OPTIMIZING OF THE USAGE OF SAMANALAWEWA WATER RESOURCES FOR POWER GENERATION

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Degree of Master of Science

Department of Electrical Engineering

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Sri Lanka

May 2016

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Dissertation submitted in partial fulfillment of the requirements for the degree Master of Science in Electrical Installation

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DECLARATION

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(Eng. W.D. A. S. Wijayapala)

ABSTRACT

Samanalawewa hydroelectric project is based on Walawe basin in southern region of Sri Lanka. It includes Samanalawewa reservoir, a water way system and a 120MW power plant as stage (I). Some provisions have been kept for stage (II) to add another 120MW power plant to meet the peak power demand with low cost hydro power. Since the impounding of the reservoir there is a leak around 2.44m^3/s and past leak mitigation activities have not succeeded. The leak accounts for more than one fifth of energy loss of the current energy generation by Samanalawewa power plant. The construction of stage (II) is suspended with lower energy generation than expected.

This research discusses about a Leak Pump Back System (LPBS) which will curtail the net water outflow from the leak. The LPBS will pump back the leak water to the reservoir and this additional water input can be used to generate power by SPP. The pumping head of LPBS is much lower than the design head of SPP. Therefore The LPBS will consume lower energy than the extra energy generation by SPP. Since the pumped back water is regulated by the reservoir, the extra energy generation is dispatch-able. This will improve the viability of Samanalawewa stage (II).

Construction works for a mini hydro power plant is underway using the leaked water. This mini hydro plant can recover less than one third of energy which could have been recovered by LPBS. The LPBS will not divert total leaked water since LPBS will not operate during peak hours and downstream irrigation water demand needs to be provided with leaked water. Therefore the combined operation of mini hydro and LPBS will give more benefits, though the LPBS is going to limit the water supply to the mini hydro plant.

Key words: Samanalawewa, Leak, Pump, Peak demand, Hydro

ACKNOWLEDGEMENT

First, I pay my sincere gratitude to Eng. W.D. Anura S. Wijayapala who encouraged and guided me to conduct this study and on preparation of final dissertation.

I am glad to extend my sincere gratitude to Prof. N.Wickramarachchi, Head of the Department of Electrical Engineering, University of Moratuwa and all the lecturers and visiting lecturers of the Department of Electrical Engineering for the support extended during the study period.

I would like to thank Eng. H.S. Somathilaka, DGM (Samanala Complex), Eng. A.R.M.M.S. Karunasena CE (Samanala Complex), Eng. U.S.H. Ambepitiya, CE (Samanalawewa) of Ceylon Electricity Board who encouraged me and provided required facilities to carry out the study.

I also like to thank Eng. H.A.S.C. Karunananda (Operations Engineer – Samanalawewa) and Eng. H.M.D. Herath, (former Civil Engineer – Samanalawewa) for encouraging and sharing their knowledge to make this project successful. Special thank goes to Mr. H.M.N.A.D. Karunananda, (Electrical Superintendent of Samanalawewa Dam Monitoring) and Mr. A.K. Wickremesinghe (Irrigation Departmant, Kaltota Scheme) for helping me to gather required data. Finally I thank all the staff members of operations, electrical maintenance and dam monitoring sections of Samanalawewa Power Station for all the support given in order to complete this project successfully.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

BHP	Brake Hose Power
CEB	Ceylon Electricity Board
CECB	Central Engineering Consultancy Bureau
dia.	Diameter
IRR	Internal Rate of Return
JICA	Japan International Corporation Agency
LPBS	Leak Water Pump Back System
MOV	Motor Operated Valve
msl	mean sea level
NWS&DB	National Water Supply and Drainage Board
O&M	Operations and Maintenance
SMHPP	Samanalawewa Mini Hydro Power Project
SPP	Samanalawewa Power Plant
WHP	Working Horse Power

LIST OF APPENDICES

Chapter 01

INTRODUCTION

1.1. Background

1.1.1. Samanalawewa Hydroelectric Power Project

Samanalawewa hydroelectric power project is built on Walawe River in southern region of Sri Lanka. The project stage (I) was completed and commercial operations of a 120 MW power plant was started in 1992. The project design has another 120 MW power plant to be implemented as stage (II) development. The project is fully owned and operated by Ceylon Electricity Board (CEB).

The project stage (I) includes construction of a dam, a water way system and a 120 MW power plant. Samanalawewa dam is rock-fill clay core type having a crest level of 463.5 m above mean sea level (msl). The dam height is 107.5 m from the river bed level and crest length is 480 m. The dam structure includes three spillway radial gates, a low level outlet and an irrigation discharge outlet on left bank. Samanalawewa reservoir maximum level is 460 m (msl), minimum level is 424 m (msl) and live storage is 215 x 10^6 m^3 which is equal to a 173 GWh energy capacity. Samanalawewa water way system includes a water intake, a concrete lined low pressure tunnel of 5.15 km long and 4.5 m diameter, a surge chamber of 18 m diameter, a portal valve house and a surface type steel penstock. Samanalawewa Power Plant (SPP) stage (I) has two 60 MW generating units and an outdoor type 132 kV switchyard. To generate 1 kWh of energy from SPP, it is required average of 1.29 m^3 water from Samanalawewa reservoir. SPP design head is 320 m and when the both generating units run at full load the water way system head loss is 12 m. The annual expected energy generation of stage (I) is 403 GWh. Table 1.1 shows the actual energy generation by SPP from 1993 to 2014.

Table 1.1: Actual Energy Generation of Samanalawewa Power Plant

Year	Annual Energy Generation (GWh)	Year	Annual Energy Generation (GWh)
1993	351.38	2004	233.60
1994	301.04	2005	240.63
1995	304.28	2006	294.47
1996	152.34	2007	229.25
1997	283.74	2008	312.84
1998	335.38	2009	285.40
1999	319.72	2010	375.44
2000	284.85	2011	292.27
2001	210.36	2012	195.21
2002	185.50	2013	402.50
2003	318.32	2014	258.50

According to the initial design, the stage (II) development had included construction of Diyawinioya reservoir, a connecting tunnel from intake of Diyawinioya reservoir to the existing surge chamber, a second penstock, an extension to the existing SPP and a new tailrace.

A plugged 6 m diameter tunnel has been constructed to connect the proposed intake of Diyawinioya reservoir tunnel to the surge chamber. A connection for second penstock at the penstock portal valve house have been made at stage (I) construction as provisions for the stage (II) development. Major part of excavation work for the second penstock has also been completed during the stage (I) constructions. The 4.5 m diameter concrete lined low pressure tunnel is adequate to cater high flows with the stage (II) development as initial design.

1.1.2. Samanalawewa Reservoir Leak

Since the impounding of the reservoir, there has been a leak from the right bank and the initial leak rate was around 2.8 m^3/s. Consequently the stage (II) couldn't be implemented and the annual average energy generation has been reduced to 280 GWh.

Grouting work is the first leak mitigation activity carried out at the beginning. As the leak flow rate couldn't be reduced by the grouting, wet-blanketing process was conducted in 1998. As a result the leak rate had reduced to an average of 2.0 m^3/s from initial leak rate of 2.8 m^3/s. After the wet-blanketing process Central Engineering Consultancy Bureau (CECB) has conducted a feasibility study for the stage (II) development in year 2000. They recommended installing of a single 60 MW unit and to keep provisions for another 60 MW unit as the most suitable solution [2].

But again in year 2007 when the reservoir was reaching its maximum level there had been a sudden increase of the leak rate and then settled down to an average leak rate of 2.44 m^3/s. With this sudden increase of the leak rate, a decision was taken to maintain the reservoir level below 455 m (msl) as a precaution against further leak burst with higher water head. The current leak rate is varying between 2.1 m^3/s to 2.8 m^3/s with the reservoir level. Figure 1.1 shows the leak variation with the reservoir level. Annex 06 shows a picture of leak portal.

