 115 kV main bus is assumed as hard-drawn copper conductor (HDCC), which is similar to that of the existing conductor.
4) The continuous allowable temperature of the 115 kV bus conductor is assumed at 90 °C.

The current carrying capacity and required conductor size of the 115 kV bus are summarized in table below.

Table 8.3.9 Required Conductor Size for 115 kV Main Bus for Alternative Plans

Plan	Generator Output [MVA]			Max. Current in 115 kV Bus	Required Conductor Size
	Additional	Existing	Total	[A]	[mm^2]
A1 A4-1 D1	50	190 + 20 (*1)	260	1,305	HDCC 725
A2 A4-2 D2	75		285	1,431	HDCC 850
B2-1 D3	100		310	1,556	HDCC 1,000
B2-2 D4	0		210	1,054	HDCC 500

Note (*1): Including power received from the Nam Leuk Hydro Power Station (20 MVA)
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It is noted that the maximum current in the 115 kV main bus during operation of the existing five units has already reached 954 A, which exceeds the current carrying capacity of the existing conductor HDCC 325 mm^2 (875 A). In the case of the alternative plans B2-2 (60 MW x 2) and D4 (60 MW x 2), the additional units are not connected to the existing 115 kV bus. Even in such case, it is preferable that the existing conductors be replaced with new ones in the appropriate size to solve the shortage of current carrying capacity of 115 kV bus. As a result, replacement of the existing conductors for the 115 kV main bus is required for all the alternative plans.

n) AC Station-Service Power Supply System for Additional Equipment/Facilities

AC station-service power supply system for each alternative plan was examined as follows:

1) Alternative Plans A1 (40MW x 1), A2 (60MW x 1), A4-1 (40MW x 1) and A4-2 (60MW x 1)

   Each of the two existing station-service transformers has sufficient extra capacity to serve for the additional equipment/facilities. Therefore, it was planned to use the two existing station-service transformers as they are, for supplying AC power to the additional equipment/facilities.

   On the other hand, the existing low voltage switchgear has no spare circuit breakers for power distribution to the additional equipment/facilities. Therefore, it was planned to add one set of low voltage switchgear for the additional equipment/facilities.

2) Alternative Plans B2-1 (40 MW x 2) and B2-2 (60 MW x 2)

   It was planned to provide one set of the station-service power supply equipment in the additional powerhouse, separately from the existing power supply system for the reason that the construction site for the additional powerhouse is located at some distance from the existing powerhouse and each of these alternative plans is provided with two additional units. The new station-service power supply system was designed to consist of two station-service transformers and low voltage switchgear. The power sources for the new power supply system will be one unit of the additional generators as well as the existing 22 kV bus. The new station-service power supply system was designed to be interconnected with the existing power supply system by a 22 kV power cable between the existing and new powerhouses.

3) Alternative Plans D2-1 (40 MW x 1), D2-2 (60 MW x 1), D2-3 (40 MW x 2) and D2-4 (60 MW x 2)

   The construction site for the additional powerhouse is located at some distance from the existing powerhouse. Therefore, it was planned to provide one set of the station-service power supply equipment in the additional powerhouse, similar to alternative plans B2-1 and B2-2. The new station-service power supply system was designed to be interconnected with the existing power supply system by constructing a 22 kV overhead distribution line between the existing and new powerhouses.

o) DC Power Supply Equipment for Additional Equipment/Facilities

DC power supply equipment for each alternative plan was examined as follows:

1) Alternative Plans A1 (40MW x 1), A2 (60MW x 1), A4-1 (40MW x 1) and A4-2 (60MW x 1)

   The existing DC power supply system consists of two sets of stationary batteries and battery chargers. Each set of the DC supply equipment has sufficient extra capacity to serve for the additional equipment/facilities. Therefore, it was planned to use the existing DC supply equipment to supply DC power to the additional equipment/facilities.

   On the other hand, the existing DC distribution panels have insufficient number of spare circuit breakers for distributing DC power to the additional equipment/facilities. Therefore, it was planned to add one DC distribution panel for the additional equipment/facilities.

2) Alternative Plans B2-1 (40MW x 2), B2-2 (60MW x 2), D2-1 (40MW x 1), D2-2 (60MW x 1), D2-3 (40 MW x2) and D2-4 (60 MW x 2)

Since the construction site for the additional powerhouse is located at some distance from the existing powerhouse, the existing DC power supply equipment can not be utilized for the additional equipment/facilities. Therefore, it was planned to provide one set of the DC power supply equipment in the additional powerhouse. The new DC power supply equipment was designed to consist of one set of stationary batteries, one battery charger and two DC distribution panels.

p) Control and Protection Equipment

The existing control room has space to install just one duplex-type control board for the additional units. For each alternative plan, however, the control and protection equipment was examined to achieve remote control of the additional units from the existing control room as follows:

1) Alternative Plans A1 (40MW x 1), A2 (60MW x 1), A4-1 (40MW x 1) and A4-2 (60MW x 1)

   It was planned to install one local control board, one relay board and one automatic control board in the machine bay for each additional unit, in the same manner as the existing system for units 3 to 5. It was also planned to install a remote control board for the additional unit in the existing control room.

2) Alternative Plans B2-1 (40MW x 2), D2-1 (40MW x 1), D2-2 (60MW x 1) and D2-3 (40MW x 2)

   It was planned to install the following control and relay boards in the new local room to be provided in the additional powerhouse:

   - One local control board, one relay board and automatic control board for the additional units.
   - One local control board and one relay board for the additional station-service power supply system.

   It was also planned to install remote control boards for the additional units and station-service supply system.

3) Alternative Plans B2-2 (60 MW x 2) and D2-4 (60 MW x 2)

   It was planned to install the following control and relay boards in the new local room to be provided in the additional powerhouse:

   - One local control board, one relay board and automatic control board for each additional unit
   - One local control board and one relay board for the additional station-service power supply system.
   - One local control board and one relay board for the additional 115 kV switchgear and bus
   - Two relay boards for the additional 115 kV double-circuit transmission line

   It was also planned to install remote control boards for the additional units, station-service supply system and 115 kV switchgear.

q) Necessity of Renewal of Existing Control System

As described in Sub-Clause 8.3.4 (1) i), the present status of the existing control system is summarized below:

a) The control and relay boards for units 1 and 2 were refurbished in 2004 under the Project for Rehabilitation of the NNI Hydro Power Station through Japan's Grant Aid Scheme and are still operating in good condition.

b) The control and relay boards for unit 5 were refurbished in July 2009.

c) The control and relay boards for units 3 and 4 are still used since 1978 and have already deteriorated due to aging. Therefore, EdL intends to carry out refurbishment of the control and relay boards in the near future.

d) EdL is planning to construct a load dispatching center (SCADA center) aiming at effective use of the NN1 Hydropower Station.

Judging from the present station, renewal of the existing control and protection systems will not be required for this expansion project.

r) Conductor Size of 115 kV Bus for Existing Thalat Substation

Each conductor of the existing 115 kV main bus for the existing Thalat Substation is ACSR 240 mm^2 of which the continuous current carrying capacity is 590 A at the maximum allowable temperature of 90 °C.

Referring to the power flow analysis, which was conducted on the basis of the power system planning of the C1 area in 2016, the potential maximum current in the 115 kV main bus of the Thalat Substation was estimated for each alternative plan as shown in Table 8.3.10. It is noted that the alternative plans B2-2 (60 MW x 2) and D2-4 (60 MW x 2), in which the additional units will not be connected to the 115 kV transmission line system of the NN1, are excluded from this examination.

Table 8.3.10 Prospective Maximum Current in 115 kV Bus for Thalat Substation

	Alternative Plans							
	A1	A4-1	D2-1	A2	A4-2	D2-2	B2-1	D2-3
Additional Output	40 MW x 1			60 MW x 1			40 MW x 2	
Max. Current in 115 kV Bus	640 A			664 A			704 A	
Required Conductor Size	ACSR 330 mm^2			ACSR 330 mm^2			ACSR 330 mm^2	

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As a result, it is expected that the maximum current in the 115 kV main bus will exceed the current carrying capacity of the existing conductors after completion of this expansion project. Therefore, replacement of the existing conductors for the 115 kV bus are required for all the alternative plans.

8.3.5 MECHANICAL EQUIPMENT

(1) Intake Facilities

1) Arrangement of facilities

The following intake facilities are considered in the study of the optimum expansion plan:

i) Intake trashracks

ii) Intake stoplogs

iii) Intake gate

The existing intake facilities of NN1 power station have the characteristics mentioned below as the function of intake for 15 MW and 40 MW units.

a) The existing intake trashracks, which consists of the removable type of screen, is adopted. When the intake stoplogs are installed, the trashracks are removed from the guide frames and the stoplogs are inserted into the same guide frames. Since the guide frames are shared for trashracks and stoplogs, the intake structures are simple and compact.

b) The intake of 15 MW has a 5 m width. As for the 40 MW intake, two-barrel intake of 5 m width each is provided for sufficient flow area. Since the barrel width is 5 m in inlets of both 15 MW and 40 MW, stoplogs with clear span of 5 m are commonly used for both 15 MW and 40 MW units.

c) As the stoplogs and trashracks of same clear span are adopted for 15 MW and 40 MW units, the stoplogs and trashracks are operated by a common gantry crane. To minimize cost, the common use of gantry crane is planned for the optimum study of the expansion plan.

2) Intake trashracks

The design of the intake trashrack arrangement is studied taking into account the limitation due to the construction and structure of the temporary enclosure as follows:

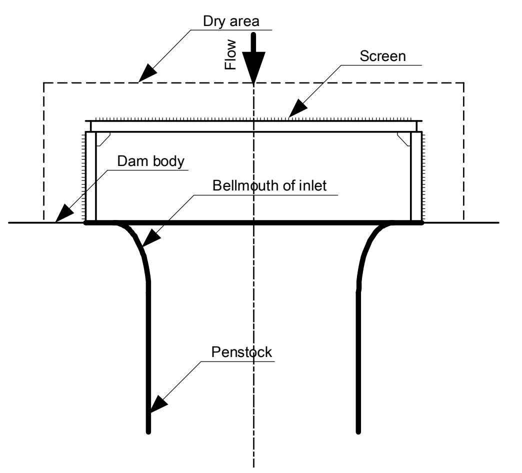
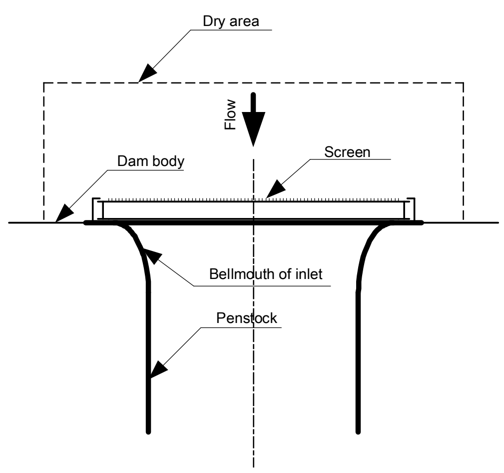
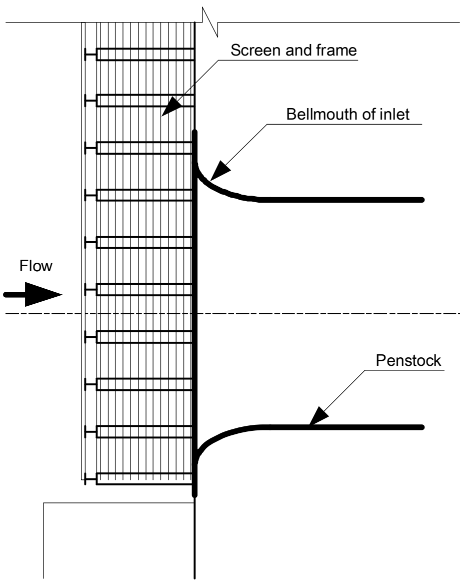
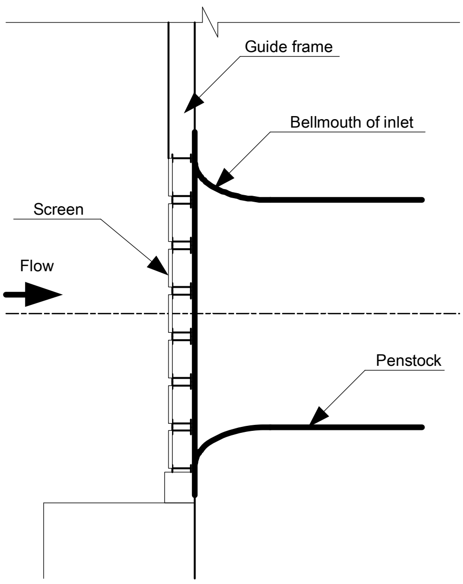
a) Because of the limitation due to the safety construction for temporary enclosure, the working space during dry condition will be provided to be 12 m width and 4 m depth for the upstream of the dam.

b) From the limitation of water depth for temporary enclosure, enough working space below the location of piercing dam will not be provided.

Considering 40 MW class generator, the working space limited by the temporary enclosure will not be enough for the arrangement of intake facilities based on the dimensions of the existing structures. Accordingly, the intake trashracks and stoplogs having the same dimensions as the existing ones cannot be arranged for the expansion plan.

As for the alternatives of intake trashracks, two plans are considered, namely Plan I: Tower type of screen taking into account the lowering of the flow velocity, and Plan II: Removable type of trashracks taking into account the sharing of the guide frame for stoplogs and trashracks, as shown in Table 8.3.11.

Table 8.3.11 Comparison of Screen for Alternative Plans

<table>
<tr><th></th><th>Plan I. Tower Type of Trashracks</th><th>Plan II. Removable Type of Trashracks</th></tr>
<tr><td>Plan</td><td>
</td><td>
</td></tr>
<tr><td>Profile</td><td>
</td><td>
</td></tr>
<tr><td>Structure</td><td>The screen is installed on the position to keep some distance from the inlet aiming the expansion of flow area to lower the flow velocity. The screens are fixed on the frames which construct a tower extended from the inlet to the dam crest. To remove trashes on the screens, some raking equipment will be newly required.</td><td>Because the inlet is directly covered with the screens of trashracks, the flow velocity is 1.27 times faster than Alternative Plan I. As the trashracks are of the removable type and sharing the guide frame with stoplogs, the existing gantry crane will be used.</td></tr>
<tr><td>Merit/ Demerit</td><td>Although flow area of the screen is about 70% of the existing intake, flow velocity is still lower compared with Alternative Plan II. Because of the extension of screen up to the dam crest, the total weight of steel is heavier. New rake is required to be provided.</td><td>The inspection and maintenance for the trashrack will be executed above the water level because of its movable type. Since the dimensions of the inlet cannot be expanded, there is no way to reduce the flow velocity of the screen.</td></tr>
<tr><td>Cost</td><td>The total weight of trashracks consisting of screens and frames is estimated to be three times that of Alternative Plan II. Considering the new raking equipment, the cost of Alternative I will reach more than four times of Alternative Plan II.</td><td>Because the guide frames are shared with the stoplogs, no additional frame will be required.</td></tr>
</table>

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Although the flow velocity of Plan II is faster than Plan I, influence to the effective head of water turbine due to increase of head loss is negligible. Because it is of the removable type, maintenance can be executed in the dry condition above the water level in case of Plan II. Plan II is beneficial compared with Plan I in terms of cost and convenience of maintenance.

3) Intake stoplogs

The existing intake of 40,000 kW unit is comprised of two barrels having a clear span of 5.0 m and a clear height of 12.0 m. For maintenance of the intake gate and waterway, twelve segments of stop log are provided for stopping water. Each segment of stop log has a clear span of 5.0 m and height of 2.05 m, and is operated using a gantry crane for installing and removing. The existing structure of stoplogs is shown in Figure 8.3.4.

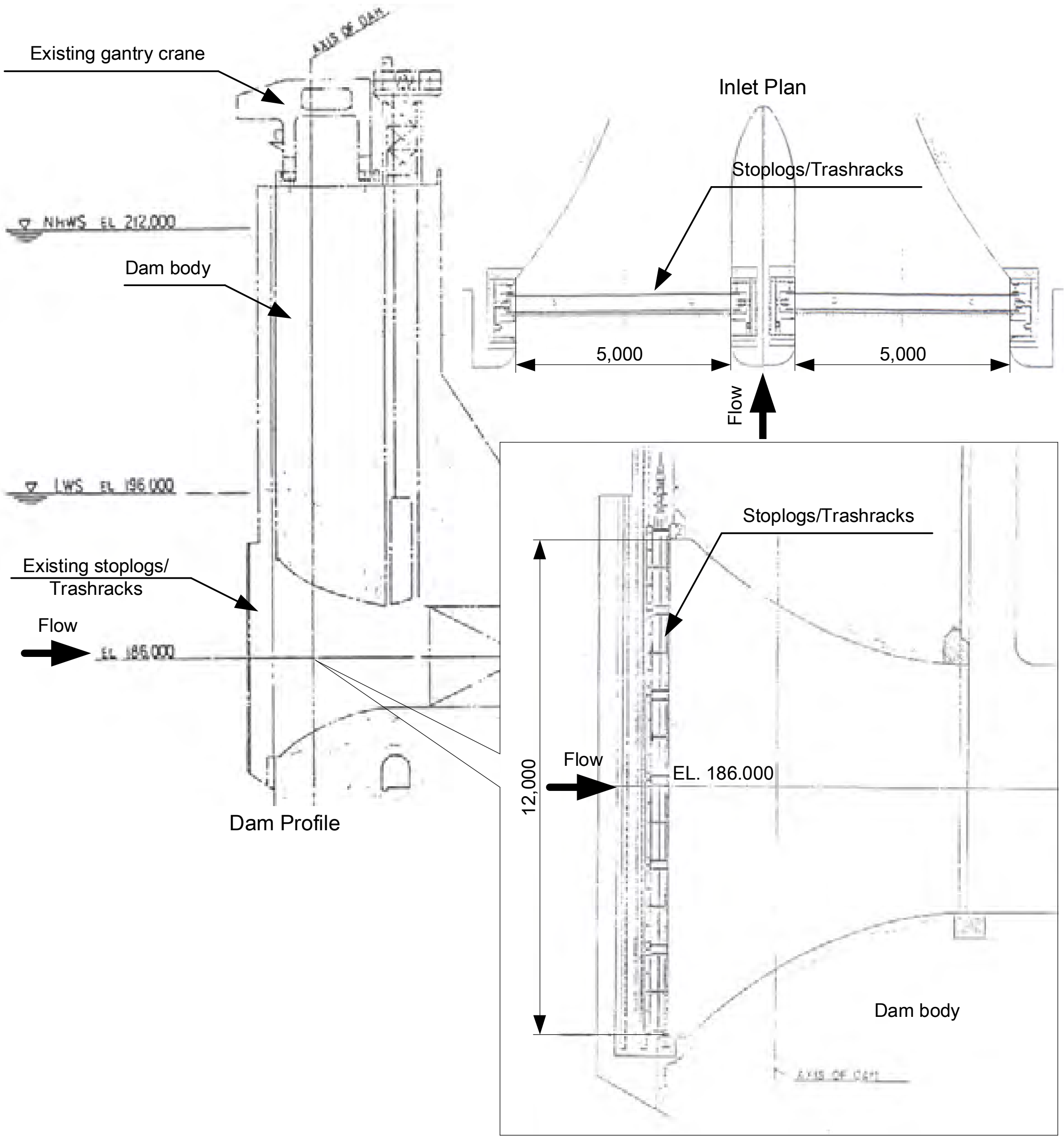

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Figure 8.3.4 Existing Stoplogs

The stoplogs are required to be installed for maintaining the intake gate and waterway in the expansion plan. The existing stoplog segments cannot be commonly used for the intake of expansion plan, because the clear span of said plan is longer than that of the existing. Although the existing stop log segments are not used for the expansion plan, the existing gantry crane will be utilized for operating the stoplogs provided to the intake of expansion plan, if rails and power supply cables are extended and replaced, respectively. To minimize the construction cost, the possibility of use of existing equipment/facilities is firstly studied.

As the lifting capacity of the existing gantry crane is 6 tons, the weight of stop log segment is limited to less than 6 tons in the expansion plan. Accordingly, the common use of the existing gantry crane is realized. Because the clear span of the stoplog for the expansion plan is longer than that of the existing, the height of one segment must be shortened and the weight adjusted to less than 6 tons.

The existing gantry crane has been installed in the first stage of NN1 Project, and 38 years have passed since the completion of its construction. Through the rehabilitation project in 2004, the deteriorated and/or damaged electrical parts were replaced. Since total replacement of gantry crane is not scheduled, the use of existing crane will continue in the future.

As for the alternatives of optimum expansion plan other than piercing dam body, the common use of existing gantry crane is not available. In such case, a new gantry crane is to be studied considering the respective weight of stoplogs and trashracks.

During the construction period in the case of piercing the dam body, the existing gantry crane will interfere with the access/transportation of equipment and materials. The existing gantry crane will be recessed to the right bank upon the extension of temporary rails adding to the permanent rail extension for common use.

4) Intake gate

The existing intake gate has the function of shutting down the flow if the guide vane of the water turbine is not closed due to malfunctioning or any accident.

In case of the power station located just behind the dam like NN1, generally the individual waterways are provided to the respective units. However, the inlet valve for water turbine is sometimes not installed due to economical reasons. Accordingly, the intake gate, instead of inlet valve, is required to have a function of shutdown. In the expansion plan, aside from the study of the intake gate arrangement, the possibility of inlet valve installation is also examined.

a) Case of providing an inlet valve

Because there is no space for installing the inlet valve between the steel penstock and spiral casing, the inlet valve will be installed on the inclined portion of steel penstock. The plan of inlet valve installation is shown in Figure 8.3.5. It seems that the installation of inlet valve is possible on the inclined portion. However, the lifting facilities of large scale are required for maintenance as shown in the figure. Furthermore, such lifting facilities will interfere with the main transformer. As the inlet valve must be planned without measurement of maintenance in the future, the plan of the inlet valve is excluded from the alternative study.

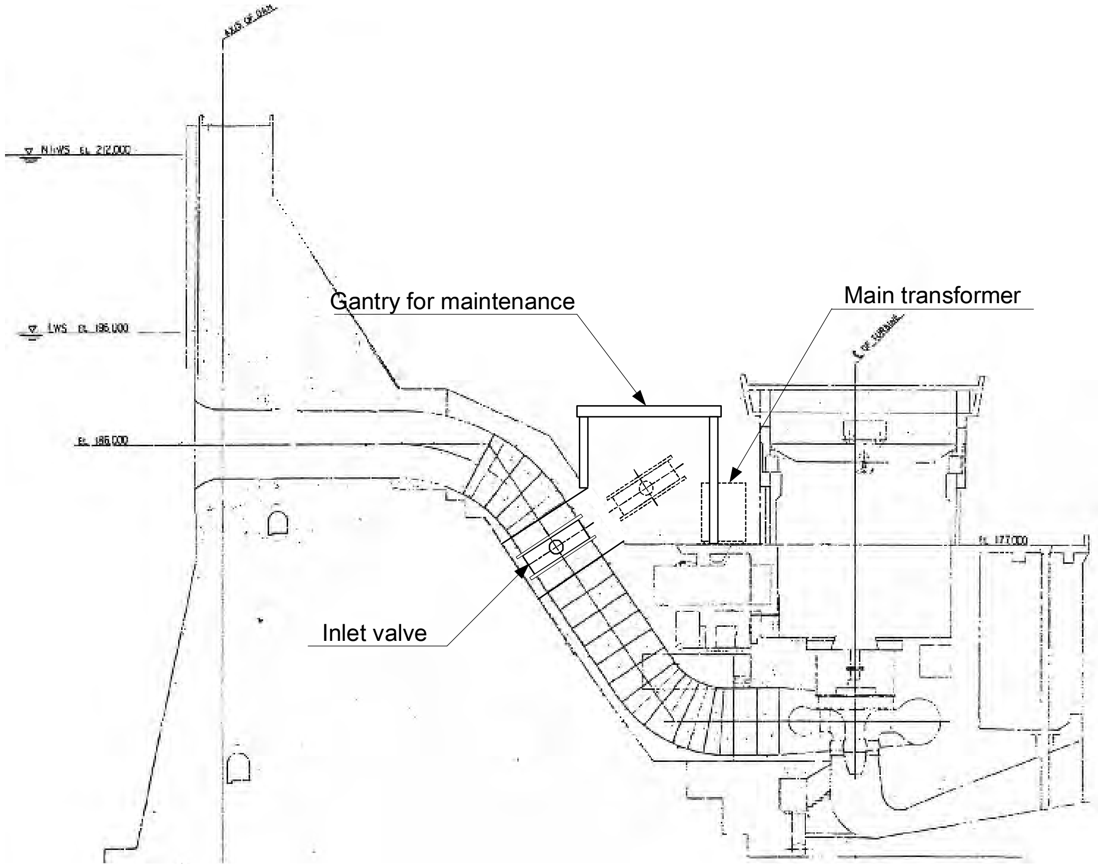

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Figure 8.3.5 Example of Location of Inlet Valve

b) Study of intake gate arrangement

In the alternative plan other than the piercing dam body, the type of wheel gate with wire rope winch hoist will be selected for the intake gate as generally adopted. As for the alternative plan of the intake gate for piercing dam body, the following three alternatives are considered for the arrangement of intake gate.

Plan i-1) Coaster gate on the upstream face of dam without stoplogs

Plan i-2) Coaster gate on the upstream face of dam with stoplogs

Plan ii) High pressure slide gate on the downstream of dam

The comparison is shown in Table 8.3.12 below.

Table 8.3.12 Comparison of Intake Gate Layout Plan (1)

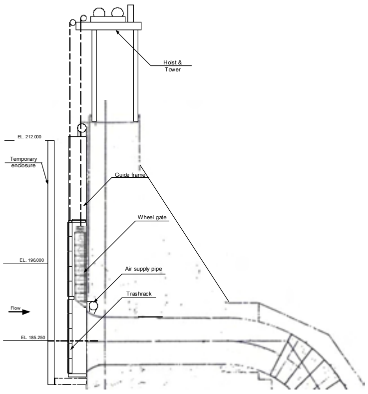
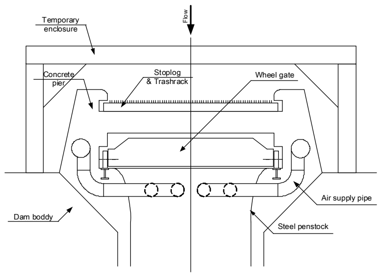
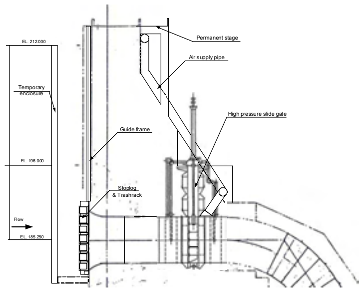
	Plan i-1) Coaster gate on the upstream face of dam without stoplogs	Plan i-2) Coaster gate on the upstream face of dam with stoplogs	Plan ii) High pressure slide gate on the downstream of dam
Outline			
Construction	A fixed wheel gate and movable trashracks are provided on the upstream surface of the dam. All the guide frames for gate and trashracks are made of stainless steel from the sill of the intake to the dam crest. The inlet bell mouth and intermediate positioned gate are covered with movable trashracks. Hoist and hoist tower will be installed after removal of steel stage for temporary enclosure.	A fixed wheel gate, movable trashracks and stoplogs are provided on the upstream surface of the dam. To install the stoplogs, concrete curtain wall and piers are constructed from the sill of the intake to the dam crest. The slot of trashracks is commonly used for the stoplogs. Adding to the hoist and hoist tower for the gate, a monorail hoist is provided for operation of trashrack and stoplogs. Temporary enclosure of 13.5 m internal width and 5 m internal depth is required for construction. Hoist and hoist tower construction sequence is the same as Plan i-1).	A bonnet type of high pressure slide gate is provided on the downstream of the dam with hydraulic hoist. Movable trashracks and stoplogs are provided on the upstream surface of dam. The guide frames are commonly used for trashracks and stoplogs operated by the existing gantry crane. A permanent stage will be constructed at dam crest for setting a lifting equipment (mobile crane) to maintain the hydraulic hoist.
Operation and Maintenance	The gate is kept at the intermediate position for the operation of shutdown of guide vane in emergency cases. Usually, the gate will be operated under balanced condition. The gate is closed when the generator and/or turbine are maintained. When the maintenance of the gate is required, the top cover of trashracks is open and the gate is fully raised. The trashracks are also raised above water level for maintenance. During maintenance of the gate leaf, water will be stopped by shutting the guide vanes.	The operation and maintenance of the gate is the same as Plan i-1). When the maintenance of trashracks is required, the trashracks are raised up one by one with the operation of monorail hoist. Stoplogs operated by the monorail hoist are installed when the maintenance of the gate and/or waterway is required.	The slide gate is usually operated under balanced condition, except in the case of shutdown operation for failure of guide vane closure. The gate will be closed when the generator and/or turbine are maintained. When maintenance of the trashracks is required, the trashracks are raised up one by one by the existing gantry crane. Stoplogs operated by the existing gantry crane are installed when maintenance of the gate and/or waterway is required.

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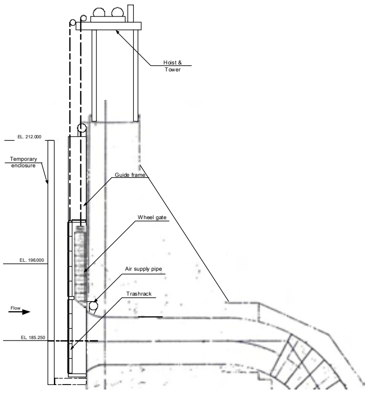
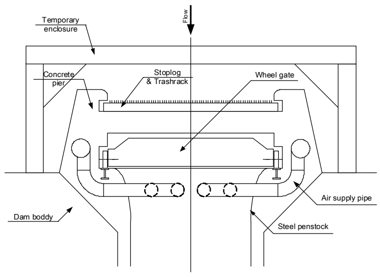
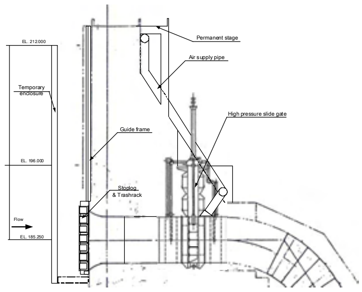
Table 8.3.13 Comparison of Intake Gate Layout Plan (2)

	Plan i-1) Coaster gate on the upstream face of dam without stoplogs	Plan i-2) Coaster gate on the upstream face of dam with stoplogs	Plan ii) High pressure slide gate on the downstream of dam
Outline			
Merit / Demerit	1.67 million dollars for gate, movable trashracks, guide frames, hoist and hoist tower, air pipe, etc. <u>Merit</u> The layout is the most general type. Excavation of downstream dam is unnecessary. <u>Demerit</u> Because there is no provision for stoplogs, the guide vanes must stop the water during the gate's maintenance. The construction period is longer than Plan ii).	3.04 million dollars for gate, movable trashracks, stoplogs, guide frames, hoist and hoist tower, and monorail hoist, air pipe, etc., including the increase cost of temporary and civil works of US$ 1.5 million <u>Merit</u> The required functions as the intake are fully provided. <u>Demerit</u> Construction period is the longest in comparison with other plans. The cost, including temporary and civil works, is comparatively the most expensive.	1.6 million dollars for gate and hydraulic hoist, movable trashracks, stoplogs, guide frames, air pipe, etc. <u>Merit</u> The required functions as the intake are fully provided. Construction period is the shortest in comparison with Plan i-1) and Plan i-2). <u>Demerit</u> There are a few records of this type of slide gate and scale of dimensions.
Evaluation	Because the stoplogs are not provided, no maintenance will be made for guide frame of intake gate. As there is no way to maintain the intake facilities, it is not recommended for the expansion plan.	Plan i-2 is evaluated to be unsuitable for the expansion plan because it requires the longest construction period and the most expensive cost among the three alternative plans.	Plan ii is the most suitable among three alternatives as it satisfies all the requirements for the intake facilities and the most advantageous in terms of construction period and cost.

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In the comparison of alternatives for the arrangement of intake gate in the plan of piercing dam body, Plan-ii is the most advantageous among three alternatives considering construction period and cost.

(2) Steel Penstock

In the expansion plan, the steel penstock is provided from bellmouth to inlet of spiral casing. The steel penstock of the embedded type is adopted in reference to the existing units.

Plate thickness of the penstock shell is decided to be the minimum plate thickness, study of static pressure and water hammer, and study of external pressure due to the seepage of reservoir water head. As for the existing steel penstock, the penstock shell is designed against external pressure with the strength of only the plate thickness without stiffener rings. The design of the existing penstock is judged to be reasonable considering the elimination of the processes of stiffener welded to the outer face of the large diameter pipe. In the expansion plan, the same concept of the existing design is applied for the design against external pressure, namely, that the penstock shell is designed without stiffener against external pressure, although thrust collars will be provided as referred to in the existing design of the steel penstock.

The following three sections of the work site are considered for the installation of steel penstock.

	Location	Access - Direction of installation
Section 1:	Bellmouth	Bellmouth is assembled on the dam crest, lifted down by crane to the inlet, and installed.
Section 2:	From bellmouth to the end of upper bend	From the temporary steel stage constructed at the downstream of the dam for the work of piercing dam body, the unit pipe of steel penstock is transported to the respective location in the dam. The steel penstock is erected from the upstream side.
Section 3:	From the end of upper bend to the inlet of spiral casing	After removal of the temporary steel stage, the unit pipe of steel penstock is lifted down from EL. 177.0 m to the respective location. The steel penstock is erected from the spiral casing to upstream side.

The site workshop will be constructed near from the NN1 power station. The access and installation schedule are studied based on the plan of unit pipe manufactured at the site workshop.

(3) Facilities for Drainage of Power Station and Dewatering of Draft Tube

Two drainage facilities are provided to the NN1 power station for general drain of the power house and drain of shaft sealing water in units 1 and 2 side, and units 3 to 5 sides, respectively. In addition to the drainage facilities, two dewatering facilities are provided to drain the respective draft tubes. The dewatering facilities are also separately provided in Unit 1 and 2 side, and Units 3 to 5 sides.

1) Units 1 and 2 side drainage facilities
2) Units 1 and 2 side dewatering facilities for draft tube
3) Units 3, 4 and 5 side drainage facilities
4) Units 3, 4 and 5 side dewatering facilities for draft tube

The shaft sealing water is drained through the pipe connected to the drain pump pit. When the water level reaches the starting level of drain pumps, said pumps will automatically be activated. After the water level lowers during drain operation, the drain pumps will automatically stop.

As to units 1 and 2 side dewatering facilities for draft tube, the water in the draft tube is initially discharged to the dewatering sump pit by gravity. The dewatering pumps will start when the water level in the dewatering pump pit rises. As to units 3, 4 and 5 side dewatering facilities for draft tube, the respective drain pipes of units 3 to 5 are directly connected with the dewatering pumps. Accordingly, there is no sump pit for the dewatering facilities. In case the expansion plan, new unit is installed beside unit 5, new dewatering and drainage pipes must be connected with the existing pipes as shown in Figure 8.3.6.

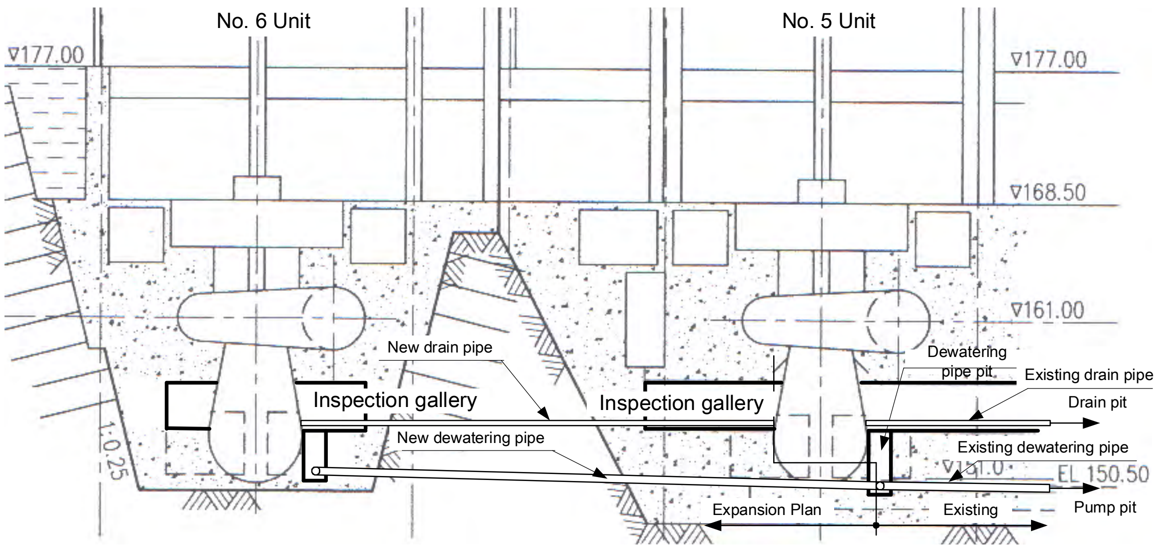

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Figure 8.3.6 Pipe Arrangement for the Case of Sharing Existing Drainage Facility

In the expansion plan, bedrock must remain between the new unit and unit 5. For connecting new and existing pipes of dewatering and drain facilities, respectively, tunnels are to be excavated to place the pipes as shown above. Comparison of the drainage and dewatering facility plans is shown in the table below, considering two cases such as shared facilities and individual facilities.

