Pumped Storage Concept and its Potential Application in Nepalese Hydropower Context – A Case Study of Chilime Hydropower Plant Rasuwa, Nepal

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ABSTRACT

Due to fluctuation in energy production from hydropower plants, the existing plants in Nepal cannot meet the current demand of energy resulting in the power cut during peak hours. Therefore, there is a dire need for an energy storage unit that can meet the surplus demand of energy during peak hours. A pumped storage plants can be used to store electrical energy during periods of low demand and consume the energy during peak energy demand periods. Such plants generally make use of Reversible Pump Turbines (RPTs). The following paper discusses the potential application of pumped storage system and RPT in context of existing and new hydropower plants in Nepal by studying the case of Chilime Hydropower Plant in Rasuwa, Nepal. The study revealed that the proper application of this technology could certainly aid in minimizing the energy crisis currently faced by Nepal.

Keywords: Hydropower, Reversible Pump Turbine (RPT), Pumped storage plant, Energy demand, Chilime Hydropower Plant

1. INTRODUCTION

Nepal, having a tremendous potential of water resources, the development of Hydropower plants seems to be the most viable and promising solution to meet the current energy crisis problem [1]. About 762 MW of electricity is generated from existing large and small hydropower plants in Nepal which is not enough to meet the peak demand of electricity (about 1094 MW) for its current consumers, let alone electrifying other areas [2, 3]. Furthermore, Nepal Electricity Authority (NEA) forecasts that a total required energy of 5859.60 GWh and a peak demand of 1271.70 MW for the year 2013/14, which is certain to aggravate the problem of power cut often popularly known as load shedding making it an inevitable part of Nepalese society [4]. Thus, this situation forces us to focus not only on developing new plants for more generation capability, but also on developing the storage technologies to store energy for dry seasons [5]. The pumped storage plant is a well-established technology capable of meeting both criteria [6]. By using this technology in existing and new hydropower plants, the peak demand of power can be satisfied by returning water back to the reservoir through pump turbine during off peak hours [7].

A pumped storage hydro-plants are commonly used for load balancing in power systems. When power demand is at its peak, water is released through the turbines to generate electric power. As the demand decreases, a large amount of electric power is available on the grid. This surplus power is used to pump water to a high level, natural or artificial reservoir, in order to utilize the stored energy at periods when it is most needed. With its ability to pump back water from the lower into the higher reservoir, the plant acts like a giant rechargeable battery, using readily available power to provide reliable and flexible power to cover peak demand [8]. Instead of using separate turbine and pump, most pumped storage system use one pump/turbine unit i.e. Reversible Pump Turbine (RPT), a shift able unit selectively displaceable to achieve alternatively, either an energy generation or an energy accumulation mode [9]. Such a machine is possible because Francis turbine is just a reverse of a centrifugal pump. The efficiency of this system is typically between 70% and 85%, making it one of the more efficient methods for storing energy [10]. The same power lines, connected to the power transmission grid, provides the electric power required to pump back water, and transport the power generated by the plant when it is operating in turbine mode.

2. APPLICATION PROSPECT AND APPROACH

Since the energy production from hydropower plants in Nepal are not always the same, there is an immense need of energy storage units for constant supply [11]. Pumped storage unit is a mature technology and a very suitable method for Nepal. Since Nepal does not have a concrete tariff plans for electricity consumption and the local electricity demand is always high [12], the idea however is different. Hydropower plants in Nepal during monsoon have an excess amount of water supply while in dry season it is difficult to meet the minimum supply of water required to run all units. But, there are several sites in Nepal with two rivers close enough with different head. RPT units can act as a link between such rivers.

As shown in Fig. 1, water can be pumped from level H1 to the upper reservoir during dry season to meet the need to run all the turbine of the main unit. Due to the head difference between H1 and H3, relatively less amount of energy is used to pump a fixed amount of water and a higher amount of energy is generated from the same amount of water using the main turbine unit. While in monsoon when the water supply is more, the excess amount of water is sent through the RPT generating an excess amount of electricity. The technology is thus feasible for country like Nepal where there are a huge number of perennial rivers that flow very close to each other and have different heads.

