

ENHANCING RENEWABLE ENERGY CAPACITY THROUGH PUMPED STORAGE SYSTEMS: A CASE STUDY

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ABSTRACT: Sri Lanka aims at achieving 70% of its power generation from renewable energy sources by 2030 to meet its electricity demand. To this end, various approaches are being explored to generate electricity with minimal or no emissions. Among these, wind and solar photovoltaic (PV) energy are becoming increasingly popular. Due to their intermittent and non-dispatchable nature, it is crucial to utilize harnessed energy whenever it is available. A Pumped-Storage System (PSS) is an effective solution for storing excess energy in the national grid. This approach helps meet peak demand with cost-effective electricity, generated from more environmentally friendly technologies. An extensive survey was conducted to identify a suitable location, referencing a 1: 10,000 map of Sri Lanka, research papers, and technological reports. The researchers propose a PSS with a capacity of 2 MW based on the Maussakele Reservoir which plays a pivotal role in Sri Lanka's hydropower generation. The upper pond for the PSS is a natural pool situated in Laxapana tea plantation. The natural elevation difference between the two reservoirs enhances the energy storage capacity. Excess energy from the national grid during off-peak hours will be stored as potential energy and subsequently converted into hydroelectricity during peak hours. The effectiveness of the proposed scheme has been validated through mathematical analysis. Accordingly, the annual expected electricity generation of 1,460 MWh would result in saving of over LKR hundred million under the current economic scenario of Sri Lanka positively to the national economy. Furthermore, the proposed PSS is designed to minimize the impact on ecosystems, habitats, and the environment,

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1. INTRODUCTION

Globally, nations are exploring alternative energy sources as alternatives to conventional fossil fuel aiming to reduce their reliance on conventional fossil fuel. Various eco-friendly energy solutions are needed to address key climate change issues effectively. Sri Lanka has set a target of achieving 70% renewable energy (RE) goal by 2030. Though it is a challenging target, we all should strive collectively to reach it to minimize the carbon footprint. The growing demand for renewable energy sources has led to increased interest in energy storage solutions to avoid energy curtailment. PSS has emerged as a promising technology to enhance renewable energy capacity and grid stability (Ceylon Electricity Board, 2023; Katsaprakakis et al., 2012; Kose et al., 2020; Penagos-Vásquez & Sanin-Villa, 2021; PUCSL, 2024).

According to Singh et al. (2017), the forecasted daily demand-supply scenario in 2030 is demonstrated in Fig.1. The excess generation of electricity during daytime could be utilized to address peak demand through energy storage. PSS and battery storage are two prominent methods for energy storage in power generation. Due to cost-effective capability for large energy storage over extended periods, longer life

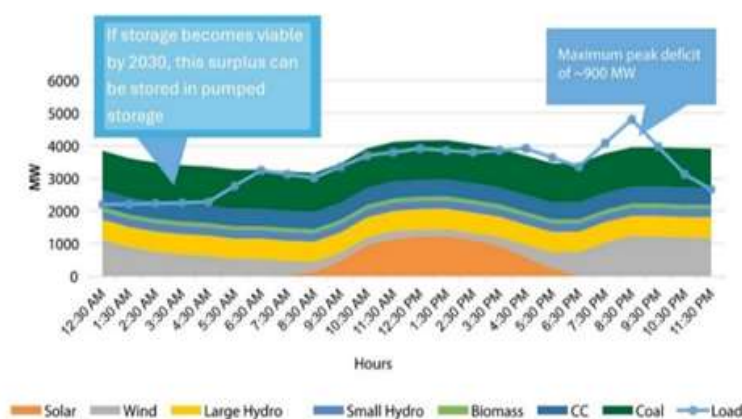


Fig.1. Hypothetical daily load curve of Sri Lanka in 2030

span, lower environmental impact, the PSS remains a reliable and efficient option and thus becomes an increasingly attractive choice (Dilrukshi et al., 2018).

This research paper examines the effectiveness of PSS in improving renewable energy integration using the *Mauassakele PSS* hydroelectric project as a case study. This approach helps meet peak demand with cost-effective electricity generated through more environmentally friendly technologies (Rehman et al., 2015). The researchers propose a Pumped-Storage System (PSS) with a capacity of 2 MW with its upper reservoir being a natural pool situated in the Laxapana tea plantation near the west bank of the Maussakele Reservoir. This pool is replenished by two natural rivulets. This will be a promising solution for Sri Lanka's pursuit of future energy security and economic growth.

