Reverse Pump Storage Scheme in Kerala: Feasibility Study

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Contents

List of Figures

List of Tables

Abbreviations

H	:	Head (m)
L	:	Length of the water conducting system (m)
AF	:	Acre Foot
O & M	:	Operation and Maintenance
S & I	:	Supply and Installation
CEA	:	Central Electricity Authority
DPR	:	Detailed Project Report
PPA	:	Power Purchase Agreement
PSS	:	Pumped Storage Scheme
CAES	:	Compressed Air Energy Storage
ETES	:	Electrothermal Energy Storage

Introduction

Electricity is one of the essential infrastructures for the country. Our gross domestic product depends on the availability of adequate amount of electricity. The demand is escalating annually and the statistics reveals that the demand is higher than the generation in our country. It results in regular load shedding and thus badly effects on industrial outputs.

An essential attribute of our nation's electric power system is grid reliability. In real time condition, the system should ensure that the generation meets the demand. Generation happens only when there is a demand. It is the primary challenge facing for ensuring reliability. Electricity demand continually changes, especially between daytime periods of peak demand and night-time periods of low demand. Grid operators have long met this challenge with a limited number of generation technologies specifically hydropower and gas-fired combustion turbines. They have the ability to start up quickly and/or vary their electric output as the demand changes. These solutions may not be enough as we move into a world with far greater amounts of renewable energy on the grid.

Hydropower pumped storage stands alone as the only commercially proven technology available for grid-scale energy storage. Developing additional hydropower pumped storage, particularly in areas with recently increased wind and solar capacity, would significantly improve grid reliability while reducing the need for construction of additional fossil-fuelled generation.

These systems may be economical because they flatten out load variations on the power grid, permitting thermal power stations such as coal-fired plants and nuclear power plants that provide base-load electricity to continue operating at peak efficiency, while reducing the need for "peaking" power plants that use the same fuels as many base-load thermal plants, gas and oil, but have been designed for flexibility rather than maximal efficiency. Hence pumped storage systems are crucial when coordinating large groups of heterogeneous generators. However, capital costs for pumped-storage plants are relatively high.

Objectives

- To study about the existing pump storage schemes in India
- To study the feasibility of PSS in Kerala

- Economic, geological as well as technical suggestions regarding the forthcoming PSS project in Kerala.

Storage technologies

Energy storage typically consumes electricity and saves it in some manner, then hands it back to the grid. The ratio of energy put in (in MWh) to energy retrieved from storage (in MWh) is the round-trip efficiency (also called AC/AC efficiency), expressed in percent (%).

It is obviously a critical factor in the usefulness of a storage technology. The higher the round-trip efficiency, the less energy we lose due to storage, the more efficient the system as whole. Grid systems engineers would like to see 80% round trip efficiency in energy storage systems when at all possible.

TABLE 1 Storage technologies and its round-trip efficiency

Hydro	from 65% in older installations to 75-80% for modern deployments
Flywheels	80% to 90%
Batteries	75% to 90%
Electrothermal (ETES)	65% to 75%
Compressed air (CAES)	65-75%

Batteries (current leakage), flywheels (friction) and electrothermal storage (heat loss) experience significant leakage over long durations, while hydro (water leaks, evaporation) and compressed air (air leaks) are quite stable.

Pumped Storage Scheme (PSS)

The basic operating principle of a PSS is to pump water from a low-level down reservoir to a high-level upper reservoir during the off-peak hours. The stored pumped water of the upper reservoir is utilized for electricity generation during peak hours.

