Feasibility Study for Up-gradation and Refurbishment of Generating Units of Mangla Power Station

Volume 1 – Executive Summary

Prepared by

Mangla Refurbishment Project (MRP) - JV

For

Pakistan Water and Power Development Authority

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PREFACE

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1. Introduction

Mangla Refurbishment Project JV (MWH and NESPAK) was retained by the Pakistan Water and Power Development Authority (WAPDA) to assist the Authority in the assessment of the condition of the key power train components and other important equipment at the Mangla Power Station, and to identify and evaluate potential capacity improvements to the plant.

The purpose of this study is to help WAPDA to identify improvements that are required to have continued reliable, safe and sustainable use of this power generating facility for another life cycle. Investigation and evaluation of a number of equipment refurbishment alternatives was done ranging from the base line of doing the minimum absolutely necessary scope to an opportunity based approach that considers additional benefits from replacement and upgrade of major power-train components and allied equipment to achieve improved plant performance characteristics that are aligned with the intended future use of the project and reservoir by WAPDA.

The goal is to make comparative analyses between presented options to help make the decision on the preferred alternative for moving forward with an actual design. As such, all of the analyses were prepared in a similar format, although these may not coincide with the actual Project implementation.

2. Hydrology Considerations

The hydrology and reservoir operations models were updated to water year 2010 using the previous modeling conducted by the Mangla Dam Raising Project as a starting point. Because the primary use of water from this project is irrigation, the water delivery determines the power generation and hence the power generation benefits. The output of the hydrology modeling is used as an input to the economic and financial modeling.

The RESOP-1 computer modeling included long-term Mangla Reservoir inflows, historic irrigation releases from Mangla Reservoir, reservoir operation rule curves, characteristics of available outlets of Mangla Dam to simulate the future long-term reservoir operation.

The hydrology was simulated from 2010-11 to 2097-98 (88 years) represented by the historic 10-day inflow series for the period from 1922-23 to 2009-10. The annual volumes of irrigation seasons – Rabi (October through March) and Kharif (April through September) were computed from the series for use in the model.

Elevation-volume curves were determined at 5-year intervals; the model interpolates for years in between and adjusts the available volume due to sedimentation. The maximum conservation level of 1242 feet and a minimum level of 1040 were used. Maximum and

minimum rule curves, as developed during the design phase of Mangla Raised Project were used.

The simulation process provided the following results.

Average annual inflow, MAF	22.75
Average annual irrigation indents, MAF	20.91
Average Kharif irrigation releases, MAF	10.24
Average Rabi irrigation releases, MAF	10.52
Average annual irrigation releases, MAF	20.75
Average annual spills, MAF	2.00

The results above show that the simulation procedure resulted in irrigation releases nearly equal to the indents provided at the start of 10-day periods. The inflows were adequately utilized and the overall spills represent 8.8 percent of the total inflow. Model spills generally occur during flood season when the reservoir was full and inflow exceeds the hydraulic capacity of the power generation facilities. **Figure E.1** indicates the hydrology model output that becomes the input to the generation model described in Paragraph 4.

