Feasibility study of a Pumped Storage Power Plant in Sri Lanka

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Abstract– *Pumped storage hydropower is a technology that stores excess and off peak electrical energy. According to the long-term generation plan of Ceylon Electricity Board, maximum storage of 600 MW pumped storage power is planned to integrate to the Sri Lankan power system by 2025.*

This research study carryout feasibility study of introducing pumped storage power plant to Sri Lankan power system. Six locations which are suitable for a pumped storage power plant are proposed and Kothmale is selected as most suitable location for further evaluation. Expected annual energy generation of the proposed plant is around 1314GWh. Total installed capacity of the plant is 600MW. Effective head of the proposed plant is 377m with maximum plant discharge of 191m³/s. After analyzing the geological and topological conditions of selected sites, water capacity of the lower and upper reservoir is calculated as 8.2 Million cubic meters (MCM) and 13.8MCM respectively. Lower dam is 39m high and 290m long while the upper dam is 27m high and 220m long.

The social and environmental effects due to introduction of this plant have been evaluated in this research. Finally load flow analysis have been carried out in both peak and off-peak durations after introducing proposed plant to the Sri Lankan power system in 2025.

Keywords: *Pumped storage, hydropower, Crest Length, Topographical, Geological, Plant capacity*

Nomenclature

Q_g - Plant discharge (m^3/s)
V_e - Effective reservoir capacity (m^3)
q_s - Suspended sedimentation ($m^3/km^2/year$)
C_a - Catchment area (m^2)
N_s - Specific speed (m-kW)
N - Speed of the turbine (rpm)
P_t - Turbine power (MW)
H - Head (m)
f - Frequency(Hz)

1 INTRODUCTION

The electricity generation and consumption do not always run together concurrently. Rapid variation of power throughout the day is more significant in countries like Sri Lanka. From the system's point of view this type of variation is not desirable and the utility companies all the time try to make the load curve flatter. This is done by different means and use of pumped storage plants is one of such methods to make the load curve flatter. Pumped storage is a grid-scale energy storage technology that can be enabled to grow its renewable energy portfolio. It helps to ensure the reliability of supply to the consumers. It also provides a contribution to maintenance of stability by absorbing grid turbulence during generation mode. System load curve in Sri Lanka has poor load factor and hence high unit cost of the Sri Lankan power system. As a solution to improve the load factor, Ceylon Electricity Board(CEB) has introduced a three-tier tariff plan for the industrial electricity consumers to improve the load factor. By introducing pumped storage power plant (PSPP) the load factor of the power system can be improved. Aim of this research is to carry out a feasibility study on a pumped storage power plant in Sri Lanka. This work includes the determination of the location of the plant, basic design of it, mainly environmental and social impacts due to proposed plant and load flow analysis after integrating the proposed plant to the electrical grid of Sri Lanka in 2025.

2 SITE SELECTION

2.1 Factors to be considered when selecting a suitable location

Topographical factors, geological factors, technical factors, environmental factors, social and cultural factors and weather condition must be considered when selecting a suitable location for a pumped storage power plant. A sufficient water source such as a river or stream should be available to fill the reservoir initially and then refill the evaporated water of the reservoirs time to time. Valley with narrow crest should be selected for dams and there should have sufficient storage capacity in the valley in minimum dam height. Zones with possibility of the earthquakes and landslides should be avoided for the protection of the dams and other structures. Avoidance of the areas of soil and weak rock conditions is necessary. Proposed plant should have enough storage capacity of the reservoirs to operate at least 6 hours per day. L/H ratio (length in to height ratio between two reservoirs) should be kept at minimum value for the cost optimization and reduced head loss.

Protected areas with natural parks and reserves should be avoided to be destroyed. Areas of critical habitats of important flora and fauna should be avoided to be affected. Population density of the selected area should be minimized. It should be feasible to access the construction areas easily and deliver material, equipment quickly and easily as well as remove the debris effortlessly. Historical, religious or cultural heritages should be avoided to be affected. Effects to the agricultural lands should be minimized. Effects to the industries, factories and commercial buildings should be minimized. Sufficient rainfall and the sufficient runoff of the streams must be there in the selected area in order to maintain the required water level of the reservoirs.

2.2 Suggested Locations

Six locations have been proposed for the evaluation. First proposal area belongs to the Nuwara Eliya district. Lower reservoir is situated in the Yoxford in Kothmale. Three options have been suggested for upper reservoirs. Second, third and fourth proposal areas belong to Badulla district and fifth proposal area is situated in Rathnapura district. Sixth proposal area again belongs to Badulla district. Summary of the technical details of the proposed locations are mentioned in table 1 and the social and environmental details are summarised under table 2.

Table 1: Technical details of the proposed locations

No	Location	Head	L/H ratio	Dam height	Crest length-Lower dam	Crest length - Upper dam
1.1	Kothmale- Caledonia	404m	26.9	38m	400m	234m
1.2	Kothmale- Radalla	439m	22.7	30m	400m	379m
1.3	Kothmale- Kotagala	471m	15.2	50m	400m	450m
2	Ella	445m	21.6	50m	404m	315m
3	Passara	461m	23	50m	488m	446m
4	Madolsima	446m	25	50m	252m	400m
5	Belihuloya	515m	21	50m	250m	358m
6	Ohiya	459m	18	50m	250m	550m

Table 2: Social and environmental details of the proposed locations

No	Location	Population (inh/km^2)	Resettlement	Agricultural lands	Nature of people
1.1	Kothmale- Caledonia	449.69	Less	Tea estates	Work as labors in tea estates
1.2	Kothmale- Radalla	449.69	High	No	Work as labors in tea estates
1.3	Kothmale- Kotagala	449.69	Less	Tea estates	Work as labors in tea estates
2	Ella	407.04	High	No	Industries based on tourism
3	Passara	358.88	High	No	Self-employment & agriculture
4	Madolsima	217.92	Less	Tea and high land crops	Engage in agricultural industry
5	Belihuloya	922.56	Less	Tea estates	Engage in agriculture
6	Ohiya	536.21	High	No	Industries based on tourism

After careful study of the above details, proposal 1.1 in Kothmale - Caledonia is selected as the most suitable location for the proposing pumped storage power plant. Even though, proposal 1.3 in Kothmale - Kotagala is having a less L/H ratio and high head, crest length of the upper dam and dam height are higher than proposal 1.1 and ability to access the upper reservoir and deliver goods is also harder than proposal 1.1. Therefore, proposal 1.1 in Kothmale – Caledonia is the best location to develop a pumped storage power plant.