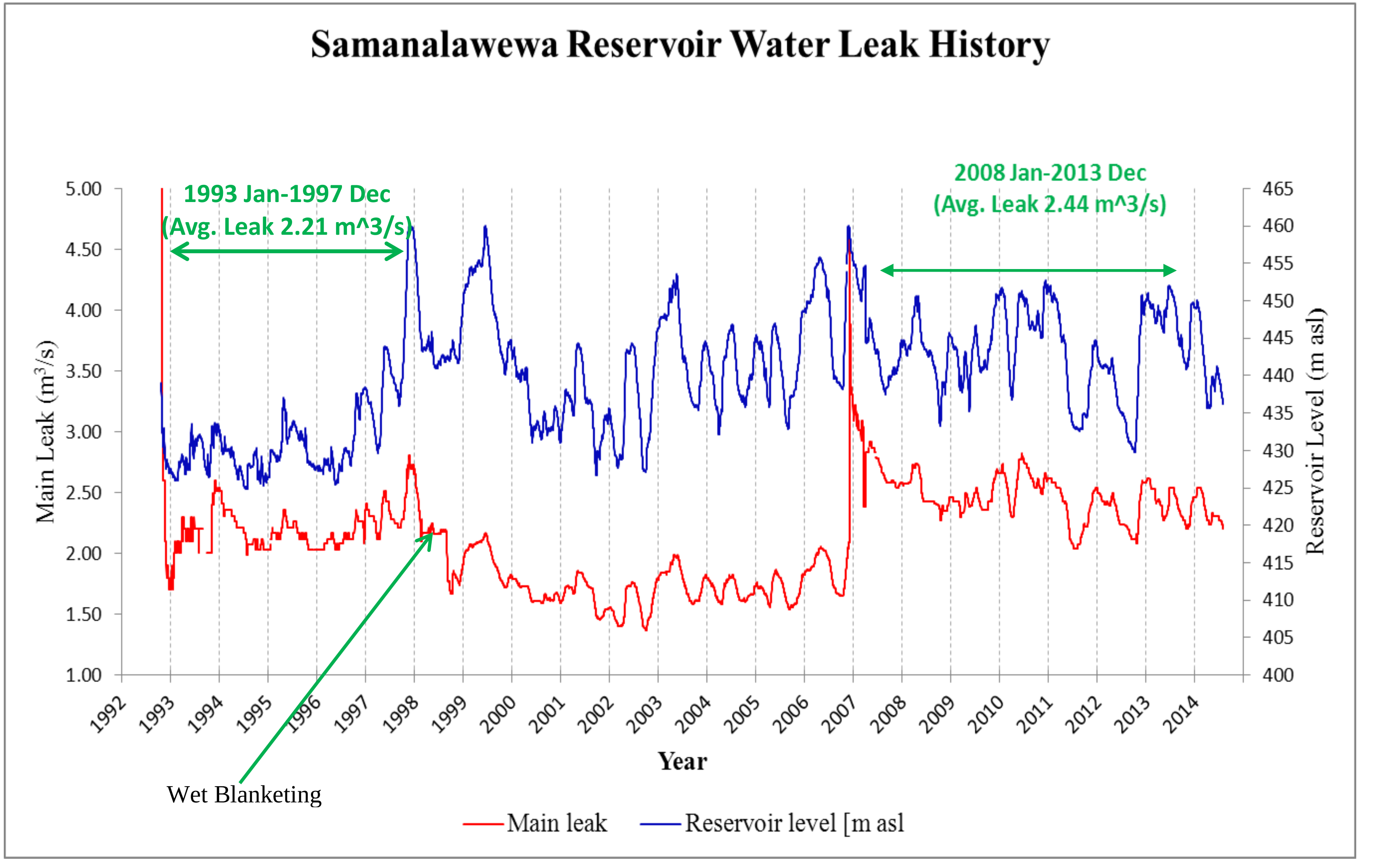

Figure 1.1: Samanalawewa Reservoir Leak Variation with Reservoir Water Level.

1.1.3. Samanalawewa Mini Hydro Power Project (SMHPP)

In recent past small hydro power development sector in Sri Lanka is widely considered to be a success story with the required incentives and assistance provided by the government to diversify the electricity sector from high cost thermal power generation. A feasibility study for a mini hydro power plant based on the leak and irrigation water release from Samanalawewa reservoir has been carried out by Sri Lanka Energies (Pvt) Ltd which is a subsidiary of CEB [1].

This mini hydro power project includes construction of a weir across the Walawe river just downstream of Samanalawewa dam, an intake structure, a headrace canal of 500 m length, a desilting tank, a fore bay tank, a penstock of 2350 m long, a power house at 318.8 m (msl), a tail race canal and powerhouse access roads. It includes installation of a turbine, a 1.1 MW generator, a transformer and erection of a switchyard and a power transmission line of 2.5 km length to connect the plant to CEB grid. The mini hydro power project has a 40 m net head and expected to generate 7.26 GWh of energy annually by the 1.1 MW generator. The design flow rate is 3.6 m^3/s and the plant factor is 0.78.

According to a Standardized power purchase agreement between CEB and Sri Lanka Energies (Pvt.) Ltd., the total energy generated by SMHPP has to be purchased by CEB at a flat rate of 16.70 LKR / kWh. Accordingly the annual revenue has been calculated as 119 million LKR. The total capital cost of the project has been estimated as 375 million LKR. The estimated Operations and Maintenance (O&M) cost is 10 million LKR per year. Then the IRR on the project has been calculated as 26%. SMHPP construction works have already been completed by Sri Lanka Energies (Pvt.) Ltd., and the plant is now in operation.

1.2. Importance of the Study

The leak water flows out from the Samanalawewa reservoir round the clock. From year 2008 to 2014 data, the average leak flow rate is calculated as 2.44 m^3/s. The average water loss by the leak is 77 x 10^6 m^3 per year. Without the leak SPP could have produced 59.6 GWh of additional energy each year. This energy loss by leak is more than one fifth of the current energy generation by SPP.

SMHPP expects to generate 7.26 GWh annually. Since a proper study has not been conducted to optimize the Samanalawewa water resources for power generation it can recover only 7.26 GWh of energy out of 59.6 GWh loss. Beyond that, mini hydro plant operates with the river flow and there is no water regulating facility. Hence the mini hydro energy is not dispatch-able. Therefore the value of energy generation by SMHPP is less than the value of energy generation by SPP.

During the stage (I) construction, extra cost has already been incurred to keep provision for stage (II) developments. This extra capital cost hasn't resulted in any returns since the stage (II) is yet to be implemented. Also CEB spends huge amount of money for providing peak power with gas turbine power plants. If Samanalawewa stage (II) had been implemented it could have generated low cost hydro power during peak hours.

1.3. Objectives

Other than the SMHPP study, there is no significant study that has been done to optimally use the low cost hydro energy potential available in Samanalawewa. The SMHPP will not be the best solution to CEB when the Samanalawewa entire project is considered together with the leak. The main objective of this study is to optimizing of the utilization of Samanalawewa water resources for power generation considering entire Samanalawewa project. The goals of the research are,

1. To optimize the utilization of the Samanalawewa leaked water for power generation by introducing a Leak Pump Back System (LPBS).

2. To improve the feasibility of Samanalawewa stage (II) by increasing the amount of energy limit in Samanalawewa through LPBS.

3. To study the effects from LPBS to SMHPP and to optimize the utilization of Samanalawewa water for power generation through combined operation of LPBS and SMHPP.