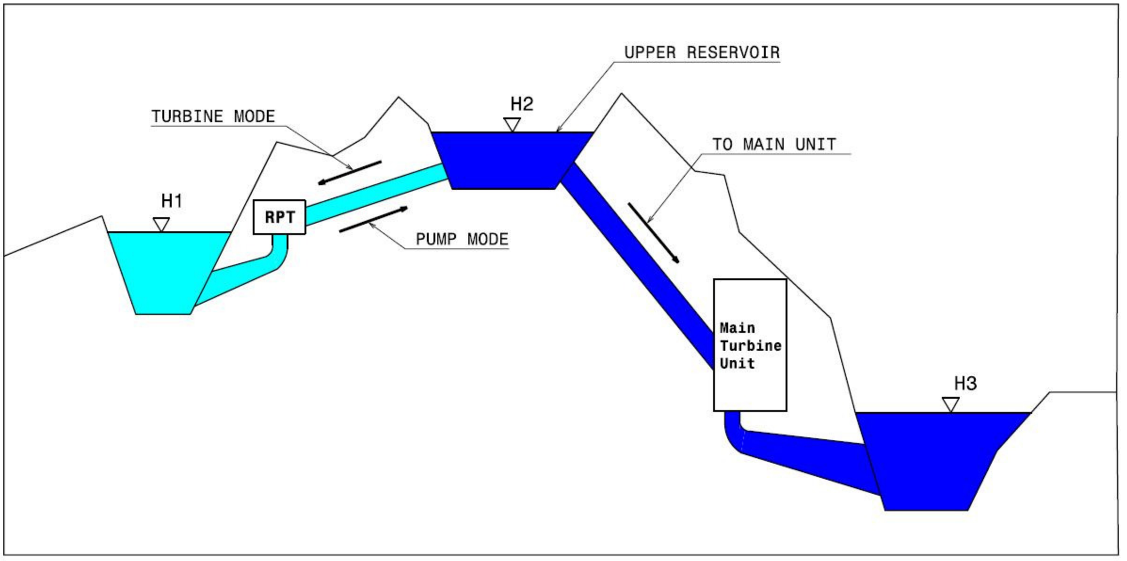

Figure 1: Schematic pumped storage plant

In Fig. 1,

H1 = Head at lower reservoir of RPT

H2 = Head at upper reservoir level

H3 = Head at tailrace level of main unit

η_t = efficiency of main unit

$\eta_{rpt/p}$ = efficiency of RPT in pump mode

$\eta_{rpt/t}$ = efficiency of RPT in turbine mode

ρ = density of water

g = acceleration due to gravity

Q = water discharge through main unit

ΔQ = additional water discharge when RPT is used

Mathematically,

1. When pump turbine is not used

Total power = $\eta_t.\rho.g.Q.(H3-H2)$ (1)

2. When pump turbine is used

During dry season,

Total power = $\eta_t.\rho.g.Q.(H3-H2) + \eta_t.\rho.g.\Delta Q.(H3-H2) - \rho.g.\Delta Q.(H2-H1+losses)/\eta_{rpt/p}$ (2)

During wet season,

Total power = $\eta_t.\rho.g.Q.(H3-H2) + \eta_t.\rho.g.\Delta Q.(H3-H2) + \eta_{rpt/t}.\rho.g.\Delta Q.(H2-H1-losses)$ (3)

3. SITE SELECTION

The site was selected under the criteria of potential capacity, location from demand centers, water availability, head conditions, accessibility and cost. After analyzing the available secondary data and obtaining new data as per the objective, Chilime Hydropower in Rasuwa was taken as reference site and the possibility of RPT installation in this site was studied.

Location. The proposed site is located at Syaphrubensi, Briddhim and Goljun VDC, Rasuwa District of Bagmati Zone. The geographical location of the project area is between latitude 28° 09’ 20’’ N to 28° 11’ 00’’ N and longitude 85° 19’ 20’’ E to 85° 20’ 45’’ E. The project area is approximately 170 km northwest of Kathmandu.