3 SELECTED SITE CONDITIONS

The project area is situated in the South Central mountainous area which is belongs to Nuwara Eliya district. It is between the altitudes $6^{0}56'$ to $70^{0}0'$ North and $80^{0}34'$ to $80^{0}40'$ East. Population density of the area is 408.76 inh./km^2 with area of 1741km^2. Project area is nearly 150-200km away from Colombo. Upper reservoir area is well developed with tea plantation and averagely populated. Lower reservoir area is less populated area with slight vegetation. Major towns around the project area are Talawakele, Watagoda and Pudaluoya with population of 3000 to 5000. Upper reservoir covers the catchment area of Agra oya and Lower reservoir covers the catchment area of the Kothmale oya and Devon oya. Major streams within the project area are Kothmale oya and its tributaries such as Puna oya, Pudal oya, Nanu oya, Dambagastaawa oya, Devon oya and Agra oya.

Geologically the project area contains highland series of Precambrian which is composed by Gneiss and Charnokite. Gensis is widely seen in the continuous cliffs on the banks of the Kothmale oya. Charnokite found under the river bank upstream of the Kothmale reservoir up to Puna oya.

The majority of the living around the project area belongs to Hindu Tamils. They are workers in tea estates and earn low income. Most of them do not own lands or houses. A minority of people are Sinhalese Buddhists. There are Christians among both Sinhalese and Tamils. Nearly 200 Muslim families also live in the area. Some areas have agricultural settlements where Sinhalese earning money through cultivation of rice, highland crops and bananas. Small proportion engage in small businesses and transport of agricultural products to markets in Colombo. Some people live nearby waterfalls make a living out of tourism. Young people work in shops and self-employment activities such as poultry while girls are employed mostly in garment factories. A minority are in respectable professions in estate sector, government offices, schools and hospitals. Proposed project does not affect any waterfall directly. Therefore, the public will not be against the project much. Public protests and legal complains from the environmental organizations can be expected due to resettlements and affects to the agricultural lands. By awareness programs and proper resettlement plans, public protests can be avoided.

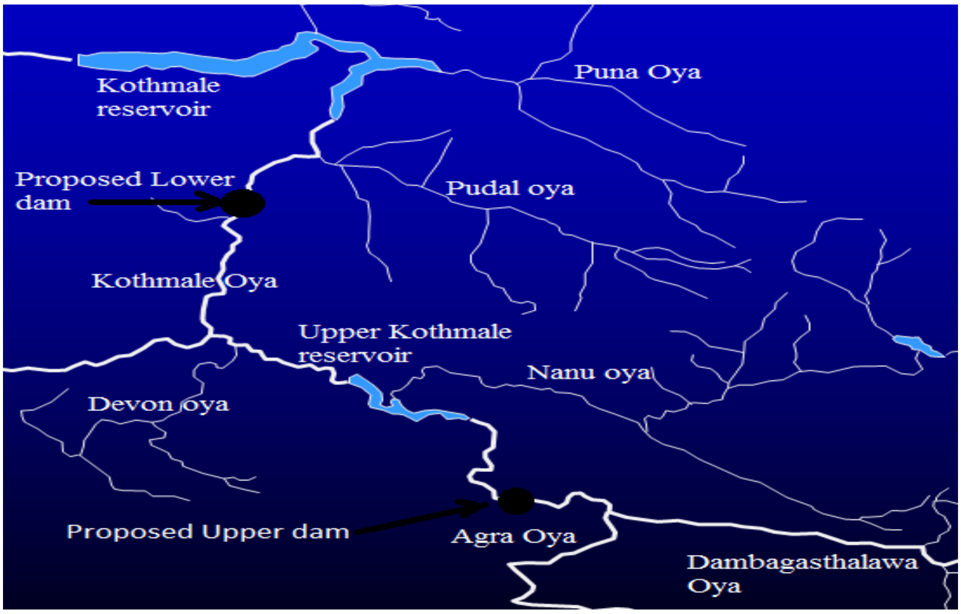

Figure 1: Waterway system

4 PLANT DESIGN

4.1 Installed capacity of the plant

Installed capacity of the plant is determined as 600MW as per the long-term generation plan. It is the maximum possible pumped storage power which can be added to the Sri Lankan power system by 2025.

4.2 Determination of unit capacity

PSPP will generate in the night peak. Therefore, the applicable unit capacity is calculated under the condition that a generator trip occur at the maximum demand in the night peak. PSPP pump up in off peak duration. Therefore, the unit capacity is calculated that a pump trip occurs at the minimum demand in one day. Minimum demand is approximately taken as 44% of maximum demand. Frequency constant (K) is taken as 4.92% S.

$$K = \frac{dP/P}{df} \tag{1}$$

dP = Power change (MW)
P = Demand(MW)
df = Frequency change (Hz)

Generator trip -	Allowable frequency deviation	= 50 – 48.75 = 1.25Hz
	Annual average demand in 2025	= 2480MW
	dP = 4.92 x 1.25 x 2480 /100	= 152.2 MW
	Therefore, applicable unit capacity	= 150MW
Pump trip -	Allowable frequency deviation	= 51.5 - 50 = 1.5Hz
	Minimum demand in 2025	= 2075MW
	dP = 4.92 x 1.5 x 2075 /100	= 153.1 MW
	Therefore, applicable unit capacity	= 150MW

4.3 Temporary fixing of maximum plant discharge

Total water discharge of the plant through turbines are calculated using the equation 2.

$$Q_g = \frac{P}{9.8\ x 0.85\ x\ H} \tag{2}$$

Q_g = Plant discharge(m^3/s)
H = Approximate head (m)
P = Rated capacity of the plant (kW)

Q_g = 600x1000kW / 9.8 x 0.85 x 404m = 178.3 m^3/s

4.4 Effective water capacity of the reservoirs (Live storage)

Live storage is the storage capacity of the reservoir above the dead storage level which constitutes usable portion of the total storage and it can be calculated using the equation 3.

$$V_e = Q_g \text{ x 6hr x } 3600s \tag{3}$$

V_e = Effective reservoir capacity (m^3)
Q_g = Plant discharge (m^3/s)
V_e =178.3 x 6 x 3600 = 3,851,280m^3 = 3.9MCM

4.5 Preparation of Water Capacity Curves

Contour lines of each reservoir is drawn for every 10m and the area of the layers are calculated. Capacity of each reservoir is computed by taking contour areas at equal intervals of 10m and water storage capacity curves shown in figure 2 and 3 are developed.