The discharged water from the turbine through the tailrace is stored on a lower reservoir or joined to a river. The plant generally utilizes the water in a controlled manner considering electricity generation and irrigation. During off peak hours, power for pumping is supplied

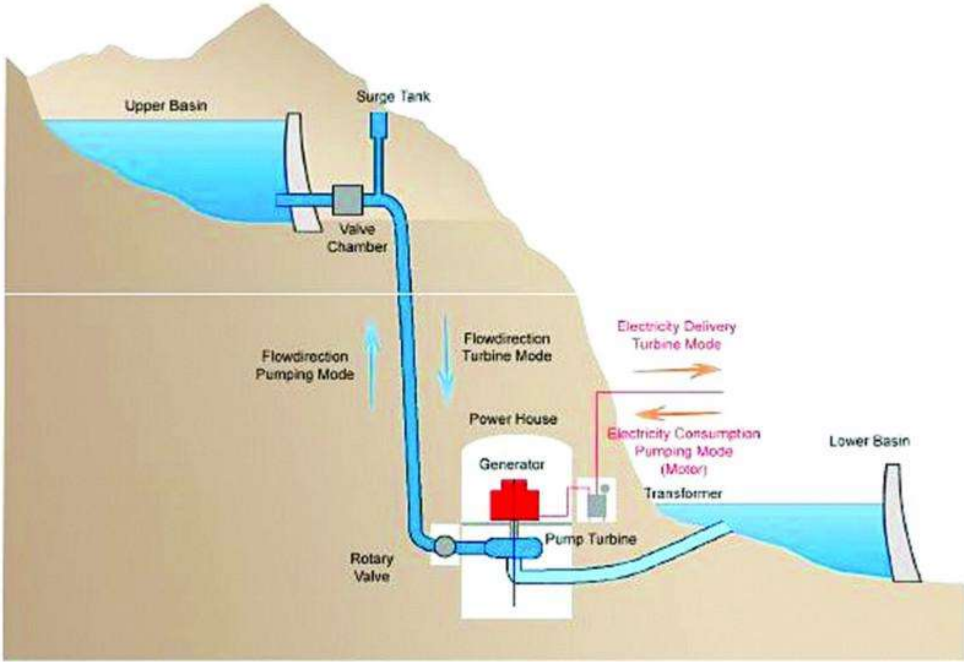

Figure 1 Pump storage scheme.

either by the conventional steam power plants, renewable energy power plants or from remote generating plants through inter connected grids.

A separate pump can be installed for pumping operation. While the system itself can be installed with a reverse operating turbine which can be operated either in generation mode or pumping mode. It operates as a usual generator and turbine during peak hours and as a motor and pump during off peak hours. For such system, the water conducting path will be same.

Classifications of PSS

Pure PSS: in this type of scheme, water is re-circulated between the reservoirs and thus electricity is generated. Small inflow of water is provided to the higher reservoir to compensate the loss of water through seepage, evaporation etc. in the system. The sizes of the two reservoirs are same. Power generation is taking place only during peak hours.

Mixed PSS: combination of conventional hydroelectric scheme and pure PSS. Upper reservoir is very large to occupy inflows to it throughout the year and to store sufficient quantity of water to generates power most of the times of the year. In this scheme water used for generation is higher than that used for pumping.

Advantages or Facts of PSS

- The net energy change of the scheme is negative due to the loss of energy during generation and pumping.

- It is economically advantageous because they convert low value, low cost off peak energy to a high value high cost peak energy.
- It helps in load levelling from the daily load fluctuations.
- It is the most attractive method of storing large amount of energy.
- It meets the peak demand of the system.
- It helps to improve the efficiency and economy of a thermal power plant.
- It can be operated as a synchronous condenser for voltage regulation and thus the voltage level and power factor can be maintained in the system.
- It is environmentally friendly.

Economic Considerations

The objective in an economic study is to determine which course of action is the low-cost plan for delivering power and energy given the specified development and operational constraints. Economic analysis includes the consideration of capital and operational costs for various technologies that may be included in a future generation mix.

The cost of construction and equipment procurement is only a portion of the total project cost and many soft costs are indirectly involved in the total cost. In a typical pumped storage project, there are substantial costs for preliminary and environmental investigations, design engineering, land procurement, financing and interest costs, legal costs, independent engineering and review costs, owner's allocated administrative and management costs, construction management costs, and O&M start-up costs.