Description. The scheme consists of an upper reservoir, an underground power house complex with access tunnels and associated waterways, 2 Pelton turbines (each rated 11.25 MW) coupled directly with generator-motors and ancillary works that include building works, roads, transmission lines and temporary and permanent infrastructure. The gross head and the discharge for the unit is 351.5 m and 8.2 m^3/s respectively.

Geology. The area has steep slope and no prominent lineament was observed during the field visit. The foothills are covered by colluvial soil. The ridges are barren rocky terrains. Gneiss and quartzite are two main rock types found at the site.

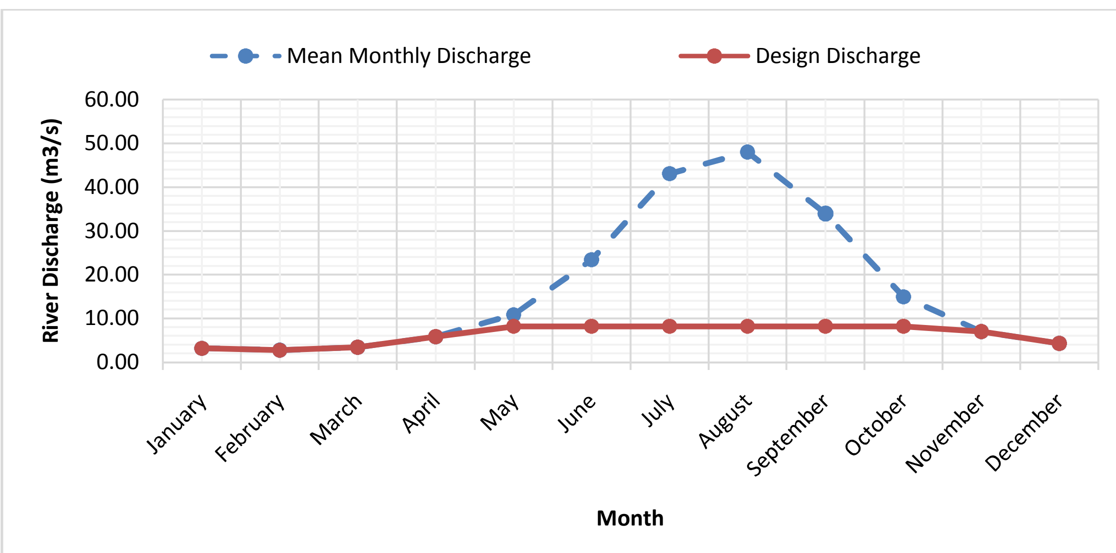

Figure 1: The Chilime River Discharge Graph

Hydrology. The existing plant utilizes the water from the Chilime River, which constitutes one of the major tributaries of the Trishuli River Basin that drains the central region of Nepal. The Chilime basin is located in between latitudes 28° 25' and 28° 10' N and longitudes 85° 5' and 85°

20' E. The total catchment area of the river is about 277 km^2 and may be divided into two parts. The upper catchment having an area of about 170 km^2 is a mountainous arid valley in the Himalayan region. The river is known as Sanjen Khola in this upper catchment, which is then known as Chilime Khola in the lower catchment after having been joined by other tributaries. The Chilime River joins the Bhotekoshi River downstream and then, the Langtang River at Syafrubesi and is known as the Bhotekoshi River afterwards.

The yearly discharge graph of the Chilime River is shown in the Fig. 2. As shown in the Fig. 2, the existing unit runs at full capacity during six months of the year and is operated in part load condition in the remaining months resulting in low efficiency and low power output. Moreover, the graph shows that during six months of the year from May to October, the discharge is far more than is actually utilized.

4. PUMPED STORAGE AND RPT FEASIBILITY

The Chilime River is a run-off river and its discharge is not constant. However, the Bhotekoshi River that flows nearby the Chilime River is a perennial river with abundant amount of water all the year round. Therefore, studies were carried out to determine the technical feasibility of using water from the Bhotekoshi River to supplement the main unit during dry season. With the current reservoir for main unit taken as the upper reservoir for RPT, the major task of the study was to determine the location for powerhouse and lower reservoir, where water from the Bhotekoshi is to be collected.