4.6 Sedimentation volume and sedimentation level

The river water carries silt. When river water reaches reservoir, its velocity and turbulence are reduced and gets deposited. The sedimentation level is determined by estimating sedimentation for 100 years.

$$V_s = q_s \text{ x } C_a \text{ x } 100 \tag{4}$$

q_s = Suspended sedimentation (m^3/km^2/year) – 18.18 m^3/km^2/year for the site area
C_a = catchment area (m^2)
V_s = Sedimentation volume (m^3)

For the lower reservoir, V_s = 18.18 x 334.6 x 100 =692,048m^3 =0.6MCM
For the Upper reservoir, V_s = 18.18 x 181.6 x 100 =330,148.8 m^3 =0.3MCM

The sedimentation level is obtained by marking sedimentation volume on the reservoir water capacity curve as shown in figure 2 and figure 3.

From figure 2, Sedimentation level of Lower reservoir = 887m
From figure 3, Sedimentation level of Upper reservoir = 1290m

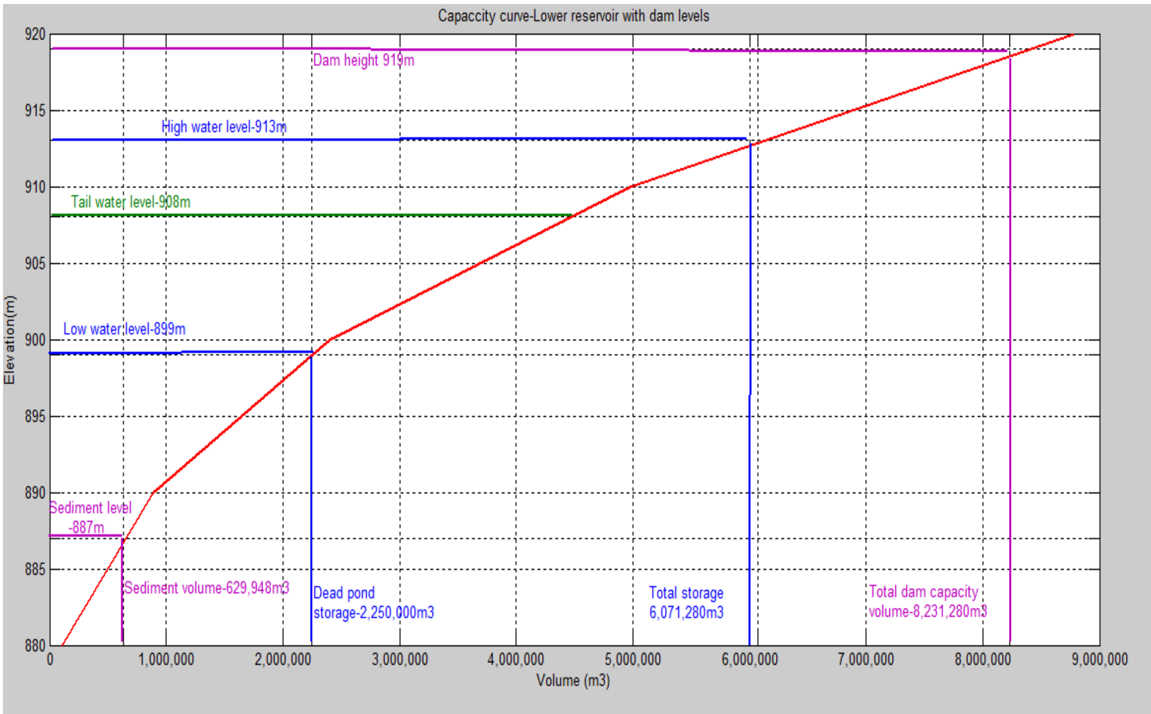

Figure 2: Water Capacity curve of the Lower reservoir

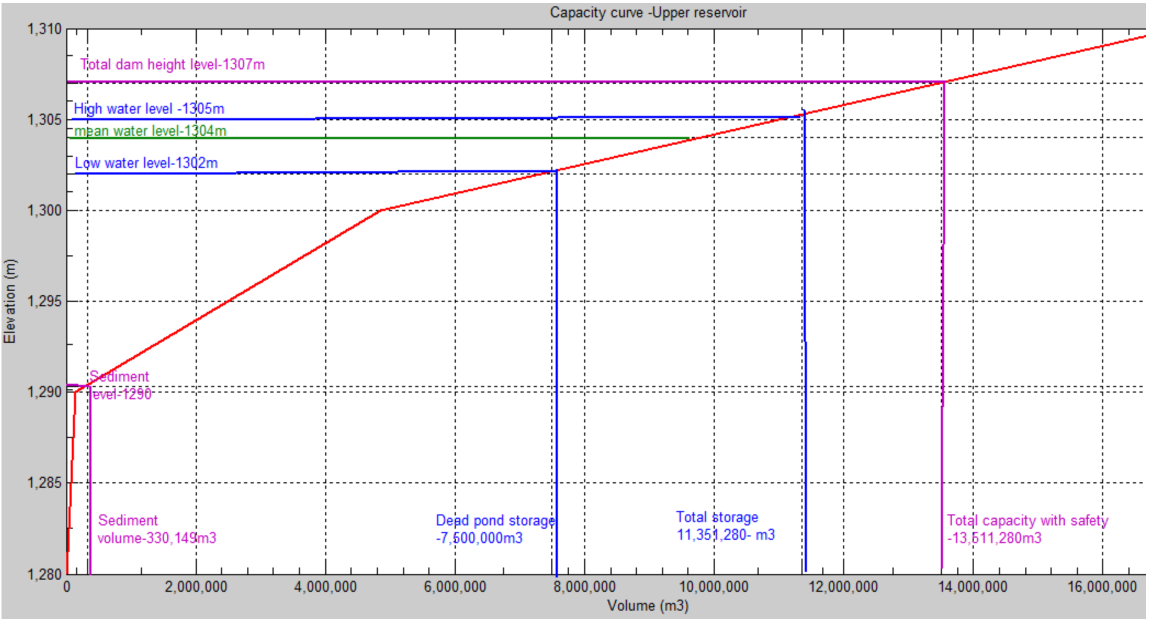

Figure 3: Water Capacity curve of the Upper reservoir

4.7 Determination of Water Levels (Upper and Lower Ponds)

4.7.1 Low Water Level

The low water level (LWL) is set at a position of about twice the inner diameter (D) of the headrace tunnel above the sedimentation level as shown in figure 2 and 3 to prevent intrusion of air into the tunnel. The tunnel inner diameter is obtained by equation 5 by setting the flow velocity at 6 m/s.