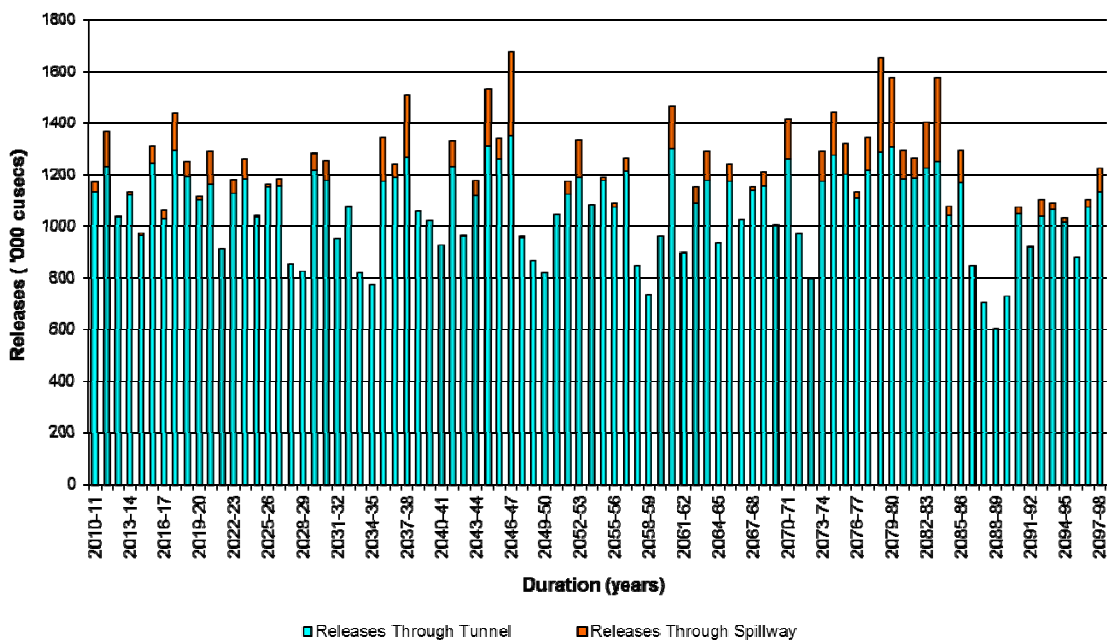

Figure E.1: Simulated Releases Through Tunnels & Spillway (2010-11 to 2097-98)

3. Hydraulic Considerations and Limitations

Limitations in the increase of power output for the Mangla Upgrade, on the basis of hydraulic constraints in the existing tunnel system and tailrace are described in Volume 2 of this report and summarized below.

The nominal existing design discharge for each of the five (5) tunnels is 9,000 cfs, for a total of 45,000 cfs existing discharge capacity. The water is released from the power units to the tailrace, the Bong canal, having a maximum capacity of 49,000 cfs. Approximately 15 km downstream of the powerhouse, up to 9,000 cfs is diverted into the Upper Jhelum Canal and the remaining is returned to Jhelum River through two gated escape structures, the Bong escape and the New Bong escape. The New Bong independent power project (IPP), is currently under construction to capture the water currently released by the New Bong Escape structure. Increases in power capacity are assumed to be roughly proportionate to this base discharge. After review of various hydraulic limits, the maximum design flow that is considered is approximately 11,000 cfs per tunnel, and that would be considered only as a tunnel flow increase with one tunnel is out of service, resulting in the same net design flow of 45,000 cfs in the Bong Canal. While increments up to 49,000 cfs are indicated as possible, long term flows at this level have not been studied, and would also create long term impacts for the New Bong IPP.

4. Evaluation of Up-gradation Options

The condition assessment portion of this report has identified a number of plant needs including Turbine/Generator and balance of plant restoration work. Each 'need' addresses a replacement in kind, without optimizing for the current system requirements and without looking into efficiency and capacity improvements. Opportunities for plant improvement include projects that are not required for continued operation, but do increase revenue or decrease costs. The opportunities defined and investigated in this study are summarized in **Table E.1** and are discussed in more detail in Volume 6 of this report.

Table E.1: Alternatives Summary

Alternative	Unit Ratings	Description	Limiting Factors
Alternative 0	Units 1-10; 115 MW	Replace in kind. New turbine runners. Incidental generator up-rate to 115MW. Minimal upgrades to isolated phase bus.	Power train.
Alternative 1A	Units 1-6; 135 MW Units 7-8; 115 MW Units 9-10; 135 MW	Generator up-rate with minimal modifications. Generator up-rate is not possible for Units 7 & 8. New turbine runners.	Generator rotor.
Alternative 1B	Units 1-6; 135 MW Units 7-8; 150 MW Units 9-10; 135 MW	An interim case that adopts Alt 1A for all units but 7 and 8 and Alt 2 for unit 7 and 8. This provides an opportunity for more flexibility on plant operation.	Same as Alt 1A for all units but 7 &8 and same as Alt 2 for units 7 & 8.
Alternative 2	Units 1-10; 150 MW	New generators, new turbine runners. Major upgrades to power train.	Dimensions of existing structure, hydraulics.

Each alternative was then evaluated and potential scope of work for each component was defined at a planning level to allow for the creation of work packages. For each work package an Opinion on Probable Construction Cost (OPCC) was defined at AACEI Class 5 Level to be used for the economic and financial analysis. The OPCC can only be used for alternative analysis and selection of an alternative. A more detailed cost estimate would be required for planning and budgeting purposes.