Chapter 02

LEAK PUMP BACK SYSTEM (LPBS)

2.1. The Concept

The best solution for the leak will be restraining the reservoir leak. Since the past efforts have not succeeded other options need to be analysed. The reservoir average level is 441 m (msl) and the leak portal level is 387 m (msl). Therefore the average water head between the leak portal and the reservoir is 54 m. If the leak water needs to be diverted to the reservoir, the leak water will be required to pump 54 m head. Then the pumped back water can be used to generate energy by SPP of having 320 m head. Ultimately a net head of 266 m can be obtained when losses are neglected. Then there will not be net water leak from the system, but energy is needed to pump the leak water back to the reservoir.

There are several advantages of LPBS when compared with SMHPP. The head gain of LPBS is 266 m which is much higher than SMHPP design head of 40 m. Mini hydro is operated with river flow since there is no reservoir to regulate the water. But the pumped back water is stored and regulated by the reservoir. So this extra energy generation is dispatch-able and more valuable than non-dispatch-able energy produced by mini hydro power plant. Further the Samanalawewa energy limit will increase which will improve the feasibility of the stage (II) to cater the peak demand as originally expected.

2.2. The Design

The leak rate is varying between 2.1 m^3/s to 2.8 m^3/s with reservoir level. So the LPBS is designed with 3 m^3/s pumping system to match the maximum leak rate. To ease the balance operation of LPBS with varying leak rate and irrigation water demand it is better to have 1 m^3/s rated three pumps with variable speed drive systems.

The dam crest level is 463.5 m (msl) and the reservoir minimum operating level is 424 m (msl). To obtain the minimum pumping head the pipe end should be at 424 m (msl) level. But laying the pipes through the dam is not advisable. So the pipes should be laid on the ground and immersed to the reservoir to utilize the negative head developed by downward pipes. Then non return valves are required to avoid the back flow of reservoir water through the pipes when the pumps are not in operation.

The LPBS system includes a sump at leak portal, three suction pipe lines of 1 m diameter, three pumps with motors, variable speed drivers and suitable instruments, valves with non-return facility, control panels, power distribution panels and delivery pipe line of 2 m diameter and 560 m in length. The nearest 33 kV feeder is available at dam site is around 1 km distance to pump house. Figure 2.1 represent the layout of the LPBS. Annex 01 shows Google earth view of the proposed LPBS site.

2.3. Calculations

2.3.1. Pump Selection Calculation

Data:

Pipe length = 560 m, head = 68 m, flow =1000 l/s (1 m^3/s).

Assumptions;

Inner diameter of pipe is 1 m and the efficiency of the pump and motor is 76%,

Calculations:

Total head = Static Head + Friction Head Loss + Velocity Head [14]

H_f = $H_s + H_e + H_p + H_v$ [14]

where H_f = friction head loss, H_s = screen head loss, H_e = elbow head loss, H_p = pipe head loss, H_v= valve head loss)

$V = Q/\pi r^2$ [14]

where V=Velocity of water in pipe, Q = volume, r = radius of pipe

$= 1/\pi\ (0.5^2) = 1.27$ m/s

Reynold number (Re) = VD/ v [14] where v = kinetic viscosity, D = dia.

Water is at 30 ^oC $v = 0.8 \times 10^{-6}\ m^2/s$ [14]

$Re = 1.27 \times 1/0.8 \times 10^{-6} = 1{,}587{,}500$

For Re is 1,587,500 and for steel pipes

$\lambda = 0.013$ [14] where λ = friction coefficient

$H_p = \lambda \times L/D \times v^2/2g$ [14]

where L = length of the pipe

$= 0.013 \times 560/1 \times 1.27^2/2 \times 9.81 = 0.6$ m

$H_e = k_T \times v^2/2g$ [14]

where k_T = head loss coefficient of elbow

$k_T = 0.15$ [14], [15]

$H_e = 0.15 \times 1.27^2 \times 2^{-1} \times 9.81 = 0.01$ m

$H_v = 0.2$ m, H_S=0.25 m (assume)

$H_f = H_s + H_e + H_p + H_v$

$H_f = 0.25 + 3(0.01) + 0.6 + 3(0.2) = 1.48$ m

Maximum Static Head = 68 m

Velocity Head $= v^2/2g$

=0.08 m

Total head	= Static Head + Friction Loss Head + Velocity Head
	= 68 + 1.48 + 0.08
	= 69.56 m
Working horse power (WHP)	= ρgQH [14]
	= 1 x 9.81 x 1000 x 69.56
	=682,383.6 W
	=682.5 kW
Brake horse power (BHP)	= WHP/ E_{pump}
	= 682.5/0.76
	= 898 kW
<u>Market available pump data:</u>	Pump capacity – 900 kW [3]