Reservoirs: The main factor that affects the cost of reservoirs is the volume of water to be stored. Larger storage volumes will obviously be more expensive, but larger storage volumes tend to exhibit lower unit cost per acre-foot (AF) of storage. The choice of dam type is made to minimize the construction costs within the site constraints, which are mainly related geological conditions and available construction materials.

Waterways: The L:H ratio is a simple ratio used to measure the initial viability of a pumped storage project in siting level studies. L is the length of the waterway from the intake structure to the tailrace outlet and H is the net rated head available for energy production. Projects having an L:H ratio under 10 show promise as a pumped storage project. The L:H ratio is also an indicator of the need with respect to surge chamber(s), shaft(s) or tank(s).

Powerhouse: A pumped storage facility may have an “underground” or a “surface” type powerhouse. Various options are examined in a feasibility-level layout study to develop the best waterway and powerhouse combination that achieves the various objectives of minimizing cost and risk, while also minimizing the construction duration. Assuming suitable geological conditions, the conventional solution for a high head project is an underground powerhouse, mainly for the reason to minimize expensive high pressure, and sometimes problematic, waterways. The underground powerhouse also permits the selection of a lower cost, higher-speed unit, without incurring a significant cost penalty for the required deeper submergence. Conversely, surface powerhouses tend to be the preferred option for low head projects.

Adjustable speed capability: The additional cost of incorporating adjustable speed capability is mainly related to the costs associated with the generator motor, excitation system, cooling system for the thyristors, and the civil structures to accommodate the space for larger and additional cubicles and equipment. The size and cost of the excitation system is related to the selected speed range above and below the nominal synchronous speed. The increase in cost of civil structures to accommodate larger equipment is nominal, probably resulting in a civil structural cost increase of up to about 5% of the powerhouse cost. In terms of the overall project cost, an incremental cost of 50 to 125% on the generator and 10 to 15% increase in the cost of powerhouse civil works results in an incremental project cost of approximately 7% to 15%.

Operation and Maintenance: it is highly project specific. Major factors in the operations and maintenance budgets are:

1. Age of facility – initial years of a project operation life tend to have slightly higher costs as the staff is becoming familiar with the facility and the efficiency of the O&M organization increases. Later in the project life, O&M costs tend to increase at the needs for equipment replacement become a factor.
2. Remote vs attended operation – remote operation would tend to reduce costs.
3. Operation mode of the plant – primarily use for energy storage vs primary use in providing ancillary benefits, where providing ancillary benefits tends to result in cycling and exercising the equipment more frequently, resulting in greater wear and tear.
4. The operational philosophy of the owner – some owners tend to spend more on O&M, while other owners may tend to defer maintenance to minimize O&M expenditures (run it until something fails).
5. Extent and type of equipment included in the O&M budget.

Ancillary services: It may be economic to charge the pumped storage project using low cost system generation resources when available. A pumped storage facility can provide a number of ancillary services, depending upon the design of the facility and the equipment installed. The ancillary services and system flexibility offered by pumped storage can substantially reduce the overall operation and maintenance cost of the interconnected electrical system. The largest component of ancillary services benefits and potential revenue result from spinning reserve, frequency regulation and load following capabilities of the pumped storage project. Other revenue producing services include stabilization service and black start service. In an open market a pumped storage project could earn revenue from the sale of frequency regulation and load following capability as an ancillary service. A single speed pumped storage project could provide system stabilization service in the generating mode; an adjustable speed machine can provide services in both modes. Ordinarily a pumped storage project would be capable of providing black start service using a source of generation that has been isolated and lacks an off-site source of electrical power.

Pump Storage System in India

In India, the first pumped storage plant was proposed at Nagarjuna Sagar in Andhra Pradesh in the year 1970. The project got commissioned on 1980-85 with an installed capacity of 700 MW and later revised to 705.6 MW. Since the tail pool dam construction is still incomplete, the project is not working in pumping mode.