$$Q = \frac{\pi \, x \, D^2}{4} x \; 6 \; m/s \tag{5}$$

Q = Plant Discharge (m^3/s)
D = Diameter of Headrace Tunnel (m)

Headrace tunnel diameter, D = [4 x 178.3 /6 x π]$^{0.5}$ = 6.15m

Then LWL of the reservoirs then can be calculated by equation 6.

$$\text{LWL} = \; Sedimentation \; level + (\, 2 \; x \; D) \tag{6}$$

D = Diameter of Headrace Tunnel (m)

Low water level of the Lower reservoir = 888 + (2 x 6.15) = 899m
Low water level of the Upper reservoir = 1291 + (2 x 6.15) = 1302m

4.7.2 High Water Level

The high-water level (HWL) is determined by using the water capacity curves shown in figure 2 and 3, adding the LWL to the available drawdown (h_a) corresponding to the effective water capacity which is obtained by equation 3 in the section 4.4.

$$\text{HWL} = \text{LWL} + \text{h}_\text{a} \tag{7}$$

HWL= High water level (m)
LWL = Low water level (m)
h_a = Available drawdown (m)

- For the Lower reservoir

Water storage of the dead pond (from figure 2) =2,250,000m^3
Total storage of dead pond and effective storage = 6,071,280m^3
Available drawdown(h_a) = 14m
High water level = 899 +14 = 913m

- For the Upper reservoir

Water storage of the dead pond (from figure 3) = 7,500,000m^3
Total storage of dead pond and effective storage =11,351,280m^3
Available drawdown(h_a) = 3m
High water level = 1305m

4.8 Determination of dam height

For the Lower dam from figure 2
Flood storage= 600m^3/s x 3600s = 2,160,000m^3
Water capacity of the reservoir = 8,231,280m^3
Maximum level of the dam = 919m
Dam height = 919m – 880m = 39m

For the Upper dam from figure 3
Flood storage= 600m^3/s x 3600s = 2,160,000m^3
Water capacity of the reservoir =13,511,280m^3
Maximum level of the dam =1307m
Dam height = 1307m – 1280m = 27m

4.9 Determination of Normal Mean Water Level and Tailwater Level

4.9.1 Normal mean water level

The normal mean water level of the Upper reservoir can be calculated using the equation 8 given below.

$$\mathrm{MWL}_{(\mathrm{U})} = HWL_{(U)} - \frac{h_{a(U)}}{3} \tag{8}$$

$MWL_{(U)}$ = Normal mean water level of Upper reservoir (m)
$HWL_{(U)}$ = High water level of Upper reservoir(m)
$LWL_{(U)}$ = Low water level of Upper reservoir(m)
$h_{a(U)}$ = Available drawdown of the Upper reservoir(m)

MWL of Upper reservoir = 1305 – (3/3) = 1304m

4.9.2 Normal Tailwater level

Tailwater level of Lower reservoir can be calculated by equation 9 given below.

$$\mathrm{TWL}_{(\mathrm{L})} = \mathrm{HWL}_{(\mathrm{L})} - \frac{\mathrm{h}_{\mathrm{a(L)}}}{3} \tag{9}$$

$TWL_{(L)}$ = Normal tailwater level (m)
$HWL_{(L)}$ = High water level of Lower reservoir (m)
$h_{a(L)}$ = Available drawdown (m)

Tailwater level of Lower reservoir = 913 – 14/3 = 908m

4.10 Preparation of Waterway Profile

The turbine centre is set at the elevation corresponding to the draft head below the low water level of the lower pond as described in the following equation 10.

$$\text{Elevation of Turbine Centre} = \text{LWL}_{(\text{L})} - \text{Draft head} \quad (10)$$

$LWL_{(L)}$ = Low water level of lower reservoir(m)

Draft Head is obtained from the relation between the maximum pumping head and draft head as shown in figure 4. Maximum pumping head is calculated using the equation 11 and ignoring the head loss.

$$Maximum\ Pumping\ Head = HWL_{(L)} - LWL_{(L)} \quad (11)$$

$HWL_{(L)}$ = High water level of the Lower reservoir (m)
$LWL_{(L)}$ = Low water level of the Lower reservoir (m)

Maximum Pumping Head = 1305m – 899m = 406m

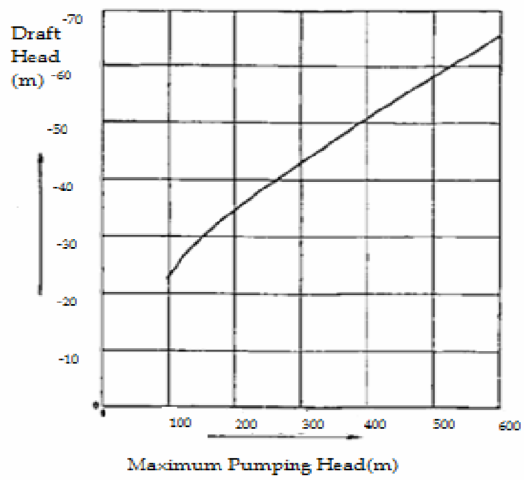

Figure 4: Relationship between maximum pumping head and draft head

Therefore, the elevation of Turbine Centre can be calculated using the equation 10 substituting LWL of lower pond as 899m and draft head as 50m.
Elevation of Turbine centre = 899 -50 = 849m

Cross section elevation graph of the water path is shown in figure 5 and the length of the penstock and headrace tunnel has been evaluated. Minimum ground clearance for the tunnels has been taken as 20m.