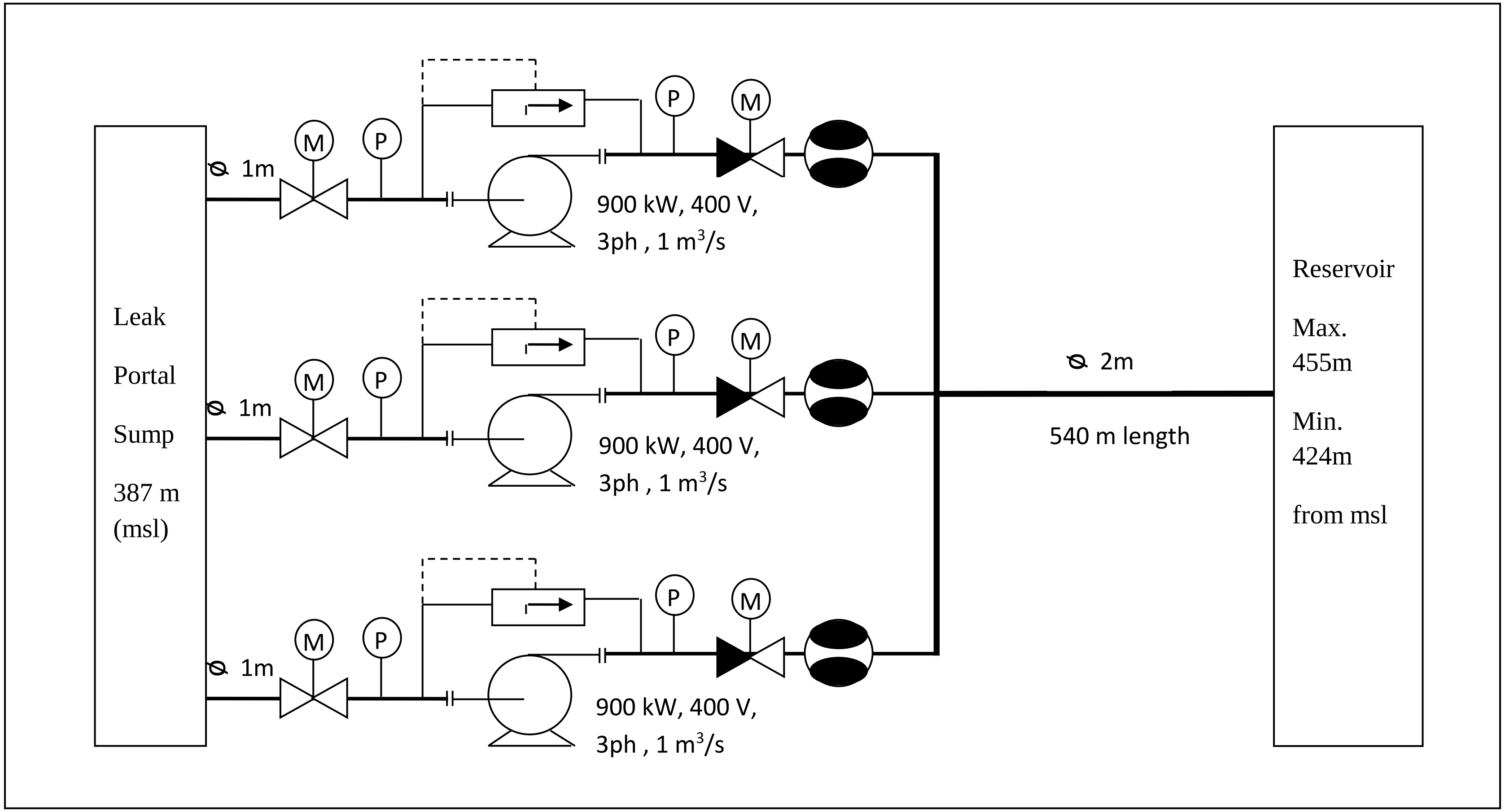

Figure 2.1: Layout of the LPBS

2.3.2. Input Energy Calculation

Average Reservoir Level = 441 m

Total head = Static Head + Friction Loss Head + Dynamic Head

= 54 + 1.48 + 0.08

= 55.56 m

<u>Break horse power</u>

WHP = ρgQH

= 1000 x 9.81 x 1 x 55.56

=545,043.6 W

=545 k W

BHP = WHP/ E_{pump}

= 545/0.76

= 717 kW

Power required to pump @ 1m^3/s rate = 717 kW

Energy required to pump for one hour @ 1m^3/s rate = 717 kWh

Energy required to pump 1m^3 of leak water back to reservoir =717 kWh / 3600

= 0.2 kWh

2.3.3. Validating the Results

<u>Samanalawewa Power Plant</u>

Water required to generate 1 kWh = 1.29 m^3

Rated head = 320 m

Energy generation from 1 m^3 water by SPP per 1 m head

= 1 kWh / (1.29 m^3x 320 m)

= 0.00242 kWh

Plant efficiency = 0.00240 x 3600 x 100 / 9.81

= 88%

<u>Leak Pump Back System</u>

Energy required to pump 1 m^3 = 0.2 kWh

Average pump head = 54 m

Energy required to pump 1 m^3 of water per 1 m head

= 0.2 kWh / 54 m

= 0.0037 kWh

Plant efficiency = 9.81 x 100 / (0.0037 x 3600)

= 74%

The lower plant efficiency of LPBS than SPP is resulted from many reasons. When comparing a 60 MW hydro power plant with 0.9 MW pumping system, the pumping efficiency is much less as assumed 76%. But for large hydro power plant the overall efficiency is more than 85%. Further SPP water way system is designed to have enough capacity for stage II; hence water way system losses are much less.

2.4. Cost Estimations

2.4.1. Construction Cost Estimate

Construction cost for supply and install of each component is listed in table 2.1. The values have been extracted from “Rate Book” issued by National Water Supply and Drainage Board and “Standard Construction Cost 2013” issued by CEB. When the required capacity of an item is not exactly matched with the references, the cost of nearest capacity item is extrapolated appropriately.

Table 2.1: Construction Cost for Supply and Installation of Each Component

Item		Unit Price (million LKR)	Qty	Total Price (million LKR)	Reference
I MVA Transformer		4.70	3	14.10	[17]
33 kV line per km		2.00	1 km	2.00	
900 kW Pump		3.30	3	9.90	[3]
Control Panel		14.00	3	42.00	[16]
VSD		26.00	3	78.00	
Pump House per ft^2		0.003	900 ft^2	2.70	
Sump per m^3		0.02	450 m^3	9.00	
5 tone Gantry Crane per m		0.21	12 m	2.52	
Pipe Line 1: 1 m dia.	length per m	0.24	150 m	36.00	
	MOV	5.00	6	30.00	
	Flow meter	1.50	3	4.50	
Pipe Line 2: 2 m dia.	length per m	0.36	540 m	194.40	
	MOV	12.00	1	12.00	
	Flow meter	1.50	1	1.50	
Sub Total				438.62	
Add 10%				43.86	
Total				482.48	

2.4.2. Operations & Maintenance Cost Estimate

The operations and maintenance cost is extracted from Samanalawewa mini hydro project feasibility study [1] since the maintenance and operation requirement will be same as the mini hydro power project of similar capacity. The manpower requirement and the operations and maintenance cost to operate LPBS are listed in table 2.2.

Table 2.2: Operations and Maintenance Costs

Item	Monthly Cost (LKR)	
Manpower		
Technical Officer	50,000.00	
Skill Labour	30,000.00	
Unskilled Labour	25,000.00	
Security Officers	50,000.00	
Clerical Service	25,000.00	
Employment tax	25,000.00	
Total Manpower		**205,000.00**
Repair and Consumables		300,000.00
Transport		70,000.00
Administration		50,000.00
Total Monthly Cost		**625,000.00**
Annual Cost		7500,000.00
Other		500,000.00
Total Annual O & M Cost		**8,000,000.00**

Sri Lanka electricity tariff of CEB reflects several cost components as generation cost, transmission cost, distribution cost, technical and non-technical losses and subsidies. The Samanalawewa hydroelectric power project is operated and owned by CEB and the LPBS is a solution for existing problems of the project. Therefore the energy cost of LPBS operation should represent the actual cost of energy available at LPBS site which comes from a 33 kV feeder from Balangoda grid substation. The generation cost component of energy cost of LPBS operation can be compensated to energy generation by SPP using pumped back water.

Distribution and Retail cost [4] = 2.73 LKR / kWh

Transmission cost [4] = 0.77 LKR / kWh

Total cost of energy supply to LPBS = 3.50 LKR / kWh

2.5. Optimization of LPBS Operations

The LPBS can be stopped to avoid consuming high cost energy during peak hours which is around 6:30 pm to 10:30 pm. The irrigation water demand can be partially matched during peak hours with this practice.

Irrigation water requirement for Kaltota area is accomplished by Samanalawewa reservoir. Currently it is provided by the leakage water. Addition to that, irrigation water is released from the reservoir when demand is high. Depending on the irrigation water requirement the LPBS will not be able to operate throughout the year. Paddy is grown in two seasons per year called Yala & Maha. For each crop season generally it is required three and half months to reap the product [6], [11]. During the other periods in the year there is no irrigation water demand.

Since the leak water is available throughout the year for Kaltota scheme farmers are not concerned on water saving practices whereas in other areas like Udawalawa scheme such practices are seen. Therefore introducing water management system to Kaltota scheme is essential to optimize the operation of LPBS. With good water management practices, water is required average of 114 days per crop season including two weeks for land preparation [6], [11]. When two crop seasons were allocated per year, 137 days remain to operate LPBS.

Further during high rainy days, irrigation water demand is less. According to the Samanalawewa rainfall data, high and consecutive rainfalls were recorded average of 60 days per year within crop seasons of a year. During this period the irrigation water demand is less and LPBS can be operated.

Therefore LPBS can be operated 197 days per year, allowing full supply of irrigation demand with good water management practices. Possibilities for partial loading of the LPBS to match the irrigation demand have not been considered in this study since the available data on irrigation demand is not enough.

2.6. Financial Analysis

Samanalawewa reservoir capacity is sufficient to generate power during peak hours by existing 120 MW SPP. So the additional water input to the reservoir by LPBS will be useful for power generation in other time slots, where the existing reservoir capacity is not enough. So this extra power generation by SPP will help to reduce base load demand provided by high cost thermal power. Therefore for financial analysis, the value of additional energy generation is taken as 8.07 LKR / kWh based on coal power unit price [5]. Table 2.3 summarizes the input data for financial analysis of LPBS.

Table 2.3: Data for Financial Analysis of LPBS.