According to the reassessment studies carried out by Central Electricity Authority of India in 1978-87, 63 schemes have been identified. Due to the topographical features of the Western Ghats, Western region has the largest potential (41% of the total) for the scheme.

TABLE 2 Pump storage schemes in India

Region	Probable Installed Capacity (MW)	Capacity Developed (MW)	Capacity under Construction (MW)
Northern	13065 (7)	0	1000 (1)
Western	39684 (29)	1840 (4)	80 (1)
Southern	17750 (10)	2005.6 (3)	0
Eastern	9125 (7)	940 (2)	0
North Eastern	16900 (10)	0	0
Total	**96524 (63)**	**4785.6 (9)**	**1080 (2)**

At present, only 9 pumped storage schemes are operated in the country with an aggregate capacity of 4785.6 MW. Out of these, only 5 schemes are being operated in pumping mode with an aggregate capacity of 2600 MW.

TABLE 3 PSS Projects operating in Pumping mode

Sl. No.	Name of Project	State	Installed Capacity (MW)
1	Kadamparai	Tamil Nadu	4 x 100 = 400
2	Bhira	Maharashtra	1 x 150 = 150
3	Srisailam LBPH	Telangana	6 x 150 = 900
4	Purulia PSS	West Bengal	4 x 225 = 900
5	Ghatghar	Maharashtra	2 x 125 = 250
			Total = 2600

TABLE 4 PSS Projects not operating in Pumping mode

Sl. No.	Name of Project	State	Installed Capacity (MW)
1	Kadana Stage I & II	Gujarat	2 x 60 + 2 x 60 = 240
2	Nagarjuna Sagar	Telangana	7 x 100.8 = 705.6
3	Sardovar Sarovar	Gujarat	6 x 200 = 1200
4	Panchet Hill	Damodar Valley Corporation	1 x 40 = 40
			Total = 2185.6

Electricity Scenario: Kerala

TABLE 5 Domestic consumer details according to 2016 report

Total	82,16,501
Total Electrified	77,35,479
Total Unelectrified	4,81,022
Rural	43,61,132
Rural Electrified	40,05,554
Rural Unelectrified	3,55,578
Urban	38,55,369
Urban Electrified	37,29,925
Urban Unelectrified	1,25,444
Annual energy sold	18,426 MU
Annual domestic energy sold	9,373 MU, 50.87%
Avg. annual energy consumption/house	1,212 kWh
Avg. daily energy consumption/house	3.32 kWh