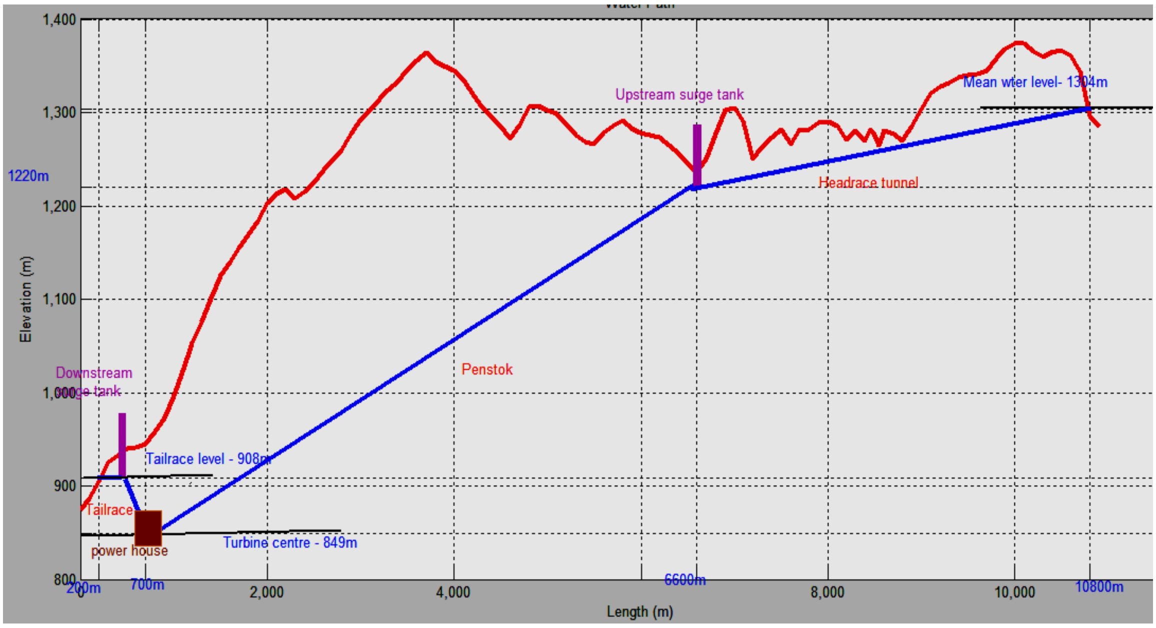

Figure 5: Waterway profile

- Headrace tunnel

Length= 4.2km
Water velocity= 6m/s
Diameter = 6.15m as per the calculation done in section 4.7.1

- Penstock

Length=9km

Water velocity = $0.125\ (2gh)^{0.5}$ (12)

$= 0.125(2 \times 9.8 \times 404)^{1/2} = 11.12$ m/s

Diameter = $\sqrt{\frac{Q}{V \times 0.7854}}$ (13)

Q = Plant discharge (m^3/s)
V = Water velocity (m/s)

Diameter = $[178.3/(11.2 \times 0.7854)]^{0.5} = 4.524$ft = 1.4m

- Tailrace

Length= 500m

4.11 Calculation of Head Loss and Effective Head

Rated heads of lower dam can be taken from the equation 14 given below.

$$\text{Rated head}_{(LD)} = HWL_{(LD)} - \frac{1}{3}(HWL_{(LD)} - LWL_{(LD)}) \quad (14)$$

$HWL_{(LD)}$ = High water level of lower dam
$LWL_{(LD)}$ = Low water level of lower dam

Rated head of lower dam = 910 – 1/3 (910 – 891) =904m

Rated heads of upper dam can be taken from the equation 15 given below.

$$\text{Rated head}_{(UD)} = HWL_{(UD)} - \frac{1}{3}(HWL_{(UD)} - LWL_{(UD)}) \quad (15)$$

$HWL_{(UD)}$ = High water level of upper dam

$LWL_{(UD)}$ = Low water level of upper dam

Rated head of upper dam = 1303 – 1/3 (1303- 1298) = 1301m

Gross head can be calculated from the equation 16 mentioned below.

$$\text{Gross head} = \text{Rated head (Upper dam)} - \text{Rated head (Lower dam)} \quad (16)$$

Gross head = 1301 -904 =397m

Effective head can be determined as follow by subtracting head loss from the gross head where the head loss is taken as 5% of the gross head.
Head loss = 379 x 5% = 20m
Effective head = 397 – 20 = 377m

4.12 Re-Calculation of Maximum Plant Discharge

Actual plant discharge is the recalculated using the equation 2 used in the section 4.3. Effective head calculated in section 4.11 is used as head.

Q_g = 600x1000kW / 9.8 x 0.85 x 377m
= 191 m^3/s
Hence discharge through one unit is 191 /4 = 47.7 m^3/s

4.13 Calculation of Annual Energy Generation

The annual energy generation is obtained by the following equation 17.

$$E = P \times T \quad (17)$$

E = Energy (GWh)
P = Rated capacity of the plant (kW)
T = Time duration which the plant operates during the year

E = 600,000 kW × 2190 hours = 1314 GWh

4.14 Re - Calculation of Effective Water Storage of the Reservoirs

Effective water storage of the reservoirs can be re-calculated using the equation 3 which is used in section 4.4.

V_e =Q_g x 6hr x 3600s
= 191 x 6 x 3600 = 4.1MCM

4.15 Crest length of the dams

4.15.1 Crest length of the lower dam

Cross section of the lower dam is shown in the figure 6. Variation of the crest length of the dam with the height is shown in the figure 7 and the maximum dam height is marked on it and finally the crest length of the lower reservoir is determined as 290m.