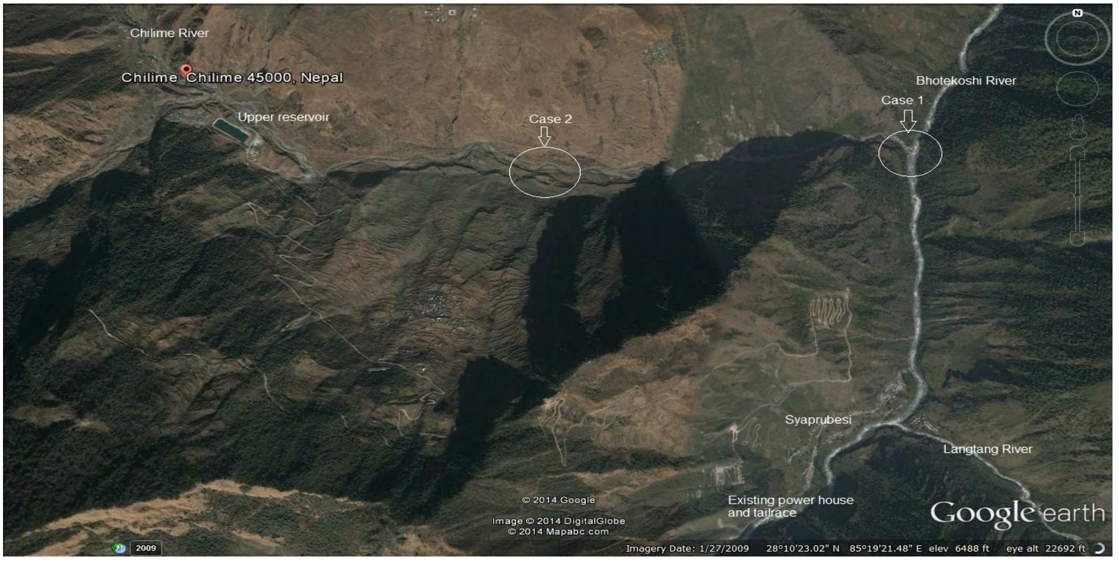

Figure 3: Aerial view of the site (Source: Google earth)

The survey study revealed that there are two feasible sites where the RPT and the lower reservoir might be built. The first site is at distance of about 6.2 km downstream the upper reservoir with the gross head of 257 m (case 1). Similarly, the second site is about 5.4 km from the upper reservoir with the total head is 126 m (case 2). Calculations were performed to estimate the amount of net energy that will be produced by installing the RPT at these sites. In order to determine which site is the best, the energy produced by installing RPT at these sites were compared with the energy produced originally without using RPT. The monthly energy production distribution is shown in the Fig. 4.

5. DATA AND ASSUMPTIONS:

$\eta_t = 80\%$, $\eta_{rpt/p} = 85\%$, $\eta_{rpt/t} = 90\%$

Net Head for main unit = 337.5 m

Energy produced/consumed by the unit = power [MW] * no. of days in a month * 24 [MWh] (4)

For case 1,
Head during pumping = 260 m
Head during turbine mode = 254 m

For case 2,
Head during pumping = 140 m
Head during turbine mode = 123 m

Table 1: Monthly Energy calculations

Month	River Discharge [m^3/s]	Energy Output without using RPT [MWh]	Main unit output with RPT [MWh]	For case 1			For case 2		
				Pumping Energy [MWh]	Output Energy from RPT [MWh]	Net Energy Output [MWh]	Pumping Energy [MWh]	Output Energy from RPT [MWh]	Net Energy Output [MWh]
1	3.15	6207.49	14090.02	8930.10		5159.92	4808.52		9281.51
2	2.73	4859.20	11978.90	8065.90		3913.01	4343.18		7635.73
3	3.42	6739.56	14622.10	8930.10		5691.99	4808.52		9813.58
4	5.82	11099.11	15637.92	5142.01		10495.92	2768.77		12869.15
5	10.82	16159.19	16159.19	0.00	4371.39	20530.58	0.00	2116.85	18276.04
6	23.40	15637.92	15637.92	0.00	9687.89	25325.81	0.00	4691.38	20329.30
7	43.07	16159.19	16159.19	0.00	10010.81	26170.00	0.00	4847.76	21006.95
8	48.03	16159.19	16159.19	0.00	10010.81	26170.00	0.00	4847.76	21006.95
9	33.97	15637.92	15637.92	0.00	9687.89	25325.81	0.00	4691.38	20329.30
10	14.92	16159.19	16159.19	0.00	10010.81	26170.00	0.00	4847.76	21006.95
11	7.00	13349.45	15637.92	2592.61		13045.31	1396.02		14241.90
12	4.28	8434.31	16159.19	8751.50		7407.69	4712.35		11446.84
Total		146601.73	184038.67	42412.22	53779.60	195406.05	22837.35		187244.20