A risk assessment was conducted to determine the initial order for refurbishment of the units so as to minimize the risk of in-service failures. A scoring system was used based on equipment condition and the likely duration of a repair outage to restore service. The results are as expected with the order being and scores shown in **Table E.2**.

Table E.2: Suggested Unit Rehabilitation Sequence

Rank	Unit	Score
1	Unit 5	1.000
2	Unit 6	0.974
3	Unit 2	0.755
4	Unit 1	0.728
5	Unit 3	0.581
6	Unit 4	0.581
7	Unit 7	0.111
8	Unit 8	0.032
9	Unit 9	0.000
10	Unit 10	0.000

Unit 5 is operating at part load from a previous in-service failure and Unit 6 is similarly ranked. Units 1 and 2 precede Unit 3 and 4 because of increased age and longer in-service hours. Units 7-8 have turbine issues and the generators are older than Units 9-10. Units 9-10 have the newest generators but damaged guide vanes and distributor. This assessment should be maintained throughout the project life and relative ranking can change up to 30 days into an outage. The ranking also maximizes grouping of identical machines.

Preliminary implementation schedules were developed for each alternative to allow for development of cash flow that includes both annual and cumulative costs. The cash flow is meant to be representative, and negotiations with vendors can result in a more even cash flow. It is important to note that this analysis did not include any costs from possible forced outages.

5. Power Generation, CDM, Economic and Financial Assessment

This section summarizes the information in Volume 2 and Volume 6 on the Mangla up-gradation energy modeling, and the resulting economic and financial analyses of up-gradation alternatives.

Pakistan is in an electricity crisis as the supply of electricity remains insufficient to meet the demand. As the units at Mangla are aging, they require increased maintenance and perform less efficiently due to degradation. Performing up-gradations to the units increases energy generation (both through increased efficiency and capacity) and reliability, and reduces O&M.

A generation model was developed and validated for Mangla power station using the hydrology simulations as input. The generation model then simulates the performance for each up-gradation alternative. The results, presented as average annual values (shown below in **Figure E.2**), become inputs to the economic and financial analyses. The “Do Nothing” scenario (Base7 curve) is used as a base case that the remaining alternatives are compared to.