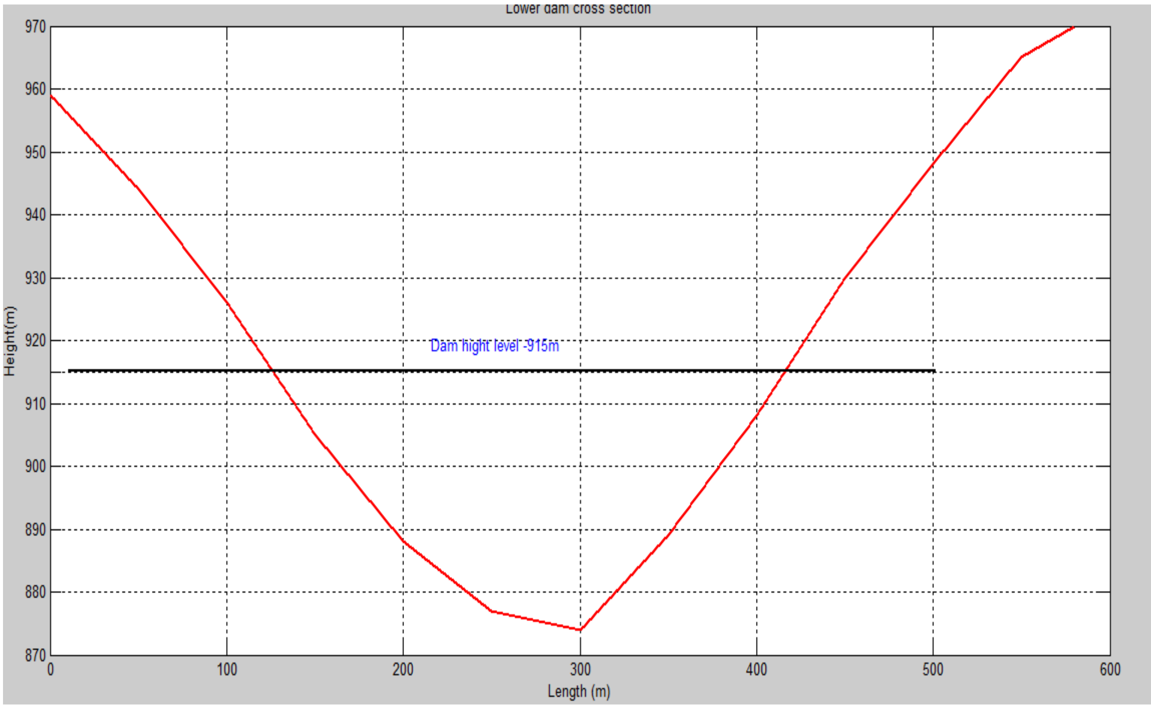

Figure 6: Cross section of lower dam

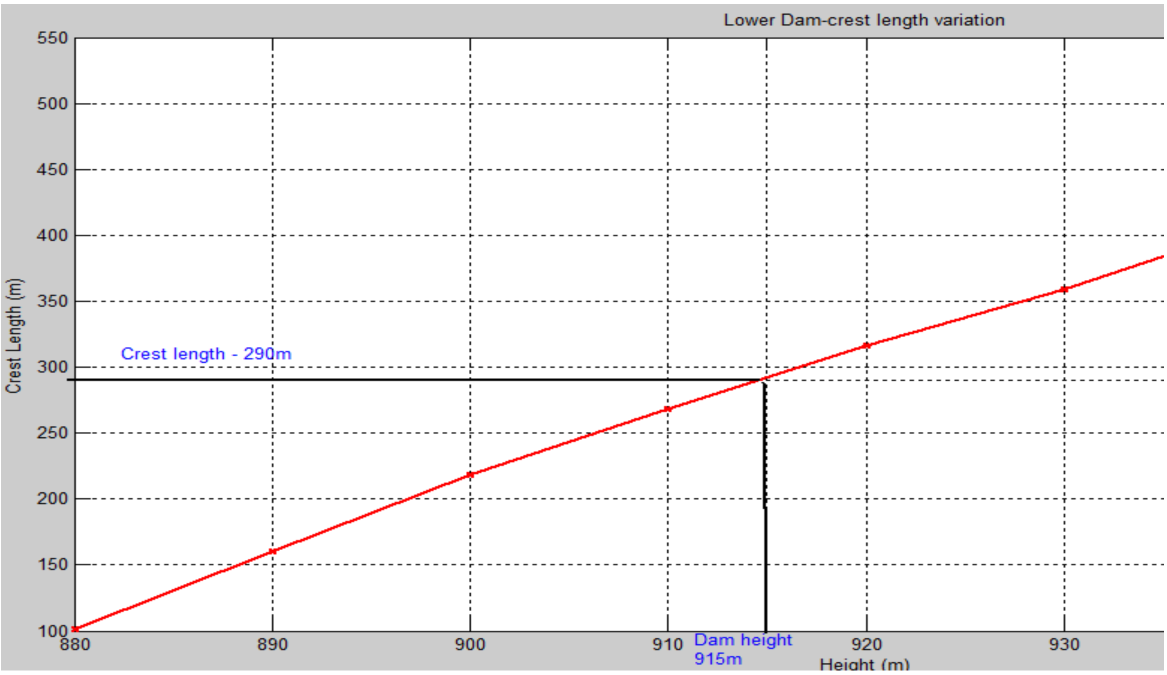

Figure 7: Variation of the crest length with the dam height in lower dam

4.15.2 Crest length of the upper dam

Crest length of the upper dam also determined by the same method used in sub section 4.15.1. As per figure 9, crest length of the upper dam is 220m