No.	Description	Unit	Value
1	Operating hours per day	hours	20
2	Average leak rate	m^3/s	2.44
3	Average leak when reservoir level is above @ 448 m (msl)	m^3/s	2.50
4	Water energy conversion ratio for SPP	m^3/kWh	1.29
5	Average pumping energy for 1 m^3	kWh	0.2
6	Value of energy produce (equivalent to coal unit price)	LKR / kWh	8.07
7	Value of energy consumption (generation cost 8.07 LKR / kWh + tranmission & distribution cost 3.50 LKR / kWh)	LKR / kWh	11.57
8	O&M cost for of 3 m^3/s pumping station per year	million LKR	8
9	Project cost of 3 m^3/s LPBS	million LKR	482.5
10	Days per year which is not covered by Yala & Maha crop seasons	Days	137
11	High and consecutive rain fall days per year within the seasons	Days	60

- The water volume that can be pumped back to the reservoir per year

  = Average leak rate x Operating duration Per Day x Number of days

  = 2.44 m^3/s x 20 h x 3600 x 197 days

  = 34.6 x 10^6 m^3

- Energy required to pump back 34.6 x 10^6 m^3 of water by LPBS

  = 34.6 x 10^6 m^3 x 0.2 kWh / m^3 = 6.9 GWh

- Cost of energy to pump back

  = 6.9 GWh x 11.57 LKR / kWh

  = 80 million LKR

- Energy generation by SPP from pumped back water

  = 34.6 x 10^6 m^3 / 1.29 m^3/ kWh

  = 26.8 GWh

- Value of energy generation

  = 26.8 GWh x 8.07 LKR / kWh

  = 216 million LKR

- Operation Profit = Value of energy generation – (energy cost + O&M cost)

  = 216 million LKR – 80 million LKR - 8 million LKR

  = 128 million LKR

IRR is calculated for LPBS with 6% price escalation for coal energy price and with 5% price escalation for operations and maintenance cost. Profitability and cash flow projection over a 20 years period are used for financial assessment. Based on above considerations obtained IRR on project is 32% (Annex 02). The Simple Payback Period is 3.8 years.

2.6. Sensitivity Analysis

Since the source of the leak water is Samanalawewa reservoir, reduction of leak rate cannot be expected other than by any leak mitigation activity. But the demand of downstream irrigation water release may increase due to dry seasons or bad water management practices. So sensitivity analysis has been carried out for 30% less rain, 20% more irrigation demand and for the case both occur together. For all three above cases, sensitivity analysis was carried out for construction cost increment by 10%, value of energy generation reduction by 10% and both together. The IRR outcomes from sensitivity analysis are shown in Table 2.4. This analysis is carried out without considering the possibilities of partial loading of the LPBS.

Table 2.4: Sensitivity Analysis for LPBS

Scenario	No Any Cost Variation	Construction Cost Increased by 10%	Energy Value Reduced by 10%	Both cost variation at same time	
No Any Water Issue	32	30	29	27	IRR (%)
Irrigation Water Demand Increased by 20%	26	24	23	21	
Rainfall Reduced by 30%	30	27	27	24	
Both water issue at same time	23	21	20	18	
	IRR (%)				

Chapter 03

SAMANALAWEWA STAGE (II) WITH LPBS

3.1. Initial Studies on Samanalawewa Hydroelectric Power Project

Several studies have been conducted for the project for investigating the feasibility of developing water resources of upper Walawe basin for power generation.

i. Samanalawewa Project Technical Report – May 1966 by Engineering Consultants Incorporated assisted by the Department of Irrigation.
   This report has proposed a 120 MW power plant with 368 GWh annual energy generation. Further the report has included construction of Samanalawewa reservoir, Diyawinioya reservoir to act as a fore-bay reservoir, connecting tunnel and a low pressure unlined tunnel of 3.3 km long 4.5 m diameter.
ii. Samanalawewa Project for Development of Hydropower Technical Report – August 1973 by Snowy Mountains Engineering Corporation assisted by the Mahaweli Development Board.
   This study has proposed a 120 MW power plant with 439 GWh annual energy generation. The proposal has included construction of Samanalawewa reservoir, Diyawinioya reservoir to act as a the upper expansion chamber for the surge shaft, a low pressure tunnel connecting Samanalawewa reservoir to Diyawinioya reservoir and 3.8 m diameter steeply inclined concrete lined tunnel.
iii. Samanalawewa Project Detailed Project Report – 1978 by Hydro Project Institute and Central Engineering Consultancy Bureau.
   This report has no major deviations from previous study and has proposed a 120 MW power plant which has estimated 440 GWh of annual energy generation.
iv. Proposal by Consortium of Consultants and Contractors in April 1984. (The consortium included the Consultants Sir Alexander Gibb and Partners & EPD Consultants and the Contractors Balfour Beatty and GEC Energy Systems of United Kingdom.)
   This proposal has omitted the construction of Diyawinioya reservoir for the stage (I) development due to the low energy input as 12 GWh from Diyawinioya

reservoir and high construction cost. The report proposed a 2.75 m diameter unlined low pressure tunnel, an underground high pressure shaft and a 120 MW power plant. The estimated energy generation figure was 431 GWh without Diyawinioya reservoir. Also it proposed to leave provisions to construct and connect Diyawinioya reservoir at a later date when Samanalawewa is to be operated as a peaking plant.

v. Review of Consortium's proposal by Electrowatt Engineering Services Ltd. In May 1984.

   This review has no major deviations from previous study and has proposed to restrict the operation of Samanalawewa as a peaking plant of 240 MW at a later date.

vi. Improvements proposed by the Consortium in October 1984.

   This study reveals the plant would be able to generate 240 MW for a period of 4.5 to 5 hours each day with limiting the drawdown of the reservoir to 448 m (msl) including Diyawinioya reservoir. The report indicates that construction of Diyawinioya reservoir is economical if the plant is to be operated as a peaking plant.

vii. Additional Studies Conducted by Electrowatt Engineering Services Ltd in August 1985.

   This study says, although a 3.8 m dia. concrete lined low pressure tunnel would be the optimal for the case of the stage (I) with an installed capacity of 120 MW, provision of a 4.5 m diameter concrete lined low pressure tunnel would help to eliminate the restrictions on the draw down levels. The Optimum maximum water level of the Samanalawewa reservoir has been estimated to 457.5 m msl.

3.2. Studies on Samanalawewa Stage (II) Development

3.2.1. CECB Study for Samanalawewa Stage (II)

The leak rate had been reduced as a result of wet blanketing process in year 1998. Thereafter CECB carried out a feasibility study for the Samanalawewa stage (II) development in April 2000 [02]. In CECB study they have mainly discussed on the capacities of the existing reservoir and the water way system to cater for the conditions after the installation of additional generating units. Also it has discussed the feasibility of the construction of Diyawinioya reservoir.

It has mentioned that most of the existing components of the water way system have sufficient capacity to cater the increased flow after the stage (II) developments. But with higher installed capacity, the flows will increase and hence the losses in water way system will increase rapidly. The estimated low pressure tunnel head loss for 180 MW power plant is 13.48 m with 67.5 m^3/s flow and for 240 MW power plant the head loss is 23.93 m with 90 m^3/s flow.

The study highlighted that some modifications will be required to increase the height of the surge chamber if two additional 60 MW units are to be installed. A separate tailrace canal will be required even for the addition of a single 60 MW unit.

CECB report has concluded that the construction of Diyavinioya reservoir is not feasible. The reason is the water tightness of the reservoir is uncertain according to the geological condition. During the excavation of Samanalawewa tunnel heavy water ingress had been reported at several locations. Any treatment for reservoir to improve the water tightness will be costly. Further, the energy gain about 23 GWh from Diyawinioya reservoir is not economical compared to the cost of development as it is required to construct a dam, intake, spillway, connecting tunnel, relocation of access roads and resettlement of villagers.