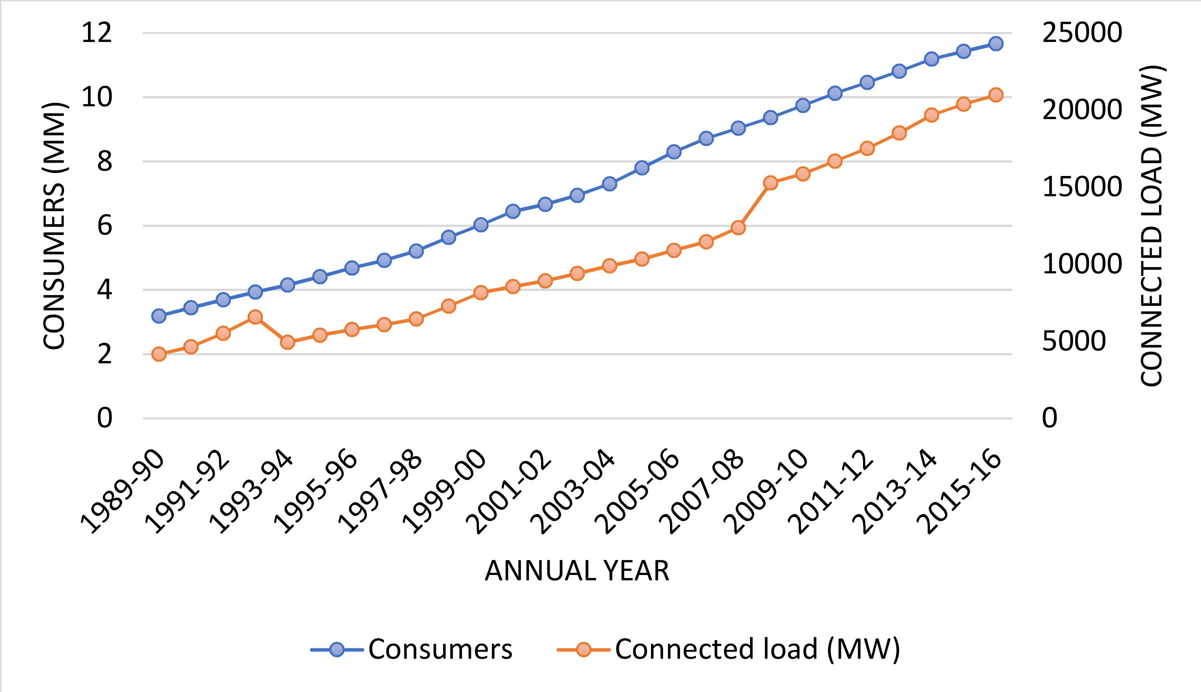

Figure 2 Consumers and connected load from 1989 to 2016

TABLE 6 Deficit or surplus power pattern

Financial Year	Energy Required (MU)	Energy Available (MU)	Surplus (MU)
2009-10	17350	17036	314
2010-11	17808	17470	-338
2011-12	19521	19140	-381
2012-13	20736	19876	-860
2013-14	21264	21940	676
2014-15*	22040	21925	-115
2015-16*	23822	22708	-1114
2016-17*	25889	26597	+708
2017-18*	27709	28093	+384
2018-19*	29620	30658	+1038