Table 8.3.14 Comparison of Drainage Facility Plans

Alternative	1) Plan of sharing facilities	2) Plan of individual facilities
Merit & Demerit	➢ It is unnecessary to provide new drainage pumping equipment. ➢ Tunnel to pass the pipes is to be excavated at bed rock between the new and existing units. As for the concrete around unit 5, drilling holes are required to pass the pipes. ➢ Although new and existing pipes are to be connected in the dewatering pipe pit, there is not enough space. ➢ The operation time of existing drainage pumps will be increased because the shaft sealing water is increased. ➢ The length of dewatering pipe up to the new unit is longer and suction side loss will be increased, consequently, there is possibility of replacement of existing pumps.	➢ Since there will be no relation between the expansion plan and the existing facilities, no limitation is considered for the design of new facilities. ➢ No study is required to examine the existing structure and bed rock affected due to excavation. ➢ The construction period and cost are shorter compared with plan 1). ➢ Running and maintenance costs are needed in addition to the cost for existing facilities.
Evaluation	It seems to be advantageous for the maintenance of pumping equipment in the future, but alternative 1) is judged to be unsuitable taking into account the need for bed rock excavation and concrete drilling.	Although it seems to be disadvantageous as to the additional cost for operation and maintenance of new pumps, alternative 2) is judged to be advantageous and is adopted, taking into account the construction period and cost.

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The method of excavation and drilling of bed rock and the existing concrete is required to be developed and verified. From the comparison mentioned above, the optimum expansion plan is studied based on the plan of providing individual facilities.

(4) Draft Tube Gate Facilities

The draft tube gates are provided for the maintenance of water turbine. If the capacity of the expansion unit is the same as the existing, there is a possibility to adopt the same dimensions of the existing draft tube gate. In such case, the existing draft tube gate and gantry crane are commonly used for the expansion unit provided that the rail and power supply cables will be extended. Because the lifting capacity of the existing gantry crane is 7.6 tons, the weight of the new draft tube gate shall be adjusted to match said capacity. The existing gantry crane is commonly used for new gate having dimensions different from the existing gate.

Since the existing gantry crane is located at the interference to the access during construction period, the crane is required to be recessed to the downstream side wall of the power house. For removal of gantry crane, the use of jack-up equipment is considered.

8.3.6 SYSTEM ANALYSIS

(1) Overview

Power flow, voltage regulation, fault current, and stability analysis were conducted in order to confirm if the transmission system as of 2016 in the C1 area including Vientiane, (after expansion of NN1 hydropower station) will satisfy EdL's power system planning criteria. The general study flow of the system analysis is shown in Figure 8.3.7.

Analyzing the system, the study evaluates focusing on whether it caused the following problems of the system or not:

a) Analysis for power flow and system voltage
   : To confirm whether over current and abnormal voltage occurred
b) Analysis for fault (short) current
   : To confirm whether over load or abnormal voltage occurred
c) Analysis for stability
   : To confirm whether the generator can continue to have stable operation

The abovementioned study items tend to mutually affect each other and have conflicting properties as shown in the figure below. For instance, utilizing conductors with larger diameter, or increasing the number of circuits can resolve overloading of the transmission line in a certain section. On the other hand, the fault current of the section increases due to the reduction in the line impedance. Taking into consideration the characteristics, modification of the planned system and analyses of the fundamental study items were executed repeatedly until all of the items satisfy the system planning criteria simultaneously.

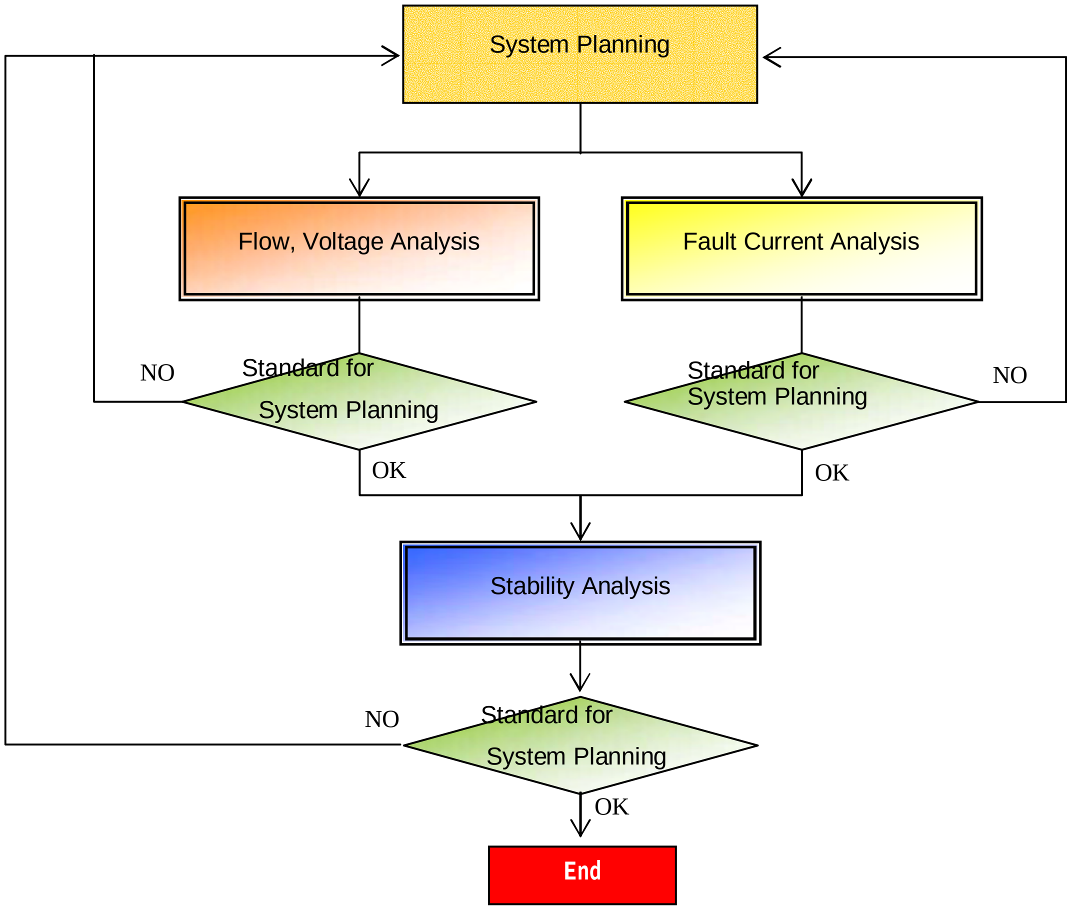

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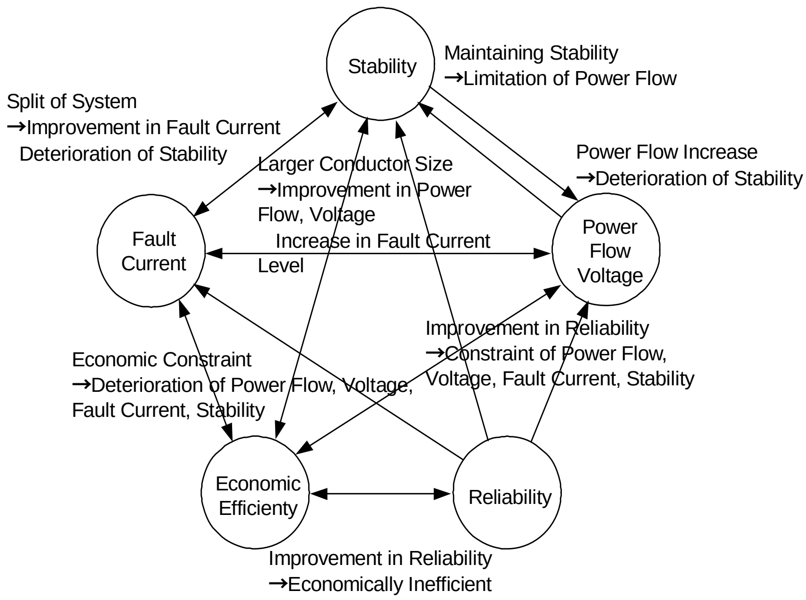
Figure 8.3.7 Study Flow of Power System Analysis



Source: JICA The Study on Master Plan of Transmission Line and Substation System in Lao People's Domestic Republic, Final Report, P.VI-23

Figure 8.3.8 Interrelationships among System Analysis Study Items

(2) Analysis Tools

Power System Simulator for Engineering (PSS/E) Ver. 31, which EdL owns and the JICA Study Team also uses, was utilized for the series of system analysis.

PSS/E is a system analysis software developed by Siemens Power Technologies International (Siemens PTI) in the USA. This software has been used by a wide variety of entities, such as electric utilities, engineering firms, educational institutions, etc. in more than 115 countries and can be regarded as an internationally universal software. PSS/E has various analysis functions such as power flow calculation, voltage analysis, fault current analysis, stability analysis, etc., and its analysis precision and results are highly reliable.

(3) Fundamental Technical Criteria and Study Conditions

Fundamental technical criteria and study conditions are described in Section 4.3.2, Chapter 4 of this report.

(4) Power Flow and Voltage Analysis

Power flow calculation and voltage analysis, as of wet season in 2016, were conducted. The calculation/analysis assumes that load capacities become the highest after the completion of the expansion of NN1 power station. The assumptions of the analysis are as follows.

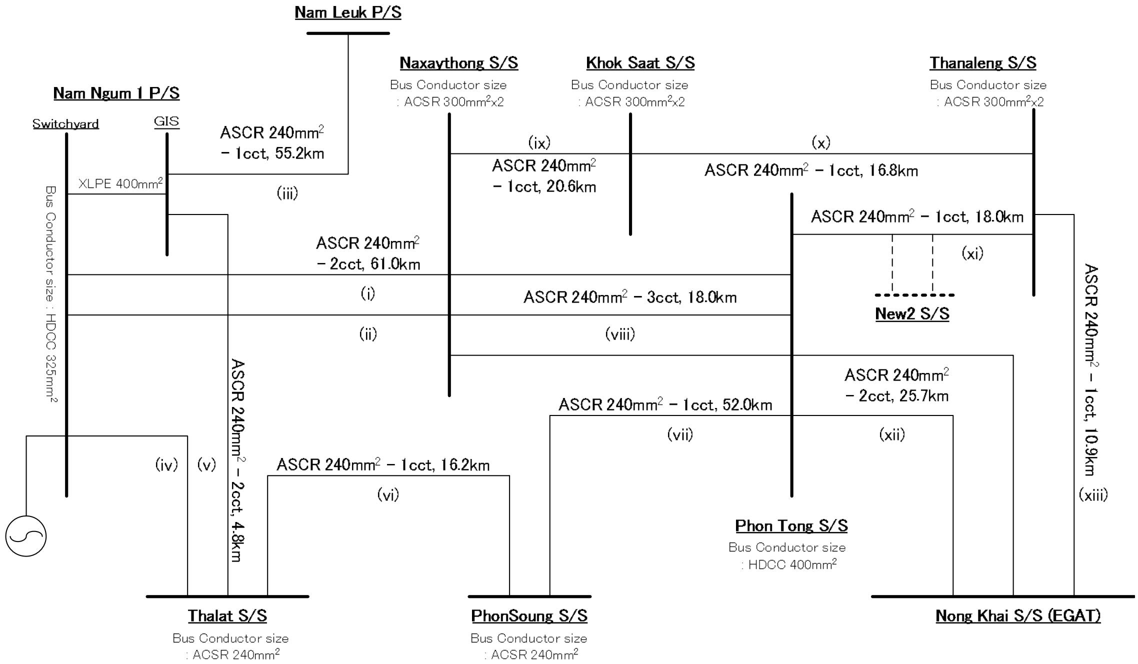
1) For wet season, peak loads are applied for substation loads.
2) In the wet season, stability calculation cannot be converged even under normal operation condition due to overloading of the 115 kV 2cct transmission lines between Sirindhom and Ubon in the Thailand side. Adding two more circuits to form 4cct in this section made the convergence calculation possible.
3) Under normal operation condition, 500/115kV transformers in Hongsa Lignite thermal power station are opened to avoid overloading of the transformers due to huge increase (119MW) in the power flow toward Thailand side in the wet season.

Based on the abovementioned assumptions, the influence of the transmission line in Vientiane and around NN1 power station, which will be caused by the proposed expansion, was analyzed. In addition, the analysis was conducted in each case of normal condition and N-1 contingency. The N-1 contingency was applied under the following two cases.

N-1 Contingency

1) Single Circuit Fault of 115 kV Transmission Line between Nam Ngum power station and Thalat Substation
2) Single Circuit Fault of 115 kV Transmission Line between Nam Ngum power station and Naxaythong Substation

The transmission lines intended for analysis are shown below.



Prepared by the JICA Survey Team

Figure 8.3.9 Transmission Lines and Substations in C1 Area Intended for the Analysis

Overload analysis was conducted not only for five transmission lines connected at NN1 power station but also transmission lines in Vientiane, which are assumed to be affected by the expansion of said power station. The analyzed load flows of transmission lines around the NN1 power station and Vientiane in each expansion capacity are shown in Table 8.3.15 and 8.3.16**,** respectively. The analyzed maximum loads of the main bus of substations which are affected by the expansion of NN1 power station are shown in Table 8.3.17. Overload of transmission line and the main bus of substations are indicated in red figures.

Table 8.3.15 Results of Load Flow of Transmission Line (around Nam Ngum 1 P/S)

Transmission Line			NN1-NXA		NN1-NLE	NN1-TLA		TLA-PSO	PSO-PTO
MW	Line No.		(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
Without Expansion	Normal		64.9	64.9	-27.1	27.4	27.4	81.3	61.4
	N-1	TLA fault	65.6	65.6	-26.5	52.0		80.3	60.5
		NXA fault	94.6		-15.8	43.0	43.0	96.3	76.0
40	Normal		72.6	72.6	-19.7	35.4	35.4	86.3	68.0
	N-1	TLA fault	73.7	73.7	-18.9	67.5		86.9	66.8
		NXA fault	94.8		-7.1	53.4	53.4	105.2	84.4
60	Normal		76.5	76.5	-16.0	39.4	39.4	91.6	71.4
	N-1	TLA fault	77.7	77.7	-15.0	75.2		90.3	70.0
		NXA fault	99.9		3.0	58.6	58.6	109.6	88.5
80	Normal		80.4	80.4	-12.2	43.5	43.5	95.3	74.7
	N-1	TLA fault	81.7	81.7	-11.2	83.0		93.6	73.2
		NXA fault	105.0		3.0	63.8	63.8	114.0	92.7
120	Normal		88.2	88.2	5.0	51.7	51.7	102.3	81.3
	N-1	TLA fault	89.8	89.8	4.0	96.7		100.3	79.4
		NXA fault	115.2		11.7	74.2	74.2	122.8	100.9

(MVA)

NN1: Nam Ngum 1 power station NXA: Naxaithong Substation NLE: Nam Leuk power station TLA: Thalat Substation PSO: Phon Soung Substation PTO: Phon Tong Substation

Prepared by JICA Survey Team

Table 8.3.16 Results of Load Flow of Transmission Line (around Vientiane)

Transmission Line			NXA-PTO	NXA-KSA	KSA-TNA	PTO-TNA	PTO-NK	TNA-NK
MW	Line No.		(viii)	(ix)	(x)	(xi)	(xii)	(xiii)
Without Expansion	Normal		64.0	15.9	77.7	38.8	55.0	68.7
	N-1	TLA fault	64.2	15.8	77.7	38.7	55.0	68.7
		NXA fault	57.0	22.4	78.5	37.0	55.3	68.5
40	Normal		67.5	14.1	81.8	40.2	63.1	76.7
	N-1	TLA fault	67.9	14.1	81.8	40.1	63.1	76.7
		NXA fault	59.9	20.2	83.0	38.1	61.3	76.2
60	Normal		69.4	13.6	84.2	41.7	66.3	79.6
	N-1	TLA fault	69.8	13.6	84.2	41.6	66.3	79.6
		NXA fault	61.3	19.6	85.4	39.4	64.3	79.1
80	Normal		71.3	13.4	86.5	43.2	69.4	82.5
	N-1	TLA fault	71.7	13.4	85.6	43.1	69.4	82.4
		NXA fault	62.8	19.0	87.8	40.7	67.2	81.9
120	Normal		74.9	13.7	91.2	46.3	75.7	88.2
	N-1	TLA fault	75.4	13.6	91.2	46.1	75.6	88.1
		NXA fault	65.3	18.2	91.8	43.5	72.8	87.5

(MVA)

NXA: Naxaithong Substation PTO: Phon Tong Substation KSA: Khok Saat Substation TNA: Thanaleng Substation
NK: Nong Khai Substation (EGAT)

Prepared by JICA Survey Team

Table 8.3.17 Results of Maximum Load of Main Bus of Substations

Substations			NN1 P/S	TLA S/S	PSO S/S	NXA S/S	PTO S/S	KSA S/S	TNA S/S
Conductor Size			HDCC325	ACSR240	ACSR240	ASCR300x2	HDCC400	ASCR300x2	ASCR300x2
MW	Current	(A)	875	590	590	1394	950	1394	1394
without Expansion	N-1	TLA fault	191.2	106.3	80.3	288.0	269.9	246.0	178.7
		NXA fault	126.1	120.4	96.3	266.3	265.2	254.3	179.6
40	N-1	TLA fault	230.5	112.0	86.9	299.1	287.5	252.3	190.5
		NXA fault	155.8	129.8	105.2	274.6	281.9	261.1	192.0
60	N-1	TLA fault	250.1	114.0	90.3	305.0	295.4	256.8	196.8
		NXA fault	181.4	134.9	109.6	279.0	289.2	265.3	198.2
80	N-1	TLA fault	269.7	117.6	93.6	314.2	303.1	261.2	203.1
		NXA fault	196.9	143.2	114.0	283.0	296.3	269.5	202.4
120	N-1	TLA fault	314.8	119.5	100.3	327.2	318.5	270.4	215.5
		NXA fault	236.6	166.5	122.8	290.8	309.5	274.4	214.9

(MVA)

NN1: Nam Ngum 1 power station NXA: Naxaithong Substation TLA: Thalat Substation PSO: Phon Soung Substation
PTO: Phon Tong Substation KSA: Khok Saat Substation TNA: Thanaleng Substation

Prepared by JICA Survey Team

Transitions of loads flow of each transmission line and transitions of maximum loads of each main bus of substations are shown in Appendix A. As shown in Appendix-B, a single circuit fault of 115 kV transmission line between NN1 power station and Naxaythong Substation has an obvious effect on the other lines. In addition, these influences can be confirmed to be the same for the main bus of substations. Therefore, the transmission line between NN1 power station assumes a significant role for supplying the generated power for NN1 to Vientiane.

Percentage on current carrying capacity of the transmission line and the main bus of substations is shown in Table 8.3.18. Hatched spaces in the table indicate overloading and the necessity of replacement of transmission line or main bus of substations.

Table 8.3.18 Percentage on Current Carrying Capacity of Conductors

Expansion Capacity (MW)			40			60			80			120		
Consditions			Normal Condition	N-1 Criteria		Normal Condition	N-1 Criteria		Normal Condition	N-1 Criteria		Normal Condition	N-1 Criteria	
				TLA Fault	NXA Fault		TLA Fault	NXA Fault		TLA Fault	NXA Fault		TLA Fault	NXA Fault
Transmission Line	NN1-NXA	61.0 km	76%	61%	79%	80%	65%	83%	84%	68%	88%	92%	75%	96%
	NN1-TLA	4.8 km	37%	56%	45%	41%	63%	49%	45%	69%	53%	54%	81%	62%
	NN1-NLE	55.2 km	21%	16%	6%	17%	13%	3%	13%	9%	3%	5%	3%	10%
	TLA-PSO	16.2 km	90%	72%	88%	95%	75%	91%	99%	78%	95%	107%	84%	102%
	PSO-PTO	52 km	71%	56%	70%	74%	58%	74%	78%	61%	77%	85%	66%	84%
	NXA-PTO	18 km	70%	57%	50%	72%	58%	51%	74%	60%	52%	78%	63%	54%
	NXA-KSA	20.6 km	15%	12%	17%	14%	11%	16%	14%	11%	16%	14%	11%	15%
	KSA-TNA	16.8 km	85%	68%	69%	88%	70%	71%	90%	71%	73%	95%	76%	77%
	PTO-TNA	18 km	42%	33%	32%	43%	35%	33%	45%	36%	34%	48%	38%	36%
	PTO-NK	25.7 km	66%	53%	51%	69%	55%	54%	72%	58%	56%	79%	63%	61%
	TNA-NK	10.9 km	80%	64%	64%	83%	66%	66%	86%	69%	68%	92%	73%	73%
Sustation	NN1 P/S	HDCC 325mm^2		132%	90%		144%	104%		155%	113%		181%	136%
	TLA S/S	ACSR 240mm^2		93%	108%		95%	112%		98%	119%		100%	139%
	PSO S/S	ACSR 240mm^2		72%	88%		75%	91%		78%	95%		84%	102%
	NXA S/S	ACSR 300mm^{2}x2		100%	92%		102%	94%		105%	95%		110%	98%
	PTO S/S	HDCC 400mm^2		152%	149%		156%	153%		160%	157%		169%	164%
	KSA S/S	ACSR 300mm^{2}x2		85%	88%		86%	89%		88%	90%		91%	92%
	TNA S/S	ACSR 300mm^{2}x2		64%	64%		66%	67%		68%	68%		72%	72%

Prepared by the JICA Survey Team

Regarding replacement of transmission line and the main bus of substations, the following conclusions are presented.

1) Transmission Line

a) No additional transmission lines will be required for expansion plans with additional units of 40 MW, 60 MW, 80 MW.

b) In case of 120 MW expansion plan, a single circuit of 115 kV transmission line between Thalat Substation and Phon Soung Substation will be overloaded. Large-scale extension or replacement of Phon Soung Substation will be required in order to connect a new transmission line in Phon Soung Substation, because the main bus configuration of Phon Soung Substation is a T-branch. Therefore, a single circuit of 115 kV transmission line between NN1 power station and Naxaythong Substation or Hin Huep Substation will be required in order to reduce the load between Thalat and Phon Soung Substations.

c) No additional transmission line around Vientiane will be required in any expansion plan.

2) Main Bus of Substations

a) In any expansion plan, the main bus conductors for NN1 power station and Thalat Substation should be replaced by bigger conductors.

b) In case of 120 MW expansion plan, replacement of the main bus conductors for Phon Soung Substation will be also required.

c) In case of over 60 MW expansion plan, replacement of the main bus conductors for Naxaythong Substation will be required.

d) In any expansion plan, the main bus conductors of Phonetong Substation will be overloaded. However, the overloading of the main bus of these substations will also occur without expansion of NN1 power station in 2016 system.

(5) Fault Current Analysis

Maximum three-phase short circuit fault currents were calculated for the system, taking into consideration the system as of 2016. As shown in the table below, the maximum three-phase short circuit fault currents for each expansion are below allowable level.

Table 8.3.19 Short Circuit Fault Current for each Expansion Plan

NN1 Expansion Capacity	230 kV Bus		115 kV Bus		22 kV Bus	
40 MW	20.47 kA	Ban Sok	12.02 kA	Naxaithong	23.30 kA	Phonetong
60 MW	20.47 kA	Ban Sok	12.10 kA	Naxaithong	23.35 kA	Phonetong
80 MW	20.47 kA	Ban Sok	12.10 kA	Naxaithong	23.35 kA	Phonetong
120 MW	20.47 kA	Ban Sok	12.24 kA	Naxaithong	23.44 kA	Phonetong
Maximum Short Circuit Fault Current	40~50 kA		25~31.5 kA		25~31.5 kA	

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(6) Stability Analysis

When all of the synchronous generators in the system can maintain synchronized operation even in the case of a fault of the equipment which constitutes the system, said system can be considered stable. The calculations were executed under the criteria that when the oscillations of the phase angles among rotors of synchronous generators constituting the system tends to converge even in case of the severest single contingency, the system is stable. Analysis cases are summarized in the table below.

Table 8.3.20 Analysis Cases for Stability

Expansion Capacity	Case Name	Stability Case	Fault Section		
40 MW	NN1_40MW_1_TLA_fault	Angle	NN1	-	TLA
	NN1_40MW_2_NXA_fault		NN1	-	NXA
60 MW	NN1_60MW_1_TLA_fault	Angle	NN1	-	TLA
	NN1_60MW_2_NXA_fault		NN1	-	NXA
80 MW	NN1_80MW_1_TLA_fault	Angle	NN1	-	TLA
	NN1_80MW_2_NXA_fault		NN1	-	NXA
120 MW	NN1_120MW_1_TLA_fault	Angle	NN1	-	TLA
	NN1_120MW_2_NXA_fault		NN1	-	NXA
Fault Sequence	0ms	Single Circuit Three-phase Short Circuit Fault			
	140ms	Fault Clearance (1cct Open)			
	10s	End of Calculation			

NN1: Nam Ngum 1 power station TLA: Thalat Substation NXA: Naxaythong Substation
Prepared by the JICA Survey Team

Generator models for the analysis were those provided by EdL. For some of the planned generators of which the model types were unknown, a salient-pole machine model was applied as shown in the table below.

Table 8.3.21 Generator Model for the unknown Planned Generator: GENSAL

T'_{d0}	T''_{d0}	T''_{q0}	H	D	X_d	X_q	X'_d	X''_d	X_l	S(1.0)	S(1.2)
6.27	0.041	0.047	4.01	0	0.93	0.61	0.31	0.2	0.13	0.1	0.37

Prepared by the JICA Survey Team

The simple exciter model was applied to planned generators. The simple exciter model is not the type of a special exciter system but shows general characteristics of a wide variety of exciters that were appropriately set as shown in the following table.

Table 8.3.22 Exciter Model: SEXS

T'_{d0}	T''_{d0}	T''_{q0}	H	D	X_d	X_q	X'_d	X''_d	X_l	S(1.0)	S(1.2)
6.27	0.041	0.047	4.01	0	0.93	0.61	0.31	0.2	0.13	0.1	0.37

Prepared by the JICA Survey Team

For the generators shown in the Table 8.3.23, the Power System Stabilizers (PSS) were applied. All governors in Laos system were out-of-service. The PSS model used for the analysis is as shown in the table below.

Table 8.3.23 Generators with PSS

Large-scale IPP Unit	Nam Ngum 2, Nam Ngum 3, Nam Theun 1, Nam Ngiep 1, Hongsa Lignite, Theun Hinboun, Nam Theun 2, Houay Ho, Xekaman 3, Xekaman 1, Xekong 4*, Xekong 5*
Domestic Supply Unit	Nam TLA 1, Nam Khan 2, Houaylamphan*

Prepared by the JICA Survey Team

Table 8.3.24 PSS Model: IEEEST

A1	A2	A3	A4	A5	A6	T1	T2	T3
0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.18	0.06
T4	T5	T6	Ks	Lsmax	Lsmin	Vcu	Vcl	
0.18	5.00	5.00	-0.75	0.10	-0.10	0.00	0.00	

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(7) Result of Stability Analysis

Behaviors of phase difference angle oscillation between generators including NN1 in the C1 area and Xeset 1 in the southern area are shown in Appendix A. The relationships between the line colors and the generators are as follows:

Green	:Nam Ngum 1 (Unit1: 17.5 MW)
Dark blue	:Nam Ngum 1 (Unit 6: Additional unit 40 to 120 W)
Light blue	:Nam Leuk
Red	:Nam Mang 3
Yellow	:Nam Lik 1/2

The summary of the results for stability analysis is shown in following table.

Table 8.3.25 Results of Stability Analysis

Expansion Capacity	Case Name	Stability Case	Fault Section (1cct)			Results
40 MW	NN1_40MW_1_TLA_fault	Angle	NN1	-	TLA	Stable
	NN1_40MW_2_NXA_fault		NN1	-	NXA	Stable
60 MW	NN1_60MW_1_TLA_fault	Angle	NN1	-	TLA	Stable
	NN1_60MW_2_NXA_fault		NN1	-	NXA	Stable
80 MW	NN1_80MW_1_TLA_fault	Angle	NN1	-	TLA	Stable
	NN1_80MW_2_NXA_fault		NN1	-	NXA	Stable
120 MW	NN1_120MW_1_TLA_fault	Angle	NN1	-	TLA	Unstable
	NN1_120MW_2_NXA_fault		NN1	-	NXA	Unstable

Prepared by the JICA Survey Team

As a result of stability analysis, stability of each generator tended to diffuse and be difficult to converge as output of the additional unit in NN1 power station increases. In other words, the amplitude is not waved and relatively large diffusion has not occurred in the expansion plan until 80 MW. On the other hand, in case of 120 MW expansion plan, it was confirmed that the amplitude was waved and the system is not stabilized due to large diffusion. As countermeasures against unstable condition, it will be necessary to install PSS at power stations which supply the power for domestic demands, and to add a circuit to the transmission line which are long length and carry large load flow. In addition, since the transmission line between NN1 and Naxaythong assumes a significant role as described on Section 8.3.6, sub-clause (4) Power Flow and Voltage Analysis, it was confirmed that a single circuit fault of 115 kV transmission line between NN1 power station and Naxaythong Substation need not be stabilized more than the single circuit fault of 115 kV transmission line between said power station and Thalat Substation.

(8) Countermeasure for Overload at Main Bus of Phontong Substation

As discussed in (4) Power Flow and Voltage Analysis, it was confirmed that the main bus of Phontong Substation as of 2016 will be overloaded even if there is no expansion of NN1 power station due to power supplied to large demand including Vientiane Municipality. As countermeasures for this problem, main bus conductor for Phontong Substation shall be replaced with bigger size conductor until around 2012. This means that construction of the 220 kV transmission line between Naxaythong Substation and Hinh Huep Substation, and Nam Ngum 5 hydro power station should be initiated in order to supply the power to Vientiane. Since the existing bus adopt a double bus configuration, it is possible that one of the bus of the substation is operated normally without rolling blackouts during replacement of another bus.

8.3.7 TECHNICAL ASSESSMENT OF ALTERNATIVES

Technical studies on each alternative were made in detail in the foregoing Sections 8.3.2 to 8.3.6. Types and dimensions decided for major structures and equipment of each alternative are listed in Appendix E-3. Conceptual design drawings (plans and sections) elaborated for major alternatives are shown in Appendix E-1.

The assessment of the alternatives from technical points of view is made as summarized in the following table. The assessment results are reflected in the final selection of the optimum plan to be made in the succeeding section.

Table 8.3.26 Technical Assessment of Each Alternative

Alter native	Capa city	Advantage	Disadvantage
A1	40 MW	• Although a large temporary enclosure is required on the upstream face of the dam for intake construction, there are precedents in Japan and its construction is easier than that for independent intake tower standing in the reservoir. • Head loss in waterway is minimal because of shortest length of waterway among all alternatives considered. This is advantageous for power generation. Layout is most compact and it makes this plan economical. • Scale of 40 MW is identical to the existing units 3 to 5. The existing OHT crane can be utilized for new unit by only extending the crane runway.	• Land space is narrow and main construction works are in a deep pit. As vehicle access to deep work area is not possible, it is necessary to rely on mobile or fixed cranes in construction work. • An access way to the existing transformers at the toe of the dam is blocked by a temporary ramp bridge to work platform for dam piercing work. Large-scale repair of the transformers is not possible during that time (10 months or so).
A2	60 MW	• Intake is larger than that in A1 and consequently temporary intake enclosure becomes larger. However, it is still easier in construction than coffer for independently standing tower structure to be built in deep reservoir. • Length of waterway from intake to turbine is short and thus head loss is less. Layout becomes compact.	• Land space is tightly narrow as for 60 MW expansion and it makes construction difficult. Powerhouse width is larger than 40 MW plan. Rock foundation of the spillway chute wall is almost undermined due to new powerhouse. Special slope stabilization measures are required. • 60 MW turbine cannot be housed in the size of existing powerhouse since it is larger than the existing 40MW turbine. Width of new powerhouse has to be 2 m wider than the existing building. • 60 MW generator rotor is heavier than the existing 40 MW rotor. Further, crane rail span in new 60 MW bay is wider than the existing span. Thus, existing OHT crane cannot be utilized. • Machine bay floor on spillway side of existing unit 5 has to be used as erection floor for new unit 6. To operate a large new crane within the unit-5 bay, roof of the bay

Alter native	Capa city	Advantage	Disadvantage
			has to be demolished and raised. During the roof raising work of 3 months, switchyard equipment on roof is not operable and consequently unit-5 generation is stopped for 3 months.
A4-1 A4-3	40 MW	• Land space for expansion is ensured by excavation of left bank hill. • Tailrace outlet for Plan A4-3 is located apart from the existing units 1 and 2 tail bay. This arrangement does not disturb operation of units 1 and 2. • Intake is similar to Plan A1. Temporary intake enclosure is easier in construction than independent tower type. • Additional powerhouse is built nearby the existing powerhouse. Operation control of new unit is easy.	• Tailrace outlet of Alternative A4-1 is located just beside the existing units 1 and 2 tail bay. Temporary coffer dike for construction of new tailrace outlet partly blocks the existing tail bay and consequently tail bay WL goes up. The operation of units 1 and 2 is affected. • If crane runway is extended from the existing powerhouse, the existing two OHT cranes can conveniently be utilized for additional unit. However, the crane runway extension requires complete demolition of the roof and upper floor rooms of the existing control building and addition of new concrete columns penetrating from bottom floor in the existing control building in order to support new crane runway. These works are more costly than provision of an additional new crane. Therefore, the plan to utilize the existing cranes is abandoned. Erection bay is additionally needed in a new unit building. • Additional unit building is located just below the existing 115 kV transmission lines. Switchyard for additional unit cannot be located on roof of new powerhouse because of lack of safety clearance below the transmission line. Insulated high voltage cables have to be extended from the main transformer of additional unit to GIS building on left abutment of dam to connect them to the existing transmission line.
A4-2 A4-4	60 MW	• There are advantages similar to alternative A4-1. • As tailrace outlet of alternative A4-4 is located apart from the exiting tail bay, operation of units 1 and 2 is not disturbed.	• Because of the large turbine size, new powerhouse building has to be 2 m wider than A4-1. • Existing 115 kV transmission lines pass over the new powerhouse. Switchyard cannot be located on new powerhouse roof due to lack of safety clearance below the transmission lines. Insulated high voltage cables have to be extended from the main transformer of additional unit to GIS building on left abutment of dam to connect them to the existing transmission line.
B2-1 B2-2	80 MW 120 MW	• Intake configuration is similar to Alternative A1. Temporary intake enclosure is easier in construction than independent type. • Additional powerhouse is located apart from the existing powerhouse. Sufficient land space can be ensured. New powerhouse does not disturb the	• Headrace waterways from intake to new powerhouse are culverts or tunnels. Rock cover over the tunnels is thin. It results in difficulty of tunneling work. • Internal water pressure acts in headrace waterway. Thin rock cover of the tunnels cannot prevent water leakage from the tunnel. Internal steel lining is required in full

Alternative	Capacity	Advantage	Disadvantage
		operation of the existing powerhouse in and after construction. • Expansion of up to 80 MW can utilize the existing 115 kV transmission line. Insulated high voltage cables have to be extended from main transformers to GIS facility on left abutment in order to feed power into the existing transmission lines via the existing roof switchyard.	length of culvert/tunnel. • In case of 120 MW expansion, the existing transmission lines are not enough in capacity. New transmission line of 54 km long is required for new unit.
D2-1 D2-2 D2-3 D2-4	40 MW 60 MW 80 MW 120 MW	• There are no obstructive structures in expansion site on the right bank. Sufficient land space can be ensured. • Existing 115 kV transmission lines are usable for transmission of power up to 80 MW. Power generated by new powerhouse can be fed to the existing roof switchyard through new overhead transmission line.	• Independent intake structure has to be constructed in deep reservoir. Special coffer structure (pipe piles, etc.) is necessary for construction of the intake without lowering reservoir WL. The coffer has to withstand high water pressure more than 30 m. Its construction is not easy and results in high cost and long construction period. • Power transmission from 120 MW units exceeds capacity of the existing transmission lines. It is necessary to add new switchyard and new 54 km long transmission line.

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In case of 40 MW expansion, Alternative A1 is technically superior to the other alternatives since it can achieve compact arrangement of waterway and powerhouse and can effectively utilize the existing facilities such as OHT cranes and draft tube stoplogs.

In case of 60 MW, Alternative A2 has the most compact layout. However, it threatens stability of adjoining spillway chute wall foundation and there is no possibility of using the existing OHT cranes. Thus, the left bank Alternative A4-4, for which land space is sufficient, is technically superior to other 60 MW cases.

In cases of 80 MW and 120 MW expansions, the left bank alternative (B2) which utilizes the existing dam body for new intake is superior to the right bank alternatives (D2), since the latter requires independent intake tower of which construction in deep reservoir is difficult and costly.