They have calculated that the energy limit of Samanalawewa scheme is about 297 GWh. It is reasoned out that this reduction from initial studies had been mainly due to the reduction of reservoir inflows by about 16% and the increase of irrigation releases by about 300%.

To estimate the suitable capacity of the stage (II) development the study has used a computer model. The input data were rainfalls to the catchments over 50 year period from year 1948 to 1998. Monthly inflows have been derived from the rainfalls. The reservoir evaporations had been obtained from a previous study of Electrowatt Engineering Services Ltd in 1984. The irrigation water requirement had been obtained from past studies and available data at that time. According to the simulation they have concluded adding a single 60 MW unit would be able to provide peaking for nearly 4.5 hrs with 98% reliability. The total generation will be 297.7 GWh. If two units are added, peaking can be done for 3.5 hrs with 98% reliability and total generation will be 286.3GWh.

Economic feasibility for the stage (II) has been included in CECB report. According to the study the IRR for adding a single unit with provisions for adding a second unit at a later date was 10.1%. The IRR for installation of two units was 8.9%. Finally the report concluded with installation of a single 60 MW unit with provisions for a second 60 MW unit.

3.2.2. JICA Study of Hydropower Optimization in Sri Lanka

A Study for Hydropower Optimization in Sri Lanka was conducted by Japan International Cooperation Agency (JICA) during the year 2001 to 2004 with assistance of Department of External Resources, Ministries of Lands, Irrigation & Energy and CEB. In this study, a comparison study was conducted on expansions the stage (II) for 60 MW and 120 MW [12].

This study was carried out based on CECB study. The JICA study also accepted that the development of the stage (II) with Diyawinioya reservoir is not feasible. To assess the monthly inflow to the Samanalawewa reservoir, they have used low-flow-runoff method for Walawe River. The energy estimates for existing power station, for one unit expansion and for two units expansion has been carried out by simulating the reservoir operation based on the daily runoff of the reservoir. The results are summarized in Table 3.1.

Table 3.1.: JICA Energy Estimate

Items	Unit	Existing	One Unit Expansion	Two units Expansion
Plant Capacity	MW	120	180	240
Peak Duration time	hr	6	4	3
95% Dependable Capacity	MW	120	172	225
Primary Energy	GWh	262	259	254
Secondary Energy	GWh	89	55	0
Total Energy	GWh	351	314	254

Following the values of CECB construction cost for the stage (II), JICA has re-estimated the project cost. One unit expansion cost has been estimated as US$ 35.4 million and for two units expansion cost has been estimated as US$ 62.2 million. The study showed that the IRR for one unit expansion and two units expansion would be 10.5% and 11.4% respectively. The JICA report concluded the viability of the expansion plan of SPP is subtle due to low capacity of the tunnel.

3.3. New Approach to Evaluate Samanalawewa Stage (II)

Problem with implementing of the Diyawinioya reservoir has been discussed in details in the CECB study and implementing of the Diyawinioya reservoir is not considered for the same reasons for this study.

3.3.1. Waterway System Capacity

Diyawinioya reservoir is going to act as a fore-bay reservoir to reduce water way system losses. Since the Diyawinioya reservoir is not practical the losses of water way system will increase. Accordingly drawdown levels of Samanalawewa reservoir will have to be limited. The total head loss of SPP is 12 m when running at 120 MW [8], out of which 6.14 m head loss occurs in low pressure tunnel [2]. The remaining 5.86 m head loss is due to the penstock and main inlet valve (MIV) onwards. The stage (II) development has a separate penstock and MIV for new power plant. Hence the head losses will increase only in low pressure tunnel and head loss due to the new penstock and main inlet valve (MIV) will be same as 5.86 m. Then the total loss and the minimum reservoir operating levels for each loading levels can be calculated with following data.

SPP head losses when two units are running at rated output	= 12 m [8]
Tailrace level when two units are running at full load	=117.3m (msl)[8]
Turbine minimum design head	= 300 m [8]

Minimum reservoir level for 180 MW load

Low pressure tunnel loss	= 13.8 m [2]
Penstock & MIV losses	= 5.86 m
Total water way losses	= 19.7m

Minimum reservoir level	= Sum of total heads
	= Tail race level + Turbine minimum rating + Total losses
	= 117.3 + 300 + 19.7
	= 437 m (msl)

Minimum reservoir level for 240 MW load

Low pressure tunnel and screen losses = 24.4 m [2]

Penstock & MIV losses	= 5.86 m
Total water way losses	= 30.3 m

Minimum reservoir level	= Sum of total heads
	= Tail race level + Turbine minimum rating + Total losses
	= 117.3 + 300 + 30.3
	= 447.6 m (msl)

The reservoir maximum level has been restricted to 455 m (msl) with the leak burst. So the reservoir energy storage above 447.6 m (msl) is 44 GWh. Only that amount can be used for peak power generation from a 240 MW power plant. Daily peak energy generation from a 240 MW power plant is 0.864 GWh and 44 GWh energy storage has enough capacity to operate a 240 MW peak power plant 68 days even without zero inflows. But even in dry season Samanalawewa reservoir has more than 0.5x 10^6 m^3 daily inflow according to the Samanalawewa reservoir operating data. Further, when the unit maintenance are arranged during dry seasons, the reservoir level can be drawn down up to 437 m (msl) for period of 84 days per year by operating the remaining three generating units (Detailed in Section 3.2.2).

3.3.2. Energy Capacity

In both CECB & JICA studies, Samanalawewa energy limit has been estimated based on several derived values from raw data like rainfall. So the actual values may have been deviated from the estimates for many reasons like errors on assumptions, errors on measurements and lack of data. Conducting evaluations based on actual values gives better results. The JICA estimated the annual energy capacity as 351 GWh in year 2004. But even in year 2000, CECB had accepted that the initial energy estimates were wrong and re-estimated it as 297 GWh.

Samanalawewa Sage (I)

According to the past 22 year’s data of SPP, it has recorded 280 GWh average annual energy generation. The 280 GWh energy generation has included all the factors as evaporations, inflows, irrigation release and the leak. So the study can be carried out with this real value of 280 GWh annual energy capacity in Samanalawewa reservoir.

Large hydro power generating plants require proper maintenance program to ensure higher availability and healthy operation of generating units. In general practice of CEB, all the hydro power units have rolling outage plans on monthly and annual basis for routine maintenance. Monthly routine maintenance is carried out during day time which doesn’t affect peak operation. But annual routine maintenance requires around three week outage, during that period the generating unit will not be available for peak power generation. If it is assumed that no other breakdowns were occurred during the peak hours for a year, a hydro power generating unit will be available for maximum of 344 days for peak power generation allowing 21 days for annual maintenance. Therefore in SPP stage (I) both units are available for 323 days and only one unit is available for 42 days per year.

The waterway system head loss is 12 m when both units run at full load [8] and when one unit run at full load the head loss is 3 m (When one unit run low pressure tunnel head loss is 1.55m [2]. The penstock & MIV head loss is extrapolated as 1.48m).