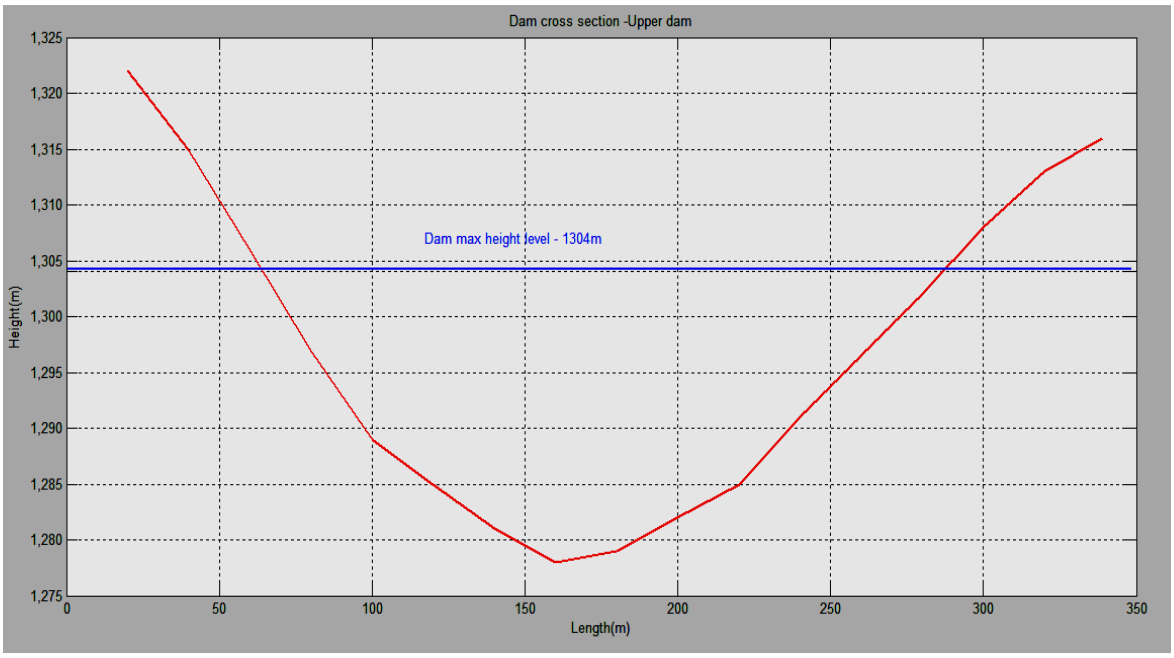

Figure 8: Cross section of upper dam

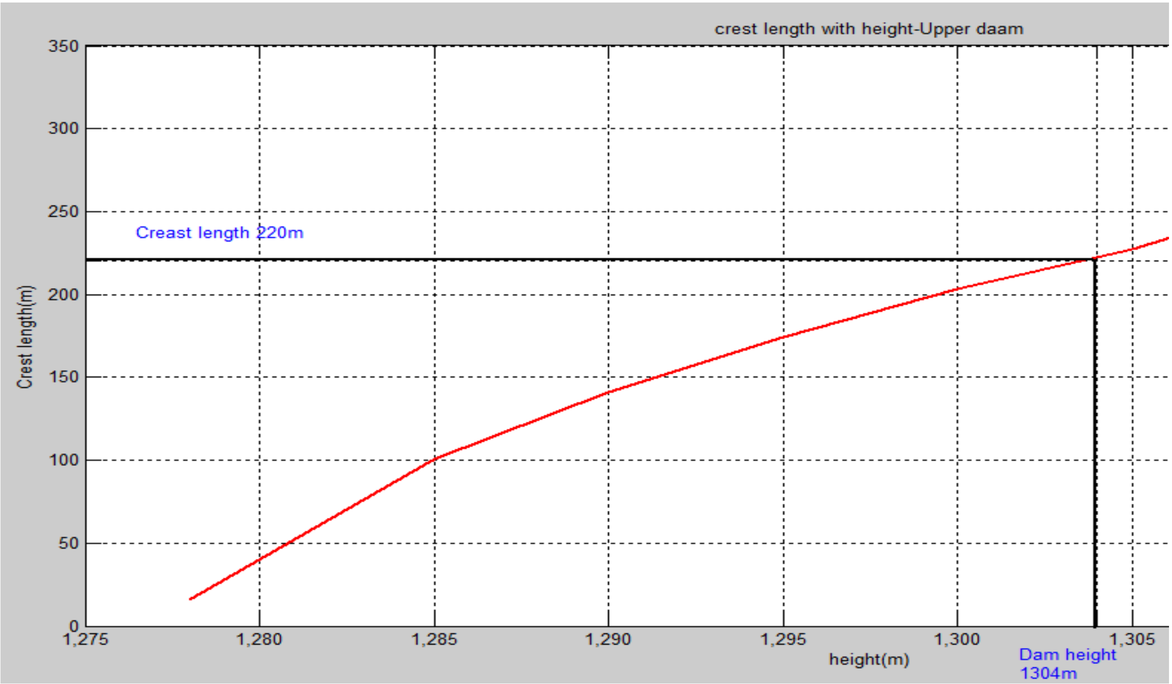

Figure 9: Variation of the crest length with the dam height in upper dam

4.16 Specific Speed Calculation

Specific speed (N_s) is the fundamental index for the selection of correct type of turbine for a particular set of conditions. It should be in the limit given by inequality 18 for a Francis pump turbine.

$$N_s \leq \frac{21000}{H+35} + 40 \tag{18}$$

N_s = Specific speed (m-kW)
H = Net head (m)
$N_s \leq [21000/(377+35)]+40$
≤ 95.83m-kW

The speed for a turbine can be calculated by equation 19. Approximate speed of the turbine can be calculated using above calculated specific speed limit.

$$N_s = \frac{N \times \sqrt{P_t} \times \sqrt{1.358}}{\sqrt[1.25]{H}} \quad (19)$$

N_s = Specific speed (m-kW)
N = Speed of the turbine (rpm)
P_t = Turbine power (MW)
H = Net head (m)

$N = N_s \times H^{1.25} / (P_t^{0.5} \times 1.385^{0.5})$
$= 95.83 \times 377^{1.25} / (150 \times 1000 \times 1.385)^{0.5}$
= 349.27 rpm

Then speed of turbine for different poles are calculated using equation 20 and nearest speed is selected as speed of the turbine.

$$N = \frac{120f}{P} \quad (20)$$

N = Turbine speed (rpm)
f = Frequency(Hz)
P = No of poles.

For 18 poles, N = 120 x 50/18 = 333.33rpm
For 16 poles, N = 120 x 50/16 = 375rpm
Then the turbine speed can be select as 333.33rpm

Recalculate the Specific speed using equation 19
$Ns = [333 \times (150 \times 1000 \times 1.358)^{0.5}] / 377^{1.25}$
= 90.47mkW
This specific speed is marked on the figure 10 and hence it is concluded that specific speed of the designed plant is under the recommended area.

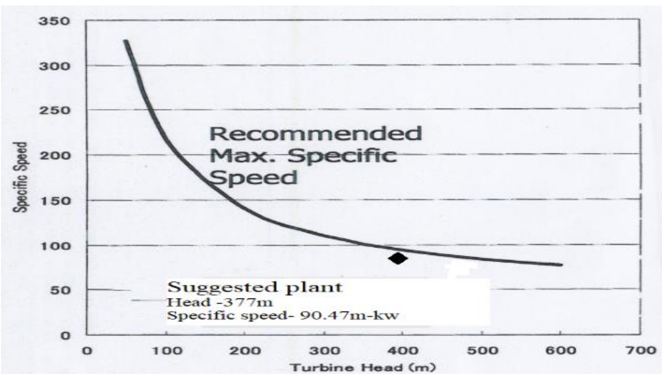

Figure 10: Recommended maximum specific speed limit curve

Head and the discharge of the one turbine is marked on figure 11 and hence it is concluded that the designed plant can use Francis pump turbine.