Environmental Impacts

Construction activities for the power station expansion are limited within the existing dam and powerhouse area. The construction activities will not cause serious change of the present environmental situation. Although new intake and powerhouse of Alternative D2 are located apart from the existing powerhouse premises, their sites are still within the area used for original dam construction in the 1960s.

Most conspicuous environmental change caused by operation of the expanded power station will be an increased fluctuation of downstream river water level. The present water level difference between peak generation (155 MW) and off-peak generation (40 MW) is estimated at 1.5 to 1.6 m in the downstream reaches (10 km from NN1 dam). In case of 40 MW expansion, the river water level fluctuation increases by 0.4 to 0.5 m due to additional peak generation. According to the environmental survey results as detailed in Chapter 6, the incremental fluctuation height within 0.5 m does not cause serious environmental impacts to the downstream riparian people and impact mitigation measures are not required.

Incremental heights of river water level fluctuation are estimated to be 0.6 to 0.7 m in 60 MW expansion, 0.8 to 0.9 m in 80 MW expansion and 1.1 to 1.3 m in 120 MW expansion. Such increased water level fluctuation results in additional inundation of river side cultivation lands and has impacts to ferry boat transportations and fish-cage operations in the river channel. Some compensation measures are required against these environmental impacts caused by larg-scale power station expansion exceeding 40 MW.

8.3.8 COST ESTIMATE FOR COMPARISON

Construction cost of civil works and electrical/mechanical works are estimated for each alternative based on the conceptual designs elaborated as mentioned above. Civil work costs are estimated by multiplying the unit price and work quantity relevant to various works. Most of the unit prices applied are based on the prices quoted in various recent international bids for similar hydropower projects in Southeast Asia. However, construction of temporary coffer enclosure in deep reservoir for penetration of penstock hole in existing dam body is unprecedented work in Southeast Asia although these are adopted in many places in Japan. Therefore, costs of the temporary enclosure in Japan are referred to. The Japanese prices, however, are not applicable directly to the NN1 expansion as the project is in Lao PDR. The Japanese prices are adjusted considering that materials for the temporary enclosure are procured and fabricated in Thailand and site installation is carried out by employing local workers. Costs of gates and penstocks and of generating equipment and transmission facilities are also based on prices quoted in recent international bids for similar hydropower projects. The most recent ternd of price increase is taken into account.

The cost estimate calculations are detailed in Appendix E-2 and summary of the estimated costs is shown in the table below.

Table 8.3.27 Summary of Estimated Construction Costs of Alternatives

	Description	Unit	40 MW Expansion				60MW Expansion				80 MW Expansion		120 MW Expansion	
			A1	A4-1	A4-3	D2-1	A2	A4-2	A4-4	D2-2	B2-1	D2-3	B2-2	D2-4
1	Construction Cost													
	a) Civil Works	M US$	24.4	28.6	28.1	43.5	29.7	35.2	34.9	51.8	52.3	62.3	58.5	75.3
	b) Hydraulic Steel Works	M US$	3.5	4.0	4.0	4.6	6.7	6.7	6.7	7.0	12.7	5.3	20.1	7.4
	c) Electrical/ Mechanical Eq.	M US$	20.0	23.3	23.3	22.4	31.6	31.5	31.5	30.5	45.0	45.0	60.1	63.6
	d) Transmission Line	M US$	0	0	0	0	0	0	0	0	0	0	5.4	5.4
	Sub-total	M US$	47.9	55.9	55.4	70.5	68.0	73.4	73.1	89.3	110.0	112.6	144.1	151.7
2	Engineering cost and environmental impact treatment cost	M US$	4.2	4.7	4.7	5.7	5.6	6.2	6.1	7.3	8.9	9.1	11.8	12.3
	TOTAL (Base Price)		**52.1**	**60.6**	**60.1**	**76.2**	**73.6**	**79.6**	**79.2**	**96.6**	**118.9**	**121.7**	**155.9**	**164.0**

(Note)：Costs of land acquisition, administration and contingency are not included

Prepared by the JICA Survey Team

In case of the 40 MW expansion, Alternative A1 (US$52.1 million) is lowest in construction cost. Alternative D2-1, which is the same 40 MW expansion option but is located on the right bank, is most costly because of the difficulty in constructing its intake tower.

In case of the 60 MW expansion, Alternative A2 (US$73.6 million) is the least costly because the waterway layout is most compact among the four plans.

In case of the 80 MW - 120 MW expansion, Alternative B2 in which the additional powerhouse is located on downstream left bank is lower in cost than Alternative D2 of which powerhouse is located on the right bank. The independent intake tower to be built in the reservoir for Alternative D2 is the main reason for the higher cost.

Even in the case of the lowest cost Alternative A1, unit construction cost per kW of installed capacity is US$1,302 /kW. This unit cost is not very low considering that no dam is to be built. The Nam Mang 3 power station (40 MW) commissioned in 2004 was US$1,575 /kW, including dam cost. The high cost of the NN1 expansion results from difficulty in construction of additional intake to be built in the existing deep reservoir without dewatering the reservoir and without stopping the operation of NN1.

8.3.9 ECONOMIC COMPARISON OF ALTERNATIVES

(1) Benefit of Expansion

Increase of Peak Capacity and Energy in Generation

The benefit of the power station expansion comes from both increments of dependable output capacity (MW) and energy production amount (GWh/year) resulting from the expansion. The increased dependable capacity and energy amount of each alternative option are obtained by the reservoir operation simulations performed in the foregoing Chapter 5. The results are listed in Table 8.3.28 below.

Economic Benefit

Economic values of increased peak capacity and energy production are estimated from the construction cost and O&M cost of the least-cost expansion alternative. Middle-speed diesel plant was selected as the least costly alternative for the NN1 expansion since it could be constructed at low cost and operated at plant factor similar to the NN1 power station. The capacity value (kW value) and energy value (kWh value) estimated from the middle-speed diesel plant are US$275.35 /kW and US$0.0783 /kWh, respectively. Calculation details of kW and kWh values are presented in Chapter 12. Annual economic benefits calculated from these kW and kWh values are shown in the table below.

Table 8.3.28 Annual Economic Benefits of Alternatives

Expansion Scale	Alternative	Incremental capacity and energy (*)		Annual economic benefit (M US$/ year)		
		Capacity increment (MW)	Energy increment (GWh/year)	Capacity benefit	Energy benefit	Total
40 MW	A1	33.83	51.93	9.32	4.07	13.39
	A4-1	33.61	50.75	9.25	3.97	13.22
	A4-3	33.54	50.27	9.24	3.94	13.18
	D2-1	33.76	51.56	9.30	4.04	13.34
60 MW	A2	51.02	54.56	14.05	4.27	18.32
	A4-2	50.71	52.59	13.96	4.12	18.08
	A4-4	50.61	51.95	13.94	4.07	18.01
	D2-2	51.04	54.70	14.05	4.28	18.33
80 MW	B2-1	78.09	66.56	21.50	5.21	26.71
	D2-3	77.16	62.40	21.25	4.89	26.14
120 MW	B2-2	116.53	71.73	32.09	5.62	37.71
	D2-4	114.52	65.49	31.53	5.13	36.66

Reference (*): Generation status before expansion (with NN2):
Dependable capacity: 110.67 MW
Energy production: 1,068.3 GWh/year

Prepared by the JICA Survey Team

Financial Benefit

In the expansion plan optimization study, financial benefit of the expansion is identified as the increased revenue gained by selling the increased electricity to the domestic market. Average tariff rate in 2008 was 6.21 US cents per kWh as detailed in Chapter 12. This rate is applied to calculate the financial benefits of each expansion alternative. Table 8.3.24 below shows the calculated annual financial benefits.

Table 8.3.29 Annual Financial Benefits of Alternatives

Expansion Scale	Alternative	Incremental energy (GWh/year)		Annual financial benefit (M US$ / year)
		Generated energy	Sold energy after loss (*)	
40 MW	A1	51.93	48.33	3.00
	A4-1	50.75	47.23	2.93
	A4-3	50.27	46.78	2.91
	D2-1	51.56	47.98	2.98
60 MW	A2	54.56	50.77	3.15
	A4-2	52.59	48.94	3.04
	A4-4	51.95	48.34	3.00
	D2-2	54.70	50.90	3.16
80 MW	B2-1	66.56	61.94	3.85
	D2-3	62.40	58.07	3.61
120 MW	B2-2	71.73	66.75	4.15
	D2-4	65.49	60.94	3.78

(*): Loss: Transmission 6.0%, Internal consumption 0.5%, Forced outage 0.5%
Loss factor = (1-0.06) x (1-0.005) x (1-0.005) = 0.9306

Prepared by the JICA Survey Team

(2) Cost

Construction costs of alternatives without contingencies are listed in Table 8.3.29 above. To express the project cost (total investment), the amount of contingencies equivalent to 10% of the construction cost is added as shown in the table below.

Table 8.3.30 Project Costs of Alternatives

Expansion Scale	Alternative	Base cost (M US$)	Contingencies (M US$)	Project cost (M US$)
40 MW	A1	52.10	5.21	57.31
	A4-1	60.60	6.06	66.66
	A4-3	60.10	6.01	66.11
	D2-1	76.20	7.62	83.82
60 MW	A2	73.60	7.36	80.96
	A4-2	79.60	7.96	87.56
	A4-4	79.20	7.92	87.12
	D2-2	96.60	9.66	106.26
80 MW	B2-1	118.90	11.89	130.79
	D2-3	121.70	12.17	133.87
120 MW	B2-2	155.90	15.59	171.49
	D2-4	164.00	16.40	180.40

Prepared by the JICA Survey Team

The project cost is disbursed during construction. Construction period, including bidding and contract process, is assumed to be five years. Disbursement of the cost is assumed to be made at 2 % in the 1st year, 3 % in the 2nd year, 20 % in the 3rd year, 40 % in the 4th year and 35 % in the 5th year. Annual O&M cost after commissioning is estimated to be 0.2 % of the initial investment.

(3) Economic and Financial Comparisons

Based on the calculated benefits and costs, ranking of economic and financial viabilities of the alternatives are analyzed. Benefit-cost (B/C) ratio is generally used as an index to present cost performance of different scales of development. Therefore, the cost performance of the expansion alternatives is compared on the basis of B/C ratio.

Economic viability is analyzed for a project life of 50 years applying a nominal discount rate of 10 %. Financial viability is also analyzed for a 50-year project life applying a discount rate of 1.405 % calculated on the basis of the assumed ODA soft loan (i=0.7 % p.a.) for the 85% portion of the total cost. It is further assumed that reinvestment of which amount corresponds to 8 % of the initial cost is made 30 years after the commissioning. The following table summarizes the B/C ratios calculated for each alternative.

Table 8.3.31 Benefit-Cost (B/C) Ratios of Each Alternative

Expansion Scale	Alternative Plan	Economic B/C Ratio (least cost alternative: Diesel) discount rate = 10%	Financial B/C Ratio (current tariff income) discount rate = 1.405 %
40MW	A1	2.06	1.65
	A4-1	1.75	1.38
	A4-3	1.76	1.38
	D2-1	1.40	1.12
60MW	A2	1.99	1.22
	A4-2	1.82	1.09
	A4-4	1.82	1.08
	D2-2	1.52	0.94
80MW	B2-1	1.80	0.92
	D2-3	1.72	0.85

120MW	B2-2 D2-4	1.94 1.79	0.76 0.66

Higher value of B/C expresses higher cost performance. As indicated in the above table, B/C ratio of Alternative A1 (40 MW) is the highest in both economic B/C ratio (= 2.06) and financial B/C ratio (=1.65).

Alternative A2 (60 MW) has the second highest economic B/C ratio (=1.99). However, its financial B/C ratio is inferior to the other 40 MW cases since energy production does not increase proportionally to the scale of expansion. Although the third highest economic B/C ratio (=1.94) appears in Alternative B2-2 (120 MW), its financial B/C ratio is 0.76. This means that investment cost is not recoverable from the financial income. It is clearly understood that the costly expansion with scale larger than 60 MW is not financially advantageous.

8.3.10 SELECTED OPTIMUM PLAN

As analyzed in the above Section 8.3.9, Alternative A1 (40 MW) is judged to be highest in cost performance among 12 alternative options considered. Alternative A1 aims to build a new unit bay building for 40MW plant in the space between the existing powerhouse and the spillway. The existing OHT cranes and draft tube gates can be utilized for the additional unit. Layout of the new powerhouse is most compact and economical among all the options. As the length of penstock and tailrace is short and waterway head loss is less, available water head can be most effectively utilized for power generation.

By comprehensively judging from the technical, economical, financial and environmental viewpoints, Alternative A1 (40MW) is selected as the optimum expansion plan for the NN1 power station.

CHAPTER 9 BASIC DESIGN OF OPTIMUM EXPANSION PLAN

9.1 PRINCIPAL WATER LEVEL AND WATERWAY DIMENSIONS

9.1.1 RATED RESERVOIR WATER LEVEL FOR UNIT 6

(1) Change of Reservoir Operation Pattern

The reservoir data of the existing NN1 power station are as follows:

Flood water level (PMF):		EL. 215.0m（identical to dam crest level）
Normal max. operation level:		EL. 212.0m
Minimum operation level:		EL. 196.0m
Water surface area (at EL. 212 m):		370 km^2
Effective storage volume (EL.212 - EL.196):		4.7 x 10^9 m^3
Annual inflow,	Total:	11.9 x 10^9 m^3 (375.5 m^3/s)
	From NN2 (main stream):	6.2 x 10^9 m^3 (197.5 m^3/s)
	From residual basins:	5.7 x 10^9 m^3 (178.0 m^3/s) (including flow from Nam Song & Nam Luek)

Figure below shows the NN1 reservoir storage volume curve available at present.

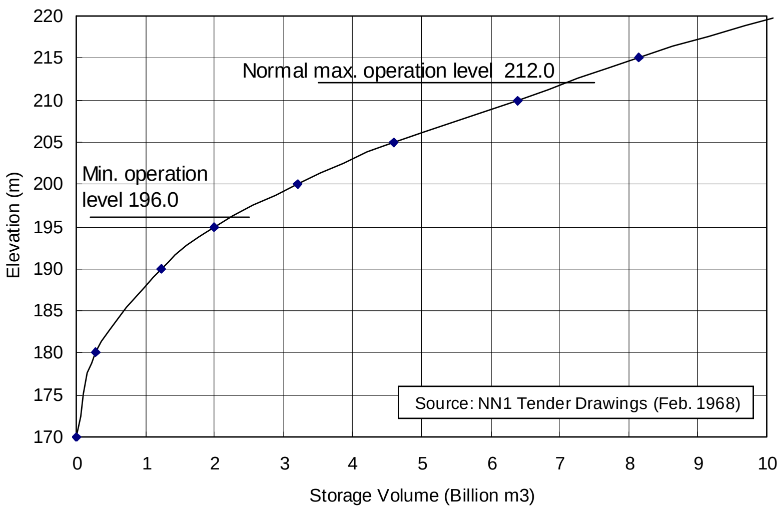

Figure 9.1.1 NN1 Reservoir Storage Curve

The Nam Ngum 2 hydropower project being constructed just upstream of the NN1 reservoir will be put into operation in 2011. Four years later, the additional 40 MW unit of NN1 will be commissioned in 2015. The NN2's reservoir has an effective storage capacity of 2.99 billion m^3, which is large enough to store almost half of the annual river flow at the NN2 site. Presently, inflows to the NN1 reservoir widely fluctuate from around 50 m^3/s in the dry season to more than 800 m^3/s during the rainy season. However, once the NN2 is completed, variation of outflow from the NN2 to the NN1 reservoir will considerably be flattened owing to the NN2's reservoir storage effect. Based on the

NN2's flow regulation function, the rate of inflow during the dry season will increase to around 150 m^3/s. On the other hand, the flood inflow rate to NNI reservoir decreases.

The annual variations on the water level of the existing reservoir that were recorded under the existing conditions without NN2 are shown in the figure below.

Source: NN1 Power Station

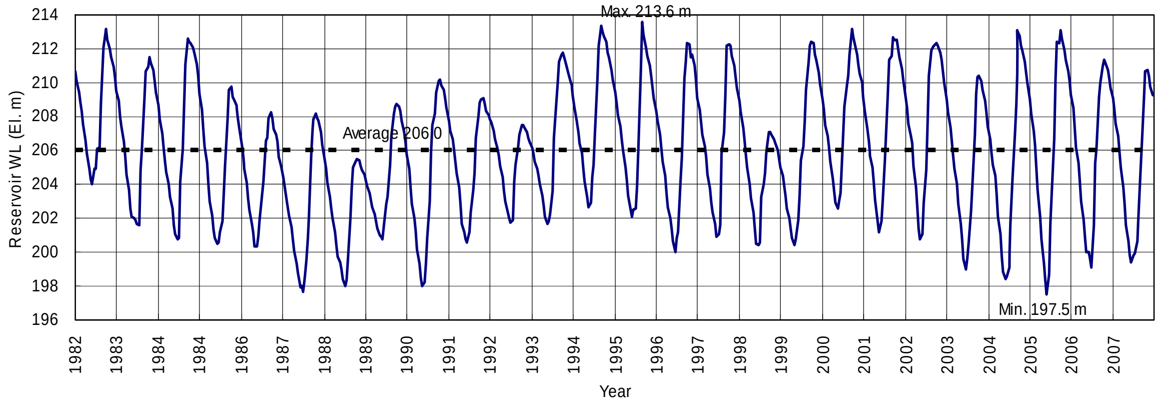

Figure 9.1.2 Reservoir WL under Existing Condition (Actually Observed in 1982-2007)

Meanwhile, the annual variations on the water level of the existing reservoir after expansion were simulated by the Survey Team by inputting the monthly inflow data of 36 years (1972-2007). The reservoir simulation result of the 40-MW expansion case with NN2 (power demand projected for year 2020) is shown in the figure below.

Prepared by: JICA Survey Team

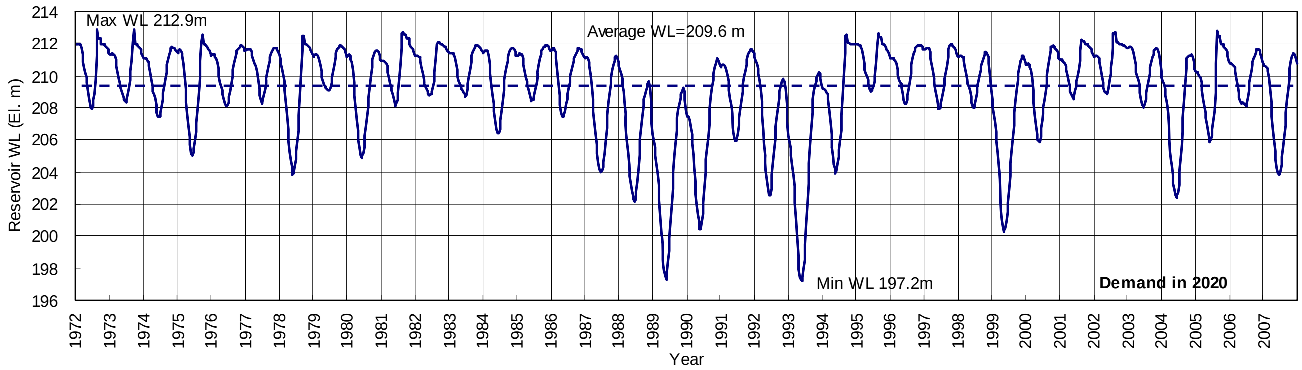

Figure 9.1.3 Simulated Reservoir WL with 40MW Expansion (with NN2)

Note: The reservoir water level variation pattern depends on the sufficiency of domestic generation sources against domestic power demand. The EdL's latest projection of future demand and supply is presented in Section 2.4. The power demand and supply projected for the year 2020 is considered to be a typical pattern for the future since the projection beyond the year 2020 seems to be less-realistic in the present PDP.

The frequency of occurrence for various reservoir water levels is illustrated in Figure 9.1.4 for each case of "before expansion without NN2" and "after expansion with NN2".

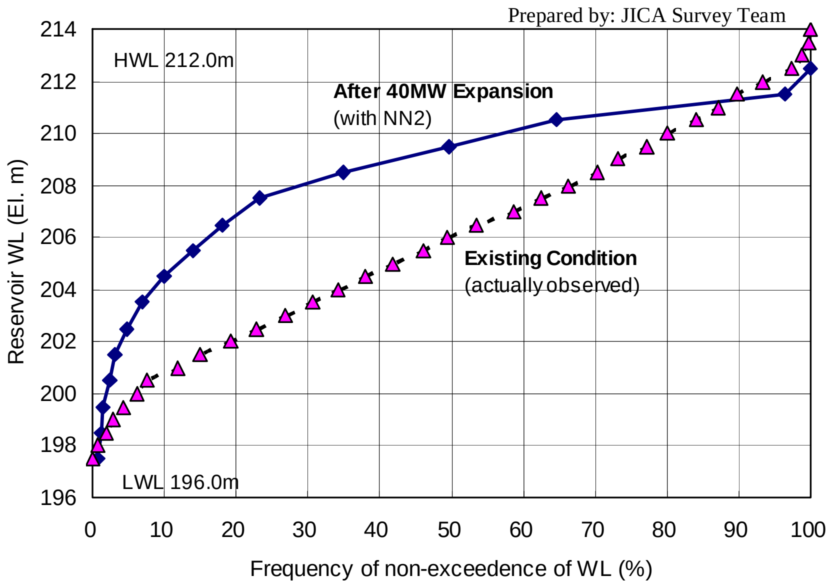

Figure 9.1.4 Reservoir WL Frequency Before and After Expansion

The following table shows the summary of the various water levels considering the conditions before and after expansion.

Table 9.1.1 Reservoir Water Level Rise after Expansion

	Reservoir Water Level	Existing condition without NN2 (EL. m)	After 40 MW expansion with NN2 (EL. m)	WL rise (m)
1	Max. WL	213.6	212.9	-0.7
2	Long-term average	206.0	209.6	+3.6
3	95 % dependable	199.6	202.7	+3.1
4	Min. WL	197.5	197.2	-0.3

Prepared by the JICA Survey Team

Based on the table above, the long-term average water level is EL. 206.0 m in the existing condition. However, the average water level estimated for the condition after expansion (40 MW) will go up to EL. 209.6 m. This means that the NN1 power station after expansion will be operated under the reservoir water level 3.6 m higher than the existing water level on average. While the 95% dependable water level is EL. 199.6 m under the existing condition, it will rise up to EL. 202.7 m after the 40-MW expansion.

(2) Rated Reservoir Water Level for New Unit 6

The rated head specified for the existing units 3 to 5 is 37.0 m. As the tailrace water level under full operation is EL. 168.0 m and head-loss is 1.0 m, the rated reservoir water level of the existing units is EL. 206.0 m (=168.0m+1.0m+37.0m).

However, as shown in Table 9.1.1, the NN1 power station after expansion will be operated with the reservoir water level higher than EL. 202.7 m during most (95%) of the time. The long-term average water level after expansion is approximately EL. 209.6 m. This is 3.6 m higher than the average water level in the existing condition.

Therefore, the reservoir water level for deciding the rated head of the new unit 6 is selected to be EL.

209.6 m. Application of the higher rated water level contributes to reduce the size of the unit 6 turbine and consequently to save cost.

(3) Tail Water Level after Expansion

The tail water rating curve (H-Q curve) of the NN1 powerhouse indicated in the 1968 tender drawings is available for the present study (refer to Figure 9.1.5). Water level and discharge records actually observed recently well coincide with the existing curve as plotted in Figure 9.1.5. Accordingly, the existing rating curve is considered to still be applicable to the expansion study.

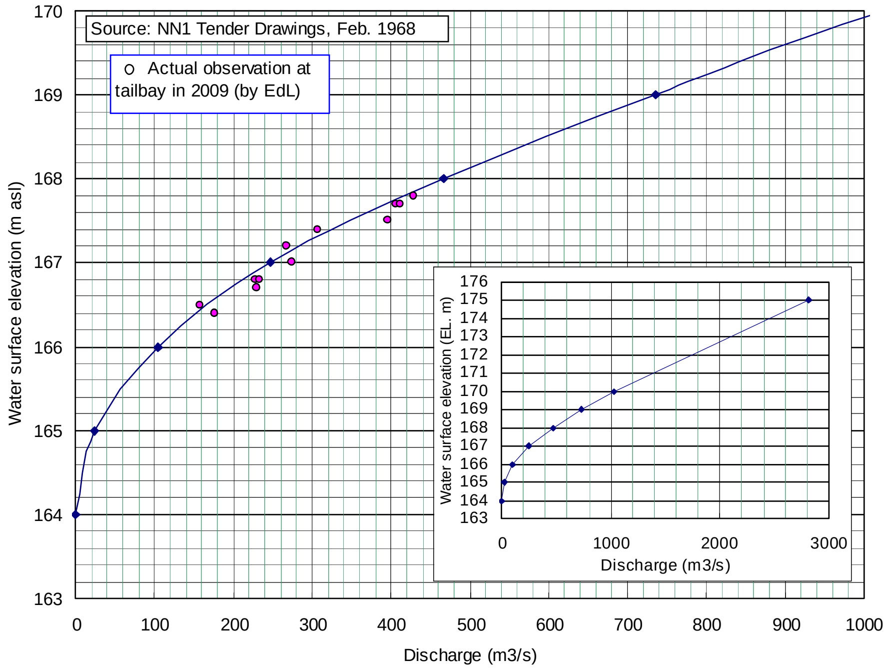

Figure 9.1.5 NN1 Power Station, Tail Water Rating Curve

It is, however, noted that the tail water level at the NN1 powerhouse during the flood season is affected by back-water from flood flows of the Nam Lik River which joins with the Nam Ngum main stream 4 km downstream from the NN1 powerhouse. Due to the back-water effect, the water level of the NN1 tail bay becomes higher than the normal water level even if the same turbine discharge is released. The water level rise due to the back-water effect can reach 1.0 m or more when there is no water release from the NN1 spillway.

The total turbine discharge of the existing units 1 to 5, when operated at their rated capacities, is approximately 465 m^3/s. The corresponding tail water level is approximately EL. 168.0 m. After the expansion, the tail water level will become higher.

After completion of the NN2 project, the range of variation of NN1 inflow will considerably be reduced. This results in higher reservoir water levels than the present status. The average reservoir water level will thus rise to EL. 209.6 m, which is 3.6 m higher than the rated water level of the existing units. In case of the existing and new turbines operated under the reservoir water level of EL. 209.6 m, turbine discharges are estimated as follows:

Turbines	Turbine discharge (m^3/s)
Units 1-2 (17.5MW x 2)	50 x 2 = 100
Units 3-5 (42MW x 3)	122 x 3 = 366
New Unit 6 (40MW x 1)	111 x 1 = 111
	Total 577

When all units, including the additional unit 6, are fully operated under the reservoir water level of 209.6 m, the turbine discharge is around 577 m^3/s and the corresponding tail water level is EL. 168.4 m. This water level is regarded as the rated tail water level for the unit 6 turbine.

It is noted that the above tail water level will be further lowered by about 0.2 m if the downstream rock hump in the river channel is removed, as studied in Chapter 10.

(4) Loss of Head in Unit 6 Waterway

The turbine discharge for 40MW output varies with the turbine effective head. If the effective head is 40 m for unit 6, the turbine discharge is estimated to be 111.2 m^3/s. Applying the penstock diameter of 5.5 m as selected in Section 9.1.2 below, loss of head in the unit 6 waterway is estimated as follows:

Turbine discharge (max.) of unit 6:	111.2 m^3/s	
Head loss (max.),	Intake and gate:	0.19 m
	Penstock pipe:	0.69 m
	Draft tube outlet:	0.30 m
	Tailrace channel:	0.02 m
	Total:	1.20 m

(5) Rated Head for Unit 6 Turbine

Based on the above studies, the rated head (effective head = gross head - head loss) for the turbine of additional unit 6 is computed as follows:

Rated reservoir water level:	EL. 209.6 m
Rated tail water level:	EL. 168.4 m
	(or EL. 168.2 m if d/s rock hump is removed)
Head loss in water way (Q=111.2 m^3/s):	1.20 m
Effective head:	40.0 m (or 40.2 m) ➔ 40.0 m

The effective head of 40.0 m is therefore selected as the rated head for the additional unit 6.

The design minimum operation level of the reservoir is EL. 196 m. Therefore, the minimum effective head is about 27 m in all-unit full open operation. When the reservoir water level is EL. 213 m in wet season, the maximum effective head is estimated to be around 43.5 m, under a no spill-out condition.

9.1.2 OPTIMUM PENSTOCK DIAMETER FOR UNIT-6

The penstock diameter of the existing units 3 to 5 (40MW each) is 6.0 m. This diameter looks excessively large for the new unit 6 since the space for penstock construction is very narrow and is tightly confined by the existing dam and additional powerhouse. Because the dam foundation level at the unit 6 penstock site is higher than the required level of penstock bottom foundation, a smaller diameter penstock is preferable in order to not threaten the structural safety of the dam. The optimum (economic) diameter of the unit 6 penstock is sought hereunder by comparing the construction cost savings with reduced energy benefit resulting from the application of smaller diameters such as 5.5 m, 5.0 m and 4.5 m.

(1) Construction Cost Saving

By using smaller penstock, sizes of the intake structure as well as temporary enclosure structure are reduced. Sizes of intake trash rack, stoplogs and gate are also reduced. Smaller penstock can save on construction cost. The cost saving from D=6m penstock for different diameters (D) of penstock is calculated from the costs of relevant civil works and hydraulic steel works as follows:

Table 9.1.2 Construction Cost of Waterway (in 1,000 US$)

		D = 6.0 m	D = 5.5 m	D = 5.0 m	D = 4.5 m
1	Civil works				
	Dam piercing	2,106	1,970	1,813	1,634
	Temporary enclosure	15,660	15,300	14,940	14,580
	Sub-total	17,766	17,270	16,753	16,214
2	Hydraulic Steel Works				
	Trash rack	52	48	36	36
	Stoplogs	441	413	343	287
	Intake gate and hoist	1,404	1,179	1,035	855
	Penstock pipe	1,498	1,302	1,120	889
	Sub-total	3,395	2,942	2,534	2,067
3	Total Cost	21,161	20,212	19,287	18,281
4	**Cost Saving from D=6.0m**	**0**	**949**	**1,874**	**2,880**

Prepared by the JICA Survey Team

As seen in this table, construction cost of US$ 949,000 is saved if the penstock diameter is reduced from 6.0m to 5.5 m. If the diameter is further reduced to 5.0 m, the cost saving becomes US$ 1,874,000.

(2) Reduction of Energy Production

By use of smaller diameter penstock for the same turbine, waterway head loss increases and consequently, energy production decreases. In order to estimate degree of energy reduction of unit 6, the power generation of all units is simulated for each of the different diameter cases for the unit 6 applying inflow data of 36 years (1972-2007). The results are shown in the following table.

Table 9.1.3 Reduction of Annual Energy and Dependable Output

		Penstock diameter			
		D = 6.0 m	D = 5.5 m	D = 5.0 m	D = 4.5 m
1	Head loss at max. turbine flow (m)	1.06	1.18	1.37	1.69
2	Energy production (GWh/y)	1,119.17	1,118.67	1,117.86	1,116.56
	Reduction from D=6m (GWh/y)	**0**	**0.50**	**1.31**	**2.61**
3	Dependable peak output (MW)	144.42	144.34	144.20	144.00
	Reduction from D=6m (MW)	**0**	**0.09**	**0.22**	**0.42**

Prepared by the JICA Survey Team

If the penstock diameter is reduced from 6.0 m to 5.5 m, energy production and dependable peak output decrease by 0.50 GWh per year and 0.09 MW, respectively. Further reduction of the diameter to 5.0 m results in reduction of 1.31 GWh/year and 0.22 MW.

(3) Economic Comparison

To compare the energy reduction with the cost saving, the annual reductions of energy production and dependable output are converted to the present values (monetary values) in economic terms as shown below.

Table 9.1.4 Economic Comparison

		D = 6.0 m	D = 5.5 m	D = 5.0 m	D = 4.5 m
1	Construction Cost Saving (1000US$)	0	949	1,874	2,880
2	Reduced Annual Benefit (1000US$/y) Energy benefit (*1) Peak output benefit (*2) Total	 0 0 0	 -38.0 -23.6 -61.6	 -101.8 -60.5 -162.3	 -203.6 -116.5 -320.1
3	Present Value of Reduced Benefit for 50 years (1000 US$) *3	0	-611	-1,610	-3,174
4	**Net Present Value, 1+3 (1000US$)**	**0**	**338**	**264**	**-294**

*1: Unit energy benefit = $0.0783/kWh
*2: Unit peak output benefit = $275.35/kW
*3: Discount rate i=10%, Production life time = 50 years
Prepared by the JICA Survey Team

Net present value (NPV) is US$ 338,000 for the penstock diameter of 5.5 m, which is highest among the four cases compared. The diameter of 6.0 m used in the existing units 3 to 5 is not necessarily most economical for the new unit 6 since the construction of the additional intake is costly due to difficult underwater works.

(4) Optimum Diameter of Unit-6 Penstock

As compared in (3) above, the diameter of 5.5 m is the most economical among the four cases of different diameters (6.0 m to 4.5 m). Therefore, the penstock diameter for the new unit 6 is decided to be 5.50 m.

9.1.3 INTAKE CENTER ELEVATION OF UNIT-6

(1) Minimum Operation Reservoir Water Level

By the NN2's flow regulation effect, the NN1 reservoir water level will be kept at considerably higher level than the existing level even in the dry season. According to the generation simulation inputting the inflow data of 36 years, the analyzed 95% dependable water level of the NN1 reservoir after the 40 MW expansion (with NN2) is EL. 202.7 m.

However, the water level fell twice to about EL. 197 m in the 36-year generation simulation for 40 MW expansion. This level is close to the minimum operational level (EL. 196 m) specified for the existing units. Therefore, this water level EL. 196.0 m is adopted as the minimum operational reservoir level for unit-6.

(2) Intake Submergence

Intake entrance level should be deep enough from the water surface in order to avoid the formation of vortex and consequent air-entraining into the intake conduit. Required intake submergence above the top of intake conduit is calculated as follows referring to Knauss's equation.

$$h = cD\frac{v}{\sqrt{gD}}$$

where: h = required intake submergence above intake conduit crown (m)
c = coefficient (= 2.43 estimated from the existing intake of units 3 to 5)
D = diameter of conduit (= 5.5 m)
v = flow velocity in conduit (m/s) when reservoir level is MOL

- Estimated flow velocity, v 4.38 m/s
- Required submergence, h 8.0 m
- Intake conduit center level = 196.0-8.0-5.5/2= EL. 185.25 m

Therefore, the elevation of the intake conduit center is decided to be EL. 185.25 m.

9.2 INTAKE AND PENSTOCK

9.2.1 INTAKE

As mentioned in the foregoing Section 9.1, the diameter of intake entrance and penstock is selected to be 5.5m and the intake center level is selected to be EL.185.25m. The maximum discharge of the new unit 6 slightly decreases than the existing units because the rated reservoir water level is set at higher level. Principal features of the intake for the existing units 3 to 5 and additional unit 6 (40MW) are shown in Table 9.2.1. The basic design of the intake is shown in Appendix G.

Table 9.2.1 Principal Feature of Intake

	Existing Units Nos.3 to 5 (40MW)	Additional Unit No. 6 (40MW)
Penstock Diameter	6.0 m	5.5 m
Intake center elevation	EL. 186.0 m	EL. 185.25 m
Max. discharge	118 m3/s	111.2 m3/s

Prepared by the JICA Survey Team

9.2.2 PIERCING DAM

The diameter of hole to be excavated in the dam body that is required to install the 5.5 m diameter penstock pipe is decided to be 6.7 m. The space between the penstock pipe and surrounding excavated face is set at 0.6 m as a necessary clearance for installing the penstock pipe. This is determined from precedents of installing penstock. Principal features of the piercing dam are shown in the table below.

Table 9.2.2 Principal Features of Piercing Dam

Items	Dimensions
Penstock diameter	5.5 m
Dam piercing diameter	6.7 m
Piercing length	22.3 m

Prepared by the JICA Survey Team

9.2.3 INTAKE TEMPORARY ENCLOSURE

If the reservoir water level can be kept at a low level during the dewatering inside the temporary enclosure for intake construction, it is possible to adopt the steel girder support type enclosure, which is considerably easier to construct than the pedestal concrete support type. Applicability of the steel girder support type is studied hereunder, taking into account the restriction on reservoir water level as specified in Table 9.2.3. Types of temporary enclosure support compared are the pedestal concrete support type (case 1) and steel girder support type (case 2), of which principal features are listed in Table 9.2.4.