Assuming the SPP has been operated at full load throughout the history, (this assumption is reasonable since partial loading accounts more losses in turbine and generating system while low water way system head loss)

The average head loss of stage (I) operations = (12 x 323 + 3.03 x 42) / 365

= 11 m

SPP needs 1.29 m^3 of water from Samanalawewa reservoir to generate 1 kWh energy. The equivalent potential energy of water can be expressed as,

Potential Energy = $vh\rho g$,

where v = volume, ρ = density, h = head and g = gravity

For SPP, 1 kWh x 1000 x 3600 s = 1.29 x $\rho g (h_1-11)$,

where h_1 = intake head with generating losses

For water $\rho = 998.77\ kg/m^3$ at 22 ^oC and $g = 9.80665\ m/s^2$ [13]

Then $h_1 = 295.9$ m

Samanalawewa sage (II) with adding one 60 MW unit

After implementing the stage (II), SPP is going to operate as peaking power plant. Therefore peak loading pattern should be analysed for the study. Generally peak duration is considered as 06:30 pm to 10:30 pm for four hours each day. The system load reaches rapidly to its maximum within an hour and get reduce slowly [7] during the peak hours as shown in daily load curve in Sri Lanka. The peaking power plants should also follow the same pattern since other plants are operated to supply the base load. The system control centre assesses the peak load and accordingly starts the peak power generating units. With the increase of peak demand the units are loaded. When system demand goes down units are unloaded and stopped gradually. So peaking plant will not run at full load throughout the peak hours but will be loaded and de-loaded with the system demand. According to the electricity demand duration curve of Sri Lanka the demand goes above 80% of its maximum, during a period of 4 hours [7]. If it is assumed that the demand duration is vary linearly from 80% to 100%, the energy generation should be 90% of total that can be generated by peak power plant during peak hours.

Annual energy generation by 180 MW during peak hours = Capacity of all units x peak duration x peak loading factor x 344 days

= (60 MW x 03) x 04 hrs x 0.9 x 344 days

= 223 GWh

Without LPBS

All three units will be available for 302 days and two units will be available for 63 days per year allowing 21 days annual maintenance for each unit. Then the average head loss will be,

Average head loss = (19.6 x 302 + 12 x 63) / 365

= 18.3 m

For SPP the average energy generation is 280 GWh. The equivalent water volume is 361.2 x 10^6 m^3.

Available Energy = $hv\rho g$

= (295.9-18.3) x 361.2 x 998.77 x 9.80665 / 3600 x 1000

= 272.8 GWh

With LPBS

When LPBS is operated, it will add further 34.6 x 10^6 m^3 of water to the reservoir.

Available Energy = hvρg

=(295.9-18.3) x (361.2+34.6)x998.77 x 9.80665/3600x1000

= 299 GWh

Therefore 223 GWh energy capacity in the reservoir is required to run a 180 MW peak power plant and Samanalawewa reservoir has enough capacity to provide the demand even without developing the LPBS. There will be excess amount of 50 GWh energy without the development of LPBS and 76 GWh excess energy with development of LPBS. The excess energy can be dispatched during day time as required. Hence LPBS doesn't have clear effect on Samanalawewa stage (II) of adding one 60 MW unit.

Samanalawewa sage (II) with adding two 60 MW units

Annual energy generation by 240 MW during peak hours = Capacity of all units x peak duration x peak loading factor x 344 days

= (60 MW x 4) x 04 hrs x 0.9 x 344 days

= 297 GWh

All units will be available for 281 days and three units will be available for 84 days per year allowing 21 days annual maintenance for each unit. Then the average head losses will be,

Average head loss = (30.3 x 281 + 19.6 x 84) / 365

= 27.8 m

Without LPBS

Available Energy = hvρg

= (295.9-27.8)x 361.2x 998.77 x 9.80665 / 3600 x 1000

= 263.5 GWh

With LPBS

Available Energy = (295.9-27.8)x 395.8x 998.77x 9.80665 / 3600 x 1000

= 289 GWh

Therefore to run 240 MW peak power plant Samanalawewa scheme energy capacity requirement is 297 GWh. Without LPBS operation there will be energy shortage of 33.5 GWh which is equivalent to 38 days peak power generation in a year. So generating units may not be able to fully utilize during peak hours throughout the year. When LPBS is implemented there will be only 8 GWh energy shortage which is equivalent to 9 days peak power generation which can be manageable. So Samanalawewa reservoir is sufficient to provide the peak power for a 240 MW power plant with development of LPBS. The LPBS has positive effect on adding 120 MW for stage (II) development.

So construction of a 120 MW power plant as stage (II) development together with LPBS is technically feasible. The CECB study was done around fifteen years back and the relevant electricity sector cost, tariff, technologies and demand may have been changed. So re-evaluation of economic feasibility together with LPBS is essential and in this research it is not discussed and remains as further work.

If Samanalawewa stage (II) had been developed with 120MW power plant and operating as peak power plant, the value of LPBS would be much significant as discussed in chapter 03. Because of the additional capacity input to the reservoir by LPBS can be compensated to high cost oil fired thermal power generation which is around 23.40 LKR / kWh. Then project IRR on LPBS will increase up to 118% and Simple payback period will be 0.9 years.

Chapter 04

SMHPP WITH LPBS

4.1. Re-evaluation of Samanalawewa Mini Hydro Power Project (SMHPP)

Though the SMHPP energy selling rate is 16.70 LKR / kWh to CEB, to comply with the tariff Option No.2 published by Sustainable Energy Authority to encourage non-conventional renewable energy, real value of energy produced by SMHPP should be considered to evaluate the real benefit to CEB. Since the mini-hydro doesn't have water regulating facility the power plant is not dispatch-able. So the energy generation can be compensated to base load generation which is mainly provided by coal power. So the actual saving from mini hydro power generation will be the energy cost of coal power which is around 8.07 LKR / kWh [4]. Accordingly the IRR is re-calculated for SMHPP with 8.07 LKR / kWh energy selling rate and obtained IRR is 15% (Annex 03).

4.2. Combined Evaluation of SMHPP and LPBS

SMHPP may not succeed with operation of LPBS since major source of water supply to SMHPP will be diverted by LPBS. SMHPP is owned by Sri Lanka Energies (Pvt) Ltd which is a subsidiary of CEB. LPBS should also be implemented by CEB. Therefore the combined evaluation of LPBS and SMHPP will help to get an idea about the importance of the LPBS and possibilities of combined operations to get more benefits.

The Samanalawewa mini hydro plant can generate energy only when LPBS is not in operation. So the total water amount that goes to the mini hydro is the leak water when the LPBS is not running and the irrigation water release.

- Water volume that goes to the SMHPP if LPBS does not operate,

  $= 3.6m^3/s \times 60 \times 60 \times 24 \times 365 \times 0.78 = 89 \times 10^6\ m^3$

  (SMHPP design flow rate is $3.6m^3/s$ and plant factor is 0.78 [1])

- Leak water volume = 2.44 x 60 x 60 x 24 x 365 = 77 x 10^6 m^3

- Average irrigation water release by irrigation valve

  = 89 – 77 = 12 x 10^6 m^3

- If the leak water volume to be pumped backed is 34.6 x 10^6 m^3 (from chapter 02) by LPBS, the leak water volume that goes to SMHPP is,

  = 77 – 34.6 = 42.4 x 10^6 m^3

- Water volume that goes to SMHPP if LPBS is operated

  = 42.4 +12 = 54.4 x 10^6 m^3

- Energy generation by SMHPP if LPBS is available (considering the water volume ratios for the mini hydro)

  = 7.26 x 54.4 / 89

  = 4.44 GWh

- Annual revenue = 4.44 GWh x 8.07 LKR / kWh

  = 36 million LKR

For LPBS and mini hydro combined project,

Project cost	= 482.5 + 375	= 857.5 million LKR
Operations & maintenance cost	= 8 + 10	= 18 million LKR
Annual insurance premium of SMHPP		= 8.5 million LKR
Total savings	= 127 + 36	= 163 million LKR

Profitability and cash flow projection over a 20 years period are used for financial assessment. Based on above considerations the obtained IRR on combined project is 22% (Annex 04). The Simple payback period is 5.94 years.

Further, if it is considered the SMHPP separately when LPBS operate, the IRR on mini hydro will reduce to 12% with 16.70 LKR / kWh energy selling rate (Annex 05) and the Simple Payback Period will be 6.8 years.