Projected based on the 18th Electricity Power Survey by CEA

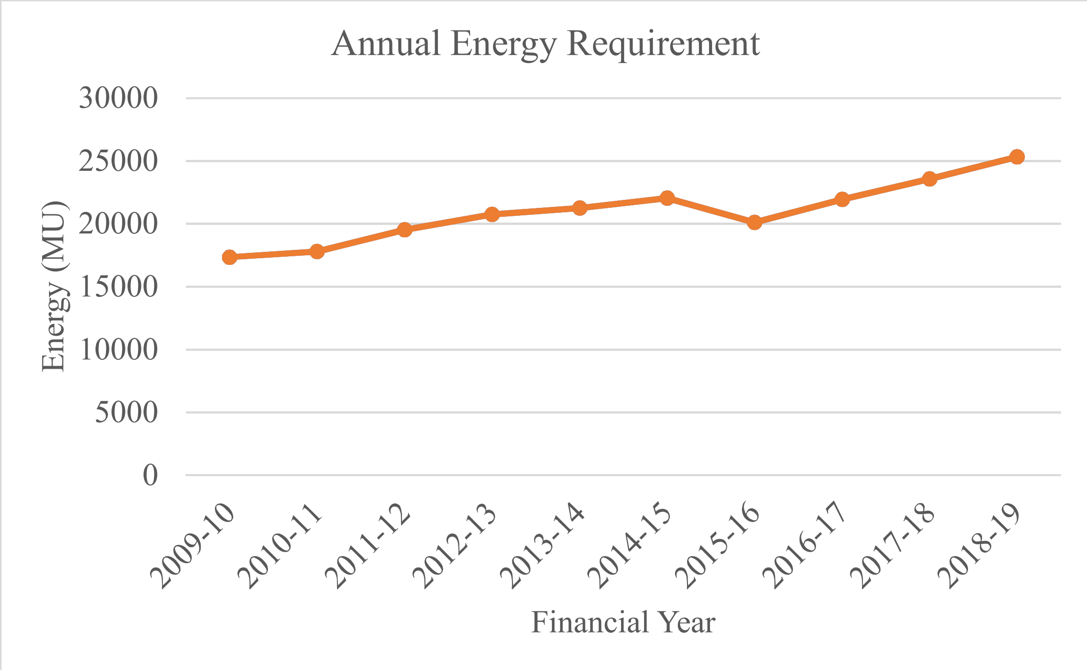

Figure 3 Annual Energy Requirement for Kerala

Based on the forecast done by the CEA, there will be surplus power in the coming years. So, an energy storage system is inevitable for Kerala. State is facing lack of water in the reservoirs during summer seasons due to the reduced rainfall as shown in Table 7. Since majority of the generating stations are hydel, a pump storage system will be more economical since it will tackle both the energy related problem and the problem relating the lack of water in the reservoirs.

TABLE 7 Annual Rainfall of Kerala (Normal annual rainfall: 2923 mm)

Year	Rainfall (mm)	Departure
2012	2187.5	-25 %
2013	3255.4	+11 %
2014	3046.4	+4 %
2015	2602.9	-11 %
2016	1870.9	-36 %

Pump Storage System in Kerala

Our state Kerala belongs to the Southern region. According to the estimation of CEA by 1978-87, 2 sites have been identified with probable installed capacity of 4400 MW. On the existing conventional projects, State Government has identified 3 schemes namely Sholayar I

(810 MW), Sholayar II (390 MW) and Peringalkuthu (80 MW) (CEA report). Non-availability of Forest clearance currently hold the S & I implementation for the schemes. State has identified Pallivasal and Idukki for the PSS. State has invited consultants to prepare DPR for the PSS scheme for Pallivasal since a land clearance of less than 1 hectare is only needed and the completion of DPR is expected within 2 years.

Simple Economic Calculation

Considering the tariff regulation, the cost per unit generated as Rs 3.25/kWh during peak hours and Rs 2.5/kWh during off peak hours.

In pumping mode during off peak hours consuming 100 units of power, system will pump water to the upper reservoir required to produce 75 units (75% minimum pumping efficiency is considered).

Plant operation charge while pumping consuming 100 unit can be assumed to Rs 1/unit.

Generating electricity during peak hours using the recycled water considering the generating efficiency as a minimum of 85% = **75 X 0.85 = 63.75 units**

Normal cost of electricity generated during peak time = **63.75 X 3.25 = Rs 207.185**

Cost of pumping need not be considered because, the surplus power is utilized for pumping and the cost for that is paid by the state under PPA even if the power is used or not. Plant operation charge is only need to be considered.

Net cost of generation = **207.185+100 = Rs 307.185**

Cost per unit generated = **307.185/63.75 = Rs 4.8**

Considering PPA, the cost for 100-unit power purchased = **Rs 300 (Rs 3/ unit)**

Cost of imported power as Rs 3/ unit is a minimum cost and the cost will be higher according to the demand and bidding. So, usage of PSS will reduce the loss in revenue of the State.

Unused 100 unit during off peak hour is utilized as 63.75 units during peak hours. Cost per unit generated increased from Rs 3.25 to Rs 4.8. Even then it is more economic than that of a Solar Power Station which has a generation cost of Rs 6 per unit. It results that even though the PSS is not energy efficient, it is efficient economically.

State currently promoting only off grid solar projects. So, a higher impact of power on grid due to solar plants cannot be forecasted because of its generation cost. There is a saving for KSEB Ltd by accounting the solar energy from off-grid solar energy systems by paying incentive at a rate of Rs.1/Unit, when compared to buying solar energy from any other sources at the present rates in the range of Rs.6/Unit to Rs.7/Unit or buying REC from exchanges at the rates ranging from Rs.9.30 (floor price) to Rs.13.40 (forbearance price) fixed by CERC.

L:H ratio of existing hydel power plants

L:H ratio is considered as the primary feasibility analysis of the pump storage system during site level studies. L:H ratio of the existing hydro projects are given in the below table in its increasing order. The projects with the ratio below 10 is only be considered for pumping storage scheme.