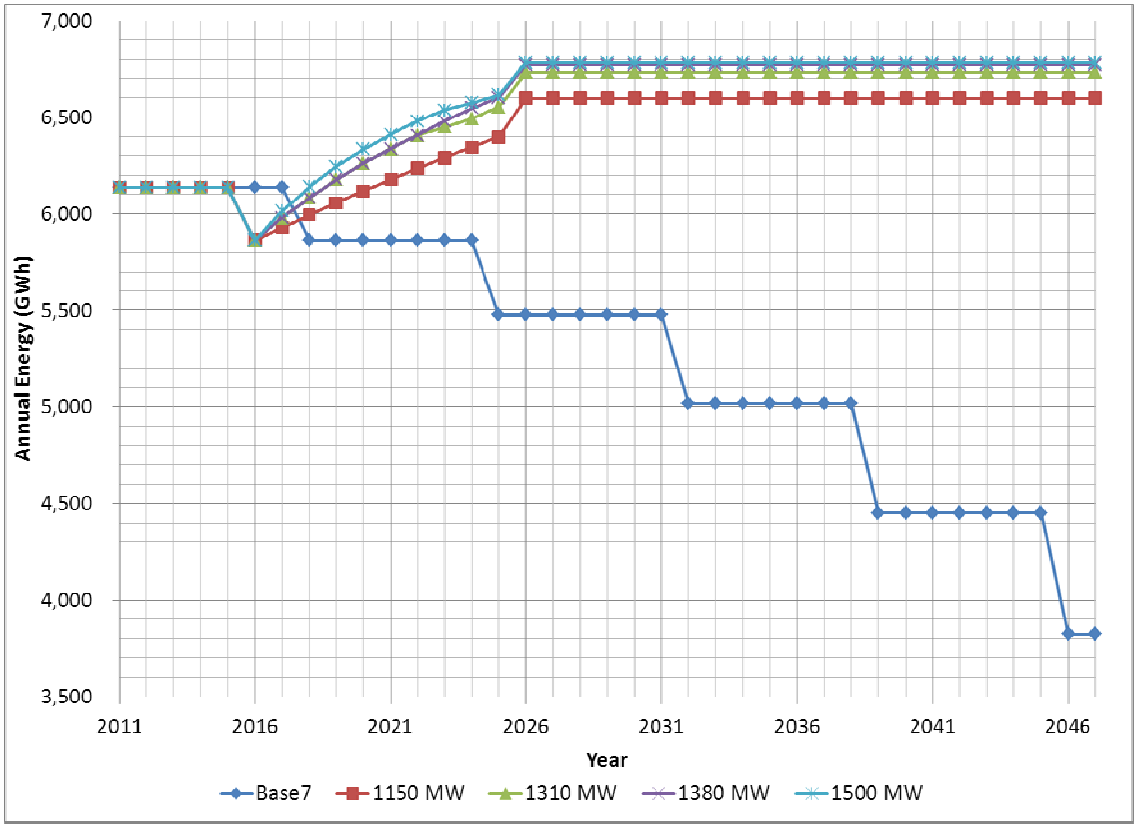

Figure E.2: Annual Energy Generation Estimates

The economic and financial assessments use a 35-year timeframe, 2013 through 2047. These assessments compare the alternatives in monetary terms by monetizing costs and benefits over the specified timeframe. The benefit of the up-gradations is primarily increased energy generation. Reduced O&M costs and the value of certified emission reduction credits are also considered in the economic and financial models. Because Mangla's eligibility for participating in the Clean Development Mechanism cannot be determined at this time, the analyses were done with and without consideration of saleable certified emission reduction (CER) credits.

The potential benefits of participating in the Clean Development Mechanism (CDM) and earning saleable CER credits were incorporated in the economic and financial assessments; the CDM benefits were not included for the 1150 alternative as it fails to meet the minimum power density of 4 W/m^2. The economic and financial attractiveness slightly increased when potential revenues from CDM benefits were included. It is important to note that the CDM values used are for estimating purposes, and in fact revenues from CER credits are not likely, if the project alternatives appear to be economically and financially viable without CER credits. More information on the CDM process is provided in Volumes 2 and 6 of this report.

The economic assessment uses year 2011 values, and calculates the Net Present Value (NPV), Benefit Cost Ratio (BCR), and Economic Internal Rate of Return (EIRR). The NPV

is a measure of the magnitude of the project benefits, whereas the EIRR and BCR are different measures of the efficiency of each investment.

The results without CDM allotment are shown in **Table E.3** and with CDM allotment in **Table E.4**. If Mangla qualifies for CDM CER credits, the benefits marginally increase the metrics.

Table E.3: Economic Analysis of Up-gradation Alternatives (2013 to 2047)

Plant capacity (MW)	**1150**	**1310**	**1380**	**1500**
Construction cost (total, million 2011 USD)	350.8	369.4	446.2	684.3
Construction cost (total, billion 2011 PKR)	29.82	31.40	37.93	58.17
NPV (million 2011 USD)	181.0	234.9	222.4	158.7
NPV (billion 2011 PKR)	15.38	19.97	18.91	13.49
EIRR	20.9%	24.0%	22.6%	17.8%
BCR	2.54	2.89	2.52	1.69

Table E.4: Economic Analysis with CDM Allotment (2013 to 2047)

Plant capacity (MW)	**1150**	**1310**	**1380**	**1500**
NPV w/ CDM (million 2011 USD)	N/A	246.5	234.3	171.1
NPV w/ CDM(billion 2011 PKR)	N/A	20.95	19.92	14.54
EIRR w/ CDM	N/A	24.5%	23.0%	18.2%
BCR w/ CDM	N/A	2.98	2.60	1.74

The 1310 MW alternative (Alternative 1A) has the highest NPV, BCR, and EIRR. The 1310 MW alternative was carried forward for the financial assessment. The FIRR resulting from the financial assessments is shown in **Table E.5**.

Table E.5: Financial Analysis (2013-2047)

Plant capacity (MW)	**1310**
FIRR	22.6%
FIRR w/CDM	23.5%

The cash flows from the financial analysis of the 1310 MW alternative, with and without CDM, are shown graphically in **Figure E.3**. The first few years show a negative cash flow, reflecting the period before the unit overhauls are complete, i.e. before the generation benefits are realized. In the later years, there is a jump in the cash flow every seven years. This reflects the jump in the energy benefit as compared to the base ("Do Nothing") scenario, where one unit is assumed to fail beyond repair every seven years.