Table 9.2.3 Restriction of Reservoir Water Level

Items	Conditions
Upper limit of water level during restriction	EL. 207m
Period of restriction	3.5 months (March, April, May & June)

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Table 9.2.4 Principal Features of Temporary Enclosure

		Case 1	Case 2
Type of enclosure		Square type	
Type of support		Pedestal concrete	Steel girder
Inside dimensions	Width	11.5 m	11.5 m
	Length	4 m	4 m
	Height	34 m	29 m
Weight of steel enclosure		830 t	580 t
Volume of pedestal concrete		1,250 m3	-

Note: Restriction of reservoir water level during dewatering of temporary enclosure is needed in Case 2.
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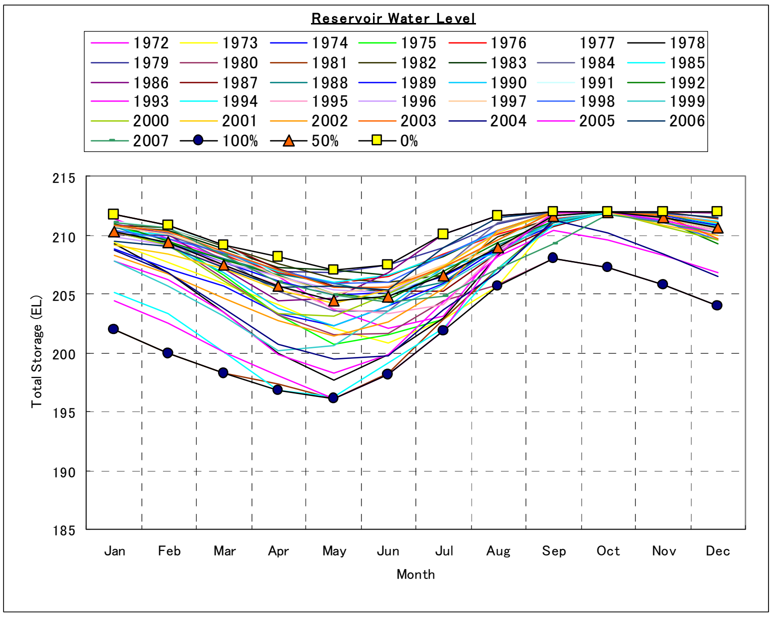
With regards to Case 2, the stability of the dam during dewatering inside the temporary enclosure is the most important and crucial matter of concern since there is no pedestal concrete which acts to resist uplift water pressure. As detailed in Section 9.2.4 below and in Table 9.2.6**,** the dam block No. 20 (unit 6 intake) is sufficiently stable even during dewatering inside the temporary enclosure of steel girder type (case 2) if the reservoir water level is restricted below EL. 207.0 m.

Meanwhile, it is desirable to keep the reservoir water level sufficiently low during the following works:

- Dewatering operation inside the enclosure
- Final break-through work of dam piercing
- Installation of intake bell-mouth steel liner and filling of concrete around the steel liner
- Installation of intake stoplog guide slot structure
- Installation of intake stoplog units and confirmation of water sealing completeness

It will take at least 3.5 months to complete all of the above works. During that period, it is necessary to keep the inside of the enclosure in dry condition.

Figure 9.2.1 shows the monthly reservoir water level variation under the ordinary generation operation without water level restriction. The data were obtained by the reservoir operation simulation (with NN2) carried out by the Survey Team using monthly inflow records of past 36 years.



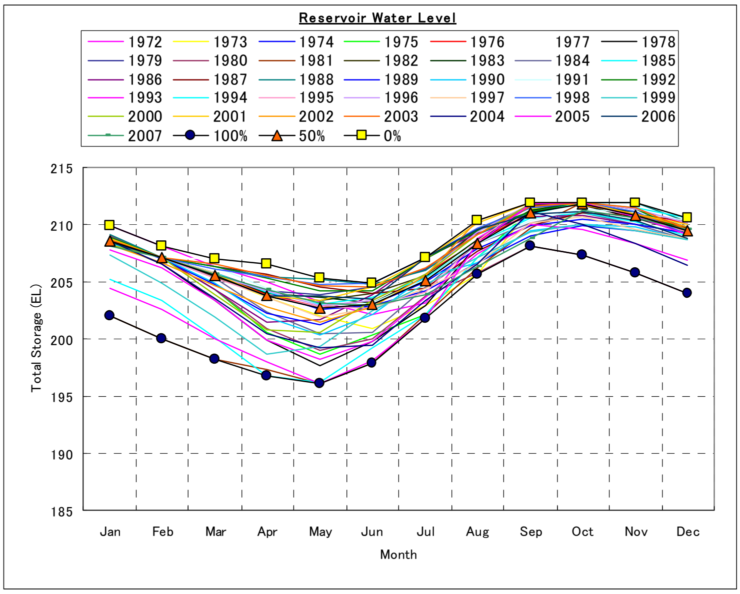
Prepared by the JICA Survey Team

Figure 9.2.1 Reservoir WL Variation without WL Restriction

As can be seen in the above figure, the reservoir water level at the end of the dry season becomes lower than EL. 207 m in almost all the simulated years. Accordingly, it is considered that restriction of the reservoir water level limited to dry season period and to around EL. 207 m will minimize loss of power generation occurring due to lowered reservoir water level. Therefore, in this study, the water level at EL 207 m is selected as the restricted water level during intake construction.

As the rainy season usually begins in the middle of June and reservoir water level starts rising at that time, the reservoir water level has to be lowered to EL. 207 m by the beginning of March in order to maintain a 3.5-month water level restriction period. Furthermore, the reservoir draw-down operation has to be commenced from December in the preceding year so that water release can be done only by power generation without wasting water through spillway. This requires compulsory lowering of the reservoir water level by several meters in any of the months from December to March. Consequently, this will result in the reduction of energy production due to the reduced water head for power generation. However, it is noted that the water level restriction is only in one year.

In order to estimate the amount of reduced energy production, the power generation simulation for 36 years was carried out by applying the condition that the reservoir water level has gone down to EL. 207 m gradually by the end of February of the design year and subsequently kept at or below EL. 207 m until mid-June. The graphical representation of the monthly water level variations simulated is shown in Figure 9.2.2 below.



Prepared by the JICA Survey Team

Figure 9.2.2 Reservoir WL Variation with WL Restriction (EL. 207 m in Mach-June)

Based on the simulation model, it was revealed that reduction of energy production due to the restriction of reservoir water level is 34 GWh per annum at a 50% probability. This reduction of energy results in the decrease of NN1's power selling. The decreased power selling income is calculated at US$ 2.1 million by applying the current tariff of 0.0621 US$/kWh.

However, the restriction of the reservoir water level during intake construction largely contributes to lower the construction cost of the temporary enclosure. In case that the water level is restricted to be lower than EL. 207 m, reduction of the temporary enclosure construction cost is estimated at US$ 4.9 million. As seen in the following Table 9.2.5, the reduced amount of construction cost is higher than the reduced income of power selling. Therefore, the plan to restrict the reservoir water level below EL. 207 m for 3.5 months from the beginning of March to middle of June is adopted for construction.

Table 9.2.5 Estimation of Decreased Benefit and Cost

	Estimated amount
Decreased energy output	34 GWh
Decreased energy benefit	2.1 x 10^6 US$
Deceased cost of enclosure	4.9 x 10^6 US$
Balance (net reduction)	2.8 x 10^6 US$

Prepared by the JICA Survey Team

By restricting the reservoir water level during intake construction, safety in the structural stability of the intake dam increases due to the reduction of water pressure including uplift pressure acting on temporary enclosure structure. Through the reduction of uplift pressure, the support structure of the temporary enclosure can be simplified by using a steel girder type instead of the pedestal concrete type. Therefore, the steel girder type support is finally adopted due to its simplicity and easier construction methods.

9.2.4 DAM STABILITY

Dam stability and stress in the foundation rock are checked by applying Case 2 of temporary enclosure (steel girder type support). Dam block No. 20 is the section to be studied. Note that the self-weight, hydrostatic pressure, hydrodynamic pressure, silt pressure, inertia force of the dam due to seismic action and uplift pressure are considered as the acting loads. Change in load conditions due to a piercing dam or temporary enclosure is considered. Principal features of the temporary enclosure are shown in Table 9.2.4 and principal features of piercing dam are shown in Table 9.2.2. The dam sections used for stability analysis are shown in Figure 9.2.3.

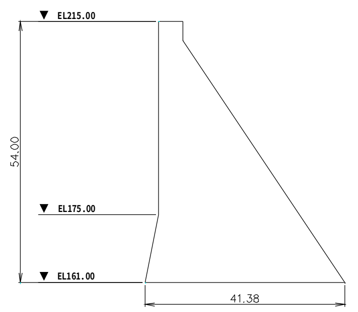
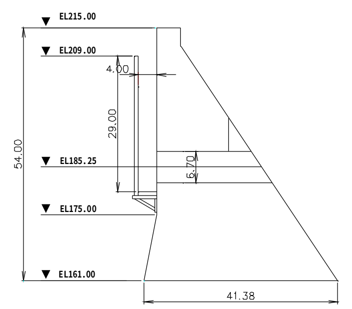
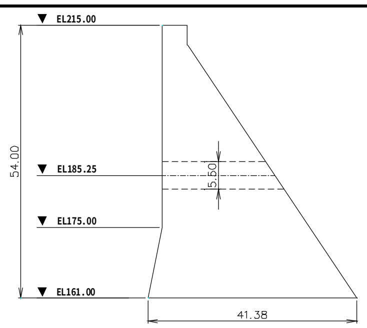
Stage A Current Condition	Stage B During Construction	Stage C After Completion
		

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Figure 9.2.3 States of Dam to be Analyzed on Stability (Block No. 20)

The loading status includes current condition, during-construction and after-completion. Loading cases to be studied are three cases such as usual, unusual (Flood, Earthquake k=0.061) and extreme (Earthquake k=0.215). Properties of materials are based on data shown in the final report on Nam Ngum Dam (1972).

Based on the discussions above, the overturning, sliding and the stress in the foundation rock are checked and validated by the Lao Electric Power Technical Standards. In the check and validation of the extreme case, the Manual of US Army Corps of Engineer is referred to and consulted.

The safety judgment criteria applied for the dam stability (overturning, sliding and foundation stress) are already described in the paragraph (6) of the foregoing Section 8.3.2. Detailed calculations of the stability analysis of dam block No. 20 (case 2) are shown in Appendix F together with figures of loading patterns. The calculation result is shown in the following Table 9.2.6.

The analysis confirmed that the dam block of the unit 6 intake is sufficiently stable. It is however noted that the reservoir water level lower than EL. 207 m is desirable in order to assure dam stability during dewatering inside the steel girder type temporary enclosure.

Table 9.2.6 Result of Dam Stability Analysis (No. 20 Block, Case 2)

Load condition		Criteria		No.20 Block_Case2 Evaluation								
				Current Condition			During Construction (Upper Limit of Water Level EL.207m)			After Completion		
Usual		Overturning	e ≤ B/6	|e| = 5.58	≤	B/6 = 6.9	|e| = 3.94	≤	B/6 = 6.90	|e| = 6.12	≤	B/6 = 6.90
						OK			OK			OK
		Sliding	n ≥ 3	n = 6.96	>	3	n = 8.67	>	3	n = 6.92	>	3
						OK			OK			OK
		Max. Stress in foundation	σ ≤ 400	σ = 90.79	≤	400	σ = 71.13	≤	400	σ = 90.67	≤	400
			tf/m2			OK			OK			OK
Unusual	Flood	Overturning	e ≤ B/4	|e| = 7.88	≤	B/4 = 10.35				|e| = 8.62	≤	B/4 = 10.35
						OK						OK
		Sliding	n ≥ 2	n = 6.79	>	2				n = 6.75	>	2
						OK						OK
		Max. Stress in foundation	σ ≤ 400	σ = 94.43	≤	400				σ = 94.34	≤	400
			tf/m2			OK						OK
	Earthquake (k=0.061) OBE	Overturning	e ≤ B/4	|e| = 8	≤	B/4 = 10.35	|e| = 6.26	≤	B/4 = 10.35	|e| = 8.59	≤	B/4 = 10.35
						OK			OK			OK
		Sliding	n ≥ 2	n = 5.86	>	2	n = 7.15	>	2	n = 5.85	>	2
						OK			OK			OK
		Max. Stress in foundation	σ ≤ 400	σ = 109.1	≤	400	σ = 86.36	≤	400	σ = 109.53	≤	400
			tf/m2			OK			OK			OK
Extreme	Earthquake (k=0.215) MCE	Overturning	e ≤ B/2	|e| = 14.13	≤	B/2 = 20.69				|e| = 15.15	≤	B/2 = 20.69
						OK						OK
		Sliding	n ≥ 1.3	n = 4.2	>	1.3				n = 4.16	>	1.3
						OK						OK
		Max. Stress in foundation	σ ≤ 532	σ = 211.04	≤	532				σ = 239.35	≤	532
			tf/m2			OK						OK

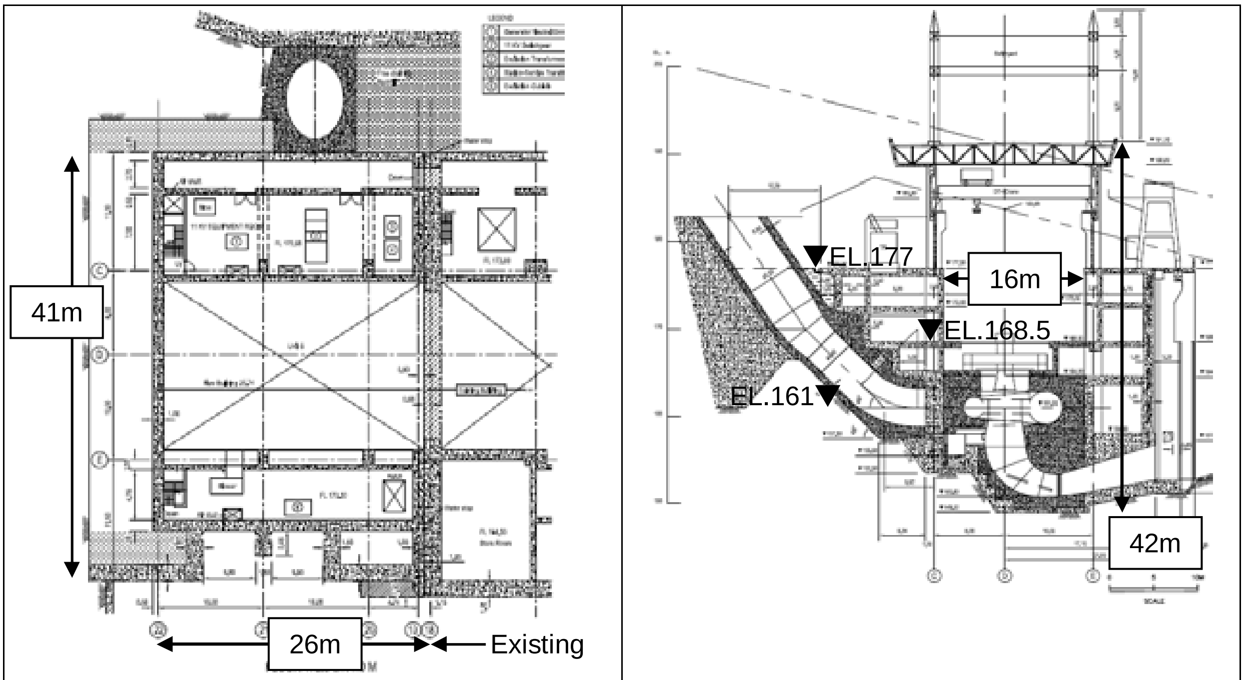
Prepared by the JICA Survey Team

9.3 POWERHOUSE AND TAILRACE

9.3.1 POWERHOUSE LAYOUT

Based on the optimum expansion plan in Chapter 8, the basic design of the powerhouse was conducted through a more detailed examination of the existing powerhouse structures, current topography and necessary equipment to be installed.

Typical plan and section of the powerhouse are shown below.



Floor Plan (EL. 172.5 & 173.0 m) | Cross Section (Unit Center)

Prepared by the JICA Survey Team

Figure 9.3.1 Plan and Section of Powerhouse

Detailed drawings of the powerhouse such as floor plans, cross sections and longitudinal sections are presented in Appendix G.

The major equipment to be installed in the powerhouse, which had been considered in the basic design, are summarized in the following table.

Table 9.3.1 Major Equipment to be Installed in Powerhouse

Floor Elevation (EL.m)	No.	Equipment to be Installed
172.5 & 173.0	1	Generator Neutral Grounding Transformer
	2	11 kV Switchgear
	3	Excitation Transformer
	4	Station-Service Transformer
168.5	1	Excitation Cubicle
	2	Low Voltage Switchgear
	3	AC/DC Distribution Panel
	4	Local Control and Relay Board
	5	Clean Water Tank
164.5	1	Unit Motor Control Center
	2	Common Motor Control Center
	3	Governor and Turbine Control Panel
	4	Governor Oil Sump Tank with Pressure Oil Pumps
	5	Pressure Oil Tank
	6	Air Compressor
	7	Primary Air Tank
	8	Brake Air Tank
158.0	1	Raw Water Tank
	2	Raw Water Strainer
	3	Water-to-Water Heat Exchanger
	4	Cooling Water Circulation Pump

Prepared by the JICA Survey Team

9.3.2 POWERHOUSE STABILITY

Stability of the powerhouse building was checked and validated as follows:

(1) Sections

i) Center of turbine/generator section in up-downstream direction (A-A section of Basic Design Drawings)

ii) Right bank section in up-downstream direction (B-B section of Basic Design Drawings)

(2) Cases

Table 9.3.2 Analysis Cases for Powerhouse Stability

Cases		Upstream WL (EL.m)	Downstream WL*) (EL.m)	Seismic Coeff. (Horizontal)
1. Normal	Usual	168.5	168.5	-
2. Earthquake	Unusual	168.5	168.5	0.061
3. Flood		177.0	177.0	-
4. Empty at up/downstream		-	-	-
5. Normal WL at upstream, Empty at downstream	Extreme	168.5	-	-

*) WL in all units full operation: 168.4 EL.m, Flood WL176.5 EL.m

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(3) Loads

Dead load, Inertia force (for earthquake), Hydrostatic pressure, Dynamic water pressure (for earthquake), Uplift

(4) Checking Standard

Following dam stability

(5) Results

Table 9.3.3 Analysis Results for Powerhouse Stability

Cases			Overturning (Eccentricity, m)	Sliding (Safety factor)	Max. Stress in Foundation (tf/m^2)
i) A-A Section	1. Normal	Usual	e=0.1 < B/6=6.0	-	q=10.6 < 400.0
	2. Earthquake	Unusual	e=1.5 < B/4=9.0	f=129.6 > 2.0	q=13.0 < 400.0
	3. Flood		e=2.4 < B/4=9.0	-	q=3.0 < 400.0
	4. Empty at up/downstream		e=2.7 < B/4=9.0	-	q=34.4 < 400.0
	5. Normal WL at upstream, Empty at downstream	Extreme	e=5.3 < B/2=18.0	f=29.3 > 1.3	q=34.5 < 532.0
ii) B-B Section	1. Normal	Usual	e=2.3 < B/6=6.8	-	q=16.3 < 400.0
	2. Earthquake	Unusual	e=3.3 < B/4=10.2	f=99.0 > 2.0	q=18.1 < 400.0
	3. Flood		e=9.3 < B/4=10.2	-	q=8.5 < 400.0
	4. Empty at up/downstream		e=2.0 < B/4=10.2	-	q=33.7 < 400.0
	5. Normal WL at upstream, Empty at downstream	Extreme	e=4.6 < B/2=20.4	f=62.9 > 1.3	q=32.6 < 532.0

Prepared by the JICA Survey Team

Based on the above results, it is concluded that there is no structural problem for the stability of the powerhouse building.

Total weight of the powerhouse building and its total uplift pressure in case of a flood are about 30,000 tf and 20,000 tf, respectively. Consequently, it is found that the powerhouse building is stable against uplift pressures because the total weight is 1.5 times of the total uplift pressure in case of flood.

9.3.3 TAILRACE LAYOUT

In addition to the powerhouse, basic design of the tailrace was undertaken referring to the topographic survey results around the powerhouse, which were obtained through sub-letting works. Main features of the tailrace channel are summarized below.

Table 9.3.4 Main Features of Tailrace Channel

Item	Features	
Type	Open channel	
Length	52m	
Width	from 11.5m to 20.5m	
Longitudinal Gradient	1:3 and 1:4	
Approach Elevation	Inlet	EL. 152.74m
	Outlet	EL. 164.00m
Cut Slope	Gradient	1:0.25
	Protection	Concrete facing with anchor bars

Prepared by JICA Survey Team

Detailed drawings of the tailrace channel are attached as Appendix G.

9.4 ELECTRO-MECHANICAL EQUIPMENT

9.4.1 TURBINES

(1) Turbine Operational Water Levels

a) Reservoir water levels

The average weighted water level of the NN1 Reservoir is EL. 206.0 m at present. However, after completion of the NN2 Power Station, which is now under construction, it is expected that the inflow into the NN1 Reservoir will be regulated by the NN2 Power Station. The average weighted water level will then increase up to EL. 209.6 m, as described in Section 9.1.1. The other water levels of the NN1 Reservoir will be unchanged from the present design conditions.

Turbine unit 6 will therefore be operated under the following water levels:

- Flood water level	EL. 215.0 m
- Normal high water level	EL. 212.0 m
- Weighted average water level	EL. 209.6 m
- Low water level	EL. 196.0 m

b) Tailrace water levels

When the existing five units of turbines are all operated with the rated outputs, the total turbine discharge will be 462.1 m^3/s. On the other hand, the rated discharge of the turbine unit 6 is 111.2 m^3/s. Accordingly, the total turbine discharge for six units of turbines including unit 6 will reach to 573.3 m^3/s. On the basis of these conditions, the tailrace water levels are reviewed and revised as follows:

- Flood water level	EL. 176.5 m
- Water level at 6-unit operation with rated output	EL. 168.4 m
- Water level at 1-unit operation with rated output	EL. 166.1 m
- Water level at all-unit stopping	EL. 164.0 m

(2) Net Heads

Referring to the results of the study on the rated net head described in Section 9.1.1, the rated net head of turbine unit 6 is determined at 40. 0 m, which is 3.0 m higher than the rated net head of 37.0 m for the existing units 3, 4 and 5. On the other hand, the maximum net head, which is defined as a net head at one-unit operation with the rated output under the reservoir high water level, is determined at 45.5 m, which is the same rated head value as the existing turbines for units 3, 4 and 5. As a result, the turbine unit 6 will be operated in the following range of heads:

- Maximum gross head	48.0 m
- Maximum net head (at one-unit operation with rated net head)	45.5 m
- Rated net head	40.0 m
- Minimum net head	26.4 m

(3) Turbine Output

The turbine rated output and maximum output for unit 6 were determined as follows:

a) Turbine rated output

The turbine rated output is defined as a full-gate output under the rated net head and is determined at 40.9 MW, which corresponds to the generator rated output of 40 MW, on assumption that the generator efficiency is 98.0 %.

b) Turbine maximum output

When the operating net head is higher than the rated net head due to the raising of the reservoir water level, the turbine output can be increased unless the generator is overloaded by exceeding the rated output in MVA. Such upper limit of the turbine output is defined as the turbine maximum output. On the other hand, each generator of the existing units 3, 4, 5 is rated for 50 MVA (40 MW at the rated power factor 0.8) but its output is often increased to 46 MW with an operating power factor of 0.92 when the reservoir water level is sufficiently high during the rainy season. Considering the actual operating performance of the existing units 3, 4, and 5, the maximum turbine output for unit 6 is determined at 47 MW (= 46/0.98) so that it can produce 46 MW at the generator terminal when conditions permit.

(4) Type of Turbine

The turbine is of vertical-shaft Francis type, which is the same as the existing turbines for all units.

(5) Turbine Rated Speed

The turbine rated speed is selected referring to the specific speed as follows:

a) Specific speed

Specific speed of turbine is calculated by the following equation:

$Ns = N \times \sqrt{Pt} / Hn^{1.25}$

where,
- Ns: Specific speed (m-kW)
- N: Turbine rated speed (rpm)
- Pt: Turbine output (kW)
- Hn: Net head (m)

b) Upper limit of specific speed for Francis turbine

Statistical implication between net head and specific speed for Francis turbine is introduced in JEC 4001 for hydraulic turbines and pump turbines. Referring to these statistical data, specific speed for a net head of 40 m is calculated as 368.6 m-kW. However, in case the specific speed exceeds 300 m-kW, the operating performance of Francis turbine will become remarkably worse. Therefore, in the selection of the turbine rated speed, the specific speed for Francis turbine should be practically limited to 300 m-kW.

c) Turbine rotational speed

Turbine rotation speed is calculated from the rated frequency and number of poles for generator by the following equation:

$N = 120 \times f/p$

Where,
- N: Turbine rotational speed (rpm)
- f: Generator rated frequency (Hz) = 50 Hz
- p: Number of poles of generator

Turbine rotational speeds corresponding to specific speed of 300 m-kW are 136.4 rpm (p = 44 poles), 142.9 rpm (p = 42 poles) and 150 rpm (p = 40 poles), and a comparison of these speeds is shown below.

Table 9.4.1 Selection of Turbine Speed for Unit 6

Turbine Output Pt (kW)	Net Head Hn (m)	Number of Poles; p	Speed N (rpm)	Specific Speed; Ns (m-kW)	Ns Upper Limit (m-kW)	Judgment
40,900	40.0	44	136.4	274.2	300	○
		42	142.9	287.3		◎
		40	150.0	301.6		×

Prepared by JICA Survey Team

d) Turbine rated speed

The higher turbine speed will make the machine size smaller, and this will increase economy. Therefore, the turbine rated speed is chosen at 142.9 rpm, which is the highest speed within the upper limit of specific speed (300 m-kW).

(6) Turbine Centerline Elevation

The turbine centerline elevation is based on the tailrace water level when one (1) unit of turbine is operated at the rated output, and it is calculated by the following equation:

Turbine Centerline Elevation = $TWL_1 + H_s$ [EL. m]

where, TWL_1: Tailrace water level at turbine one-unit operation with rated output = 164.0 m

H_s: Static suction head referred to the turbine centerline elevation = $H_a - H_v - \sigma_p \times H_d$

H_a: Atmospheric pressure at TWL_1: 164.0 m = 10.12 m

H_v: Vapor pressure = 0.32 m

H_d: Design head of turbine = 40.0 m

σ_p: Cavitation coefficient = 0.2682

The required suction head H_s is calculated at -1.0 m and therefore it is required that the turbine centerline elevation should be set at EL. 163.0 m or lower. On the other hand, the turbine centerline elevation of the existing Unit 3, 4, 5 is EL. 161.0 m. Based on the result of the above calculation, the turbine centerline for unit 6 can be set at a different elevation from those for units 3, 4, and 5. Taking the following matters into consideration, however, the turbine centerline for unit 6 is set at the same elevation with units 3, 4, and 5, which is EL. 161.0 m.

1) Since the existing erection bay has no sufficient space to assemble the turbine and generator for unit 6, a space between units 5 and 6 should be arranged as the equipment assembly area.

2) In order to use the space between units 5 and 6 widely as an assembly bay, the generator top cover for unit 6 should be set at EL. 168.5 m, which is the floor elevation of the machine bay for unit 5, so that no step should be provided between the two units.

3) The principal dimensions of the turbine and generator for unit 6 are almost the same with those for units 3, 4, and 5. If the generator top cover for unit 6 is set at EL. 168.5 m in a similar way to units 3, 4, and 5, the turbine centerline elevation for unit 6 will consequently become EL. 161.0 m.

(7) Comparison with Existing Turbines for Unit 3, 4, 5

The operating conditions and turbine ratings are compared between unit 6 and the existing units 3 to 5. The results of the comparison are summarized as follows:

Table 9.4.2 Comparison of Turbine Operating Conditions and Ratings

Items		Unit 6	Unit 3, 4, 5	Reference
1.	Reservoir Water Level			
(a)	Flood water level	EL. 215.0 m	EL. 215.0 m	
(b)	Full supply water level	EL. 212.0 m	EL. 212.0 m	
(c)	Weighted average water level	EL. 209.6 m	EL. 206.0 m	Item 1) (a)
(d)	Low water level	EL. 196.0 m	EL. 196.0 m	
2.	Tailrace Water Level			
(a)	Flood water level	EL. 176.5 m	EL. 176.5 m	
(b)	When all units operating with rated output	EL. 168.4 m	EL. 168.0 m	Item 1) (b)
(c)	When one unit operating with rated output	EL. 166.1 m	EL. 166.2 m	Item 1) (b)
(d)	When all units being stopped (no flow)	EL. 164.0 m	EL. 164.0 m	
3.	Heads			
(a)	Maximum gross head	48.0 m	48.0 m	
(b)	Maximum net head at one unit operating	45.5 m	45.5 m	Item 2)
(c)	Rated net head	40.0 m	37.0 m	Item 2)

(d)	Minimum net head	26.4 m		Item 2)
4.	Type of Turbine	Francis turbine	Francis turbine	Item 4)
5.	Turbine Ratings			
(a)	Rated output	40,900 kW	40,000 kW	Item 3) a)
(b)	Maximum output	47,000 kW	53,000 kW	Item 3) b)
(c)	Rated speed	142.9 rpm	136.4 rpm	Item 5)
(d)	Specific speed	287.3 m-kW	298.9 m-kW	
6.	Turbine Centerline Elevation	EL. 161.0 m	EL. 161.0 m	Item 6)

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(8) Turbine Parts

a) Materials

The turbine main parts will employ the materials having high resistance against erosion and corrosion in order to achieve long-term sustainable operation with minimum maintenance work. In particular, the following parts, which are prone to damage due to cavitation pitting, will use stainless steel with high strength, cavitation resistance and weldability.

- Runner
- Guide vanes
- Upper draft tube liner

b) Bearings

In order to prevent water pollution due to grease and other pollutants, and in order to assure of easy maintenance work, it is desired that the bearings for the guide vanes will be grease-less and self-lubricating types. In addition, these kinds of bearings will also be adopted to all regulating mechanisms and other bearings that will be in constant contact with water.

(9) Inlet Valve

An inlet valve is omitted from unit 6, along the same lines of turbine design for the existing units.

(10) Main Water Supply System

Because of the structure problem for the additional powerhouse, the main water supply system for unit 6 will be provided separately from that for the existing units. The main water supply system designed to provide the cooling water to the turbine guide bearing, generator thrust and guide bearings, generator air coolers, etc for unit 6 is based on a closed-circuit water circulation system with water-to-water heat exchangers, similar to the existing water supply system.

The main water supply system for unit 6 consists of three sub-systems: for open-circuit raw water supply, water-to-water heat exchangers, and closed-circuit cooling water circulation. These sub-systems are all duplicated for normal/standby duty operation. The schematic diagram for the main water supply system is shown in Drawing No. E-012 of Appendix G.

a) Open-circuit raw water supply system

The mode of operation will be that the raw water for the cooling water system will be taken from the draft tube and then return it to the same tube through a water-to-water heat exchanger. The open-circuit raw water supply system will consist of two AC motor-driven raw water pumps, two automatic strainers, and water piping complete with all necessary pipes and valves.

b) Water-to-water heat exchangers

Each water-to-water heat exchanger will be of the plate-type with high heat-transfer efficiency and compact design.

c) Closed circuit cooling water circulation system

The closed-circuit cooling water circulation system is provided to distribute the cooled water among the water-to-water heat exchanger and the respective coolers of the turbine and generator. The closed-circuit cooling water system will consist of two AC motor-driven cooling water pumps, one clean water tank for replenishing leakage water, water flow meters, and water piping complete with all necessary pipes and valves. Clean water will be supplied from the existing clean water supply system by extending the clean water pipe.

(11) Water Drainage and Dewatering System

Because of the structure problem of the additional powerhouse, the water drainage and dewatering system for unit 6 is provided separately from those for the existing units. For this purpose, a new station sump pit is added for exclusive use of unit 6. The sump pit will collect the water discharged and leaked from the turbine and generator as well as seepage water from the powerhouse wall.

The water drainage system will consist of two AC motor-driven drainage pumps, two water level switches and water piping complete with all necessary pipes and valves to discharge the water in the station sump pit to the tailrace. The dewatering system will consists of two AC motor-driven dewatering pumps and water piping complete with all necessary pipes and valves to evacuate the water in the draft tube directly to the tailrace. Two pumps for each system will be arranged for normal/standby duty operation. The schematic diagram for the water drainage and dewatering system is also shown in Drawing No. E-012 of Appendix G.

Types and ratings of the water drainage and dewatering pumps are determined referring to the existing pumps as shown below.

Table 9.4.3 Types and Ratings of Drainage and Dewatering Pumps

Items		Unit 6	Unit 3, 4, 5
1.	Water Drainage Pumps		
(a)	Type of drainage pump	Submersible	Submersible
(b)	Displacement volume of each pump	1.0 m^3/min	0.9 m^3/min
(c)	Pumping head	30 m	30 m
2.	Draft Tube Dewatering Pumps		
(a)	Type of dewatering pump	Vertical-shaft	Vertical-shaft
(b)	Displacement volume of each pump	5.0 m^3/min	4.2 m^3/s
(c)	Pumping head	30 m	30 m

Prepared by the JICA Survey Team

9.4.2 GENERATOR

(1) Generator Rated Power Factor

The rated power factor of the existing generators for units 3, 4, and 5 is selected to be 0.8. On the other hand, in many hydropower projects in Lao PDR, which are recently developed or are now under construction, the rated power factor is commonly selected to be 0.9 as shown in the table below.

Table 9.4.4 Generator Rated Power Factors for Other Hydropower Stations in Lao PDR

Hydropower Station	Generator Output	Rated Power Factor
Nam Leuk	34.5 MVA	0.90
Nam Man 3	22.5 MVA	0.90
Nam Lik 1/2	58.8 MVA	0.85
Nam Lik 1	35.5 MVA	0.90
Nam Ngum 5	70.6 MVA	0.85

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Based on these available data, a comparison of the rated power factor for unit 6 is made between 0.8 and 0.9 as shown below.

Table 9.4.5 Comparison of Generator Rated Power Factor between 0.8 and 0.9

Rated Power Factor	0.8	0.9
Turbine Rated Output	40,900 kW	40,900 kW
Turbine Max. Output	45,900 kW	40,900 kW
Unit Rated Output	40,000 kW	40,000 kW
Unit Max. Output (under power factor of 0.9)	45,000 kW	40,000 kW
Generator Rated Output	50,000 kVA	44,400 kVA
Transformer Rated Power	50,000 kVA	50,000 kVA
Cost (C)	+622,367 USD	0 USD
Annual Energy Production	+2 GWh	0 GWh
Benefit from energy production for 50 years (B)	+1,189,776 USD	0 USD
(B) - (C)	+567,409 USD	0 USD
Turbine Design Conditions (a) Turbine rated net head = 40.0 m (b) Turbine rated speed = 142.9 rpm (c) Turbine specific speed = 287.3 m-kW		
Present Worth Factor Calculating Conditions (a) Lifetime of Unit 6 = 50 years (b) Discount rate = 10 %/annum		

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As a result of this comparative study in Table 9.4.5, the power factor of 0.8 will bring greater benefit and more advantageous than the power factor of 0.9. Accordingly, the generator rated power factor for unit 6 is determined at 0.8.

(2) Generator Rated Output

Based on the turbine rated output 40.9 MW, generator rated power factor 0.8 and the generator efficiency 0.98 (assumed value), the generator rated output is calculated at 50 MVA as shown below:

Generator rated output = (Turbine rated output) x (Generator efficiency) / (Generator rated power factor)
= 40.9 x 0.98 / 0.8
= 50.0 MVA

(3) Type of Generator

The generator for unit 6 is of three-phase, vertical-shaft, synchronous alternator with umbrella type construction, which is the same as the existing generators for units 3, 4, and 5.

(4) Generator Rated Voltage

The generator rated voltage is selected at 11 kV along the same lines of the existing generators for units 3, 4 and 5.

(5) Generator Neutral Grounding System

The neutral point of the generator stator winding will be grounded through a neutral grounding transformer with a secondary resistor, along the same lines of the existing generators for units 3, 4, and 5.

(6) Generator Fire Fighting System

The generator will be provided with water spray-type fire fighting system along the same lines of the existing generators for all units. The water for the generator fire fighting system will be supplied from the existing clean water tank by extension of the water pipe.

(7) Synchronizing Method of Generator

The generator synchronizing will be made by the 115 kV circuit breaker on the main transformer circuit, along the same lines of the existing generators for units 3, 4, and 5.

(8) Generator Main Bus

The segregated phase bus duct will be used as the generator main bus for connection between the generator and the main transformer. This is because the segregated phase bus duct is superior in quality and will guarantee the safety of the system. The ratings of the segregated phase bus duct will be rated for 12 kV, 3,000 A, 40 kA.

9.4.3 MAIN TRANSFORMER

(1) Type and Cooling Method

The main transformer is of single-phase, oil-immersed, two-winding, outdoor installation type intended to be connected directly to the generator in such a way that it may be subjected to load rejection conditions. Single-phase transformer is selected along the same lines of the existing main transformers for units 3, 4 and 5. The cooling method is selected at natural oil circulation forced air cooling (ONAF) along the same lines of the existing main transformers for units 3, 4 and 5. The new main transformer for unit 6 should be designed to have the same construction and dimensions with the existing main transformers for units 3, 4 and 5, so that the new transformer should be interchangeable with the existing spare single-phase transformer.

(2) Main Transformer Rated Power

The rated power of the main transformer should be 16,666 kVA/phase (50,000 kVA for three-phase), which is the same value of the existing single-phase transformer for units 3, 4 and 5.