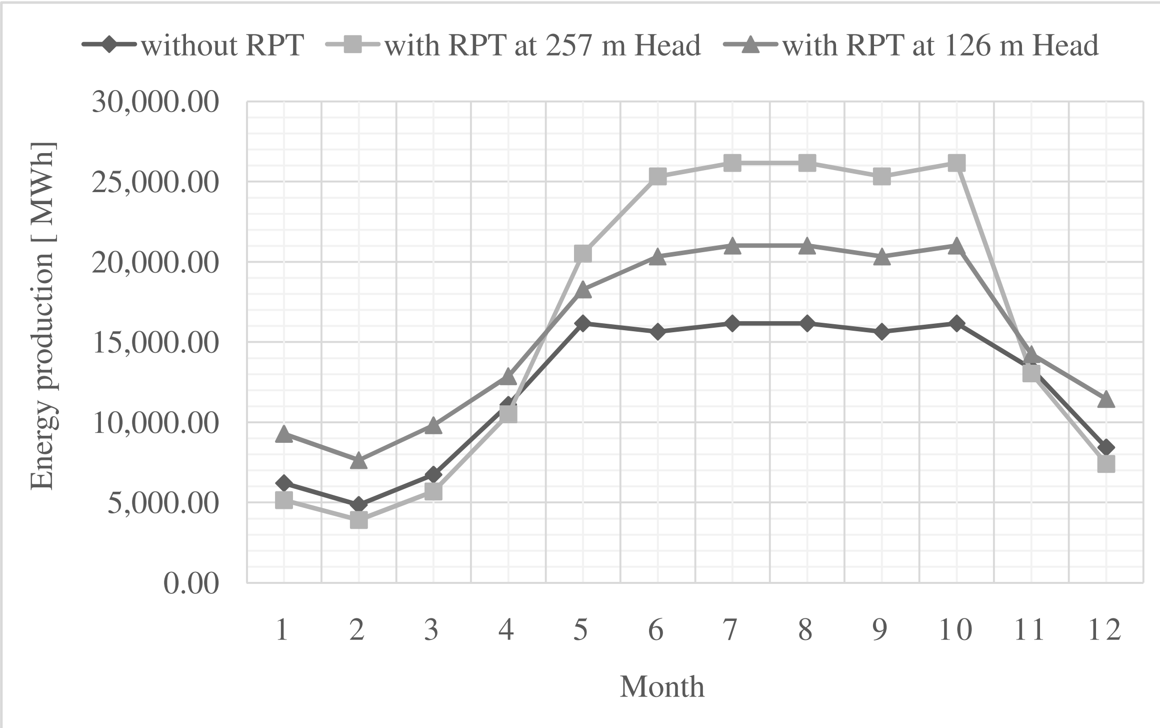

Figure 4: Energy production graph

6. ANALYSIS

The graph shows three curves indicating

a) Monthly energy production in present case (without RPT)

b) Energy produced when RPT installed at gross head of 257 m (case 1)

c) Energy produced when RPT installed at gross head of 126 m (case 2)

The graph shows that during wet season, more energy is produced since the RPT works as turbine in this case. But, it is during dry season when the RPT is needed most. Note that, if all the units were ideal (i.e. no losses in the system), then the net energy produced will be the function of head difference only. Thus, in such case, installing the RPT at any position with less head difference than the main unit would result in feasible system. However, in real case, various losses occur in the system, which may result in net decrease in production of energy when RPT is used as evident in case 1. From Table 1 and Fig. 4, the net energy production for case 1 during dry season is less than the energy produced in current case. As discussed before, this is because the pumping energy required for pumping the water from lower reservoir to upper reservoir is more than the net energy generated by running the same water through the main turbine unit due to various losses in the system. Hence, the result is a net consumption in energy by using RPT in pump mode resulting low energy production in total.