2. METHODOLOGY

The selection criteria for the proposed Pumped-Storage System (PSS) location considers several critical factors. The chosen site for the upper reservoir must be capable of retaining sufficient water and providing a high head to generate the expected power output. Additionally, the construction of the reservoir, powerhouse, and related infrastructure should minimize environmental and ecological impacts. Other key considerations include the availability of adequate rainfall and a substantial catchment area (Kabo-Bah et al., 2023).

The proposed location for the 'Maussakele PSS' is in the south-central mountainous region of Sri Lanka, within the Nuwara Eliya District. It is situated northwest of the Maussakele Reservoir, in Laxapana tea estate, at an altitude ranging from approximately 6,000 to 7,000 feet. A 1:10,000-scale map of Sri Lanka was used to determine the location and distances between the selected sites. Real-time data were also analyzed to evaluate site suitability, focusing on factors such as soil conditions, average rainfall, population density, and land use, including farming activities.

The upper reservoir (UR) is an existing natural pond covering approximately 5,830 m², located in a well-developed tea plantation area with a relatively low population density. The lower reservoir (LR) is the Maussakele Reservoir, which has sparse vegetation and is similarly less populated. The UR lies within the Maussakele catchment area, characterized by numerous small waterways, while the LR is an existing water tank built on the Maskeliya *Oya* to support the Wimala Surendra Power Plant.

The basic design of the PSS is shown in Fig. 2, with the Maussakele Reservoir serving as the lower reservoir and the natural pond in Laxapana tea estate acting as the upper reservoir. The elevation profile has been analyzed to confirm the feasibility and energy storage capacity of the system (Fig.3).

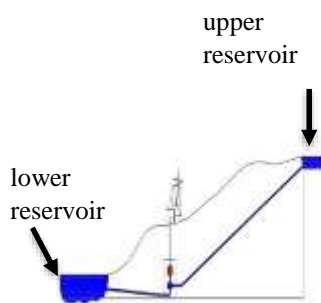


Fig. 2. The basic design of the PSS



Fig. 3. Elevation profile of LR and UR

It was proposed to perform design calculations for a 2 MW pumped-storage plant. This capacity can be increased by enhancing the depth of the upper reservoir (UR). The PSS is intended to operate during the nighttime peak demand period, which typically lasts for approximately two hours, from 7:00 PM to 9:00 PM. Table 1 shows the results obtained and the respective equations used in the process of obtaining the annual energy generation of the proposed 2MW PSS.

Table 1. The results obtained and the respective equations used in calculations

Equation used	Value/ values obtained
$Q_{max} = P/\eta\rho gH_e$	Maximum plant discharge (apparent) = $2.05\text{m}^3\text{s}^{-1}$
$V_e = Q_{max} \times T \times 3600\text{m}^3$	Required capacity of upper reservoir = 14760m^3
$V_s = q_s \times Ca \times 100$	Calculated sedimentation vol. of LR = $235,431\text{m}^3$ Calculated sedimentation vol. of UR = 836.28m^3 Calculated sedimentation level of LR = $1,142\text{m}$ Calculated sedimentation level of UR = $1,286.5\text{m}$
$Q_{max} = (\pi \times D^2/4) \times 5\text{ m/s}$	Inner dia. (D) of the headrace tunnel = 0.72m Low water level of LR (LWL(L)) = 1143.44m Low water level of UR (LWL(U)) = 1287.94m High water level of UR (HWL(U)) = 1296.36m High water level of LR (HWL(L)) = 1143.44m
$RH\text{ of UR} = HWL(U) - 1/3(HWL(U) - WL(U))$	RH of UR = 1293.56m
Head loss = $GH \times 5\%$	Head loss = 7.5m Effective head = 142.62
$Q_{max} = P/\eta\rho gH_e$	Actual plant discharge = $1.68\text{ m}^3/\text{s}^{-1}$
$E = PT$	Annual energy generation = 1460MWh (assume night peak occurs for 2h)