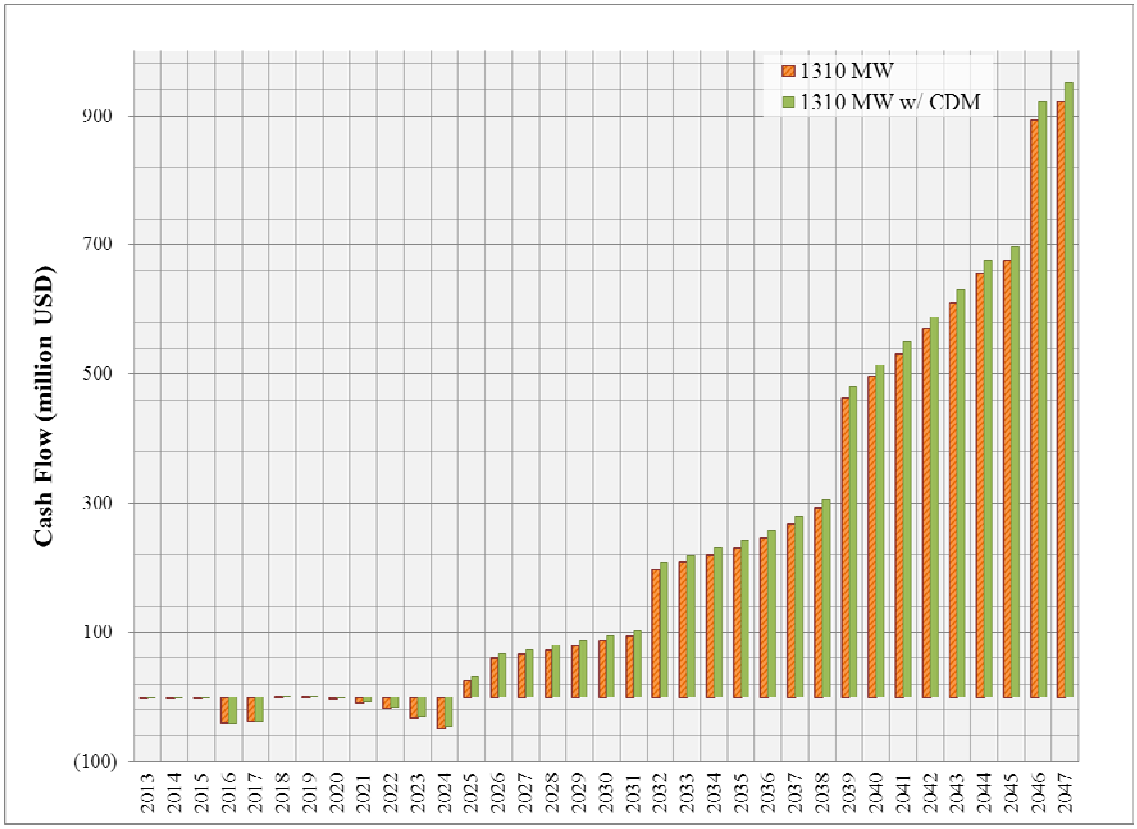

Figure E.3: Cash Flow, Financial Assessment

The economic levelized cost of generation was determined for each rehabilitation alternative. The assessment assumes that all previous investments have been amortized and the current investment costs are amortized over a 35-year period. Based on this assessment, the economic levelized cost per kWh at the Mangla bus for the 1310 MW case is $0.0227 (PKR 1.93). For other alternatives, see Volume 6.

Alternative 1A (1310 MW) is the most economically attractive option, and shows good financial results. The sensitivity cases show that the 1310 MW alternative remains attractive as input assumptions are adjusted. The BCR only dips below 1 and returns a negative NPV when the benefits are assessed against the most conservative baseline. That baseline assumes that no capacity is lost from the 10 units, and no incremental degradation will occur during the assessment period. This conservative baseline demonstrates comparison with a new plant.

Two special sensitivity cases were performed in Volume 6 to check the Bong Canal flow limitation and to check on 0.9 power factor operation at 168 MVA.