(3) Main Transformer Fire Fighting System

The main transformer will be provided with water spray type fire fighting system for each single-phase transformer, along the same lines of the existing main transformers for the other units. The water for the main transformer fire fighting system will be supplied from the existing clean water tank by extending the existing distribution water pipe.

9.4.4 115 kV Outdoor Switchyard Equipment

(1) 115 kV Bus Arrangement

The existing outdoor switchyard is of conventional, outdoor open type bus-and-switch arrangement for 115 kV switchgear and is located on the roof of the powerhouse. The 115 kV bus is arranged for “main and transfer bus scheme” in which a transfer bus is added to the single-bus scheme.

(2) Additional 115 kV Switchgear for Unit 6

The existing 115 kV outdoor switchyard will be expanded by about 25 m, as shown in Drawing Nos. E-021 and E-022 in Appendix G, for additional installation of the following 115 kV switchgear for unit 6:

1) One circuit breaker rated for 123 kV, 1250 A, 31.5 kA
2) Three disconnectors rated for 123 kV, 1250 A, 31.5 kA (for 3 s)
3) Three single-phase current transformers rated for 123 kV, 300/5 A, 31.5 kA (for 3 s)
4) Three (3) single-phase capacitor voltage transformer for 123 kV, 115/√3//0.11/√3 kV
5) Three (3) single-phase surge arresters

The single-line diagram for the additional 115 kV switchgear for unit 6 is shown in Drawing No. E-002 in Appendix G.

(3) Additional Installation of 115 kV Disconnector for Main Bus Sectionalizing Purpose

In order to permit flexible and convenient operation of the 115 kV main bus to minimize the period of power interruption due to unexpected fault and maintenance work, one 115 kV disconnector will be added to the 115 kV main bus for the purpose of sectionalizing the main bus, as shown in Drawing Nos. E-001 and E-021 in Appendix G. This 115 kV sectionalizing disconnector will be installed on the existing beam structure between unit 3 and unit 4 (between 115 kV transmission lines TL2 and TL3).

(4) Replacement of 115 kV Main Bus Conductor

The existing conductor for the 115 kV main bus is a HDCC (hard-drawn copper conductor) 325 mm^2 and its continuous current carrying capacity is just 875 A at its permissible operating temperature of 90 °C. On the other hand, the maximum continuous current in the 115 kV main bus will reach to 1,305 A after completion of unit 6. Therefore, the conductors for the 115 kV main bus will be replaced by HDCC 725 mm^2 for the following reasons:

1) HDCC is also used for the other conductors connected to the 115 kV main bus and such other conductors will remain unchanged even after the 115 kV main bus conductors are replaced by new ones. In order to avoid any problem on mis-coordination with different kinds of conductors, it is preferable that the new main bus conductor should be of the same kind as the existing conductors (HDCC).

2) All the clamps and connectors on the existing 115 kV main bus will also be replaced by new ones together with the 115 kV main bus conductors. In order to prevent electrolytic corrosion with different kind of conductor, it is preferable that the new main bus conductor should be of the same kind as the existing conductor (HDCC).

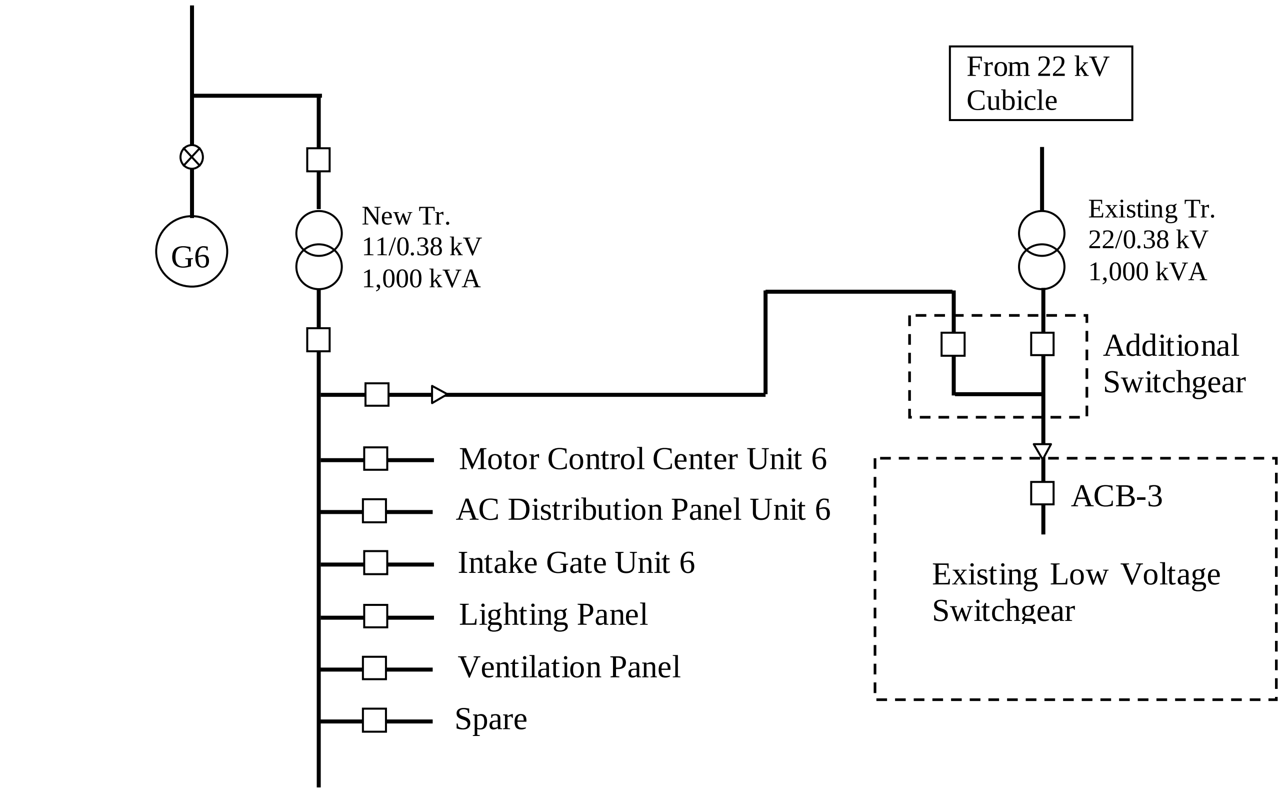
3) In case of HDCC, the minimum required size is 725 mm^2 for the current carrying capacity of 1,305 A.

The scope for the replacement of the 115 kV conductors includes the existing main bus conductors in the area of units 3, 4, and 5. These are shown in Drawing No. E-001 in Appendix G.

9.4.5 STATION-SERVICE POWER SUPPLY SYSTEM

There are two existing station-service transformers; one is 11/0.38 kV transformer and the other is 22/0.38 kV transformer. Each of the two existing station-service transformers is rated for 1,000 kVA and has sufficient extra capacity to serve for the additional equipment/facilities for unit 6. However, the 22/0.38 kV station-service transformer is connected to the 22 kV circuits, which are served for power supply to the local consumers. When the 22 kV circuit is used as a power source for the station-service transformer, station-service power supply is liable to become unstable especially in rainy season. Judging from this situation, the 22/0.38 kV station-service transformer will not be reliable as a power source for station-service power supply.

On the other hand, the existing low voltage cubicle has no spare circuit breakers and its modification to add another circuit breaker will also be difficult from the complexity of the circuits. Therefore, the existing low voltage cubicle will not be available to supply power to the additional equipment/ facilities for unit 6. As a possible solution for this problem, it is suggested that one (1) 11/0.38 kV station-service transformer should be added as a part of Unit 6 and should be arranged to change over the station-service power supply from the existing 22/0.38 kV transformer to the additional 11/0.38 kV transformer or vice versa, as shown in Figure 9.4.1.



Prepared by JICA Survey Team

Figure 9.4.1 Station-Service Power Supply System for Unit 6

9.4.6 DC POWER SUPPLY EQUIPMENT

(1) Stationary Batteries

Each of two sets of the existing stationary batteries has sufficient extra capacity for DC power supply to the additional equipment/facilities for unit 6, and therefore, these will be available as needed. The existing stationary batteries were replaced by new ones in 2004, hence, there is a concern that the stationary batteries' life may expire before this expansion project's completion in 2015. It is therefore planned to replace the two sets of existing stationary batteries by new ones. The new stationary batteries will be designed for the same specifications with the existing ones as follows:

1) Type: Sealed construction, valve regulated type lead acid batteries
2) Capacity: 300 AH at 10-hour discharge rate
3) Number of cells: 53 cells/set

(2) Battery Chargers

Each of two existing battery chargers will have sufficient extra capacity for DC power supply to the additional equipment/facilities for unit 6, and thus, will be used as they are.

(3) DC Distribution Panel

The existing DC distribution panels have no sufficient number of spare circuit breakers for DC power distribution to the additional equipment/facilities. Therefore, one DC distribution panel will be provided in alignment with the new AC control source distribution panel, in the area adjacent to the additional unit.

9.4.7 CONTROL AND PROTECTION SYSTEM

(1) Local Control and Relay Board

One local control board, one relay board, and one automatic control board will be installed in the new cubicle room, which is located adjacent to the machine bay for unit 6, in the same manner as the existing system for units 3, 4 and 5. Concerning the electrical protective relays for the generator and main transformer, digital type relays will be used in accordance with current design practice. For the automatic control board, a programmable logic controller will be used in accordance with current design practice.

(2) Remote Control Board

One remote control board for unit 6 will be installed in the existing control room, in alignment with the existing control board for unit 5. The new remote control board will be of bench type to be well-coordinated with the existing panel design. The new remote control board will be linked with the programmable logic controller by way of an optical data way for high-speed data transfer.

9.4.8 REPLACEMENT OF 115 KV MAIN BUS CONDUCTORS IN THALAT SUBSTATION

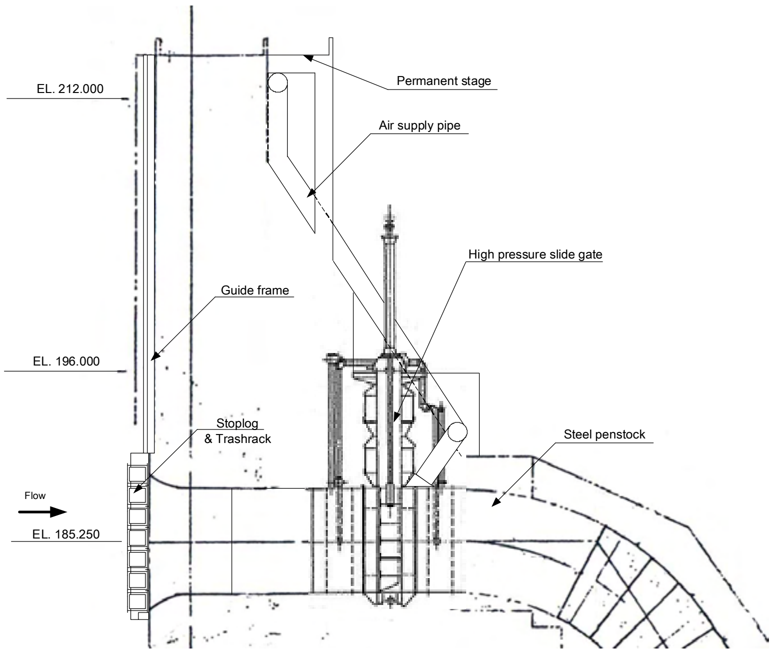
One of the concerns for the expansion project is that the maximum current in the 115 kV main bus of the Thalat Substation will exceed the current carrying capacity of the existing conductors after completion of the expansion project. Therefore, the existing conductors for the 115 kV main bus will be replaced by new ones, simultaneous with the replacement of the 115 kV main bus at the NN1 Power Station.

Referring to the preliminary calculation for the required conductor size, ACSR 330 mm^2 may be sufficient for the new conductors. However, ACSR 410 mm^2 is recommended to allow a margin of error.

9.5 MECHANICAL EQUIPMENT

9.5.1 ARRANGEMENT OF INTAKE FACILITIES

Through the study for selection of optimum expansion plan, the high pressure slide gate on the downstream of dam is selected as the optimum plan for the gate structure. The intake facilities arrangement of the selected plan is shown in Figure 9.5.1 below.



Prepared by the JICA Survey Team

Figure 9.5.1 Arrangement of Intake Facilities

The arrangement of facilities is summarized as below:

a) Movable trash racks are provided on the upstream surface of the intake bell mouth. The guide rails for trash racks are arranged so as to be commonly used for the trash racks and intake stoplogs.

b) When the stoplogs are operated, the trash racks must be removed because the stop log slot and guide rails are commonly used for trash racks.

c) The intake trash racks and stoplogs will be operated by the existing gantry crane. The rails and power supply cables for the gantry crane will be extended up to the new intake location for the expansion plan.

d) A bonnet type of slide gate is installed on the downstream face of the dam as the guard gate of the guide vane.

The basic design results of the respective intake facilities are described as follows:

9.5.2 INTAKE TRASHRACKS

(1) Principal dimension of trashracks

According to the intake dimension of civil structures, the principal dimensions of the trash racks are as follows:

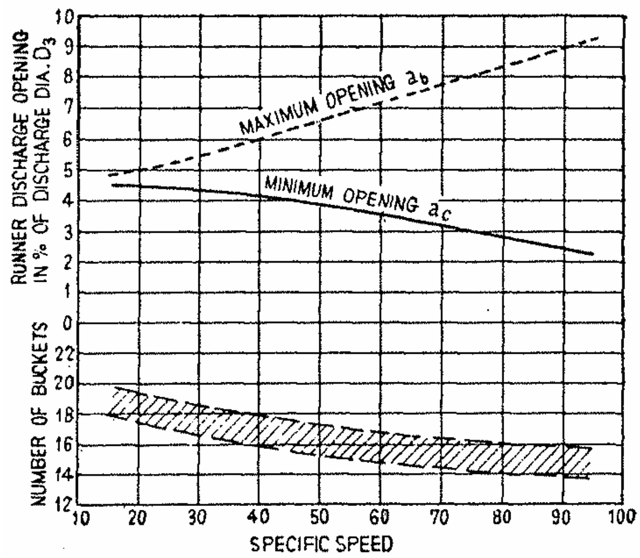
Clear span:	7,150mm
Clear height:	7,150mm
Number:	One span

(2) Design velocity at trashracks

The water flow velocity at trashracks shall be calculated from the circular area of diameter of the clear span, because the intake has a circular bell mouth shape. The average velocity passing through the trashracks is 2.94m/s at 118m^3/s discharge flow.

(3) Pitch and dimension of screen bar

In the case of the Francis turbine, the pitch of screen bars is generally decided so as to be less than the minimum opening of runner vanes. Although the detailed dimension of the runner is not yet defined in the basic design stage, the minimum opening of runner vane is decided based on Figure 9.5.2 below.



Source: Trashracks and Raking Equipment, Water Power, 1960, p9

Figure 9.5.2 Experience Data for Approximate Determination of Clear Openings in Francis Runners

As the specific speed (Ns) is indicated by the unit of ft-HP in Figure 9.5.2, the figures should be multiplied by 3.81 to convert into the unit of m-kW. The estimated Ns is nearly 300 m-kW but limited to be 300 m-kW at maximum in the basic design, 79 ft-HP is equivalent to 300 m-kW in Figure 9.5.2. From the Ns of 79 ft-HP, the minimum opening of the runner vanes will be 2.9% of the turbine discharge diameter. The estimated minimum opening is 130 mm from the expected turbine discharge diameter of 4600 mm. Although the screen bar pitch of existing trashracks is 75 mm, the bar pitch should be decided to be larger to strengthen the screen bars by increasing the bar thickness and preventing the head loss from increasing due to the screen. Considering the bar pitch of the existing trash racks, the bar pitch is decided to be 100 mm.

(4) Supporting span of intake trashracks

Supporting span of trash racks is the same as the stoplogs, because the guide frame and rails are commonly used for both.

(5) Material of screen bar and frame

When the operation of the generator and turbine is temporarily stopped due to its periodic or yearly maintenance and check ups, the removable trashracks will be raised on the dam crest and the appropriate maintenance cleanings and other repairs will be likewise done. It has to be noted that the old and damaged coatings can be retouched or repaired during this maintenance period. However, maintenance works on those accessories of the trashracks that were made of stainless steel will not be required.

As for the structural frames of the trash racks, and the screen panels which are fixed and welded together on the same frames, it is advisable to use rolled steels material for the trashracks which are more economical and easier to assemble. Corrosion allowance of 1 mm is considered for the screen bars and frames.

(6) Others

For raising and lowering the trashracks through the guide rails smoothly and safely, two guide rollers are provided on each side of the frames of trash racks.

9.5.3 INTAKE STOPLOGS

(1) Principal dimension of stoplogs

According to the dimensions of the intake structures, the principal dimensions of stoplogs are:

Clear span:	7,150 mm
Clear height:	7,150 mm
Number:	One span

As the existing gantry crane is commonly used for the expanded intake facilities, where one segment weight of stoplogs is to be less than six tons from the lifting capacity of gantry crane. From the limitation of weight, the height of one segment is decided to be 1,050 mm; accordingly, the total height of seven (7) segments is 7,350 mm, which is enough for covering the clear height of 7,150 mm.

(2) Supporting span of stoplogs and arrangement of sealing seat

Taking account of the location of installation for guide frames to transfer the water pressure load to the concrete structure, the supporting span of stoplogs is decided to be 7,450 mm against the clear span of 7,150mm. The sealing seat of side seal rubber will be provided within the distance of 150 mm between the edge of clear span and the center of the supporting point.

(3) Material and structure of stoplogs

Since the stoplogs are of the welded structure, rolled steels for welded structure are to be adopted as materials for the stoplogs, taking also into account the weldability of steel structure. Corrosion allowance is not considered for the stoplogs because these are kept in air. Painting is adopted for protection of steel, and zinc-chlorinated rubber paint will be applied taking its durability and better performance against ultraviolet rays. As a limiting guide, the maximum deflection of stoplogs is specified to be less than 1/600 in accordance with the technical standards of dam and weir facilities in

Japan. A by-pass valve is equipped with one segment installed on top of the seven segments for watering the penstock in order to attain pressure balance between the upstream and downstream of the stoplogs.

(4) Guide frame

The sealing seat plates of stainless steel are provided on four edges of a circular bell mouth. The guide frames located on both sides of the bell mouth are of the strength structures to support the water pressure load from the stoplogs, and the guide frames are encased in the concrete. As for the guide frame above the bell mouth location, guide rails up to the dam crest are fixed on the surface of dam with the use of mechanical anchors but without concrete encasement.

The exposed surface of guide frame located beside the bellmouth is of stainless steel material. Because the guide rails without concrete encasement are totally exposed in water, stainless steel is adopted as the material of guide rails taking account of difficulty of future maintenance in water.

(5) Storing of stoplogs

The stoplogs will be used during the yearly maintenance of generator and turbine. The existing stoplogs for Units 1 to 5 are stored on the respective stoplogs slots. For the expansion plan, the storage space is provided on the upstream surface of dam beside stoplogs slot. The lifting beam for stoplogs is also stored on the stoplogs.

9.5.4 INTAKE GANTRY CRANE

In the optimum expansion plan, the existing facilities are utilized as far as possible. The rails and power supply cables for the gantry crane are extended up to the new intake location for the expansion plan from the existing end point.

9.5.5 INTAKE GATE

(1) Design data of intake gate

From the study of the optimum expansion plan, the design data of intake gate are decided as below:

Type:	Bonnet type of circular slide gate
Quantity:	one set
Clear diameter:	5,500 mm
Design head:	30 m
Sealing system:	Downstream four edges rubber seal
Hoisting method:	Hydraulic cylinder

(2) Material and structure of intake gate

The intake gate is comprised of three main parts as mentioned below:

Gate leaf: The leaf is of frame structure operated by hoisting equipment. As the leaf is of the welded structure, rolled steels for welded structure are to be adopted for the material of the leaf taking account the weldability of steel structure. As for the bearing shoes sliding on the bearing plate on the casing, aluminum bronze is adopted to prevent the shoe from sticking with seat. Stainless steel materials are adopted for fixing plates and bolts for future maintenance.

Casing: The casing is located between the upstream and downstream steel penstocks, and constructed for sealing water and supporting the gate leaf. Although the casing is of the welded structure and rolled steels for welded structure are to be adopted for the material, the seat and bearing plates are of stainless steel.

Bonnet: The bonnet is the structure above the casing and the enclosure space for the gate leaf fully raised. The structure and material are the same as the casing. Stainless steel is used for the bearing plates. The top of the bonnet is closed with a cover equipped with the stuffing box to pass the cylinder rod of hoist. The bonnet cover is detachable for future removal of gate leaf for maintenance.

(3) Hoisting speed

The intake gate is kept at fully raised position and closed when the turbine is maintained. The intake gate is operated under balanced water pressure condition. In normal case, it is unnecessary to operate for a short time; accordingly, the hoisting speed is decided to be 150 mm/min, considering the operation time of approximately 30 minutes for stroke of 5,500 mm open or close.

In case of shut down operation for any problem with the guide vanes, the intake gate is required to be closed quickly, generally within around ten minutes. Accordingly, the hoisting speed of shut down is decided to be 550 mm/min.

(4) Arrangement of oil pressure unit

Hydraulic pressure unit is provided to operate the hydraulic cylinder and installed in the local control room for the intake gate. The local control room will be constructed on the same ground level as the power station, i.e., EL. 177.0 m, taking account of the accessibility for the operation and maintenance. The location of the local control room will be selected within the space between the existing steel penstock of unit 5 and the new penstock of the expansion plan. A local control panel is installed in the local control room and a remote control panel is installed in the control room of the power station.

(5) Others

For the inspection and maintenance of the gate leaf, a manhole is provided downstream of the gate.

By-pass pipes and valves are provided to connect between the upstream and downstream of the casing to achieve pressure balance, with water filling the steel penstock located downstream of gate, when the gate is operated. The by-pass valves are operated with the motorized actuator and controlled from the local or remote control panel.

An air pipe of 1,200 mm inside diameter is provided on the top and downstream side of the casing for air supply during the shut down operation. The air pipe is installed on the downstream surface of the dam up to the dam crest.

9.5.6 STEEL PENSTOCK

The minimum shell plate thickness of the steel penstock is decided in accordance to the technical standards for gates and penstocks in Japan. To calculate the plate thickness, the following formula is applied.

$$t = \frac{D + 800}{400}$$

where, t: Minimum plate thickness (mm)

D: Internal diameter (5,500mm)

From the above, the minimum plate thickness is found to be 16 mm. For the 16mm shell plate thickness, the allowable water head is 68 m. Since the design head of expansion plan is 65 m, with the design static head and water hammer, the minimum plate thickness of 16mm is enough to withstand against the internal pressure.

As for the design external pressure, the pressure will not work on the penstock because the seepage water will be drained by the drain pipe. However, half of the head difference between the HWL of the reservoir and the center of penstock is deemed to act on the embedded penstock in the dam considering the safety. In case stiffeners are provided against external pressure, the material weight and man-hour of manufacturing cost more than increasing the plate thickness without stiffener. Accordingly, no stiffener is considered for the design of the penstock.

An air vent valve is provided at the upstream of intake gate to vent air from the upstream penstock when the water filling is made for the penstock through the by-pass valve of stoplogs.

9.5.7 DRAFT TUBE STOPLOGS AND GANTRY CRANE

(1) Stoplogs

The dimension of the draft tube outlet will be decided according to the existing stoplogs to be used commonly for the expansion plan. In the expansion plan, new stoplog segments will not be provided to the new generating unit, but only guide frames. Because of the common use of the existing stoplog segments, the guide frames to be installed in the expansion plan are of the same guide frames installed in the existing generating unit.

(2) Gantry Crane

In addition to the common use of draft tube stoplog segments, the existing draft tube gantry crane is also commonly used for the expansion plan. The traveling rails and power supply cable are extended up to the new draft tube of the generating unit. The power supply cable including cable reel will be replaced totally in the expansion plan.

CHAPTER 10 STUDY ON THE TAILRACE WATER LEVEL

10.1 PRESENT CONDITION OF TAILRACE WATER LEVEL

At the section 500 m downstream from the Nam Ngum 1 Hydropower Station, there is a line of rock outcrops at the riverbed in the transverse direction. There is water fall of 40 to 50 cm depth at this river section as shown in the photo below. Due to these rock outcrops, the water level at upstream of this section is lifted up and tailrace water level is affected.

Photo Rock Outcrop located 500 m downstream of NN1 Hydropower Station

On the other hand, the discharge–tailrace water level curve is shown in Figure 9.1.5 (Chapter 9), and the historical yearly minimum tailrace water levels are shown in Table 10.1.1. The yearly minimum tailrace water level was recorded on hourly basis. As shown in the table, the yearly minimum level is basically not lower than EL.166.00 m. This means that power generation has continued through many years. However, there is a record of minimum tailrace water level with EL.165.00 m in 2003. According to the information related to the power station, this tailrace water level was recorded when all power generation units were stopped. This was made only once in the past power generation history.

In the discharge–tailrace water level curve, the lowest tailrace water level at no discharge is at EL.164.00 m. However, the recorded minimum tailrace water level was EL.165.00 m. This is because the downstream area of units 1 and 2, in which there is the tailrace water level measurement device, has riverbed elevation of EL.165.00 m as the highest point and it is enclosed with concrete separation wall located between the downstream areas of units 2 and 3. Therefore, the tailrace water level measured at downstream of units 1 and 2 could not be lower than EL.165.00 m.

Table 10.1.1 Yearly Minimum Tail Water Levels

Minimum Water Level (masl)

Date	Tail Water Level
25/05/1981	166.6
12/06/1982	167.0
08/05/1983	167.0
13/03/1984	167.0
10/04/1985	167.0
20/06/1986	166.7
02/08/1987	166.6
31/12/1988	166.4
08/04/1989	166.6
01/03/1990	166.6
04/06/1991	166.6
08/06/1992	166.2
24/05/1993	166.0
01/11/1994	166.0
17/12/1995	166.2
16/02/1996	166.2
05/12/1997	166.5
26/12/1998	166.3
04/05/1999	166.6
31/01/2000	166.7
22/01/2001	166.2
23/03/2002	166.5
2003/12/27	165.0
13/02/2004	166.2
18/05/2005	166.5
01/07/2006	166.1
15/06/2007	166.5
12/01/2008	165.8

Source: NN1 Hydropower Station

Drawdown of the tailrace water level will possibly affect the operating performance of the existing turbines especially for their cavitations characteristics. The extent of the influence on cavitation characteristics of the existing turbines was assessed by studying the required turbine setting elevation in Chapter 10.3.

10.2 POSSIBILITY OF LOWERING OF TAILRACE WATER LEVEL

Through the excavation of the exposed riverbed located at about 500 m downstream of the powerhouse, tailrace water level (tail water level) is lowered, the effective head is increased, consequently increasing the generated energy.

In order to estimate the lowered depth of tailrace water level, the following works as shown below were conducted and the details of the hydraulic analysis are presented in Appendix H.

(1) River Cross Section Surveys

In addition to the total 25 sections located at the area between the powerhouse and the 10 km downstream with 500 m intervals (including three sections in Nam Lik before the confluence with Nam Ngum), the detailed river cross section survey for the 15 sections were made at the area between the tailrace and 1 km downstream.

(2) Regeneration of the current river condition

The current river conditions were regenerated through hydraulic analysis (one-dimensional non-uniform flow analysis) based on the following conditions:

- Longitudinal Section: 3 km between the powerhouse and the river confluence with Nam Lik
- Cross Sections: Total 20 sections consisting of 15 sections located at the area between tailrace and 1 km downstream, 4 sections located at the area between downstream of the 15 sections and the river confluence with Nam Lik, and assumed section located at the exposed riverbed
- Water levels: Observed water level data through the river cross section surveys, Tailrace water level data observed in the powerhouse (by EdL), existing tailrace water level rating curve

The analysis results are shown in the table below.

Table 10.2.1 Hydraulic Analysis Results for Current Condition

Discharge (m^3/s)	105	167	247	351	440	467	735	1,025	2,815
Upstream WL (EL.m)	166.2	166.5	166.9	167.3	167.6	167.7	168.9	169.9	174.9
WL Difference at Exposed Riverbed (cm)	54	55	47	42	39	36	16	7	2
Downstream WL (EL.m)	165.6	165.9	166.3	166.7	167.0	167.1	168.5	169.5	174.5

Prepared by JICA Survey Team

The above upstream water levels are consistent with the observed water level data through the river cross section surveys and the tailrace water level data observed in the powerhouse. In addition, the above water level difference also coincides with the water level difference observed through the river cross section survey (440 m^3/s, 39 cm). Consequently, it can be evaluated that results of the regeneration are appropriate.

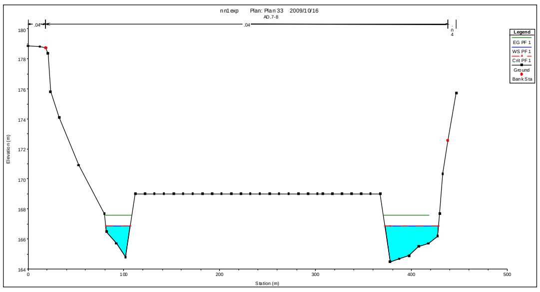
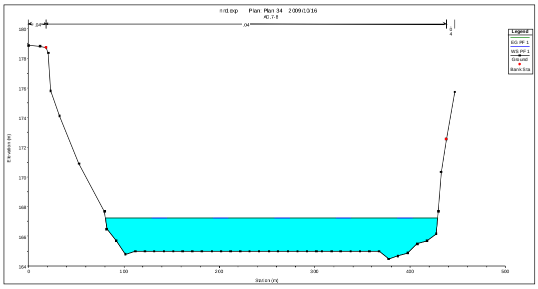
In accordance with the results, it is observed that the flow areas at the exposed riverbed are secured and the gaps of water level are decreased in case of discharges over the discharge in existing five units fully operational (466 m^3/s).

(3) Prediction of the river condition after excavation of exposed riverbed

Referring to the above analysis model, the river conditions after excavation of the exposed riverbed were predicted through similar hydraulic analysis based on the following conditions:

- Longitudinal Section: Same as the current river condition

- Cross Sections: For the sections used in the regeneration analysis, the section at the exposed riverbed and the most upstream section (section after excavation for unit 6 tailrace) were modified.

	
【Section before Excavation of Exposed Riverbed】	【Section after Excavation of Exposed Riverbed】

- Water levels: Same downstream water levels at the current river condition are applied.

The results are shown in the table below.

Table 10.2.2 Hydraulic Analysis Results for Condition After Riverbed Excavation

Discharge (m^3/s)	105	167	247	351	440	467	735	1,025	2,815
Upstream WL (EL.m)	165.7	166.0	166.4	166.9	167.2	167.3	168.8	169.8	174.9
WL Difference at Exposed Riverbed (cm)	0	1	1	1	1	0	1	1	0
Downstream WL (EL.m)	165.6	165.9	166.3	166.7	167.0	167.1	168.5	169.5	174.5

Prepared by the JICA Survey Team

The above results show that the gaps of water level at the exposed riverbed are much decreased and water levels smoothly change in the up to downstream directions.

(4) Estimation of lowered depth of tailrace water level

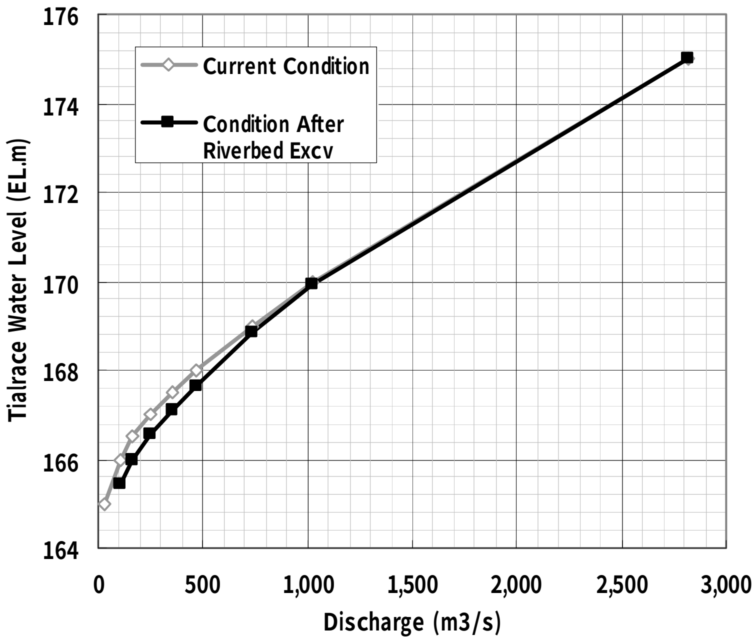
Based on the above analysis, the lowered depths of tailrace water level are estimated as shown below.

Table 10.2.3 Difference of Tailrace Water Level Before and After Riverbed Excavation

Q (m^3/s)	105	167	247	351	440	467	735	1,025	2,815
U/S WL - Before (EL.m)	166.2	166.5	166.9	167.3	167.6	167.7	168.9	169.9	174.9
U/S WL - After (EL.m)	165.7	166.0	166.4	166.9	167.2	167.3	168.8	169.8	174.9
Difference of Tailrace Water Level (m)	-0.54	-0.54	-0.46	-0.40	-0.35	-0.34	-0.14	-0.06	-0.01

Prepared by the JICA Survey Team

The tailrace water level rating curve after riverbed excavation based on the above estimation is shown below.



WL (El.m)	Q (m3/s)
175.0	2,815
169.9	1,025
168.9	735
167.7	467
167.1	351
166.5	247
166.0	167
165.5	105

Prepared by the JICA Survey Team

Figure 10.2.1 Tailrace Water Level Rating Curve After Riverbed Excavation

(5) Confirmation of difference of water velocity due to excavation of exposed riverbed

The following table shows the water velocity at about 200 m downstream of the powerhouse, before and after the riverbed excavation.

Table 10.2.4 Difference of Water Velocity Before and After Riverbed Excavation

Discharge (m^3/s)	105	167	247	351	440	467	735	1,025	2,815
Water Velocity - Before (m/s)	0.08	0.12	0.16	0.22	0.26	0.27	0.34	0.42	0.72
Water Velocity - After (m/s)	0.09	0.13	0.18	0.23	0.28	0.29	0.35	0.42	0.72
Difference of Water Velocity (m/s)	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.00	0.00

Prepared by JICA Survey Team

As shown in the above results, there are almost no changes between the water velocities before and after the riverbed excavation. Consequently, it is most likely that erosion of the river course will not occur.

10.3 INFLUENCE ON EXISTING TURBINES

10.3.1 SPECIFIC SPEED OF EXISTING TURBINES

Specific speed (Ns) is calculated from the following equation:

$$Ns = \frac{N * Pt^{1/2}}{Hd^{5/4}} \quad [\text{m-kW}]$$

where, N_s : Specific speed (m-kW)
N : Rated rotational speed (rpm)
H_d : Design head (m)
P_t : Turbine rated output (kW)

Specific speeds of the existing turbines were calculated as shown in the table below.

Table 10.3.1 Specific Speed of Existing Turbines

Existing Turbines	Speed (rpm)	Design Head (m)	Turbine Output (kW)	Specific Speed (m-kW)
Unit 1/Unit 2	176.5	37.0	18,300	268.0
Unit 3/Unit 4/Unit 5	136.4	37.0	40,000	298.9

Prepared by JICA Survey Team

10.3.2 CAVITATION COEFFICIENT

Equations to calculate the cavitation coefficient are introduced in various technical literatures. Referring to the technical journal "Water Power & Dam Construction (August 1987)", the cavitation coefficient was calculated using the following equation:

$$\sigma_p = 0.0245 \text{ x } e^{(0.00833 * Ns)}$$

where, σ_p : Cavitation coefficient
N_s : Specific speed (m-kW)

The cavitation coefficients for the existing turbines were calculated as shown in Table 10.3.2 below:

Table 10.3.2 Cavitation Coefficient of Existing Turbines

Existing Turbines	Specific Speed (m-kW)	Cavitation Coefficient: σ_p
Unit 1/Unit 2	268.0	0.2284
Unit 3/Unit 4/Unit 5	298.9	0.2955

Prepared by JICA Survey Team

The cavitation coefficient σ_p refers to the turbine centerline elevation. This σ_p is required to have sufficient safety margin against the critical cavitation coefficient σc, which is the lower limit to operate the turbine stably without significant efficiency drop due to the cavitation phenomena. Then, it was confirmed that the cavitation coefficient σp calculated for each existing turbine has a safety margin of more than 1.5 against the critical cavitation coefficient σ_c.

10.3.3 TURBINE CENTERLINE ELEVATION

The turbine centerline elevation is based on the tailrace water level when one (1) unit of the turbine is operated at the rated output and is calculated by the following equation:

Turbine Centerline Elevation = $TWL_1 + H_s$

where, TWL_1 : Tailrace water level at turbine one-unit operation with rated output = 164.0 m

H_s : Static suction head referred to the turbine centerline elevation = $H_a - H_v - \sigma_p * H_d$

H_a : Atmospheric pressure at TWL_1: 164.0 m = 10.12 m

H_v : Vapor pressure = 0.32 m

H_d : Design head of turbine = 37.0 m

σ_p : Cavitation coefficient
= 0.2284 (Unit 1 and Unit 2)
= 0.2955 (Unit 3, Unit 4 and Unit 5)

The required turbine centerline elevations for the existing turbines are calculated as shown in Table 10.3.3 below.