Where,

Expected Power Generation, $P = 2\text{MW}$

LR volume = $133.3 \times 10^6\text{m}^3$

Head between UR and LR = 130m

Effect. head bet.ⁿ UR and LR = $130 \times 0.9 = 117\text{m}$

Peak duration of the PS, $T = 2\text{h}$

Available drawdown (h_a) = 8.42m

Rated head (RH) of LR = 1143.44

Gross head (GH) = 150.12m

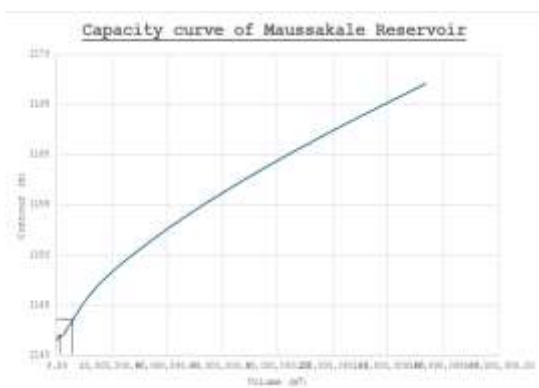


Fig. 4. Capacity curve of LR (Maussakele)

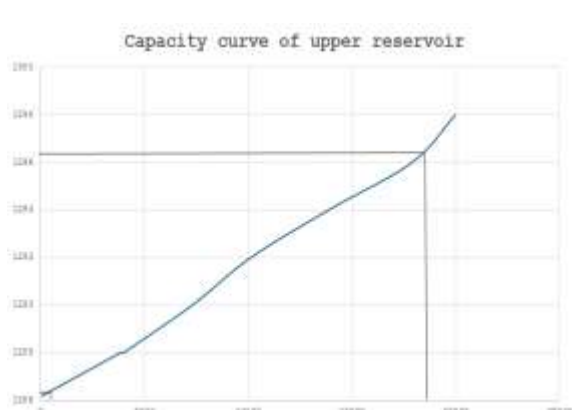


Fig. 5. Capacity curve of UR

Calculation of annual saving on cost of generation:

If we assume the average unit cost of electricity generation based on naphtha and PSS are 80/- LKR and 8.50 LKR respectively, by running the PSS during peak hours (i.e. from 7.00 to 9.00PM) for 2h,

Amount of foreign exchange saving= $1460 \times 10^3 \times (80.00 - 8.50) = 104.39 \times 10^6 \text{LKR}$

According to Economic and Social Statistics-2024, (CBSL, 2024), the annual electricity generation based on fuel oil (FO) in Sri Lanka is 3135GWh (1975GWh from CEB and 1160GWh from private sector). A considerable amount of this FO is utilized to meet the night peak demand (Singh et al., 2017). So, by running the PSS during peak demand hours, it is possible to save 104.39×10^6 LKR directly.

3. RESULTS AND DISCUSSION

It is possible to generate 1460MWh with the proposed PSS which has a generation capacity of 2MW. The rated heads of the upper reservoir (UR) and lower reservoir (LR) are 1,293.6 m and 1,143.4 m, respectively, with an effective head of 142.6 m.

This would result in significant saving for the country as the peak demand is usually addressed by thermal power plants. The current average unit cost of thermal power generation is around 80 LKR. If this proposed PSS could be brought to reality, it could directly save LKR 104.39 million foreign exchange. This saving would have a considerable positive impact on the country's economy and GDP.

Since the UR is an existing pond in Laxapana tea plantation, constructing the PSS, would involve a minimal environmental impact. Additionally, the potential relocation of communities, if needed, would be less challenging, as the population density is low and mostly comprised of tea plantation residents. Other benefits include reduced construction costs, minimal disruption to local water tables, and an overall more sustainable approach.

Further, the capacity of the power plant can be increased by deepening the UR, leading to additional savings on FO.

4. CONCLUSION

The results show the benefits that can be achieved through pumped storage power generation. Hence, the proposed methodology based on PSS is a viable and effective solution to enhance the renewable energy capacity of Sri Lanka. It promises substantial savings of over hundreds of millions of rupees, with a positive impact on the national GDP, while causing minimal disruption to the ecosystem and natural habitats.

This research study is still in progress. A key part of the study involves collecting technical data, such as collecting technical information such as the number of affected families, the number of trees to be removed, the extent of tea plantations impacted, and the availability of relocation facilities that would not disrupt the affected individuals' lifestyles. Sufficient funds and time constraints are some limitations for collecting data. This data would be incorporated in more accurately assessing the actual savings and benefits of the proposed PSS.

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