There are several advantages of combined operation of the LPBS and SMHPP. During peak hours the LPBS can be stopped to avoid consumption of high cost energy and start mini hydro plant generating peak power demand. There is more than 2 km long pipe line along Walawe river to get the leak water to SMHPP. This pipe line will reduce the water loss of river which will reduce the irrigation water demand.

Chapter 05

CONCLUTIONS AND RECOMMENDATIONS

The excess energy generation by SPP through the water input by LPBS cannot be directly measured. It will stop the leak water outflow from the system. The benefits of the LPBS are the high water head gain by pumping small water head for power generation and the pumped water is dispatch-able. The construction of LPBS is an attractive option for Samanalawewa leak if the leak mitigation is not possible. The analysis has shown that the LPBS is always feasible even with full supply of irrigation water demand. Since the LPBS project benefit depends on the amount of the water pumped back, a good water management system should be implemented to Kaltota scheme to reduce the water demand for irrigation. It is recommended to study the other options available to supply irrigation water demand other than providing by Samanalawewa reservoir.

When the LPBS is developed, SMHPP will suffer from less water. Since the benefits on LPBS are much more than SMHPP, the combined operation of LPBS and SMHPP is the best solution since both projects belong to CEB and SMHPP construction work has been completed.

With the operation of LPBS, Samanalawewa stage II development with 120 MW plant has become technically feasible. Further, if Samanalawewa is going to operate as peak power plant, the implementing of the LPBS is a must since project IRR is more than 100%. Therefore it is highly recommended to implement LPBS with 3 m^3/s pumping capacity. Studying on the financial feasibility of Samanalawewa stage II development with 120 MW plant for peak power generation is required to be carried out.

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Appendix 1: Google Earth View of LPBS Site

Appendix 2: IRR Calculation for LPBS

	Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
a	Initial Cost (million LKR)	**482**																				
b	Unit Cost for Pump Back (LKR /kWh)		11.57	12.26	13.00	13.78	14.61	15.48	16.41	17.40	18.44	19.55	20.72	21.96	23.28	24.68	26.16	27.73	29.39	31.16	33.02	35.01
c	Cost for Pump Back (M LKR) (a x 6.89 GWh)		79.68	84.47	89.53	94.91	100.60	106.64	113.03	119.82	127.01	134.63	142.70	151.27	160.34	169.96	180.16	190.97	202.43	214.57	227.45	241.09
d	O&M Cost (M LKR)		8.00	8.40	8.82	9.26	9.72	10.21	10.72	11.26	11.82	12.41	13.03	13.68	14.37	15.09	15.84	16.63	17.46	18.34	19.25	20.22
e	Unit Rate for Energy Sale (LKR / kWh)		8.07	8.55	9.07	9.61	10.19	10.80	11.45	12.13	12.86	13.63	14.45	15.32	16.24	17.21	18.25	19.34	20.50	21.73	23.03	24.42
f	Revenue form Generation (M LKR) (e x 26.83 GWh)		216.51	229.50	243.27	257.86	273.34	289.74	307.12	325.55	345.08	365.78	387.73	411.00	435.66	461.79	489.50	518.87	550.00	583.00	617.99	655.06
g	Net Cash Flow (M LKR) (f – d – c)	-482	129	137	145	154	163	173	183	194	206	219	232	246	261	277	294	311	330	350	371	394
	IRR	**32%**																				

Appendix 3: Re-Calculations for IRR on SMHPP with 8.07 LKR / kWh Energy Selling Rate

Year		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Capital Cost (M LKR)	375																				
Insurance (M LKR)		8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
O&M Cost (M LKR)		10	10.5	11.03	11.58	12.16	12.76	13.4	14.07	14.77	15.51	16.29	17.1	17.96	18.86	19.8	20.79	21.83	22.92	24.07	25.27
Unit Price (LKR)		8.07	8.554	9.067	9.611	10.19	10.8	11.45	12.13	12.86	13.63	14.45	15.32	16.24	17.21	18.25	19.34	20.5	21.73	23.03	24.42
Revenue (M LKR)		57.4	60.85	64.5	68.37	72.47	76.82	81.43	86.31	91.49	96.98	102.8	109	115.5	122.4	129.8	137.6	145.8	154.6	163.8	173.7
Net Cash Flow (M LKR)	-375	38.9	41.85	44.97	48.29	51.81	55.55	59.52	63.74	68.22	72.97	78.01	83.36	89.04	95.08	101.5	108.3	115.5	123.1	131.3	139.9
IRR	**15%**																				

Appendix 4: IRR on Combined Projects of SMHPP & LPBS

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Initial Cost of LPBS (M LKR)	482.48																				
Unit Energy Cost for pump back (LKR)		11.57	12.26	13	13.78	14.61	15.48	16.41	17.4	18.44	19.55	20.72	21.96	23.28	24.68	26.16	27.73	29.39	31.16	33.02	35.01
Energy for Pump Back (M LKR)		79.68	84.47	89.53	94.91	100.60	106.64	113.03	119.82	127.01	134.63	142.70	151.27	160.34	169.96	180.16	190.97	202.43	214.57	227.45	241.09
O&M Cost of LPBS(M LKR)		8	8.4	8.82	9.261	9.724	10.21	10.72	11.26	11.82	12.41	13.03	13.68	14.37	15.09	15.84	16.63	17.46	18.34	19.25	20.22
Unit Rate for Energy Sale (LKR)		8.07	8.554	9.067	9.611	10.19	10.8	11.45	12.13	12.86	13.63	14.45	15.32	16.24	17.21	18.25	19.34	20.5	21.73	23.03	24.42
Revenue Form LPBS (M LKR)		216.51	229.50	243.27	257.86	273.34	289.74	307.12	325.55	345.08	365.78	387.73	411.00	435.66	461.79	489.50	518.87	550.00	583.00	617.99	655.06
Initial Cost of Mini Hydro (M LKR)	375.1																				
Insurance (M LKR)		8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
O&M Cost of Mini Hydro (M LKR)		10	10.5	11.03	11.58	12.16	12.76	13.4	14.07	14.77	15.51	16.29	17.1	17.96	18.86	19.8	20.79	21.83	22.92	24.07	25.27
Revenue From Mini Hydro (M LKR)		35.67	37.81	40.08	42.48	45.03	47.73	50.6	53.63	56.85	60.26	63.88	67.71	71.77	76.08	80.65	85.48	90.61	96.05	101.8	107.9
Net Cash Flow (M LKR)	-857.58	145.99	155.44	165.47	176.10	187.39	199.36	212.06	225.54	239.83	255.00	271.09	288.16	306.26	325.47	345.85	367.47	390.40	414.73	440.53	467.91
IRR	**22%**																				

Appendix 5: IRR on SMHPP when LPBS is Operated with 16.70 LKR / kWh Energy Selling Rate

Year		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Capital Cost (M LKR)	375.1																				
Insurance (M LKR)		8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
O&M Cost (M LKR)		10	10.5	11.03	11.58	12.16	12.76	13.4	14.07	14.77	15.51	16.29	17.1	17.96	18.86	19.8	20.79	21.83	22.92	24.07	25.27
Unit Price (LKR)		16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7
Revenue (M LKR)		73.81	73.81	73.81	73.81	73.81	73.81	73.81	73.81	73.81	73.81	73.81	73.81	73.81	73.81	73.81	73.81	73.81	73.81	73.81	73.81
Net Cash Flow (M LKR)	-375.1	55.31	54.81	54.29	53.74	53.16	52.55	51.91	51.24	50.54	49.8	49.03	48.21	47.36	46.46	45.51	44.52	43.49	42.39	41.25	40.04
IRR	**12%**																				

Appendix 6: Samanalawewa Leakage Portal

Appendix 7: Samanalawewa Leakage Flow