Table 10.3.3 Turbine Centerline Elevation of Existing Turbines

Existing Turbines	Tailrace Water Level (m)	Suction Head (m)	Turbine Centerline Elevation (m)	
			Calculated Value	Actual Value
Unit 1/Unit 2	164.0	+ 1.35	165.35	165.5
Unit 3/Unit 4/Unit 5	164.0	- 1.12	162.88	161.0

Prepared by JICA Survey Team

10.3.4 CAVITATION STATUS ON EXISTING TURBINES

(1) Unit 1 and Unit 2

No significant cavitation pittings have been observed on the runners after unit 1 and unit 2 were refurbished in 2004.

(2) Unit 3, Unit 4, Unit 5

Cavitation pittings are often observed on the runner for each unit and most of the damages are minor. When the turbines are operated under the low head for a long time, the runners will be damaged by cavitation pittings to some extent. However, such cavitations damages are still within allowable range and can be repaired on site.

The cavitation damages are repaired every year on site by the use of grinding tool and resin material.

10.3.5 REVIEW RESULTS

(1) Unit 1 and Unit 2

As shown in Table 5.3.3, the turbine centerlines of the existing unit 1 and unit 2 are set at EL. 165.5 m without any safety margin to the calculated values.

In case the drawdown of the tailrace water level is expected, a cofferdam or another structure should be provided at the turbine outlets of the existing unit 1 and unit 2, so that the operating tailrace water level is not lowered below EL. 164.0 m.

(2) Unit 3, Unit 4 and Unit 5

As shown in Table 5.3.3, the actual setting values of the turbine centrelines for the existing unit 3, unit 4 and unit 5 have safety margins of more than 1.8 m. Since this seems rather big as a safety margin for the cavitations problem, it is supposed that said margin is attributed to the layout of the turbine and generator assemblies for these existing units.

In case the tailrace water level is lowered, there is a possibility of slightly increasing the cavitations damages on the runners.

Even in such case, the cavitations damages will not exceed the allowable limit and are repairable on site.

This means that the existing turbines for unit 3, unit 4 and unit 5 could possibly secure the necessary suction head to prevent the occurrence of excessive cavitations on the condition that the drawdown of the tailrace water level is less than 1.8 m.

Therefore, it is expected that the drawdown of the tailrace water level will not affect seriously the existing turbines for unit 3, unit 4 and unit 5. In case unit 6 is additionally installed, the tailrace water level will be raised which will mitigate the influence to units 3, 4 and 5.

(3) Conclusion

The elevation of the existing river bed at the downstream side of the tailrace for unit 1 and unit 2 is EL. 165.0 m. The excavation of the river bed will be carried out not to affect the tailwater level for the existing units 1 and 2.

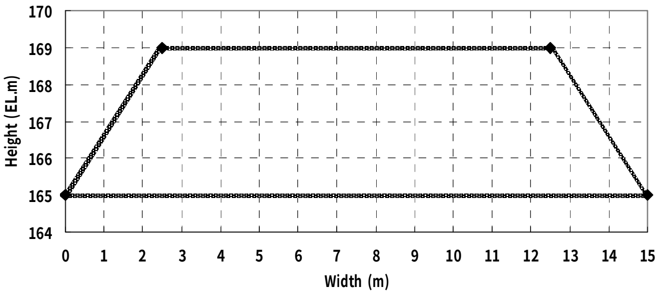
If the river bed at downstream side is excavated, it is expected that the tailrace water level for the existing unit 3, unit 4 and unit 5 will possibly be lowered. In such case, the excavation work will be planned so that the drawdown of the tailrace water level should not exceed 1.8 m.

10.4 BENEFIT AND COST OF LOWERING OF TAILRACE WATER LEVEL

Based on the calculation using the tailrace water level rating curve after excavation of exposed riverbed, it is estimated that an increase of the annual generated energy is 5 GWh.

Cost of the excavation of exposed riverbed is estimated as about 74 million JPY (0.78 million USD) based on the following conditions:

- Excavation area: 50 m^2



- Excavation length (crossing direction): 260 m
- Excavation volume: 13,000 m^3
- Unit rate of excavation (underwater): 60 USD/m^3

Economic and financial aspects considering the above benefit and cost are evaluated in Chapter 12.

CHAPTER 11 IMPLEMENTATION PLAN AND COST ESTIMATE

11.1 OUTLINE OF THE PROJECT

The proposed optimum plan for the Nam Ngum 1 (NN1) Hydropower Station Expansion Project is to extend the existing machine hall towards the spillway and provide a new generator with 40.0 MW capacity as the unit 6, according to the basic design of the JICA preparatory survey in 2009. The NN1 Hydropower Station raises its generation capacity to 195.0 MW in total from the existing 155.0 MW, through the implementation of the expansion project. The NN1 power station has the following chronicles in its commissioning operation.

- 1971: 15,000 kW x 2 sets for No. 1 and 2 generators
- 1975: 40,000 kW x 2 sets for No. 3 and 4 generators
- 1984: 40,000 kW x 1 set for No. 5 generator
- 2004: Up-rating 2,500 kW x 2 sets for No.1 and 2 by rehabilitation
  Total generating capacity before expansion: 155.0 MW

The principal features of the proposed expansion project for the new unit 6 under the basic design study are as follows:

- Rated head : 40.0 m
- Intake center level : EL. 185.25 m
- Penstock diameter : 5.5 m
- Intake gate : Bonnet type high pressure slide gate
- Turbine : Francis type, rated output 40,900 kW
- Generator : Umbrella type, rated output 50,000 kVA
- Main transformer : Single phase type, rated capacity 16,666 kVA x 3

The proposed layout of the expansion project has the following characteristics.

- A new intake at the upstream dam face is located between the intake for unit 5 and the spillway
- A new penstock installed in pierced hole through the dam body
- An extension of the existing power station to accommodate the new turbine, generator and ancillary plant of unit 6
- A tailrace downstream of the power station extension.

The expansion project, located in Viengkham, Keo Oudom District, Vientiane Province in the northeast direction of Road No. 13N, is approximately 90 km from Vientiane. The Project includes three major construction works namely, 1) civil works, 2) hydro-mechanical works, and 3) electro-mechanical works. No stoppage of the existing NN1 power plant is planned during the construction of the expansion works.

11.2 PROJECT IMPLEMENTATION

(1) General

The basic design was undertaken by the Survey Team on NN1 Hydropower Station Expansion under the financing of JICA. Thus, execution of the project presented in this report is deemed as a basic design level.

(2) Executing Body

The Project will be implemented by the Department of Electricity (DOE), Ministry of Energy and Mines of Lao PDR.As the executing agency, DOE will also undertake management and supervision of the project construction. The DOE will organize an implementation team/management board, as an internal organization, during the construction.

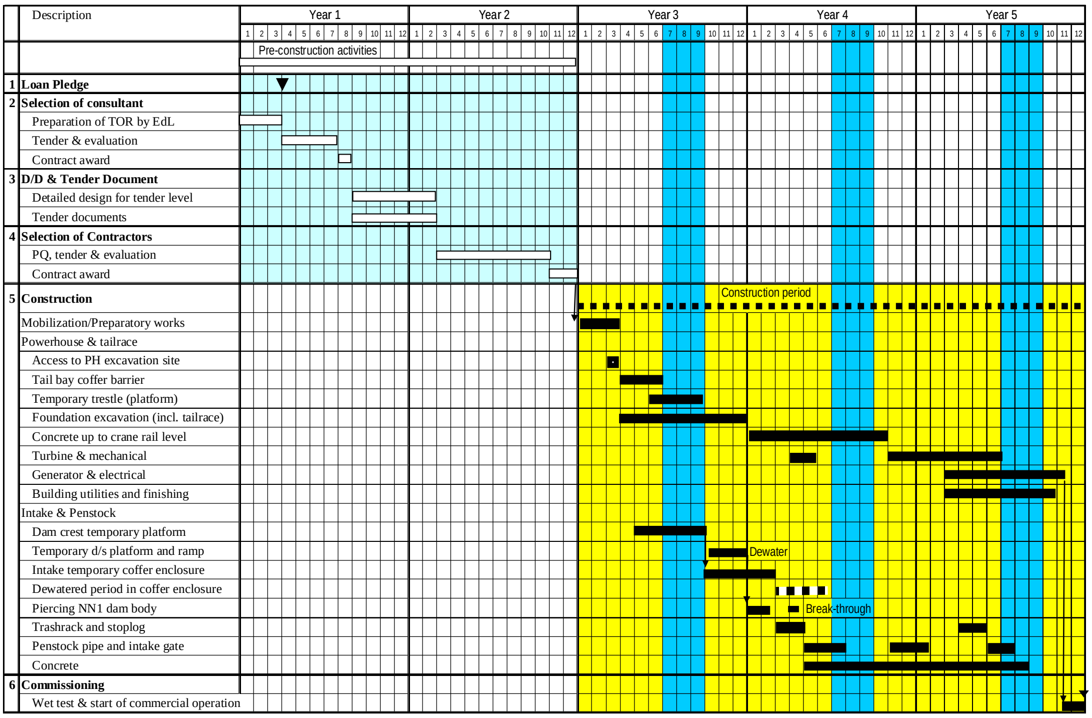
After completion of all the construction works, the permanent structures and facilities will be transferred to the Electricite du Laos (EdL), who will be the project owner.

The selected international consulting engineer and associated local consulting firms will be employed for the detailed design, preparation of tender documents, and construction supervision, to assist the DOE in implementing the Project.

(3) Implementation Schedule

The Project is proposed to be implemented in five (5) years including pre-construction stage and conducted as shown in the subsequent Figure 11.2.1 (or Appendix I-1). Work items for the project implementation are summarized below.

- Financial arrangement
- Selection of consultant
- Detailed design and preparation of tender documents
- Tender and selection of contractors
- Construction execution, construction supervision and environmental management
- Commissioning tests and trial operation
- Completion (Start of commercial operation)



Prepared by the JICA Survey Team

Figure 11.2.1 Overall Tentative Implementation Schedule

(4) Financial Source

For the funding arrangement, Japan's official soft Yen loan for Least Developed Countries (LDC) is expected to be applied for the Project.

(5) Procurement Plan and Contract Packages

In selecting the contractors for the Project, the International Competitive Bidding (ICB) process will be expected to be adopted in principle. Initially, however, the bidders will be screened through a pre-qualification process. The contractor will be selected in accordance with the guidelines of JICA and the DOE.

The contract packages will include the following three lots for ensuring sufficiency of magnitude and successfully attract international bidders, allow smooth construction management and control of the overall Project to be maintained, and other related matters.

- Lot 1: Civil works
- Lot 2: Hydro-mechanical works
- Lot 3: Electro-mechanical works

It is assumed in the study that contractors or plant builders having sufficient experience in executing similar works are employed for actual construction. A one-envelope method will be applied in the bid procedure for all the three lots.

11.3 CONSTRUCTION PLAN AND SCHEDULE

(1) Scope of Works

For the NN1 power station expansion project, the scope of works is summarized as follows:

- A Civil works
  - A1 Preparatory works
  - A2 Intake and penstock
  - A3 Powerhouse and tailrace
  - A4 Roof switchyard
- B Hydro-mechanical works
  - B1 Intake and penstock
  - B2 Draft tube stoplog facility
- C Electro-mechanical works
  - C1 Generation equipment
  - C2 Thalat substation improvement
- D Engineering and environmental management works

(2) Civil Works

<u>Access to Site</u>

Mechanical and electrical equipment, construction plant, and the main construction materials are expected to be transported from or through Thailand by road, via the Friendship Bridge across the Mekong River. Access from there to the expansion site is via RN 13 to Ban Phonhong, and then by a paved road to Ban Thalat and the bridge over the Nam Ngum River.

<u>Construction Resources</u>

The expected raw materials to be used for the expansion works include cement, sand and gravel, timber, water. Cement supply is assumed to be from Thailand, unless the quality of those produced in Lao PDR is confirmed to be acceptable. Concrete aggregates are assumed to be taken from the Nam Lik riverbed deposits.

To expand for the new unit 6 generator, several types of construction equipment, such as bulldozer, dump truck, and crane, will be required. Middle to light class equipment with operator may be available on rental basis at Vientiane, Lao PDR. However, heavy-lifting crane may need to be mobilized from Thailand. A concrete mixing plant will be necessary to supply concrete imported from Thailand.

Skilled labor such as divers for welding and rigging works under the Nam Ngum reservoir water for temporary enclosure and open air, drilling operator for piercing the dam body, operators of heavy lifting cranes and other specialized tasks will have to be recruited from ASEAN countries and Japan.

<u>Construction Sequence</u>

The construction works will be conducted under two sections such as intake and penstock (upstream side), and powerhouse and tailrace (downstream side). These shall be executed almost in parallel after mobilization.

Construction Schedule

Construction schedule is formulated as part of the construction plan, and presented in bar chart form in Appendix I-2. This is intended to show detailed timing of works to be carried out from commencement to final taking-over by each civil works contractor, including hydraulic steel works and electrical/mechanical works. This schedule should clearly show which work items are on critical path.

In planning the time schedule, the monthly variation of reservoir water level is taken into account since the water level variation affects the temporary enclosure works for the intake. The schedule should indicate that the NN2 power station is already commissioned prior to the NN1 expansion work. Influence of the NN2 operation is taken into account in estimating the NN1 reservoir water level variation.

Preparatory Works

Temporary construction facilities should be initiated prior to commencement of main civil works. These include preparatory works such as access roads, contractor's office and accommodations, and employer's and engineer's office and accommodations. These facilities are constructed in the downstream left bank, mainly close to the NN1 dam. Required area is approximately 2.0 ha. Availability of required land has been confirmed between EdL and the Survey Team during the basic design meeting held on August 3, 2009. Appendix I-3 shows a layout plan for these temporary facilities and yards. Waste disposal site is proposed at the left bank and downstream of the power station, within a 2.0-km hauling distance

Temporary Enclosure

Access to the intake works area is the 5.5 m wide Nam Ngum dam crest. The existing traveling crane on rails and the crest will be temporarily removed to the right abutment side to allow access for items of plant of greater dimension.

A temporary coffer enclosure in the reservoir is required for the construction of intake. The gate and/or rectangular steel coffer structure has been planned in the basic design stage. H-type and angular steel materials (SM 490 or equivalent) are applied as the main coffer materials. The temporary enclosure coffer plans have the following dimensions situated in the new intake side of the reservoir.

Inside: 11.5 m x 4.0 m (46.0 m^2)

Outside: 13.1 m x 4.8 m (62.88 m^2)

Depth: 30 m (EL. 179.0 m – EL. 209.0 m)

Required steel will be approximately 580 tons in total. The steel materials are assembled as gate-type steel structure on the ground outside the reservoir to meet the coffer size mentioned above, which is 2.0 m high. The weight per piece of the gate-type steel structure is 40 tons. Number of components assembled for such gate-type steel structure is 15 sets (depth 30 m/height 2.0 m=15). Each piece of steel structure is installed in the reservoir equipped with the dam body, supported by chemical type anchoring (l = 40-50 cm, M36 x 200 pcs.) and by cantilever method after being transported.

The coffer works will be carried out in the following sequence, within about 5.0-month duration:

(Coffer installation)

1) Preparatory works (0.25 months) → 2) Barge assembling (0.25 months) → 3) Survey/ centering/level check (0.5 months)→ 4) Setting steel to dam body (1.5 months) and assembling gate type steel structure at ground (2.5 months) → 5) Installation of gate type steel structure (2.5 months) → 6) Dewatering (0.5months) → 7) Install elevator (0.5 months) → finish

(Coffer demolition)

1) Preparatory works (0.25 months) → 2) Barge disassemble and demolition (0.25 months) →3) Demolition coffer (2.0 months) → 4) Site clearing (0.25 months) → finish

The selection of maximum load of the barge will have to be clarified for the study. The lifting work for the assembled gate-type steel structure will be by a 150- to 200-ton class heavy crane installed temporarily at the working platform on the dam crest. These coffer works are to be done under water by skilled divers, that require complete safety measures, quality control and construction management. Reservoir water level will be controlled during temporary coffer construction. Major equipment required for the temporary coffer enclosure will be as follows.

Equipment	Specification	Application	Notes
Truck crane	200 t class	Coffer setting/remove	Max. weight 40t, max. working radius 14m, 1-unit, rough terrain crane also applicable
Truck crane	200 t class	Assembling/loading	Max. weight 40t, max. working radius 14m, 1-unit, rough terrain crane also applicable
Trailer	40 t class	Transport to dam crest	Max. weight 40t * , 1-unit
Anchor barge	10 t lifting	Miscellaneous works	Self-propelling, 1-unit
Transport ship	60 PS	Crew transport	2-units
Barge	20 t loading	Support diver work	Uni-float type, 5.5mx2.5mx1unit
Concrete pump car	60 m^3/h	Pouring mortar	Common use of P. house, 1-unit
Pier			Scaffolding, uni-float
Muddy water prevent film		Uni-float barge with safety net	

* Maximum weight is the weight of the assembled structure with 2 m height of one stage

Working conditions of diving work for the underwater temporary enclosure work are as follows:

- 5 to 6 of working groups
- Diving under air system
- Continuous work even during Saturdays and Sunday
- 1 time diving per 1 day by 1 group
- 1 hour diving and 30 min. to 60 min. rest

Working platform will be constructed on the crest of dam (block no. 19 and 20) for the intake and penstock works including coffer enclosure. This platform will be 36.0 m long and 10.1 m wide.

Intake and penstock

Major construction work items and approximate quantities required for the intake and penstock are as follows:

1) Construct temporary working platform at EL. 181.0 m and access ramp
2) Piercing dam, hole section 6.7 m x 6.7 m, length 22.0 m for horizontal part of penstock, and 9.0 m x 5.0 m for vertical intake gate part, piercing volume of 1,450 m^3 in total
3) Concrete fill of 1,130 m^3 for penstock (bell mouth to inclined part above EL. 177 m)

The slot-drilling and breaking method will be adopted for the dam piercing. Slot drilling machine will be a 27-ton machine with bit diameter of 102 mm. Breaker of 1,400 kg class and twin load header will be used for further breaking and mucking the hole. After the slot-drilling, the penstock hole is bored through the dam with the remaining 5.0 m long bell mouth part of penstock. Concrete are filled after the penstock installation. Major equipment required for the dam piercing will be as follows. The required number is 1 unit of each type of equipment, assuming 1.0 m piercing length progress by one cycle.

Equipment	Specification	Application	Notes
Drill jumbo	Wheel type	Slot drilling	2-boom, 150kg class, possible to horizontal drilling to 6.7m height
Breaker	Hydraulic type	Primary break	2 t class
Wheel loader	0.9 m^3 class	Loading muck	
Dump truck	10 t class	Hauling muck	
Backhoe	0.35 m^3 class	Muck treatment	Common for secondary break and twin header
Breaker	Hydraulic type	Wall break	Secondary break, 1.4 t class
Twin header		Wall break	
Concrete pump car	60 m^3/h class	Fill concrete	Common use with power house

Dewatering period in the coffer enclosure is scheduled for 3.5 months. Breakthrough of piercing for 5.0 m remaining part is to be performed in the initial stage of the dewatering period. This is intended so that the succeeding works, such as bell mouth pipe installation, setting the stoplog guide frame, stoplog installation and other works, could be done within the dewatering period.

Powerhouse and Tailrace

Major civil works are 1) foundation excavation of the powerhouse and tailrace, 2) underwater excavation outside tailrace, and 3) building and tailrace concreting. The construction of powerhouse and tailrace, including the electro-mechanical works, has a critical path of 36.0 months within this expansion project. This is implied in the following work order and duration.

Mobilization	:	2.0 months
Access way preparation (draft tube deck)	:	1.0 month
Foundation excavation (above EL. 168 m)	:	6.0 months
Foundation excavation (below EL. 168 m)	:	5.0 months

Building concrete (up to OHT crane runway base)	:	7.0 months
Crane runway steel girders	:	1.0 month
Turbine spiral casing	:	2.0 months
Spiral case second concrete	:	2.0 months
Installation of generator and electrical auxiliaries	:	8.5 months
Wet test for commissioning	:	1.5 months
Total	:	36.0 months

The excavation for the extension of the powerhouse will cover the area between the ends of the present building and the spillway. The powerhouse and tailrace excavation will be carried out through two steps, namely, open excavation of 39,000 m^3 above EL. 168 m (upstream side) and pit excavation of 24,000 m^3 below EL. 168 m from the bottom (downstream side).

The excavation above EL. 168 m should commence from the upstream side and finish early to ensure that construction of the working platform starts timely at EL 181.0 m, for the piercing of the dam body for the penstock and intake gate.

It will be required to provide a temporary coffer at the river side and trestle for the loading platform of excavated muck at EL 177 m, crossing the tailrace for the pit excavation. Existing concrete wall and natural rock at crest EL 171 m should be utilized for the coffer upon reinforcement, through grouting and rock anchoring. Existing concrete deck on the tailrace side of the powerhouse building shall be used as haul road of excavated muck upon removal of the stoplog crane on the deck.

Rock excavation in the powerhouse extension area should be executed using rock breakers or blasting, depending on the hardness and degree of jointing encountered. Where the use of heavy breakers or blasting is required, the transmission of vibration to the existing machine foundations will be limited by line drilling at the perimeter of the excavation with the use of delay detonators. Water jet method will be studied in the detailed design stage. Rock bolting and shotcrete will be required on all cut slopes.

Excavation in the tailrace area would be carried out using 1,300 kg class giant breaker equipped with 0.8 m^3 class backhoe base machine. Loading and hauling will be executed using a combination of 0.8 m^3 class backhoe and 10-ton class dump truck. Waste disposal site will be provided at the left bank of the Nam Ngum River, within 2.0 km hauling distance.

The excavation volume of underwater outside the tailrace and coffer is 2,600 m^3, which will require a giant breaker for excavation and 0.8 m^3 class backhoe for loading on pontoon barge. A small barge will be provided for the hauling of excavated soil and rock.

Required concrete volume is approximately 15,000 m^3 in total. Concrete aggregates will be taken from Nam Lik riverbed deposits. A 50 m^3/h class batcher plant will be provided at the left bank of the Nam Ngum River, close to the construction site. Agitator truck of 3 m^3 class and concrete pump car will be utilized for concrete placement. The chute method will also be applied for pouring concrete. A tower crane will also be provided and erected at the upstream side of the tailrace and in the north side for the powerhouse concrete, and other works.

Removal of Rock Outcrops at Downstream Stretch

The volume of rock outcrops to be removed at the downstream stretch of powerhouse is estimated at 13,000 m^3. The underwater removal works will be done using a giant breaker on pontoon barge. A 0.8 m^3 class backhoe on the pontoon barge will be used for the loading of excavated rock and soil, and a small barge will be provided for the hauling of excavated soil and rock.

(3) Hydro-mechanical Works

The construction items of the hydro-mechanical works for the 40 MW NN1 expansion are as follows.

Intake and penstock	1) Trash rack, 12 t
	2) Stoplog, 59 t
	3) Intake gate and hoist, 131 t
	4) Gantry crane rails and cable extension, LS
	5) Penstock steel pipe, 186 t
Draft tube stoplog facility	1) Gantry crane rails and cable extension, LS
	2) Draft tube stoplog slot guide rails

The hydro-mechanical works are carried out by a selected contractor under the contract package for lot 2, comprising the design, manufacture, delivery, installation and water-filling in the penstock and gate operating tests. These works are accomplished to meet the construction time schedule of civil works. The installation of hydro-mechanical equipment is scheduled to start from the second year after the site delivery and requires 15.5 months duration, including the design and manufacture. The bell mouth pipe, trash rack and stoplog will be installed during the dewatered condition of the temporary coffer enclosure carried out for 3.5 months. Said installation will be executed using 150- to 200-ton class heavy crane installed temporarily at the working platform on the dam crest.

The bonnet type high pressure slide intake gate will be installed for about one month after the installation of the trash rack and stop log using the same 150 to 200 ton crane. The 5.5 m-diameter penstock will be installed in order of the part of the upper horizontal, lower bend, inclined pipe and upper bend in the second to third year. Concrete filling follows the installation. The draft tube and other equipment will be installed using a station crane. Secondary concrete will be placed using a concrete pump car.

(4) Electro-mechanical Works

The construction items for the 40 MW NN1 expansion electro-mechanical works are as follows.

Generating equipment	1) Turbine and auxiliaries, LS
	2) Generator and auxiliaries, LS
	3) Transformers, LS
	4) Indoor switchgear, LS
	5) Outdoor switchyard equipment, LS
	6) Control and protection equipment, LS
	7) Auxiliary equipment, LS

	8) Miscellaneous materials, LS
Thalat substation improvement	1) Overhead power conductors, LS

The electro-mechanical works are done by a selected contractor under the contract package for lot 3. This comprises the works and same procedures as for the hydro-mechanical works. The period assumed for the works is 22 months after the site delivery for electro-mechanical equipment, excluding the draft tube steel liner, which is planned for earlier delivery in about 6 months. The draft tube steel liner and spiral casing are planned to be installed in the second year. The spiral casing is installed using a powerhouse station crane. Other works are executed in the third year. The second stage concrete for the draft tube is poured in the second year, and for the spiral case, in the third year after the installation.

The advantageous arrangement is achieved by extending the existing main machine hall over the new unit so as to utilize the existing main station crane, lay down and loading areas. The roof extension of the power station superstructure accommodates the additional high voltage switchyard bay, as for the existing units.

11.4 COST ESTIMATION

(1) Conditions and Assumptions for Cost Estimate

- It is assumed that implementation period for the expansion project is about five years.
- Estimation of construction costs is carried out on the basis of the construction plan and schedule, elaborated based on estimated construction work quantities from the basic design and cost data collected and analyzed in the field survey.
- The cost estimation is conducted for the following major items, in which foreign currency (JPY) and local currency (Kip) components are separated:
  - Direct construction cost (on each package of civil, electrical/mechanical, etc.)
  - Indirect cost
  - General costs in head office and field office
  - Consulting service cost for design and construction supervision
  - Executing agency's expenditures for administration, land preparation, environmental management, etc.
  - Import tariff and value added tax (VAT) in Lao PDR.
  - Contingency (price and physical)
  - Interest during construction
- Base cost consists of direct cost for civil works, hydro-mechanical works, electro-mechanical works and cost for consulting services.
- Fiscal year is April – March.
- Exchange rate to US$:

US$ 1.00 = JPY 95.0
US$ 1.00 = Kip 8,510.0

- Base year for the cost estimate is August 2009
- For civil works cost, the unit price of each work item is first estimated taking into account the construction method and work quantity. The work item cost is then calculated by multiplying the work quantity with the corresponding unit price. Unit prices quoted from recent international bids for similar civil works in Southeast Asia are referred to in the cost estimate. As to uncommon civil works, like the temporary coffer enclosure for deep water intake, records of actual costs incurred for similar works in Japan are used as reference. Cost reduction for locally procured/fabricated materials should be taken into account.
- Costs for hydro-mechanical and electro-mechanical equipment are estimated on the basis of the consultant's database related to recent international bid prices for similar works.
- Consulting service cost comprises related costs and fees. To estimate the consulting service cost, the scope of the necessary consulting services and corresponding manning schedule are defined through coordination with DOE/EdL. A proposed TOR for the consulting services are as follows.
  - Review of basic design
  - Tender design, additional survey (topographic survey, geology, material), detailed design, preparation of tender documents
  - Supporting work of tender (tender evaluation, contract support)
  - Construction supervision
  - Advising for environmental management
- Tentative manning schedule for the consulting services is shown in Appendix I-8 including type of experts.
- Direct cost for the consulting services estimates referring the other on-going project cost data such as World Bank financing project for the following major cost items.
  - International airfare
  - Per-diem allowance
  - Accommodation allowance
  - Vehicle rental
  - Office rental
  - International and domestic communication charge
  - Office supply and operation
  - Sub-contracts cost
- Environmental management cost is included in the owner's administration cost.
- It is assumed that foreign currency portion of 85% and local currency portion of 15% are considered for the estimated direct construction cost, under the basic design stage.
- No Value Added Tax (VAT) of Lao PDR is included considering the tax exemption measure

exclusive for the Project by the Government.

- No import duties on construction resources (materials and equipment) are included considering the tax exemption measure exclusive for the Project by the Government of Lao PDR.
- Land acquisition and compensation cost is considered zero account due to the constitution of Lao PDR under Article 17.
- Rate of interest during construction is estimated at 0.01% of total construction cost.
- No account the commitment charge following the Japan's loan condition.
- Administration expenses for the executing agency are estimated at 5.0% of the total construction cost.
- Price contingency is estimated at 2.4% for foreign currency portion which is G7 countries' average annual inflation rates of CPI in 2004 to 2008. For the local currency portion, 7.32% average annual inflation rate is applied based on CPI in 2004 to 2008 of Lao PDR.
- Physical contingency is estimated at 10% of total construction cost and 5.0% of total consultant services cost.
- Annual disbursement schedule is estimated based on the estimated costs and overall implementation schedule.

(2) Financial Cost of the Project

The financial cost estimated in the basic design stage is summarized below. Total fund requirement is shown in Appendices I-4 and I-5.

Financial Cost without the removal cost of rock outcrops

Total of foreign currency portion (FC)	: JPY 5,546 million	(= US$ 58.4 million)
Total of local currency portion (LC)	: Kip 122,224 million	(= US$ 14.4 million)
Total of FC and LC	: JPY 6,910 million	(= US$ 72.7 million)

Financial Cost with the removal cost of rock outcrops

Total of foreign currency portion (FC)	: JPY 5,621 million	(= US$ 59.2 million)
Total of local currency portion (LC)	: Kip 124,066 million	(= US$ 14.6 million)
Total of FC and LC	: JPY 7,006 million	(= US$ 73.7 million)

(3) Summary of Direct Construction Cost

Appendices I-6 and I-7 show the summary of estimated direct construction cost. Grand total of direct construction cost is estimated to be Japanese Yen 5,448 million equivalent, including the costs for removal of rock outcrops and consulting services, with the following cost components.

Direct Construction Cost without the removal cost of rock outcrops

Civil works:	JPY	2,446 million
Hydro-mechanical work:	JPY	307 million
Electro-mechanical works:	JPY	1,882 million
Consulting services:	JPY	739 million
Total:	JPY	5,374 million

Direct Construction Cost with the removal cost of rock outcrops

Civil works:	JPY	2,520 million
Hydro-mechanical work:	JPY	307 million
Electro-mechanical works:	JPY	1,882 million
Consulting services:	JPY	739 million
Total:	JPY	5,448 million

CHAPTER 12 ECONOMIC AND FINANCIAL ANALYSIS

12.1 ECONOMIC ANALYSIS

12.1.1 METHODOLOGY

The economic analysis aims at measuring the economic benefits of the expansion project to the national economy. The cost-benefit analysis will be performed by applying the discounted cash flow method based on economic values. Indices used in this economic evaluation are Economic Internal Rate of Return (EIRR), Net Present Value (NPV) and Benefit-Cost (B/C) Ratio.

The EIRR is a discount rate at which the present value of two cash flows, i.e., benefit and cost, becomes equal, as defined in the following equation:

$$\sum_{t=0}^{n} C_t / (1+r)^t - \sum_{t=0}^{n} B_t / (1+r)^t = 0$$

Where;

C_t : Cost
B_t : Benefit
t : Year
n : Project Life (Year)
r : Discount Rate (= EIRR)

12.1.2 BASIC ASSUMPTIONS

The following basic assumptions are adopted in the analysis with reference to the existing reports for the similar projects in Lao PDR and technical discretion by the study team:, the following basic assumptions are adopted in the analysis.

(1) Opportunity Cost of Capital (Social Discount Rate)

The opportunity cost of capital refers to an interest rate at which the appropriateness of an investment can be justified by comparing with the EIRR of a particular project. A rate of 10% is used based on the rates used for other projects in Lao PDR, such as “Master Plan Study on Small-hydro in Northern Laos” (JICA, 2005). This rate is used as the discount rate to calculate present values.

(2) Standard Conversion Factor

The standard conversion factor of 0.95, which is widely used in similar projects with international organizations, is applied as coefficient to calculate the economic price of the local currency portion of the construction costs originally expressed in market price.

(3) Project Life (Calculation Period)

The project life for the analysis is 55 years; i.e. 50 years of service life of civil work facilities and five years of construction period.

(4) Cost Estimate

Estimation of costs is based on the price level of 2009. Costs of the existing facilities constructed before the project is considered as sunk cost and excluded from the analysis.

(5) Price Escalation

Price escalation is not considered in the analysis; economic values are expressed in constant price.

(6) Tax

Taxes and duties such as VAT are considered as transfer items and excluded from the analysis.

(7) Interest during Construction

Interest during construction is excluded from the calculation since the analysis aims at calculation of the project IRR of total capital used.

12.1.3 ECONOMIC COST OF THE PROJECT

The economic cost of the project is calculated based on the project cost estimation presented in Chapter 11. The annual operation and maintenance (O&M) cost and reinvestment (replacement cost) are also estimated. The economic cost is calculated by excluding transfer items such as taxes and conversion of the local currency portion with the standard conversion factor presented above.

(1) Initial Investment (Construction Cost)

The initial investment at economic price sorted by major item is shown in the table below.

Table 12.1.1 Initial Investment Cost (Economic Price)

Description	1st Year		2nd Year		3rd Year		4th Year		5th Year		Total		
	FC	LC	FC	LC	FC	LC	FC	LC	FC	LC	FC	LC	Total
I. Construction Cost													
Civil Works	0	0	1,824	306	7,295	1,223	7,295	1,223	5,471	917	21,886	3,669	25,555
Hydro-mechanical Works	0	0	229	38	916	154	916	154	687	115	2,749	461	3,210
Electro-mechanical Works	0	0	1,403	235	5,612	941	5,612	941	4,209	706	16,836	2,822	19,658
Total Base Cost	0	0	3,456	579	13,823	2,317	13,823	2,317	10,368	1,738	41,470	6,952	48,423
Physical Contingency (10%)	0	0	346	58	1,382	232	1,382	232	1,037	174	4,147	695	4,842
Total Construction Cost	**0**	**0**	**3,801**	**637**	**15,206**	**2,549**	**15,206**	**2,549**	**11,404**	**1,912**	**45,617**	**7,648**	**53,265**
II. Consulting Services													
Base Cost	1,288	38	1,309	45	1,552	61	1,671	64	1,664	67	7,484	276	7,760
Physical Contingency (5%)	64	2	65	2	78	3	84	3	83	3	374	14	388
Total Construction Cost	**1,352**	**40**	**1,375**	**47**	**1,629**	**64**	**1,755**	**68**	**1,747**	**71**	**7,859**	**289**	**8,148**
III. Administration Cost													
Administration Cost	**0**	**68**	**0**	**297**	**0**	**1,020**	**0**	**1,059**	**0**	**844**	**0**	**3,289**	**3,289**
TOTAL (I to III)	**1,352**	**108**	**5,176**	**982**	**16,835**	**3,633**	**16,961**	**3,676**	**13,151**	**2,827**	**53,476**	**11,226**	**64,702**
TOTAL (FC + LC)	**1,461**		**6,158**		**20,468**		**20,637**		**15,978**		**64,702**		

Prepared by JICA Survey Team

(2) O&M Cost

The annual O&M cost of the constructed facilities are calculated based on the following conditions:

- Civil Works： 0.5% of initial investment cost of civil works excluding temporary works
- Hydro-mechanical Works: (i) 0.75% of initial investment for the intake gate and hoist
  (ii) 0.25% of initial investment cost of trash rack and stop log

- Electro-mechanical Works: 1% of initial investment for total electro-mechanical works

Table 12.1.2 O&M Cost (Economic Price)

(US$1,000)

Item	Construction Cost (incl. Physical Contingency)	Factor	O&M Cost
Civil Works (excl. Tenporary Works)	10,784	0.50%	54
Hydro-mechanical Works			
Intake Gate and Hoist	1,573	0.75%	12
Trash Rack and Stop Log	503	0.25%	1
Electro-mechanical Works	21,424	1.00%	214
Total	---	---	281

Prepared by the JICA Survey Team

(3) Reinvestment (Replacement Cost of Equipment)

The reinvestment cost is estimated for hydro-mechanical and electro-mechanical works over a period of 30 years after commissioning.

- Hydro-mechanical Works: 5% of initial investment for intake gate and hoist
- Electro-mechanical Works： (i) 70% of initial investment for turbine and generator
  (ii) 100% of initial investment for other equipment

Table 12.1.3 Reinvestment Cost (Economic Price)

(US$1,000)

Item	Construction Cost (incl. Physical Contingency)	Factor	Reinvestment Cost
Hydro-mechanical Works	1,573	5%	79
Electro-mechanical Works			
Turbine and Generator	17,132	70%	11,992
Others	4,292	100%	4,292
Total	---	---	16,363

Prepared by the JICA Survey Team

12.1.4 ECONOMIC BENEFIT

The economic benefit of the project is the incremental benefit between “without project” case and “with project” case. In this analysis the benefit is estimated as the economic value of the alternative power source to NN-1 hydropower station. In the current situation of the C1 grid, the imported power from Thailand could be regarded as the alternative power source to the project. However, as mentioned in 12.4, EdL and EGAT of Thailand interchange energy to each other and the electricity tariffs set for the cross-border trade are on low level so that it is not appropriate to estimate the project’s benefit based on such tariff level.