Conversely, in case 2, the energy produced during wet season is comparatively lower than in case 1 since the total head is lesser than case 1. But, the lower head means less pumping energy required for pumping water during dry season. As a result, the net amount of energy produced in dry season is more than the energy that was originally produced proving the viability of the project.

7. BENEFITS

The concept of RPT and pump storage system is new for Nepal. Yet, it can prove to be a promising solution to the major problem of water shortage in hydropower plants in dry season. The installation of RPTs as a supplement to the major hydropower plants can aid in utilizing the water from nearby river to operate the main unit to run at best efficiency point all the year round. It does not affect the natural load curve but its double face characteristics (load or generator) helps to avoid the unnecessary peak plant construction and also the better utilization of the existing base power plants. This will not only help conserve energy and money, but it will also help to meet the high electricity demand during dry season. Further, the running of main unit at constant discharge condition all the year round increases the efficiency and life of the main unit. Apart from this, the use of single machine acting as both pump as well as turbine saves the cost of one full machine and eliminating elaborate hydraulic connections, piping and couplings.

8. CONCLUSION

Most hydropower plants in Nepal are run-off type with no storage potential, which cannot meet the current peak demand of electricity leading to omnipotent power curtailing problem. Pumped Storage Hydroelectricity improves the efficiency of power plants by allowing them to run at maximum efficiency without wasting energy. They can also serve the electricity storage needs required in order to provide a consistent and reliable grid, which can match the demand.

The case study of Chilime Hydropower Plant suggests that out of the two possible alternatives for pump turbine installation, the one with gross head of 126 m is more suitable than the one with 257 m head since the net energy production is more in the former than the latter. The study also strengthens the concept of using pump storage system as auxiliary unit along with the existing main unit to make the maximum utilization of available water resources. Although the application philosophy is somewhat unorthodox, the idea certainly has a potential to increase the effectiveness of hydro power plants and meets the short term as well as long term energy needs of Nepal and hence, further research in the topic is highly recommended.

REFERENCES

[1] Bhattari B, Budha B. *On hydro-power development: Prospects and challenges*. in The Himalayan Times, ed. Nepal, 2012.

[2] *Electricity Generation Power Plants and Projects*. A Year in Review-Fiscal Year 2012/13, ed. Nepal, 2013: 111.

[3] *Total Energy Available and Peak Demand*. A Year in Review-Fiscal Year 2012/13, ed. Nepal, 2013: 105.

[4] *Load Forecast*. A Year in Review-Fiscal Year 2012/13, ed. Nepal, 2013: 109.

[5] Kádár D P. *Pumped Storage Hydro Plant model for educational purposes*. Hungary: Dept. of Power Systems, Budapest Tech: 5.

[6] Steffen B. *Prospects for pumped-hydro storage in Germany*. University of Duisburg-Essen (Campus Essen), Germany 2011.

[7] *Hydroelectric pumped storage technology: international experience*. Task Committee on Pumped Storage, Committee on Hydropower of the Energy Division of the American Society of Civil Engineers, New York: American Society of Civil Engineers.

[8] Ciocan G, Tellor O, Czerwinski F. *Variable Speed Pump Turbines Technology*. U.P.B. Science Bulletin, vol. 74, 2012: 10.

[9] Atencio F. *Reversible pump-turbine*. US Patent US 4275989 A; Jun 30, 1981.

[10] Lal J. *Recent Trends in the Development of Water Turbines and Modern Hydro Power Plants*. Hydraulic Machines. Metropolitan Book Co. Pvt. Ltd., 2009: 285-292.

[11] *Nepal Hydropower Overview*. Information on http://www.hidcl.org.np/nepal-hydropower.php

[12] Gautam S. *Future of Nepal's Electricity: long term policy suggestions*. in EngeryForNepal vol. 2014.