Figure 6.4 shows a cash flow report for recommended Alternative 1A, 1310 MW over the duration of the rehabilitation project. Both annual and cumulative costs are summarized, indicating the levels of annual funding needed for the Project, with annual funding at the peak of about $60 million.

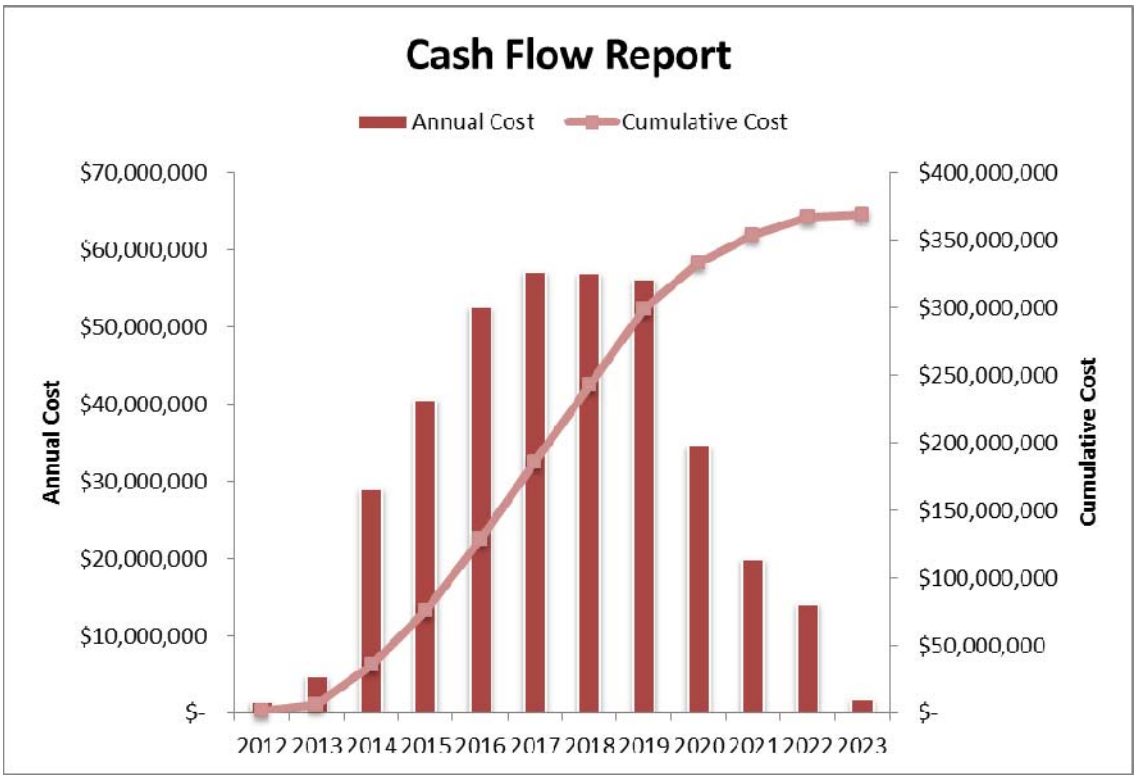

Figure 6.4: Expenditure, Cash Flow

6. Condition Assessment Summary

6.1 Generators and Unit Electrical

The generator and unit electrical assessment is based on the visual inspection and observations collected during Mangla site visits as well as testing of the generator, interviews with site personnel and a review of available plant information and drawings. The major features listed in **Table E.6** were examined and evaluated in detail.

These items are further identified in subsequent volumes with major conditions that need to be addressed for continuing reliable operation of the Mangla generators and major electrical balance of plant equipment. The necessary work on the equipment logically occurs during a unit refurbishment outage, although transformer work might occur independently, depending on the magnitude and duration required for the work.