For this purpose, the economic benefit is measured by the capacity benefit (kW value) and the energy benefit (kWh value) increased by the expansion project through valuation of alternative thermal power. Another economic benefit of the project is the O&M cost saving derived from the expansion project for the existing generation units No. 1 to 5.

(1) Alternative Thermal Power

In the alternative thermal power method, the costs of construction and operation of an alternative thermal power plant are assumed as the economic benefit of the subject hydropower station. The capacity benefit (kW value) of the hydropower is represented by the annualized construction cost and fixed operational cost; and the energy benefit (kWh value) is calculated as the variable costs of the thermal power such as fuel cost.

The alternative thermal power for the evaluation should be suitable to the domestic energy supply situation. Lao PDR is a landlocked country and its product imports for primary energy are basically limited to land transport. Its petroleum product supply for transport and domestic uses is dependent on imports from neighboring countries like Thailand. The country imported approximately 2.8 million barrels of petroleum products in 2006, of which gasoline accounts for 30%, diesel fuel for 65% and heavy fuel oil for 1% (DOE information). Diesel power plant fueled with heavy oil is considered as the alternative thermal power rather than natural gas-fired power plant because of difficulty in fuel import and transport. On the other hand, PDP plans construction of lignite thermal power plants in Hongsa and Viengphukha in the northern region. However, lignite coal-fired power is normally considered as base power supply and has limited mobility to meet peak demand thus deemed unsuitable to be an alternative to the hydropower station.

The data of two types of diesel power plants i.e. middle-speed and low-speed diesel power plants (retrieved from the existing JICA study in Cambodia) are used to estimate the kW and kWh values. As mentioned above, lignite thermal power is not applied because it does not have flexible mobility, and PDP plans this to be used only as base power supply with capacity as large as 1,500 MW with 80% plant factor.

1) Adjustment Factors

First, the adjustment factors are calculated to adjust the difference between thermal power and hydropower in power and energy loss rates (see table below).

Table 12.1.4 Adjustment Factors of Thermal Plant

Item	Hydropower		Diesel Power /1	
Transmission Loss	6.00%	A	6.00%	E
Overhaul and maintenance /2	0.00%	B	7.67%	F
Auxiliary Power Consumption	0.50%	C	4.60%	G
Forced outage	0.50%	D	2.19%	H
kW Adjustment Factor /3	-		1.149	I
kWh Adjustment Factor /4	-		1.043	J

Notes:
/1 Feasibility Study on The Sihanoukville Combined Cycle Power Development Project in The Kingdom of Cambodia, JICA (Jan 2002)
/2 Scheduled overhaul and maintenance of hydropower is taken into calculation of energy generation
/3 I = ((1-A)*(1-B)*(1-C)*(1-D)) / ((1-E)*(1-F)*(1-G)*(1-H))
/4 J = ((1-A)*(1-C)) / ((1-E)*(1-G))
Prepared by the JICA Survey Team

2) kW Value

The kW values are calculated based on the construction and fixed operating costs of the two types of diesel power plants as illustrated in the following table.

Table 12.1.5 Calculation of kW Value

	Item	Unit	Middle Speed Diesel Power (90MW/unit)	Low Speed Diesel Power (90MW/unit)
A	Construction Cost per kW	US$/kW	1,370.0	2,020.0
B	*Adjusted for Price Escalation*	US$/kW	*1,804.4*	*2,660.6*
C	Economic Life	Years	20	20
D	Discount Rate		10%	10%
E	Capital Recovery Factor		0.1175	0.1175
F	Fixed O&M Cost	US$/kW	21.0	21.0
G	*Adjusted for Price Escalation*	US$/kW	*27.7*	*27.7*
H	kW Adjustment Factor		1.149	1.149
I	kW Value (Power Value)	US$/kW	275.35	390.91

Notes:
A, C, F - Feasibility Study on The Sihanoukville Combined Cycle Power Development Project in The Kingdom of Cambodia, JICA (Jan 2002)
B, G - Adjusted for average inflation rates of world prices (2002-2008: 131.71%): retreived from World Economic Outlook, IMF (April 2009)
I = (G + B * E) * H
Prepared by JICA Survey Team

3) kWh Value

The kWh values are calculated based on fuel cost and variable cost of the diesel power as shown in the following table.

Table 12.1.6 Calculation of kWh Value

Item		Unit	Middle Speed Diesel Power (90MW/unit)	Low Speed Diesel Power (90MW/unit)
A	Fuel Type		Heavy Fuel Oil	Heavy Fuel Oil
B	Fuel Price	US$/L	0.3587	0.3587
C	Caloric Value	kcal/L	9,958	9,958
D	Thermal Efficiency		43%	49%
E	Heat Rate	kcal/kWh	2,000.0	1,755.1
F	Fuel Amount	L/kWh	0.2008	0.1763
G	Fuel Cost	US$/kWh	0.0720	0.0632
H	Variable O&M Cost	US$/kWh	0.003	0.003
I	kWh Value Adjustment Factor		1.043	1.043
J	kWh Value (Energy Value)	US$/kW	0.0783	0.0691

Notes:

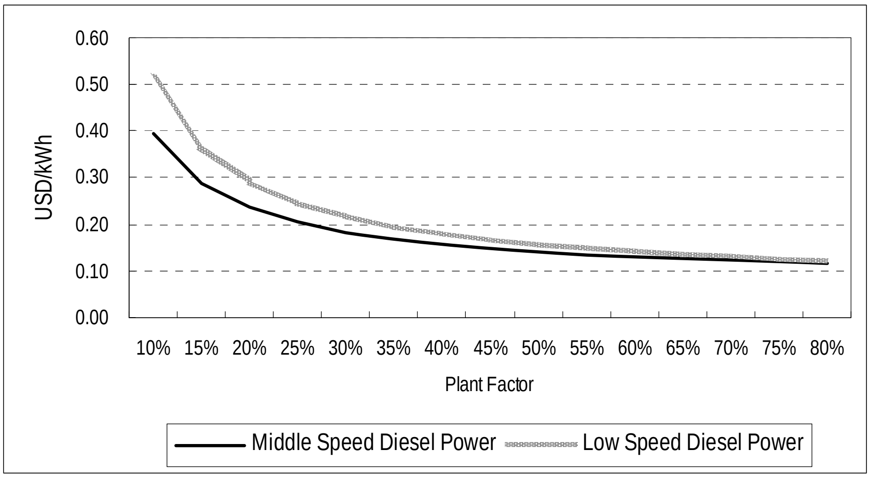
A, C, D, H- Feasibility Study on The Sihanoukville Combined Cycle Power Development Project in The Kingdom of Cambodia, JICA (Jan 2002)

B - Fuel Oil CIF average price per litre: Lao State Fuel Company (May 2009)

J = (G + H) * I

Prepared by JICA Survey Team

Figure 12.1.1 below shows that the middle-speed diesel power station is more cost efficient than the low-speed diesel power station; hence, the middle-speed diesel power station is adopted as the alternative thermal power for the analysis.



Prepared by JICA Survey Team

Figure 12.1.1 Per kWh Value of Diesel Power Plants

4) Calculation of Annual Benefit

The following table shows the calculation of economic benefit based on kW and kWh values as well as generated energy and dependable capacity of the expansion project.

Table 12.1.7 Annual Energy and Capacity Benefits

Item	Unit	Without Project	With Project	Net
Annual Energy				
Year 2015 -	GWh	1,067.85	1,121.47	53.62
Year 2020 -	GWh	1,072.75	1,144.80	72.05
Year 2025 -	GWh	1,071.16	1,114.98	43.81
Dependable Peak Capacity				
Year 2015 -	MW	67.9	108.5	40.63
Year 2020 -	MW	78.2	115.9	37.69
Year 2025 -	MW	76.0	101.4	25.40
Energy Benefit: kWh Value (US$0.0783/kWh)				
Year 2015 -	US$1,000	83,579	87,776	4,197
Year 2020 -	US$1,000	83,963	89,603	5,639
Year 2025 -	US$1,000	83,839	87,268	3,429
Capacity Benefit: kW Value (US$275.35/kW)				
Year 2015 -	US$1,000	18,688	29,875	11,188
Year 2020 -	US$1,000	21,526	31,904	10,378
Year 2025 -	US$1,000	20,920	27,914	6,994
Total Annual Benefit				
Year 2015 -	US$1,000	102,267	117,652	15,385
Year 2020 -	US$1,000	105,489	121,507	16,018
Year 2025 -	US$1,000	104,758	115,182	10,423

Prepared by JICA Survey Team

(2) Reduction of O&M Cost for Existing Generation Units

The expansion project will improve the operational efficiency of the whole power station. Thus it is envisaged that the project will result to reduction of the O&M cost of the existing generation units. As shown in Table 12.1.8, the average reduction in the operation time rate will be 12.4% in the with-project case. Therefore, an annual savings of US$281 thousand on the O&M cost of the existing units (US$1,090 thousand for 155MW in total, estimated from the O&M cost of the 40MW expansion unit, US$136 thousand) will be realized.

Table 12.1.8 Operation Time Rate and O&M Cost Saving

Item	Unit	Without Project	With Project	Change %
Operation Rate (Unit No.1-No.5)				
Year 2015 -		80.5%	69.2%	14.1%
Year 2020 -		79.3%	71.2%	10.3%
Year 2025 -		79.7%	69.4%	13.0%
Average		-	-	**12.4%**
O&M Cost (Unit No.1-No.5)	US$1,000	1,090	954	**136**

* O&M Cost of Unit No.1 - 5 = Unit No.6 O&M Cost / 40MW * 155 MW

Prepared by JICA Survey Team

12.1.5 CALCULATION OF EIRR

The cash flow projection is developed based on the economic cost and benefit presented above. Based on Table 12.1.9, the calculated EIRR is 17.68%. The computed NPV is US$36,758 thousand and B/C is 1.76 with 10% discount rate. The results show the EIRR exceeding the 10% social discount rate and with positive NPV value. Therefore, the project is evaluated economically feasible.

Table 12.1.9 Calculation of EIRR

	Year	Cost			Benefit				
	Year	Construction and Reinvestment	Operation and Maintenance	**Total**	Capacity Benefit	Energy Benefit	Unit No.1-5 OM Cost Saving	**Total**	**Net Benefit**
1	2010	1,461	0	**1,461**	0	0	0	**0**	**-1,461**
2	2011	6,158	0	**6,158**	0	0	0	**0**	**-6,158**
3	2012	20,468	0	**20,468**	0	0	0	**0**	**-20,468**
4	2013	20,637	0	**20,637**	0	0	0	**0**	**-20,637**
5	2014	15,978	0	**15,978**	0	0	0	**0**	**-15,978**
6	2015	0	281	**281**	11,188	4,197	135	**15,520**	**15,239**
7	2016	0	281	**281**	11,188	4,197	135	**15,520**	**15,239**
8	2017	0	281	**281**	11,188	4,197	135	**15,520**	**15,239**
9	2018	0	281	**281**	11,188	4,197	135	**15,520**	**15,239**
10	2019	0	281	**281**	11,188	4,197	135	**15,520**	**15,239**
11	2020	0	281	**281**	10,378	5,639	135	**16,153**	**15,872**
12	2021	0	281	**281**	10,378	5,639	135	**16,153**	**15,872**
13	2022	0	281	**281**	10,378	5,639	135	**16,153**	**15,872**
14	2023	0	281	**281**	10,378	5,639	135	**16,153**	**15,872**
15	2024	0	281	**281**	10,378	5,639	135	**16,153**	**15,872**
16	2025	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
17	2026	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
18	2027	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
19	2028	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
20	2029	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
21	2030	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
22	2031	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
23	2032	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
24	2033	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
25	2034	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
26	2035	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
27	2036	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
28	2037	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
29	2038	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
30	2039	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
31	2040	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
32	2041	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
33	2042	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
34	2043	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
35	2044	16,363	281	**16,644**	6,994	3,429	135	**10,558**	**-6,086**
36	2045	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
37	2046	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
38	2047	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
39	2048	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
40	2049	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
41	2050	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
42	2051	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
43	2052	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
44	2053	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
45	2054	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
46	2055	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
47	2056	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
48	2057	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
49	2058	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
50	2059	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
51	2060	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
52	2061	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
53	2062	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
54	2063	0	281	**281**	6,994	3,429	135	**10,558**	**10,277**
55	2064	-5,454	281	**-5,173**	6,994	3,429	135	**10,558**	**15,731**
Total		75,611	14,061	**89,672**	387,586	186,348	6,756	**580,691**	**491,019**
Discount Rate:		10.0%	PV (Cost):	48,096			PV (Benefit):	84,855	
								EIRR:	**17.68%**
								NPV:	**36,758**
								B/C:	**1.76**

Prepared by the JICA Survey Team

12.1.6 SENSITIVITY ANALYSIS

(1) Conditions for Analysis

The sensitivity of the economic evaluation indices is analyzed in the following cases with different conditions.

Case 1 The project cost increase by (a) 10%; (b) 20%

Case 2 The fuel cost of alternative thermal power decreases by (a) 10%; (b) 20%

Case 3 The project cost increases by 20% and the fuel cost of alternative thermal power decreases by 20%

(2) Results

The results of the sensitivity analysis are shown in Table 12.1.10 below. The computed EIRRs in the different cases range from 14.08% to 17.21% which exceed the 10% discount rate. Even in Case 3 with the most unfavorable conditions, the project shows that it is still economically feasible.

Table 12.1.10 Results of Sensitivity Analysis

Case	1a	1b	2a	2b	3
EIRR	16.20%	14.92%	17.21%	16.73%	14.08%

Prepared by JICA Survey Team

12.2 FINANCIAL ANALYSIS

12.2.1 METHODOLOGY

The financial analysis aims at evaluating the project's financial profitability from the executing agency's viewpoint through calculation of the financial internal rate of return (FIRR). The same assumptions in economic analysis are applied for the project life, cost estimation, price escalation, and interest during construction.

12.2.2 FINANCIAL COST

The costs of the expansion project consist of the initial investment cost (construction cost) estimated at market price in Chapter 11, the O&M cost and the reinvestment (replacement cost) calculated based on the conditions presented in the economic analysis.

(1) Initial Investment (Construction Cost)

Table 12.2.1 shows the initial investment (construction cost) at financial price by major item.

Table 12.2.1 Initial Investment Cost (Financial Price)

(US$1,000)

Description	1st Year		2nd Year		3rd Year		4th Year		5th Year		Total		
	FC	LC	FC	LC	FC	LC	FC	LC	FC	LC	FC	LC	Total
I. Construction Cost													
Civil Works	0	0	1,824	322	7,295	1,287	7,295	1,287	5,471	966	21,886	3,862	25,748
Hydro-mechanical Works	0	0	229	40	916	162	916	162	687	121	2,749	485	3,234
Electro-mechanical Works	0	0	1,403	248	5,612	990	5,612	990	4,209	743	16,836	2,971	19,807
Total Base Cost	0	0	3,456	610	13,823	2,439	13,823	2,439	10,368	1,830	41,470	7,318	48,789
Physical Contingency (10%)	0	0	346	61	1,382	244	1,382	244	1,037	183	4,147	732	4,879
Total Construction Cost	**0**	**0**	**3,801**	**671**	**15,206**	**2,683**	**15,206**	**2,683**	**11,404**	**2,013**	**45,617**	**8,050**	**53,667**
II. Consulting Services													
Base Cost	1,288	40	1,309	47	1,552	64	1,671	68	1,664	71	7,484	290	7,775
Physical Contingency (5%)	64	2	65	2	78	3	84	3	83	4	374	15	389
Total Construction Cost	**1,352**	**42**	**1,375**	**50**	**1,629**	**67**	**1,755**	**71**	**1,747**	**74**	**7,859**	**305**	**8,163**
III. Administration Cost													
Administration Cost	**0**	**72**	**0**	**313**	**0**	**1,074**	**0**	**1,115**	**0**	**889**	**0**	**3,462**	**3,462**
TOTAL (I to III)	**1,352**	**114**	**5,176**	**1,034**	**16,835**	**3,824**	**16,961**	**3,870**	**13,151**	**2,976**	**53,476**	**11,817**	**65,293**
TOTAL (FC + LC)	**1,466**		**6,210**		**20,659**		**20,830**		**16,127**		**65,293**		

Prepared by JICA Survey Team

(2) O&M Cost

Table 12.2.2 shows the O&M cost of the project including physical contingency.

Table 12.2.2 O&M Cost (Financial Price)

(US$1,000)

Item	Construction Cost (incl. Physical Contingency)	Factor	O&M Cost
Civil Works (excl. Tenporary Works)	10,866	0.50%	54
Hydro-mechanical Works			
Intake Gate and Hoist	1,585	0.75%	12
Trash Rack and Stop Log	507	0.25%	1
Electro-mechanical Works	21,586	1.00%	216
Total	---	---	283

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(3) Reinvestment (Replacement Cost)

Table 12.2.3 shows the reinvestment cost (replacement cost) of the project including physical contingency.

Table 12.2.3 Reinvestment Cost (Financial Price)

(US$1,000)

Item	Construction Cost (incl. Physical Contingency)	Factor	Reinvetment Cost
Hydro-mechanical Works	1,585	5%	79
Electro-mechanical Works			
Turbine and Generator	17,261	70%	12,083
Others	4,325	100%	4,325
Total	---	---	16,487

Prepared by the JICA Survey Team

12.2.3 FINANCIAL BENEFIT

(1) Electricity Tariff Revenue

The increase in electricity tariff revenue brought about by the project is the financial benefit of the project. The table below shows the electricity revenue calculated based on the average domestic tariff in 2008 (USc6.21/kWh) and the projection of energy sold throughout the project life.

Table 12.2.4 Financial Benefit (Electricity Revenue)

Item	Unit	Without Project	With Project	Net
Annual Energy				
Year 2015 -	GWh	1,067.85	1,121.47	53.62
Year 2020 -	GWh	1,072.75	1,144.80	72.05
Year 2025 -	GWh	1,071.16	1,114.98	43.81
Loss Rates				
Transmission Loss	%	6.0%	6.0%	
Auxiliary Consumption	%	0.5%	0.5%	
Forced Outage	%	0.5%	0.5%	
Electricity Sold				
Year 2015 -	GWh	993.77	1,043.67	49.90
Year 2020 -	GWh	998.33	1,065.38	67.05
Year 2025 -	GWh	996.85	1,037.62	40.77
Electricity Revenue (US$0.0621/kWh)				
Year 2015 -	US$1,000	61,713	64,812	3,099
Year 2020 -	US$1,000	61,996	66,160	4,164
Year 2025 -	US$1,000	61,904	64,436	2,532

Prepared by the JICA Survey Team

(2) Reduction of O&M Cost for Existing Generation Units

As explained in the economic analysis, it is envisaged that one of the effects of the project will be the reduction of the O&M cost of the existing generation units. As shown in the following table, the average reduction in operation time rate will be 12.4% in the with-project case. Therefore, it is estimated that an annual reduction of US$283 thousand in the O&M cost of the existing units (US$1,098 thousand in total for 155MW, estimated from the O&M cost of the 40MW expansion unit which is US$136 thousand) will be realized.

Table 12.2.5 Operation Time Rate and O&M Cost Saving

Item	Unit	Without Project	With Project	Change
Operation Rate (Unit No.1-No.5)				
Year 2015 -		80.5%	69.2%	14.1%
Year 2020 -		79.3%	71.2%	10.3%
Year 2025 -		79.7%	69.4%	13.0%
Average		-	-	**12.4%**
O&M Cost (Unit No.1-No.5)	US$1,000	1,098	962	**136**

Prepared by the JICA Survey Team

12.2.4 CALCULATION OF FIRR

The cash flow projection is developed based on the aforementioned financial cost and benefit to calculate the FIRR tabulated in Table 12.2.6. The calculated FIRR is only 2.75%. Cheap domestic tariff level is considered as a major factor contributory to the low FIRR. The increase in peak capacity cannot be reflected in the FIRR calculation because of the absence of TOD rates in the domestic tariff system. It is considered that a concessionary loan such as ODA Loan will be necessary to enhance the financial viability of the project.

Table 12.2.6 Calculation of FIRR

	Year	Cost			Benefit			Net Benefit
		Construction and Reinvestment	Operation and Maintenance	Total	Incremental Revenue	Unit No.1-5 OM Cost Saving	Total	
1	2010	1,466	0	**1,466**	0	0	**0**	**-1,466**
2	2011	6,210	0	**6,210**	0	0	**0**	**-6,210**
3	2012	20,659	0	**20,659**	0	0	**0**	**-20,659**
4	2013	20,830	0	**20,830**	0	0	**0**	**-20,830**
5	2014	16,127	0	**16,127**	0	0	**0**	**-16,127**
6	2015	0	283	**283**	3,099	136	**3,235**	**2,952**
7	2016	0	283	**283**	3,099	136	**3,235**	**2,952**
8	2017	0	283	**283**	3,099	136	**3,235**	**2,952**
9	2018	0	283	**283**	3,099	136	**3,235**	**2,952**
10	2019	0	283	**283**	3,099	136	**3,235**	**2,952**
11	2020	0	283	**283**	4,164	136	**4,300**	**4,017**
12	2021	0	283	**283**	4,164	136	**4,300**	**4,017**
13	2022	0	283	**283**	4,164	136	**4,300**	**4,017**
14	2023	0	283	**283**	4,164	136	**4,300**	**4,017**
15	2024	0	283	**283**	4,164	136	**4,300**	**4,017**
16	2025	0	283	**283**	2,532	136	**2,668**	**2,385**
17	2026	0	283	**283**	2,532	136	**2,668**	**2,385**
18	2027	0	283	**283**	2,532	136	**2,668**	**2,385**
19	2028	0	283	**283**	2,532	136	**2,668**	**2,385**
20	2029	0	283	**283**	2,532	136	**2,668**	**2,385**
21	2030	0	283	**283**	2,532	136	**2,668**	**2,385**
22	2031	0	283	**283**	2,532	136	**2,668**	**2,385**
23	2032	0	283	**283**	2,532	136	**2,668**	**2,385**
24	2033	0	283	**283**	2,532	136	**2,668**	**2,385**
25	2034	0	283	**283**	2,532	136	**2,668**	**2,385**
26	2035	0	283	**283**	2,532	136	**2,668**	**2,385**
27	2036	0	283	**283**	2,532	136	**2,668**	**2,385**
28	2037	0	283	**283**	2,532	136	**2,668**	**2,385**
29	2038	0	283	**283**	2,532	136	**2,668**	**2,385**
30	2039	0	283	**283**	2,532	136	**2,668**	**2,385**
31	2040	0	283	**283**	2,532	136	**2,668**	**2,385**
32	2041	0	283	**283**	2,532	136	**2,668**	**2,385**
33	2042	0	283	**283**	2,532	136	**2,668**	**2,385**
34	2043	0	283	**283**	2,532	136	**2,668**	**2,385**
35	2044	16,487	283	**16,770**	2,532	136	**2,668**	**-14,102**
36	2045	0	283	**283**	2,532	136	**2,668**	**2,385**
37	2046	0	283	**283**	2,532	136	**2,668**	**2,385**
38	2047	0	283	**283**	2,532	136	**2,668**	**2,385**
39	2048	0	283	**283**	2,532	136	**2,668**	**2,385**
40	2049	0	283	**283**	2,532	136	**2,668**	**2,385**
41	2050	0	283	**283**	2,532	136	**2,668**	**2,385**
42	2051	0	283	**283**	2,532	136	**2,668**	**2,385**
43	2052	0	283	**283**	2,532	136	**2,668**	**2,385**
44	2053	0	283	**283**	2,532	136	**2,668**	**2,385**
45	2054	0	283	**283**	2,532	136	**2,668**	**2,385**
46	2055	0	283	**283**	2,532	136	**2,668**	**2,385**
47	2056	0	283	**283**	2,532	136	**2,668**	**2,385**
48	2057	0	283	**283**	2,532	136	**2,668**	**2,385**
49	2058	0	283	**283**	2,532	136	**2,668**	**2,385**
50	2059	0	283	**283**	2,532	136	**2,668**	**2,385**
51	2060	0	283	**283**	2,532	136	**2,668**	**2,385**
52	2061	0	283	**283**	2,532	136	**2,668**	**2,385**
53	2062	0	283	**283**	2,532	136	**2,668**	**2,385**
54	2063	0	283	**283**	2,532	136	**2,668**	**2,385**
55	2064	-5,496	283	**-5,212**	2,532	136	**2,668**	**7,880**
Total		76,284	14,167	**90,451**	137,595	6,807	**144,402**	**53,951**

FIRR:	**2.75%**

Prepared by JICA Survey Team

12.2.5 SENSITIVITY ANALYSIS

(1) Conditions for Analysis

The sensitivity of the FIRR is analyzed in the following cases with different conditions.

Case 1 (a) 10% increase, (b) 20% increase in the project cost

Case 2 Electricity tariff variations:

(a) 1,274 kip/kWh (USc14.97/kWh), proposed as "Base Investment Case" in "Tariff Study Update 2009" by World Bank;

(b) 720 kip/kWh (USc8.79/kWh) proposed as "Low Investment Case" in the said study;

(c) USc7.45/kWh, equivalent to 120% of the tariff level in 2008

Case 3 Project cost increase variations in the "Low Investment Case" tariff (USc8.79/kWh)

(a) 10% increase; (b) 20% increase

(2) Results

The results of the sensitivity analysis are shown in the table below. The FIRRs in the different cases range from 1.67% to 9.75%, which exceed the current interest rate of JICA ODA Loan for Lao PDR (0.01% p.a.). However, low financial viability is observed in Case 1(a) and (b), with FIRR of only 2.17% and 1.67%, respectively, where construction cost is increased without tariff increase. It is suggested that a significant increase in tariff will improve the financial viability of the project.

Table 12.2.7 Results of Sensitivity Analysis

Case	1a	1b	2a	2b	2c	3a	3b
FIRR	2.17%	1.67%	9.75%	5.09%	3.92%	4.41%	3.81%

Prepared by JICA Survey Team

12.2.6 REVISION PLAN OF ELECTRICITY TARIFF

The sensitivity analysis for each electricity tariff variation is analyzed in the case 2 of the previous section. On the other hand, the latest revision plan of electricity tariff was obtained from EdL and the financial analysis with realistic revision plan of electricity tariff was carried out. The procedure of revision of electricity tariff, the previous revised contents, the latest revision plan of electricity tariff and the results of the financial analysis are summarized below.

(1) Procedure of Revision of Electricity Tariff

The departments concerned with the revision of electricity tariff are Business – Financial Division and Static Planning office of EdL. The procedure of revision of electricity tariff is shown below.

- Preparation of the revision plan of electricity tariff by EdL and confirmation of revision plan by DOE

- Submission of revision plan to the MEM from the DOE
- Submission of the revision plan to the Prime Minister by the MEM for approval
- Consultation in the economic survey unit under the direct control of the Prime Minister and discussion in the meeting with all Ministers
- Report of the results of discussion to the EdL through the MEM

(2) Previous Revision of Electricity Tariff

Following the procedure of revision of electricity tariff mentioned above, the revision plan of electricity tariff from 2005 to 2011 was proposed by the EdL and approved by the concerned agency on 24 July 2004. In this revision, the increase in electricity tariff for each category of power demand side was setup and the increase rate of 1 % of electricity tariff in average was approved. In particular, the increase rate of electricity tariff for the category of minor power consumer was setup to be more than 1 % and the electricity tariff for the category of governmental organization and industry is decreased.

(3) Latest Revision Plan of Electricity Tariff

The study on electricity tariff in Laos was carried out by the World Bank aiming at the review of electricity tariff of EdL and the final report was submitted in June 2009. In this study, the new tariff system was proposed on the basis of income of electric power selling required for the facility investment of EdL in future. As the results, the electricity tariff of 1,210 Kip/kWh as of 2015 which is quite higher than present electricity tariff of 530 Kip/kWh was proposed as a base case. This result was disclosed to the concerned agency in the workshop for the explanation of the final report and the proposed revision plan of electricity tariff was not accepted due to high increase ratio. Therefore, the other revision plan was studied and proposed which has electricity tariff of 720 Kip/kWh as of 2015 as a low case due to minimize the cost for facility investment of EdL. However, since the minimized cost for facility investment of EdL was setup to be low and unrealistic, the EdL decided to review it again.

As of November 2009, the EdL is finalizing the revision plan which has electricity tariff of 750 ~ 800 Kip/kWh as of 2015 as a middle case. The EdL intends to finalize the electricity tariff within this range and submit to the Lao government through the DOE and MEM.

The results of financial analysis for the latest revision plan of electricity tariff are shown below.

Table 12.2.8 Results of Sensitivity Analysis with Electricity Tariff Increase

Case	2015 Average Tariff Level	
	750 kip/kWh	800 kip/kWh
FIRR	5.11%	5.60%

Prepared by JICA Survey Team

12.3 EFFECT OF ROCK OUTCROPS EXCAVATION

This section discusses the economic and financial effects of removal of rock outcrops proposed in Chapter 10.

12.3.1 COST AND BENEFIT OF ROCK OUTCROPS EXCAVATION

(1) Economic Cost

The removal of rock outcrops will increase the civil works construction and administration costs to US$898 thousand at economic price, resulting in the initial investment cost of US$65,600 thousand, the O&M cost of US$285 thousand per year, and reinvestment of US$16,363 thousand.

Table 12.3.1 Cost Increase by Excavation (Economic Price)

(US$1,000)

Description	1st Year		2nd Year		3rd Year		4th Year		5th Year		Total		
	FC	LC	FC	LC	FC	LC	FC	LC	FC	LC	FC	LC	Total
I. Construction Cost													
Civil Works	0	0	55	9	221	37	221	37	166	28	663	112	775
Physical Contingency (10%)	0	0	6	1	22	4	22	4	17	3	66	11	77
Total	**0**	**0**	**61**	**10**	**243**	**41**	**243**	**41**	**182**	**31**	**729**	**123**	**852**
III. Administration Cost													
Administration Cost	**0**	**0**	**0**	**4**	**0**	**15**	**0**	**15**	**0**	**12**	**0**	**46**	**46**
TOTAL (I and III)	**0**	**0**	**61**	**14**	**243**	**56**	**243**	**56**	**182**	**43**	**729**	**169**	**898**
TOTAL (FC + LC)	**0**		**75**		**299**		**299**		**225**		**898**		

Prepared by JICA Survey Team

(2) Financial Cost

The financial costs of civil works and administration will also increase to US$906 thousand. The total initial investment will be US$66,199 thousand. Accordingly, the O&M cost and reinvestment is calculated as US$288 thousand per year and US$16,487 thousand, respectively.

Table 12.3.2 Cost Increase by Excavation (Financial Price)

Description	1st Year		2nd Year		3rd Year		4th Year		5th Year		Total		
	FC	LC	FC	LC	FC	LC	FC	LC	FC	LC	FC	LC	Total
I. Construction Cost													
Civil Works	0	0	55	10	221	39	221	39	166	29	663	117	780
Physical Contingency (10%)	0	0	6	1	22	4	22	4	17	3	66	12	78
Total	**0**	**0**	**61**	**11**	**243**	**43**	**243**	**43**	**182**	**32**	**729**	**129**	**858**
III. Administration Cost													
Administration Cost	**0**	**0**	**0**	**4**	**0**	**16**	**0**	**16**	**0**	**13**	**0**	**48**	**48**
TOTAL (I and III)	**0**	**0**	**61**	**15**	**243**	**59**	**243**	**59**	**182**	**45**	**729**	**177**	**906**
TOTAL (FC + LC)	**0**		**75**		**302**		**302**		**227**		**906**		

Prepared by the JICA Survey Team

(3) Benefit

The removal of rock outcrops will increase the annual generated energy by approximately 5 GWh and dependable capacity by 0.9-1.3 MW. This represents an increase in the economic benefit by US$633 thousand to US$764 thousand per year, and an increase in financial benefit of US$290 thousand to US$311 thousand per year.

Table 12.3.3 Incremental Benefit by Excavation

Item	Unit	With Project (Without Excavation)	With Project (Excavation)	Net
Annual Energy				
Year 2015 -	GWh	1,121.47	1,126.50	5.03
Year 2020 -	GWh	1,144.80	1,150.06	5.25
Year 2025 -	GWh	1,114.98	1,120.35	5.38
Dependable Peak Capacity				
Year 2015 -	MW	108.5	109.4	0.87
Year 2020 -	MW	115.9	117.1	1.28
Year 2025 -	MW	101.4	102.3	0.89
Economic Benefit				
Energy Benefit: kWh Value (US$0.0783/kWh)				
Year 2015 -	US$1,000	87,776	88,170	393
Year 2020 -	US$1,000	89,603	90,014	411
Year 2025 -	US$1,000	87,268	87,689	421
Capacity Benefit: kW Value (US$275.35/kW)				
Year 2015 -	US$1,000	29,875	30,115	239
Year 2020 -	US$1,000	31,904	32,257	353
Year 2025 -	US$1,000	27,914	28,160	246
Total Annual Benefit				
Year 2015 -	US$1,000	117,652	118,284	633
Year 2020 -	US$1,000	121,507	122,271	764
Year 2025 -	US$1,000	115,182	115,849	667
Financial Benefit				
Electricity Revenue (USc6.21/kWh, loss adjustment 0.931)				
Year 2015 -	US$1,000	64,812	65,102	290
Year 2020 -	US$1,000	66,160	66,464	304
Year 2025 -	US$1,000	64,436	64,747	311

Prepared by JICA Survey Team

12.3.2 RESULTS OF EIRR AND FIRR CALCULATION

The results of EIRR and FIRR calculations are presented in the following table. The improvement of both EIRR and FIRR values shows the economic and financial feasibility of the proposed rock outcrop removal.

Table 12.3.4 Results of EIRR and FIRR Calculation

	With Project (Without Excavation)	With Project (Excavation)
EIRR	17.68%	18.18%
FIRR	2.75%	3.30%

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12.4 EFFECTS TO ELECTRICITY TRADE BALANCE

As explained in 12.1.4, the economic analysis is made through the alternative thermal power method to calculate the project’s effect to the national economy. On the other hand, the imported energy could be also regarded as the alternative to the economic benefit of the project. Hence, in this section, the economic effect of the project to the electricity trade balance with Thailand (EGAT) is estimated based on the demand-supply forecast presented in Chapter 2, as supplement to the economic analysis through the alternative thermal power method.

(1) Electricity Trade Tariff

The current electricity trade tariff with EGAT is illustrated in Table 12.4.1. In C1, grid EdL exports its excess energy to EGAT and also imports energy as needed. The tariff system for C1 has characteristics of (i) small price difference between peak time and off-peak time and (ii) THB 0.19/kWh higher basic import tariff than export to EGAT. In case EdL imports exceed exports in a year, additional surcharge payment is required. The surcharge calculation is based on the domestic tariff in Thailand. In short, the excess import by EDL is virtually charged similar prices to those for large-scale customers in Thailand.

Table 12.4.1 Electricity Trade Tariff with EGAT

Exports

Export	to	Peak (Mon-Fri 09:00-22:00)	Off-peak (Mon-Fri 22:00-09:00, Holidays 24hrs)	Locations	Remarks
EDL	EGAT (Thailand)	THB 1.60 / kWh (4.70 US cents)	THB 1.20 / kWh (3.52 US cents)	Nam Ngum 1(C1) , Xeset 1 (South)	

Imports

Import	from	Peak (Mon-Fri 09:00-22:00)	Off-peak (Mon-Fri 22:00-09:00, Holidays 24hrs)	Locations	Remarks
EDL	EGAT (Thailand)	THB 1.79 / kWh (5.26 US cents)	THB 1.39 / kWh (4.08 US cents)	Vientiane (C1), Bolixamxai (C1), Khamouan (C2), Savannaket (C2), Bangyo	* For C1 and South PPAs: Surcharges applied in case of EDL annual trade deficit with EGAT
	EGAT (Thailand)	*THB 2.7595 / kWh (8.10 US cents)*	*THB 1.3185 / kWh (3.87 US cents)*	*Xepon Gold & Copper Mine (C2), Cement Factory (C2)*	*Fixed Service Charge, Demand Charge, Fuel Adjustment are applied*

* PPAs for C1 and South: The following surchage is applicable in case of EDL annual trade deficit with EGAT

Unit Price: Demand Charge = 74.14THB/kW
Energy Charge: Peak = 2.7595 THB/kWh, Off-peak = 1.3185THB/kWh
Ft (Fuel Adjustment) = Variable THB/kWh (Ministry of Energy, Thailand)
Servive Charge = 228.17THB/month (Fixed)

A. Normal Import Tariff (THB) = Annual Peak Import (kWh) * 1.79 THB/kWh + Annual Off-peak Import (kWh) * 1.39 THB/KWh
B. Identify the month of maximum energy consumption (kWh) by EDL:
(i) Demand Charge (THB) = Peak load of the month (kW) * 74.14THB/kW
(ii) Energy Charge (THB) = Peak Import of the month (kWh) * 2.7595 THB/kW + Off-peak Import of the month (kWh) * 1.3185 THB/kWh
(iv) Ft Charge (THB) = Total Import of the month * Ft (THB/kWh)
(v) Service Charge (THB) = 228.17 THB (Fixed)
(vi) Sum of (iii) to (vi) divided by Total Import of the Month (kWh) = Average Tariff (THB/kWh)
C. Average Normal Import Tariff (A. divided by total annual import) minus (vi) Average Tariff (THB/kWh) = Surcharge Unit Price (THB/kWh)
D. C. Surcharge Unit Price (THB/kWh) * Annual Excess Import (deficit) (kWh) = Surcharge Payment of the year (THB)

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(2) Change in Trade Balance by the Project

Table 12.4.2 shows the projected change in the electricity trade balance by the NN1 expansion. Peak power supply strengthened by the project will improve the trade balance with EGAT by US$3 million to US$4 million annually. Surcharge payments will also be reduced by around US$1.5 million where trade deficit of EdL is projected (year 2015, 2016 and 2025). These are regarded as the economic benefit of the project if the imported energy is deemed as the alternative to the energy from NN1 hydropower station.