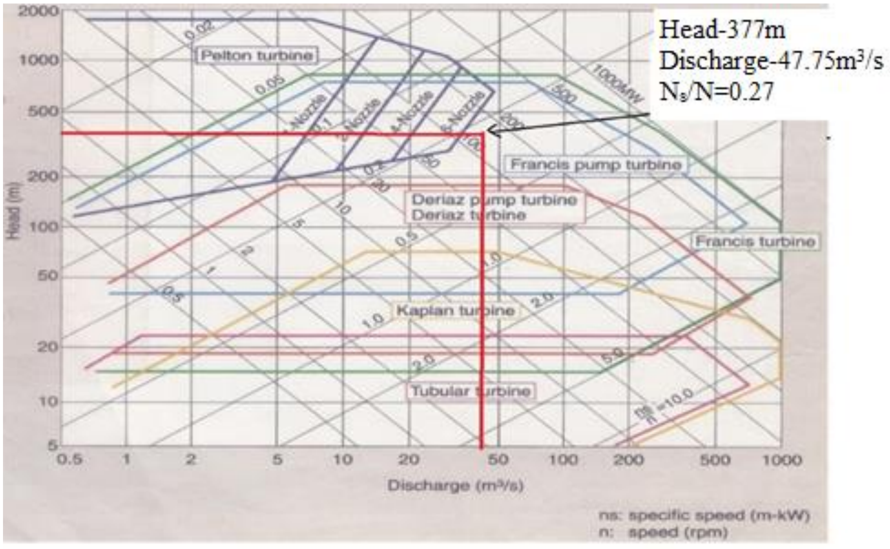

Figure 11: Turbine selection curve

5 IMPACTS AND BENEFITS

5.1 Social impacts

The implementation of the proposed project will affect a number of residential houses, tea estate buildings and sub roads directly or indirectly. Many residential houses and tea plantation areas are covered by upper reservoir. Submerging area of the lower reservoir includes several small residential houses and less amount of agricultural areas of highland crops and small individual tea plantation areas. Most submerged area of the lower reservoir is abundant forest cover. None of the historical heritages, temples, churches or kovils are affected by the proposed plant. During the construction period considerable amount of waste would be accumulated. The debris collected during excavating and blasting can be used for land filling or solid can be used for civil construction industry. Furthermore, the dust during the blasting will cause respiratory diseases to the people nearby. Preventive methods should be used to avoid spreading dust. Heavy vehicles with huge load will be travelling in the access roads frequently to clear the debris during construction and hence the access roads will be damaged and the traffics will be formed. This will influence the regular habitual life of the public in the project area.

5.2 Environmental impacts

Part of the forest cover will be submerged by the lower reservoir and no any by upper reservoir. But during the construction, forest cover will be cleared in some amount for access roads, storage facilities and for the worker's sites. This will lead to landslides and soil erosions. *"Oolu Muwa"* is an inhabitant animal in the project area. Huge noise and vibration during construction will lead forest animals to leave the nearby forest areas. During construction the vibration due to drilling will affect the base rock system. Loose rock will lead to landslides and underground water springs will be affected. Therefore, a study on the base rock system of the project area should be carried out and suitable preventive actions should be taken initially. During the construction seepage water is pumped out while drilling. Oil will be mixed with this seepage water and hence this water should not directly add to the natural water sources without treating. Moreover, cycling the water between lower and upper reservoir will add some pollutants to the water and with the discharged water to the Kothmale reservoir, those pollutants will add to the Mahaweli River. Furthermore, due to cycling the water, algae will be produced and will pollute the downstream water. In addition to this pollutions in the cycling water will be leaked to the ground water while water is flowing through the tunnelling system. And also in a pumped storage power plant, water level in the reservoirs fluctuate rapidly and hence the damages to the embankments are high and then the soil contamination in the water is raised. During the construction period, due to blasting and operating heavy vehicles will discharge certain amount of CO_2, toxic gases and dust to the environment. But the CO_2 emission of this project is less than a thermal power plant with same generation capacity. When compared the lifetime this CO_2 emission is negligible.

5.3 Technical Impacts

Proposed lower reservoir is situated between the existing Upper Kothmale reservoir and the existing Kothmale reservoir. Therefore, collecting the initial water storage of the proposed reservoir will reduce the water flow to the Kothmale reservoir and hence the generation of the Kothmale power plant will be reduced accordingly. Hence the initial water storage of the proposed reservoir should be filled by flood water.

5.4 Social Benefits

This project will provide number of local employment during the construction phase. The project will also fuel business growth with opportunities creates by the presence of construction camps and hence increase income of the villagers. The project will furnish infrastructure developments including roads, electricity, communications, water supply, hospitals, land reclamation, etc. These improvements will certainly enhance continuing development area.

6 LOAD FLOW ANALYSIS

Suggested plant is planning to be connected to the national grid via Kothmale grid substation. Required implementations should be done in Kothemale grid substation. Transmission line length from suggested power house to the Kothmale grid is 15.5km. Kothmale grid is 200kV transmission grid. Furthermore, it is planned to take main pump up energy for the suggested PSPP from Puttalam coal power plant. Therefore, in load flow analysis only 200kV Transmission network part is considered. Initially demand was converted to the forecasted demand in 2025. Victoria has been taken as the swing bus. Then the suggested plant is added as a generating plant and load flow analysis is run in peak. Voltage of the buses which the suggested pumped storage plant is added has not changed more than the 10%. Therefore, it is acceptable to run the proposed plant in peak duration. Then in the off peak, suggested plant is added to the network as a load and load flow is run. Voltage variation of the buses which the suggested plant is attached are within 10%. Therefore, the plant can be run taking the pump-up energy from the network in off peak duration.

7 CONCLUSION

Weaknesses of the Sri Lankan power sector is analyzed and identified the significance of introducing PSPP to improve those weaknesses such as low load factor, peak demand generation and limitation of adding renewable energy to power system. Several factors that should be analyzed before selecting favorable site for a PSPP is identified and six suitable locations are proposed for the further evaluation as per those factors. Then those proposed sites are evaluated and best location is selected in Kothmale. Lower reservoir is proposed in Yoxford across the Kothmala Oya and Upper reservoir is proposed in Caledonia across Agra Oya. It is understood that the flood water should be used to fill the initial water storage of the reservoirs in order to avoid any affect to the power generation of existing Upper Kothmale and Kothmale power plants. Selected site is further evaluated and relevant information such as rainfall and runoff details are gathered. Then the basic design figures of the suggested PSPP is determined by developing the water capacity curves of the reservoirs. Finally, the part of the transmission network of 220kV is simulated by PSSE after introducing the plant in both peak and off-peak hours as a generation point in peak and a load point in off-peak. As per the load flow analysis it is concluded that the proposed plant is significant to the welfare of the power system in Sri Lanka.

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