TABLE 8 L:H ratio calculated for hydel power stations in Kerala

Project	Rating (MW)	Rated Head H (m)	Length of water conductor system L (m)	L : H
Kakkad	50	132.6	11000	83
Pallivasal	37.5	572	6000	10.5
Sholayar	54	325	1500	10.6
Kallada	15	45	56	1.2
Idukki	780	660	3300	5
Idamalayar	75	109	2000	18.3
Neryamangalam	45	188	4000	21.3
Sengulam	48	341.4	3600	10.5
Kuttiyadi	225	658.4	3000	4.5
Panniyar	30	231	3700	16
Sabarigiri	360	715	8000	11.2
Peringalkuthu	48	170	2000	11.8
Lower Periyar	180	184	12700	69

The calculations are done considering the rated head and the length of the water conductor system. Kallada, Idukki and Kuttiyadi have lower L:H ratios. To implement PSS on other projects having L:H ratio higher than 10, a lower basin or upper basin needed to be constructed. Kallada power station utilises the water release from Kallada Irrigation Reservoir. Idukki is in the proposal made by the state. Idukki dam can be used as the upper reservoir but a lower basin need to be constructed. A new project with Idukki dam as upper reservoir and

Figure 4 Idukki reservoir

Kulamavu lake as lower basin is feasible considering geographical features. State has invited tender from consultants to create DPR for Pallivasal PSS. Tailrace of the Pallivasal is fed to the Muthirapuzha river. It can be used as a lower basin but need to construct an upper basin if the existing project is extended as a PSS.

Suggestions for PSS in Kerala

- In Kerala, major share of the power generated within the state is from hydel. If a pumping scheme is implemented, the pumping operation will operate only during the off-peak hours and it can store energy in the form of water. This will be a great relaxation because the state is facing the low water level at reservoirs during summer.
- Rainfall statistics in Kerala is in a reduced manner annually. Increasing atmospheric temperature can increase the evaporation rate which is considered as a loss in the reservoir capacity. Considering these, water recycling using PSS is an effective method in Kerala which will help for the vegetation also.
- Since it's a new scheme in Kerala, implementation of pumping system alone is not economical. Addition or extension of current hydel plants with reversible turbine

machines will be economical so that the same machine can be operated during both generation and pumping.

- Variable speed vertical speed turbine-pump can be operated as both pump and generator. Advantage of installing this kind of machine is that the speed of machine for pumping can be varied so a single or a set of machine can be operated in pumping so as to store the exact surplus power. Surplus power as such cannot utilized for storage if a fixed machine is used.
- Water level in the lower reservoir only require with a reserve capacity for 1-2 days. Pumping mode operation will not continue to operate continuously more than half a day. So instead of constructing a lower basin, check dam construction at the tail race of the plant having the reserve capacity will save the land for the construction of another lower basin and it finds more economical. This may also feasible because the reservoir of some of the power plants are the tail race of its top level generating stations.
- Power from floating solar PVs can be used for pumping application. It will be more economical and environmental friendly.
- Planned shutdown of hydro generators due to the surplus power can be avoided by running it as a pump if the same machine can be operated as a generator and pump.

Conclusion

In Kerala, major share of electricity generation is from hydel power stations. Energy from these plants can met only about 20 to 30% of the state's demand. Many of the reservoirs has dual purpose for both electricity generation and irrigation. Water storage in reservoirs has great role in Kerala for both in power and irrigation sector. Annual reports show that the rainfall rate will be lower in the coming years and there will be surplus power as forecasted by the regulatory authorities. So, a PSS scheme is the only way to utilize the surplus power wisely and save the water. State has a plan for capacity addition on existing hydel projects. From the initial surveys and studies including L:H ratio, state has invited applications to create DPR for Pallivasal and Idukki PSS. New additions for these schemes installing with reversible turbine-pump generators will be more economical, since the same machine can be operated for power generation and pumping. It is economically feasible such that the energy from a PSS is cheaper than from a Solar Power project.