Table E.6: Generator and Unit Electrical Features Examined

Feature	Details Examined
Stators	Windings, cores, frames, and foundation
Rotors	Spider, rim, and poles
Shafts	Shafts, couplings and bolting hardware

Table E.6: Generator and Unit Electrical Features Examined	
Feature	**Details Examined**
Cooling System	Water supply, piping, and surface air coolers
Ventilation	Baffles, windage, and end turn cooling
Bearings	Thrust capability
Excitation	Power source (rotating or static), regulator system
Collector	Collector ring, brushes and rigging, slip rings
Brakes and Jacks	Cylinders, pads, and brake ring
Main and Neutral Leads	Leads, CTs, neutral grounding
Isolated Phase Bus	Capacity and variations between units
Protective Relays	Age, types, obsolescence
Control System	Age, obsolescence
Main Unit Transformer	Age, capacity, physical size, cooling requirements

6.2 Turbines and Unit Mechanical

The turbines and unit mechanical assessment is based on interviews with site personnel, a review of available plant information and visual inspection and observations of equipment conditions during the site visits. The major features listed in **Table E.7** were examined and evaluated in detail.

These items are further identified in subsequent volumes with major conditions that need to be addressed for continuing reliable operation of the Mangla turbines and major mechanical balance of plant equipment. Effectively all of the work must be performed during unit refurbishment outages.

Table E.7: Turbine and Unit Mechanical Features Examined	
Feature	**Details Examined**
Inlet Valves	Operator, seals, discs, slip joints
Spiral Cases and Stay Rings	Coatings, bushing bores, guide vane facing plates,
Turbine Runners	Blades, crown, bands, wear ring surfaces, aeration device
Guide Vanes	Vane condition, end seal gaps, vane to vane gaps,
Guide Vane Mechanisms	Linkages, bushings, pins, servomotors
Head Covers	Guide vane facing plates, coatings, bores,
Turbine Shaft	Visual inspection of shaft
Shaft Seals	Observation of functionality
Draft Tube and Discharge Ring	Coatings, surface and cavitation damage

6.3 Station and Units Common Features

The station and generating unit common features were assessed in the same manner as previously described for the turbines and generators. The items that were reviewed by this

assessment are listed in **Table E.8**. In order for the project refurbishment to be complete, some of these components must also be renewed or upgraded. Except when a component is tied to a unit outage, the program expects this work to be completed before the first unit outage is undertaken.

Table E.8: Station and Generation Unit Common Features Examined

Feature	Details Examined
Intake Gates	Seals, trash racks
Power Intakes	Concrete surface, articulated joints
Power Tunnels, Bifurcations, Penstocks	Liner, coatings
Irrigation Valves	Water passages, coatings, disc, operator
Draft Tube Gates	Slots, gates, storage pits, drainage of slots
Powerhouse Bridge Cranes	Controls, lift capability, wheels, rails
Cooling Water System	Piping, Valves,
Station Drainage & Dewatering	Piping, valves, controls, pumps, capacity,
Station Fire Protection/Detection	Water supply, piping, valves, sprinklers, detectors
Generator Fire Protection (CO_2)	Bottles, firing mechanisms, detectors,
Standby Generators	Engine/generator, fuel system
Elevators	Car, machine room

6.4 Concrete Inspection

The concrete condition assessment is based on interviews with site personnel and visual inspection of the facilities during the site visits. The major features listed in **Table E.9** were examined and evaluated in detail.

These items are further identified in subsequent volumes with conditions that need to be addressed for continuing reliable operation of the Mangla powerhouse.

Table E.9: Station and Generation Unit Common Features Examined

Feature	Details Examined
Generator Sole Plates	Grout Pockets, underlying concrete structure
Upstream Powerhouse Wall	Water seepage
Draft Tube Man-doors, Gallery Walls	Large gaps at construction joints
Power Tunnel Concrete Supports	Grout, concrete condition after fire in tunnel
Downstream Crane Wall	Displacement, rail alignment, load capability
Switchyard Concrete Foundations	General visual examination

7. Conclusions and Recommendation

Alternative 1A (1310 MW) is recommended because it satisfies all the objectives of the Scope of Work, and of the alternatives considered, has the highest Net Present Value, Benefit to Cost Ratio, and Economic Internal Rate of Return. It also shows an acceptable Financial Internal Rate of Return.

It is further recommended to consider implementation of Alternative 1C, which is a modification of Alternative 1A. Although beyond the scope of this study, investments in other equipment such as "Static Var Compensators" or other means to satisfy the necessary reactive power requirements for the power system might be a wise strategy. This would allow not only Mangla, but also other power stations to maximize their primary function of supplying megawatts.