Table 12.4.2 EdL Trade Deficit and Surcharge Payment

(US$1,000)

Year	EDL Trade Deficit with EGAT			EDL Surcharge Payment to EGAT		
	Without Project	With Project	Benefit	Without Project	With Project	Benefit
2015	96,097	92,642	*3,455*	54,741	53,222	*1,520*
2016	38,242	34,550	*3,693*	19,059	17,511	*1,548*
2017	-2,563	-6,106	*3,543*	-	-	-
2018	-25,981	-29,450	*3,470*	-	-	-
2019	-23,584	-27,079	*3,495*	-	-	-
2020	-38,000	-42,179	*4,179*	-	-	-
2021	-43,471	-47,648	*4,177*	-	-	-
2022	-28,890	-33,261	*4,371*	-	-	-
2023	-12,815	-17,050	*4,235*	-	-	-
2024	5,117	808	*4,308*	-	-	-
2025	24,494	21,430	*3,064*	14,556	13,065	*1,492*

Prepared by the JICA Survey Team

On the other hand, in the point of view of EdL, or the executing agency of the project, this projected change in trade balance could be also considered as financial benefit in its financial management.

(3) Estimation of EIRR

The EIRR is estimated by applying the improvement of trade balance as benefit (the benefit in 2025 is assumed for the yearly benefit from 2026). Other preconditions are adopted from the economic analysis. The calculated EIRR is 5.47%, which is lower than the discount rate of 10%. The low IRR in this analysis is primarily because of the low tariff level with small peak energy value. It does not necessarily reflect the economic value of alternative energy source to the project for Lao PDR.

CHAPTER 13 OPERATION AND MAINTENANCE PLAN

13.1 OPERATION AND MAINTENANCE FOR ELECTROMECHANICAL EQUIPMENT

The NN1 Hydropower Station has been operated for over 37 years by the power station staff. The power station has sufficient number of operators and maintenance crews with enough experience on O&M of the power station. Therefore, they will be able to manage the customary O&M of the additional equipment of unit 6 without the need for modification of their current organization.

13.1.1 OPERATION OF ADDITIONAL EQUIPMENT

The additional equipment will be operated under the following three operation modes in the same manner as the existing equipment:

(1) Remote-Automatic Operation

The remote-automatic operation is carried out from the existing control room in front of the remote control board for unit 6.

It will be applied to the daily operation of the additional equipment.

(2) Local-Automatic Operation

The local-automatic operation is carried out from the local control board to be installed in the new cubicle room next to the machine bay for Unit 6. The automatic start-stop operation of Unit 6 is performed under automatic sequential control with the aid of the programmable logic controller.

It will be utilized for the purpose of testing and trial operation or when the remote-automatic control system is out of service.

(3) Local-Manual Operation

The local-manual operation of the additional Unit 6 is carried out at the equipment bay in front of the governor cabinet, the turbine control cubicle, the generator excitation cubicle and the motor control centers for the associated auxiliary equipment.

The local-manual operation of the switchgear is carried out in front of its switchgear cubicles or its local control cabinet in the outdoor switchyard.

It will be carried out for the purpose of testing and trial operation after the associated equipment is overhauled, repaired or replaced.

13.1.2 MAINTENANCE OF ADDITIONAL EQUIPMENT

Ordinary maintenance work for the additional equipment will be carried out periodically in the same manner as the existing equipment to maintain their performance.

In addition to the ordinary maintenance works, overhauling of the turbine and generator is essentially required to be performed at least every five years, which includes carrying out detailed inspection and repair of the damaged parts to restore their performance.

However, the power station staffs have yet acquired satisfactory technical skills for dismantling and re-assembling turbines and generators, which are required for overhauling works. Therefore, upskilling of the maintenance crews and organization of an overhauling team with skilled workers are urgently needed.

13.1.3 SPARE PARTS

The following spare parts will be supplied for satisfactory operation of the additional equipment:

(1) Wearing parts, fuses, indicator lamps and other consumables for two years' operation.

(2) Gaskets, packing, seals and other materials to be replaced, determined during the interior inspections of the turbine and generator.

(3) Replacement materials necessary for carrying out one time overhauling of the turbine and generator.

(4) Spare parts for the components that are likely to be damaged during normal operating conditions.

13.2 MECHANICAL EQUIPMENT

(1) Intake Trashracks

1) Operation of trashracks

The intake trashracks are operated by the existing gantry crane. Because the width of the trashracks of the expansion plan is longer than the existing one, a new lifting beam will be provided for the trashracks of the expansion project. The trashracks will be lowered or raised one by one with the lifting beam.

2) Maintenance of trashracks

When the generator is stopped for annual maintenance, the trashracks will be removed from the bell mouth position to the dam crest. Maintenance works such as cleaning, checking/inspecting the damages/deformation of structure, repairing damaged parts and defects of painting will then be conducted.

(2) Intake Stoplogs

1) Operation of stoplogs

The intake stoplogs are operated by the existing gantry crane. Because the width of the stoplogs of expansion plan is longer than the existing one, a new lifting beam which will be commonly used for the intake trashracks will be provided for the expansion plan. Each segment of the stoplogs will be lowered or raised one by one using the lifting beam. The segment equipped with the bypass valve will be installed on top of the segments of stoplogs and the bypass valve will be opened with the lifting beam when the penstock is watered. The intake stoplogs will be operated under balanced condition.

2) Maintenance of stoplogs

The intake stoplogs are used for the maintenance of intake gate and steel penstock located upstream of the intake gate. The stoplogs will be removed from the bellmouth position to the dam crest and cleaned after maintenance of the gate/penstock. The stoplogs will be inspected for defects and/or damages and such damaged parts including defects of painting will be repaired before storage, if necessary.

(3) Intake Gate

1) Operation of intake gate

The intake gate is operated through the local or remote control panel. The intake gate is operated under balanced condition in normal case, but the gate can be closed under flow condition in case of shutdown operation. In case the intake gate is totally closed and the penstock gate downstream is dewatered, the penstock is watered with the bypass valves and the intake gate is opened under balanced condition after completion of maintenance of the generator.

2) Maintenance of intake gate

When maintenance of intake gate is required, the intake stoplogs are installed to stop water flow. The access is available through the manhole installed just downstream of the gate. The gate leaf and casing can be inspected when the gate leaf is either half or totally open and easy repair works can be undertaken at the site. The gate leaf will be removed from the casing/bonnet if large scale repair/rehabilitation is required. A mobile crane will be set on the working stage of the dam crest for removing the hydraulic cylinder with bonnet cover and gate leaf.

(4) Steel Penstock

The intake gate and draft tube stoplogs are closed and the steel penstock and draft tube are dewatered during maintenance of the generator and turbine. The steel penstock will be also inspected and maintained during the maintenance period. The manholes provided at the spiral casing and intake gate are used as access to the penstock. Safety equipment and/or tools are required for safely executing the inspection and maintenance of the inclined portion of the penstock.

CHAPTER 14 CONCLUSION ND RECOMMENDATIONS

The preparatory survey on Nam Ngum 1 Hydropower Station Expansion started in February 2009 with the aim of confirming the policy of the Government of Lao PDR on the implementation of the expansion of NN1 with Japanese funding. Based on the survey results, the expansion plan with 40 MW was judged to be feasible from the technical, economical & financial, and environmental view points. The conclusions and recommendations are discussed below.

14.1 CONCLUSION

(1) Background of Survey

In Laos, the domestic demand of peak power and energy are increasing at an average rate of 10% from 2000 up to 2006. It is expected that demand for domestic power and energy will increase rapidly in the future since the Government of Lao PDR aims at increasing the rate of household electrification and development of mines such as copper and bauxite. The existing power sources in Laos are insufficient to cover the rapid increase of power demand. The present power supply to the metropolitan area (C1 area) relies on Nam Ngum 1 (NN1) Power Station (155 MW), Nam Leuk Power Station (60 MW) and Nam Mang 3 Power Station (40 MW). Surplus power is exported to Thailand during wet season. However, during dry season, the country partially relies on power import from Thailand. Therefore, the development of additional power source in Lao PDR is important in view of energy security.

Based on the foregoing background, the Government of Lao PDR requested the cooperation on Nam Ngum 1 Hydropower Station Expansion from the Japanese Government, which has a lot of experience on hydropower development in Laos. In response to the request, the Japan International Cooperation Agency (JICA) confirmed and signed the Preparatory Survey on Nam Ngum 1 Hydropower Station Expansion on 10 February 2009. In the preparatory survey, the optimum expansion was selected from several alternatives and its feasibility was confirmed by technical (basic design), economic and financial evaluations.

(2) Power Demand and Supply

The present power supply to the C1 area relies on Nam Ngum 1 (NN1), Nam Leuk and Nam Mang 3 power stations. The amount of power generation for each power station is adjusted to meet the power demand. In the dry season of 2008, the total power output generated by the three power stations was insufficient to meet the power demand and C1 area has to import power from Thailand. On the other hand, the total generated power during rainy season is much higher than power demand and surplus power is exported to Thailand. As for the daily load curve in 2008, the peak load of a day appears at night time in which much lamp load is consumed and a middle peak load appears in daytime because of the load of business and factory use. The daytime middle peak distinctively occurs in week days, but on holidays, high peak does not appear.

(3) Purpose of Expansion of NN1

The necessity and adequacy of expansion of NN1 had roots in the following conditions:

1) Growth of night power demand in Laos;
2) Regulation of inflow into NN1 reservoir due to hydropower development in upstream of Nam Ngum River;
3) Aging of existing power generation facilities of NN1; and
4) Increase of transmission interchanging capacity with neighboring country.

Based on these conditions, the necessity and adequacy of the expansion plan of NN1 is described below.

The power demand in Laos is increasing rapidly, particularly the night peak demand. As a countermeasure to ensure the source of power supply over a short-term period, the expansion of NN1 is projected to concentrate its power generation in peak time instead on off-peak time. On the other hand, the NN2 power station will be constructed with huge reservoir just upstream of NN1 reservoir, and the inflow into NN1 reservoir will be regulated throughout the year. Due to this change of inflow pattern, power generation can be kept with relatively high reservoir water level and unnecessary water release through the spillway can be minimized. Subsequently, the increase of annual power generation can be expected due to the expansion.

The existing power generation facilities have been installed in series since 1971. All of the units are getting older although units No.1 and 2 have already been rehabilitated. The yearly maintenance is carried out only during the dry season to minimize invalid water release and there is no ample space to adjust the timing of the maintenance. The expansion of additional one unit would contribute not only the decrease of power generation time ratio and maintenance cost but also to the planning of maintenance with sufficient time period and safety power generation.

Furthermore, the total installed capacity of NN1 power station will become 195 MW due to the expansion and the surplus power generated during the rainy season would be exported to Thailand. In this regard, the existing transmission interchanging capacity of 100 MW with Thailand would be increased to 600 MW in 2016 and the limitation of power export would be resolved.

The balance of power demand and supply was studied based on the power demand forecast in C1 and northern areas and the latest information of EdL power development plan. As a result, the power supply would be short in 2015, and the generated power can be exported to the neighboring countries in the rainy season in 2020. The same situation would continue for several years and power supply will be short again in 2025 due to delay of power development for domestic power supply.

(4) Reservoir Operation

The reservoir operation plan of NN1 hydropower station is studied based on the observed hydrological data, existing data in the previous study report, and historical operation record. The Survey Team considered the expected change of flow regime into NN1 reservoir due to the commencement of NN2 hydropower operations in 2011. NN2 is located just upstream of NN1 reservoir and its existence is important for the NN1 expansion plan. After the commencement of NN2 hydropower, the river flow into NN1 reservoir will be regulated throughout the year because of the storage effect of the NN2 reservoir. By assuming NN2 commencement in 2011, the reservoir operation rules were developed for expansion scales of 40 MW, 60 MW, 80 MW and 120 MW. The energy production is estimated using the reservoir operation rule. The calculation resulted in additional annual energy production of 56 GWh for 40 MW expansion case. When the expansion capacity is more than 60 MW, the increment in the energy production is limited regardless of the magnitude of expansion scale. On the basis of these results, the expansion alternatives were compared with respect to the construction cost, and the 40 MW expansion plan was selected as the optimum plan.

The reservoir operation is further studied using characteristics of the additional 40 MW turbine and generator determined in the basic design. The reservoir operation study has two aspects of policies which are: 1) effective utilization of water resources as economic aspects, and 2) revenue improvement from domestic electricity sales and profit of electric power interchange with EGAT as accounting aspect.

The first approach on the reservoir operation study focuses more on economic aspects, i.e. energy production. Meanwhile, the latter approach focuses on the account of selling electricity to domestic consumers and EGAT using the current tariff system. The first case aims at energy maximization while the latter case employs revenue maximization as the objective of optimization. However, if the reservoir operation is solely targeting either energy maximization or revenue maximization, the results tend to import electricity during dry season and generate electricity for export in the rainy season to maintain the reservoir water level in high elevation. The Lao PDR government’s policy is that the power import from EGAT should be as less as possible and the domestic electricity demand should first be served by the domestic power sources. Therefore, the operation study considers minimization of the imported energy as prerequisite of energy and revenue maximization. Both approaches consider the scenarios of the power demand supply balance in the year 2015, 2020 and 2025, and for the cases of with/without NN2, and before/after expansion.

The reservoir operations of EdL’s Nam Mang 3 and Nam Leuk hydropower stations were considered in the reservoir operation study for economic analysis. The reservoir operation optimization is performed aiming at energy maximization: then the energy production of NN1 is simulated for the calculation scenarios. The results show that the NN1 expansion enable to operate the reservoir flexibly, the present average annual power generation of 1,012 GWh can be increased to 1,071 GWh (59 GWh rise) after the commencement of power generation of NN2, and to 1,127 GWh (56 GWh rise) by the expansion of 40 MW. The power generation pattern after the expansion will consist of the night peak with full power output and the daytime peak with adjusted power output. The simulation study results that the NN1 seldom generates electricity for 24 hours with full capacity in rainy season after expansion.

For the study of the reservoir operation in the Nam Ngum River basin with revenue maximization, EdL hydropower stations (NN1, Nam Mang 3, and Nam Leuk) supplying electricity to the C1 area were taken into consideration. Nam Lik 1/2 hydropower station is further considered in the after expansion case. The optimization studies were carried out, and it was found that the revenue balance and import energy is generally a trade-off relation. The increase in imported energy in the dry season may contribute to increase in annual revenue. However, importing too much energy from Thailand will result in increase of excess charges that will worsen the annual revenue balance.

If Nam Lik 1/2 is operated together with NN1, Nam Leuk and Nam Mang 3, it will contribute to the significant reduction of energy import when the electricity demand exceeds domestic supply capacity throughout the year. However, the effect of involving Nam Lik 1/2 operation is limited when the domestic power supply and demand is almost balanced.

(5) Social and environmental consideration

Unlike construction of a new dam and hydropower project, no significant and irreversible impact on the social and natural environment is expected in the Nam Ngum 1 Hydropower Station Expansion Project. The expansion project needs neither creation of reservoir nor construction of new transmission lines. In terms of socio-economic impact, no relocation or land acquisition is required. Compensation is not necessary in the selected optimum scale of the project. As a result of IESE study, it is concluded that environmental and social impacts of the NN1 expansion project are basically insignificant. Negative impacts can be avoided or mitigated by conventional construction management with proper instruction and operation under the Environmental and Social Management Plan.

On the other hand, continuous impact that may affect to natural and social environment is expected due to larger daily water level fluctuation in downstream of the Nam Ngum River. This is due to the change of operation pattern in NN1 power station after the expansion work. The downstream river water level is reduced during off-peak time and increased in peak-time. The downstream discharge fluctuation comes from the change of output and discharge at the NN1. River side gardening may be possibly affected by the water level increase during peak time. On the other hand, boat transportation and fishery may be affected by water level decrease during off-peak time. Irrigation and river water pumping may also be affected by the water level decrease. These water level fluctuations will happen only in the dry season. Based on the results of social survey and hydrological analysis in IESE, the water level fluctuation range was confirmed to be within the allowable level at the downstream in case of 40 MW expansion.

(6) Optimum expansion plan

Eight candidates of the expansion alternatives ranging from 40 MW to 120MW were taken into account in the start of this Survey. In choosing these alternatives, the results of the feasibility study performed in 1995 by Lahmeyer/Worley under IDA finance were referred to and a new left bank tunnel plan was additionally taken up. In order to select the optimum plan for expansion, an initial screening was performed to choose four prospective alternatives out of the eight candidates so that detailed comparison could be done on the prospective alternatives within the limited time. The initial screening was made during the inception stage by means of engineering assessment without quantitative comparison.

In the next step, the selected prospective alternatives were compared in detail by analyzing power generation efficiency, designing of powerhouse expansion layout and estimating construction cost. The final selection of the optimum expansion plan was made on the basis of economic/financial comparison of the alternatives.

Alternative A1 (40 MW) is judged to be highest in cost performance among the eight alternative options considered. Alternative A1 is to build a new unit bay building for 40 MW plant in the space between the existing powerhouse and the spillway. The existing OHT cranes and draft tube gates can be utilized for the additional unit. The layout of the new powerhouse is most compact and economical among all options. Since the length of penstock and tailrace is short and waterway head loss is less, available water head can be most effectively utilized for power generation.

By comprehensively judging from technical, economical and financial points, Alternative A1 (40 MW) is selected as the optimum expansion plan for the Nam Ngum 1 power station.

(7) Basic design

The basic design for the optimum expansion plan was carried out. The design conditions required for the basic design are discussed below:

Rated Reservoir Water Level for New Unit 6

The present long-term average water level is EL. 206.0 m. However, the average water level estimated for the condition after expansion (40 MW) goes up to EL. 209.6 m which is 3.6 m higher than the present status. After completion of the NN2 project, variation range of NN1 inflow will be considerably reduced. Based on the above, the rated head (effective head = gross head - loss head) for the turbine of additional unit 6 is 40 m.

Optimum Penstock Diameter for Unit-6

The penstock diameter of the existing units 3 to 5 (40 MW each) is 6.0 m. Because the dam foundation level at the unit-6 penstock site is higher than the required level of penstock bottom foundation, a smaller diameter penstock is preferable in order not to threaten the structural safety of the dam. By use of smaller diameter penstock for the same turbine, waterway head loss increases and consequently energy production decreases. In order to estimate the degree of energy reduction of unit-6, the power generation of all units is simulated for each of the different diameter cases for unit-6 applying inflow data of 36 years (1972-2007). The comparison shows the diameter of 5.5 m is the most economical among four cases of different diameters (4.5 m to 6.0 m). Therefore, the penstock diameter for the new unit 6 is decided to be 5.50 m.

Intake Center Elevation of Unit-6

The NN1 reservoir water level will be kept at considerably higher level than the existing level even during dry season because of river flow regulation effect of the upstream NN2 plant which will be commissioned in 2011. However, the minimum operation level will fall to about EL. 197.0 m twice in a 36-year simulation. This water level is close to the minimum operation level (EL. 196 .0 m) specified for the existing units. Therefore, EL. 196.0 m is adopted as the minimum operation reservoir level for unit-6. The intake entrance level should be deep enough from the water surface in order to avoid formation of vortex and consequent air-entraining into the intake conduit. Therefore, the elevation of the intake conduit center is decided to be EL. 185.25 m.

Intake and Penstock

The diameter of the hole to be excavated in the dam body to install the 5.5 m diameter penstock pipe is decided to be 6.7 m. The clearance between the penstock pipe and surrounding excavated face is set at 0.6 m as a necessary space for installing the penstock pipe.

The restriction of the reservoir water level during intake construction largely contributes to lower the construction cost of the temporary enclosure. In case the water level is restricted to be lower than EL. 207 m, the construction cost of the temporary enclosure is estimated to be reduced by US$4.9 million. The reduced amount of construction cost is beyond the reduced income of power selling. Therefore, the plan to restrict the reservoir water level below EL. 207 m for 3.5 months from the beginning of March to middle of June is adopted for construction.

Dam Stability

Dam stability and stress in the foundation rock are checked applying temporary enclosure (steel girder type support). The dam block No. 20 is the section to be studied. Change in load conditions due to a piercing dam or temporary enclosure is considered. Result of the study proves the dam is stable with the temporary enclosure of steel girder support type.

(8) Lowering of Tailrace Water Level

It was judged that the tailrace water level would be lowered by removal of rock outcrops located at the downstream of NN1 Power Station. The river cross section survey was carried out for hydraulic calculation in order to analyze the change of water surface level due to removal of rock outcrops. It was confirmed that the tailrace water level at the downstream of the power station would be lowered by 40 cm due to removal of rock outcrops and subsequently results in additional annual energy of 5 GWh. In case the original expansion plan of 40 MW will be combined with the removal of rock outcrops as a one set of expansion plan, the total economical and financial benefit would be higher. Therefore, the expansion plan of NN1 hydropower station consists of the additional power generation facilities of installed capacity of 40 MW and removal of rock outcrop located at the downstream side.

(9) Implementation plan and cost estimation

The grand total of construction cost has been estimated at ¥7,006 million including the cost for consulting services. The total construction period from preparation works to commencement of power generation is 36 months, and power generation would be commenced in 2015.

(10) Financial and Economic Analysis

The EIRR of the expansion plan is calculated with kW value and kWh value of the middle-speed diesel power. The calculated economical internal rate of returns (EIRR) is 17.68% and it is judged to be economically feasible.

On the other hand, the FIRR of the expansion plan is calculated with benefit of the tariff revenue from domestic consumers. The computed financial internal rate of returns (FIRR) is 2.75% and it is judged to be financially feasible with soft loan of low interest.

14.2 RECOMMENDATOIN

In Laos, the domestic demand of peak power and energy are increasing with an average rate of 10%. The increase of power demand of day time and night time peak is remarkable. On the other hand, IPP hydropower projects aiming at domestic power supply are under planning and construction. However, these domestic IPPs are not big in reservoir capacity compared with NN1 and the power plants for peak power supply are minor. Therefore, the expansion of NN1 power station, which has high potential of peak power generation with huge reservoir, aiming at power supply for domestic peak demand is effective. The early implementation of the expansion of NN1 is recommended.

Through the processes of fund procurement, additional geological survey, detailed design and other preparatory works this expansion plan would be able to start power generation in 2015. The following issues should be resolved prior to its implementation:

(1) The expansion plan includes the construction of additional power station with 40 MW and the construction of transmission lines between the power station and demand center is not required. Therefore, it is judged that the construction cost will be minimized and the project is economically viable. Further, the reservoir water level will be the same as the existing condition and no resettlement will be involved. This expansion plan is not harmful to the environment. It is expected that the procedures required for the implementation will be smooth. It should be confirmed again that the NN1 expansion project will be mentioned officially in the power development plan of Lao PDR. Further, it is necessary to start the preparation of discussion about funding between Japan and Lao PDR.

(2) The detailed design should be carried out by following the points of reminder to be described and the results of the additional investigations. The opinion of the staff of the NN1 power station should be taken in the preparation of the tender documents.

(3) Although the new intake structure will be constructed by piercing of dam body, the reservoir water level should be kept so as to keep the power generation. Therefore, the installation of temporary closure at reservoir side with deep underwater operation will be an important issue. In this regard, the detailed design and construction planning with attention to safety and economic efficiency should be established considering the experiences of same type of expansion in Japan.

(4) Since the new power station building will be constructed just beside of the existing power station building, it is possible that the vibration due to foundation excavation may affect the existing power generation facilities and power generation itself. Therefore, the vibration issue should be studied in detail considering geological conditions and vibration during blasting for foundation excavation for establishment of safety measures in the detailed design stage.

(5) The financial analysis of the expansion plan was made on the basis of domestic electricity tariff of 2009. The increase of electricity tariff is connected with the FIRR directly. Therefore, the electricity tariff in Laos should be followed from the view point of financial viability.

(6) The NN2 hydropower station will commence the power generation in 2011, and the inflow into the Nam Ngum Reservoir will be flattened throughout a year. Thus, the operation ratio of power generation facilities will be increased, and the power generation time in dry season will be longer. Therefore, the long term maintenance plan shall be made to ensure the time for the regular maintenance. Furthermore, the maintenance plan after the expansion shall be studied to evaluate the degree of its contributions.

(7) In IESE of this survey, this discharge requirement presumes the maintenance flow is based on that the Nam Lik River flow at least equals to the draught discharge. If the discharge is less than the draught discharge, IESE confirmed that the reduction of the flow will affect to the downstream inhabitants. Therefore, the Nam Lik 1/2 hydropower project is required to release the water at least to fulfill the draught discharge at the confluence of the Nam Lik River and Nam Ngum River. Furthermore, the actual release from the Nam Lik 1/2 should be monitored under DOE supervision to determine whether the discharge pattern of the Nam Lik 1/2 does not cause adverse effect to the downstream inhabitants. If the adverse impacts are recognized, then DOE together with WREA should request to Nam Lik 1/2 hydropower entity to mitigate such impacts.

CHAPTER 15 SUGGESTIONS FOR PROJECT IMPLEMENTATION

The main component of the expansion plan of Nam Ngum 1 Power Station is the construction of one unit power station with 40 MW capacity to complement the existing five units with 155 MW. The project has shorter construction period and has less social and environmental impact. During the determination of the expansion scale, the basic conditions such as power demand and supply plan, tariff system in Laos and change of river flow due to hydropower development in the Nam Ngum river basin were considered. Such basic conditions should be re-confirmed in the detailed design stage and in the project implementation period.

Towards the implementation stage of the project, the points to be considered after the present preparatory survey are discussed below.

15.1 POINTS TO CONSIDER FOR IMPLEMENTATION

15.1.1 CONFIRMATION OF POWER DEMAND AND SUPPLY PLAN IN C1 AND NORTHERN AREAS

Judgment of the necessity for the NN1 expansion and selection of expansion scale are based on the power demand forecast in C1 and northern areas, and the power supply plan mentioned in the Power Development Plan of Lao PDR. In this survey, the power demand was forecasted considering the power demand of industrial sector with rapid growth. Therefore, the actual power demand within a few years should be monitored while comparing the value of power demand forecast. With regards to the IPP project aiming at domestic power supply, the completion date will be delayed due to difficulties in PPA negotiation and environmental issues such as resettlement and natural negative impact. Furthermore, the power development plans after 2020 are still under concretization stage with shortage of electricity against forecasted power demand. Survey accuracy enhancement and review of power development plan with EdL and DOE are necessary.

15.1.2 CONFIRMATION OF RIVER FLOW CONDITIONS AFTER DEVELOPMENT OF HYDROPOWER PROJECT IN NNRB

The inflow into NN1 reservoir will be regulated through the year after the commencement of power generation of NN-2 in 2011, which is located just upstream of the NN1 reservoir. The annual energy of NN1 will be increased by 6% due to NN-2 reservoir operation. The NN1 expansion will be completed and will start power generation in 2015. The annual energy of NN1 will be increased by 5% due to the expansion. The simulation calculation of power generation was carried out on the basis of NN1 reservoir operation policy of EdL and Lao PDR, which is “giving priority to minimization of power supply deficit in domestic power demand”. The annual energy and fluctuation of reservoir water level throughout the years after commencement of NN-2 power generation in 2011 should be observed and the results of the simulation calculation in this preparatory survey should also be verified.

15.2 TRANSITION OF ELECTRICITY TARIFF IN LAO PDR

In the preparatory survey, the FIRR was evaluated with average electricity tariff of US$0.0621 as of 2009. However, the FIRR of the expansion plan is not so high compared with usual hydropower development plan because the purpose of the expansion is strengthening the capacity of peak power supply and no difference of electricity tariff in peak and off-peak electricity is considered. The financial benefit of the expansion project depends on the domestic electricity tariff. In parallel with this preparatory survey, the study on transition of electricity tariff is being studied by the other donors. After this study, the policy of EdL on electricity tariff should be confirmed. The financial benefit of the expansion in 2015 should be verified using a new electricity tariff, if available. In order to re-evaluate the FIRR, the reference values mentioned in the sensitive analysis in this report should be considered.

15.3 FOLLOW-ON WORKS FOR DETAILED DESIGN

15.3.1 TOPOGRAPHIC AND GEOLOGICAL INVESTIGATIONS

For the detailed design, it is recommended to carry out the following investigations:

(1) Topographic survey

a) Cross section survey of the powerhouse expansion construction area topography (including underwater area)

b) River cross section survey of rock outcrop area in the downstream river channel

(2) Geological investigations

a) Geology of foundation (core boring, etc.)

- Excavation area below downstream toe of dam (Block No. 20)
- Excavation area below spillway wall
- Rock barrier to be left between existing and new tailbay (including grout injection test)
- Rock outcrop area to be removed in downstream river channel

b) Core boring in rock outcrop area in the downstream river channel

(3) Concrete material test

a) Concrete aggregate: Tests of strength, gradation, etc. of river deposit sand and gravel in Nam Lik River and survey for estimating available quantity

b) Cement: Physical and chemical properties of cement produced in Lao PDR and supply capacity of cement factory

15.3.2 ENVIRONMENTAL SURVEY

An Environmental and Social Management Plan (ESMP) was prepared to avoid or mitigate negative social and natural impacts of the expansion project during construction and operation and maintenance. In the detailed design stage, review of the following items will be necessary:

- Environmental mitigation plan, environmental monitoring plan, and contractor environmental management plan (CEMP) were prepared in this survey. Those should be reviewed in detailed design stage. CEMP should be included in the bidding of contractors.
- Off-peak operation should generate with at least a single unit of 40 MW. Zero generation should be avoided to confirm maintenance flow at downstream. Single operation with 18 MW unit may be operated in case discharge of the Nam Lik is more than 117 m^3/s. The hydrology data should be updated and the above condition should be reviewed accordingly in the detailed design.
- Hourly discharge should be measured and detailed hydrology data should be collected at NN1 dam site, at downstream of the Nam Ngum and at the Nam Lik during detailed design and first half year after the start of operation to reconfirm the downstream effects.
- The effect of water level increase due to peak operation of Nam Lik 1/2 should be checked in the dry season. If the peak level of the Nam Ngum and the Nam Lik is overlapped at the downstream of the confluence, request should be made to the IPP of Nam Lik 1/2 so that large water level increase at downstream can be avoided. It needs to confirm to Nam Lik 1/2 to secure maintenance flow so that discharge of the Nam Lik become more than 90% dependable discharge.
- When shifting from off-peak to peak operation, step-wise increase by 80 MW at maximum has to be kept. Additional output increase should be conducted after 30 minutes or 1 hour to reach the maximum operation. Operation rule should be set accordingly.
- It is necessary to install warning signboard to explain about rapid water level increase (2.0-2.3 m) at the time of shifting from off-peak to peak time at riverside, where fishing, washing, pumping, gardening, and swimming is done. In the detailed design, the location where a signboard is needed should be confirmed. In addition, the necessity of setting up an automatic warning system should be studied.

15.3.3 DESIGN ISSUES

(1) Civil Works

a) The foundation rock below downstream toe of the dam block No. 20 will be removed for additional powerhouse. The structural safety of the dam and foundation should be verified by stability analysis and, if necessary, the foundation strengthening plan should be established.

b) The foundation rock beside the spillway wall will be deeply excavated for construction of new powerhouse and tail bay. The structural safety of the excavated rock slope should be verified by stability analysis and slope stabilization measures should be established.

c) The intact rock between the existing tail bay and the new tail bay will be left unexcavated and the unexcavated rock body will be utilized as coffer wall during construction. The structural safety of the unexcavated rock body against external water pressure should be verified by stability analysis and, if necessary, methods of strengthening the rock body should be established.

d) A large size horizontal hole will be excavated in the existing concrete dam body. Stresses in the concrete around the hole should be computed to verify that no excessive tensile and compressive stresses may occur around the hole.

(2) Electromechanical Equipment

The following items will be examined in the detailed design of the electromechanical equipment.

a) Construction of turbine and generator

Each generator for unit 3, 4, and 5 is arranged for a special construction to support the thrust bearing from the turbine head cover. It is therefore required that the design of the turbine and generator for unit-6 should be the same construction with the existing units.

b) Dimensions and construction of main transformer

It is required that the main transformer for unit-6 should be interchangeable with the existing spare transformer of single-phase type. Therefore, the design of the main transformer for unit 6 shall have the same dimensions and construction of the existing units. On the other hand, the 11 kV main bus between the 11 kV cubicle and the main transformer will employ the segregated phase bus (SPB) which is different from the existing one. It is therefore required that the SPB should be designed for successful connection to the existing spare transformer.

c) Construction of remote control board

The remote control board for unit-6 will be installed in the existing control room aligned with the existing remote control board for unit-5. It is therefore required that the design of the new remote control board should be the same construction with the existing control board for unit-5.

d) Data transmission between control system and central hydropower station control center

EdL is planning to construct a central hydropower station control center in the Nam Ngum 1 Power Station. When it is realized, the control system for unit-6 is required to transfer the operational data to the control center. The data transfer system shall be designed in closer coordination with EdL especially for data transfer item, communication method and communication protocol.

e) Installation route of new cables

In order to establish the control system and station-service power supply system for unit-6, the power and control cables will be installed in the following sections:

- Control cables between the new local control board for unit-6 and the new remote control board for unit-6 in the existing control room
- Power and control cables between the new low voltage switchgear cubicle for unit-6 and the exiting low voltage switchgear
- Power cables between the new DC distribution panel and the existing DC distribution panel for units 1 and 2 in the existing control room

The exact routes of the above cables should be examined in the detailed design stage.

f) Replacement of existing 115 kV main bus conductors and additional installation of 115 kV main bus sectionalizing disconnector

Replacement of the existing 115 kV main bus conductors as well as additional installation of a 115 kV main bus sectionalizing switch will require shutting down of all units 3, 4, and 5 at the same time. Allowable period for the three units shutdown will be off-peak time only (mid-night, early morning, Saturday and Sunday). Therefore, it is required to make a good schedule so that these work can be completed within the allowable period.

(3) Mechanical Equipment

The following points should be examined for mechanical equipment in detailed design stage.

a) Intake trashracks

- Study of structural and fabrication measures related to the vibration of screen bars due to high flow velocity
- Required area for storage and maintenance of screen panels on the dam crest

b) Intake gate

Although the bonnet type high pressure slide gate is selected as the optimum type for intake gate considering the construction time and cost, prior to the detailed design of intake gate, the type of coaster gate on the upstream face of dam with stoplogs should be re-studied about the possibility to adopt as the alternative for intake gate, because the type of coaster gate with fixed wheel has a still merit for operators in the Nam Ngum 1 considering their experience and knowledge for the actual maintenance and operation of intake gate. As for the detailed design of high pressure slide gate, the following should be taken into account.

- Detailed study about the material of bearing and sealing parts of gate leaf
- Backup equipment for hydraulic unit in case of power failure
- Power and control cable route study and structural design of cable routes
- Equipment arrangement for hydraulic unit room considering operation and maintenance of machine

c) Intake and draft tube gantry cranes

- Modification of cable reel for gantry cranes
- Study of removal of control cabin for intake gantry crane

d) Steel penstock

- Study of accessories such as seepage ring, corrector pipes for seepage water, penstock drain pipe and valves, etc.

15.3.4 INFLUENCE TO EXISTING STRUCTURES

It is anticipated that construction activities for the powerhouse expansion will give adverse influences to the existing structures or equipment located near the expansion work. These influences need to be picked up and studied in the detailed design stage, and necessary countermeasures should be established. The major influences foreseen are listed below:

a) The magnitude of influence of vibration caused by excavation work for making a large hole in the dam should be verified by vibration analysis and the allowable maximum limit of vibration for the dam body should be defined.

b) The magnitude of influence of vibration caused by rock excavation work in the new unit-6 bay area should be verified by vibration analysis and the allowable maximum limit of vibration for existing powerhouse building and generating equipment should be defined.

c) The existing access way to the main transformers will be blocked by a temporary ramp way (elevated steel bridge) for the work of piercing dam. Maintenance/ repair work of the main transformers will be difficult due to the ramp way. Protection method of the transformer for safety and transformer repair method for emergency should be established.

d) Both gantry cranes for the intake and the draft tube outlet need to be relocated temporarily during the expansion work. The intake stoplogs and draft tube gates cannot be handled by the gantry cranes during the relocation. Method of handling the stoplogs or gates in case of emergency should be established.