PROSPECTS OF PUMPED-STORAGE HYDROPOWER FOR ENHANCING INTEGRATED NEPAL POWER SYSTEM

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ABSTRACT

The electricity demand of Integrated Nepal Power System (INPS) is covered mainly by run-off-river hydropower plants with limited storage due to which it evidently fails to provide electricity during peak demand hours. The energy produced by these plants can be optimally utilized by introducing Storage and Pumped-storage hydropower schemes in the power network. Kulekhani (90 MW) is the only storage project of Nepal and we are forced to fulfill the demand during peak hours by the use of diesel power plants, which cannot be a good solution simply because they are non-renewable, environmental unfriendly and a factor for climate change. It might surprise many people that despite of the power deficit, we do have surplus energy in our system. The problem is that it is difficult to store electricity and the trajectories of the graph of supply and demand do not match thereby creating power outages at one time and at other times leaving extra power in the system. The idea of Pumped-storage is to utilize this surplus power in pumping so that electricity can be generated during the peak demand hours. This paper aspires to introduce this sustainable technology that has gained much popularity in the developed world but is still new in Asia and Asia Pacific Region. A sample case study of ‘Rupa and Begnas Lake’ is a part of the study. The concept of Pumped-storage is certainly an agenda for discussion and it has to be included in the National Policy of Power Planning because first, it takes out the expensive and harmful diesel plants out of the network so that we can have pollution free development and secondly, it helps countries like Nepal, which is so much dependent on its water resources for development, to sustainably manage its natural resources.

KEYWORDS
Sustainable development, Pumped-storage hydropower, Renewable-energy
INTRODUCTION

Among the several natural resources that has been bestowed upon Nepal, fast running rivers with high grade are present abundantly, which provide great scope for developing hydropower projects. Despite of this, Nepal is suffering from power outages and load shedding. The reason for this is the lack of sustainable management of power in the INPS (Integrated Nepal Power System) that is not possible without the introduction of pumped storage schemes in the system. Electricity, unlike other energy carriers can only be stored in large quantities in rare circumstances. However, pumped storage is the largest form of commercially proven technology available for grid – scale energy storage.

There are varieties of conventional power plants like nuclear plant, fuel fired (coal, gas, oil) plant, run-off river type hydropower plant and non-conventional power plants such as PV, wind etc. to fulfill daily electrical energy demand. But, when it comes to adjust with the rapidly changing demand on electricity, they seem unsuitable (Ilyinykh, 1982). These power plants are generally used to fulfill the base-load and do not always match with the demand at peak periods or keep on producing electricity beyond the demand causing frequent shut down of plant that results in environmental pollution, spillage of energy and deterioration of plant economy.

The Integrated Nepal Power System (INPS) is dominated by run-off river type hydropower plant (NEA, Annual Report, 2012). Electricity from such conventional power plants has to be used as soon as it has been generated. This is why grid control and electricity dispatching systems are important; they have to balance the demand for electricity with supply. Once one fails to match the other, problems occur. Therefore it is important to store electrical energy or supply electricity through stored reserves to maintain a balance between system demand and supply.

Furthermore, Nepal is marching towards production of green energy like solar and wind. However, the green energy is dependent on environmental variables and has not gained much significance in making up the power balance (Boyson, 2010). This necessitates the buffer between electricity generation and consumption to optimize utilization of green energy sources, optimize the use of transmission line infrastructure, and generate revenue by capturing otherwise wasted energy by incorporating Pumped-Storage power plant in INPS.

PUMPED-STORAGE HYDROPOWER (PSH) AND ITS BENEFITS

PSH is a type of hydropower used generally for load balancing by
other power plants. However, it does not add to installed capacity. The basic idea of PSH is simple. It stores energy in the form of hydraulic potential energy of water, pumping water from a lower elevation reservoir to a higher elevation reservoir using low cost off peak energy and when recovery of energy is required at peak period, the water is released from the upper reservoir to lower reservoir through turbines which drive electrical generators to produce electricity at higher price (Pumped-Storage Projects, 2014). Although the losses of pumping make the plant a net consumer of energy, the system increases revenue by selling more electricity during periods of peak demand when electricity prices are highest. The system is economical also because it smoothens out load variations on the power grid by helping base-and intermediate-load power plants to operate more efficiently at peak efficiency (Ilyinykh, 1982).

A Pumped-Storage plant contributes to the total peaking capacity of the system. Pumped-Storage plant helps in load and frequency regulation by continuously matching system generation with the system load. These plants also acts as standby and spinning reserves as its operating is synchronized and can be brought to full load in a short time. Pumped-Storage project in spinning and standby reserve modes are available to provide system frequency control, and to respond to and correct low frequency occurrences. A Pumped-Storage project can also operate in condenser mode to generate or to absorb reactive power (phase compensator mode) as may be required for system voltage regulation. Furthermore, a Pumped-Storage project contributes to system reliability and restart in case of system-wide failure of the transmission or generation system (Lohiya, 2009). In the developed world, pumped storage hydropower schemes have already been established as one of the wonders of the energy industry because the cycle of pumping, storing and generating provides a flexible and valuable balancing service to the grid system. The pumped storage schemes can not only be used as a tool to balance peak loads but also as a short term operating reserve in order to provide a short term rapid changes in power demand or compensate for a sudden loss of power stations.

Pumped storage already accounts for more than 99 percent of installed storage capacity for electrical energy around the world equaling around 127 Giga watts according to EPRI (Electric Power Research Institute – the research arm of America’s Power Utilities). The pumped storage scheme becomes economical because water is pumped at off peak times when the electric prices are low and used to supply during high demand time when electric prices are high. Also a hydropower plant offers a long asset life of 50 to 100 years giving enough
time to recover the costs in the long run.

ENVIRONMENTAL FRIENDLY TECHNOLOGY

In the recent past, Asia has seen a strong economic growth and has raised the living standards of people in the region. However, this socio-economic development has been achieved at the cost of environment because the development activities have been unsustainable with intensive use of resources. Energy plays a major role in development of nations. Over the years, hydropower has established itself as a clean form of energy and has been widely accepted as an alternate to fossil fuel energy. The price we pay for using fossil fuel is too high and causes irreversible damage like resource depletion and pollution resulting into global issues like climate change and loss of biodiversity.

In Nepal, diesel power plants have emerged as the alternative solution to the problem of power outages. This is a backward step in sustainable development because diesel power plants are contributors to CO$_2$ emission. All over the world there has been a tremendous increase in renewable energy with growth of wind and solar generation and the governments have been introducing various policies. Our electric grid is facing new challenges in the form of addition of intermittent renewable energy sources and they are reaching high levels of grid penetration. Recently, Nepal government has announced to install 25 MW solar PV at various hydropower project sites either with peaking run-of-capacity or storage. AEPC (2008) estimates about 3 GW of electrical energy from wind resources in Nepal. Electricity from these sources could be connected to National Grid. The increase of renewable energy in the grid is a good thing; however it also brings in the need for storage of this intermittent energy. As mentioned earlier, for grid-scale energy storage, pumped storage is the only technology that has been proven commercially. The development of pumped storage hydropower plants would improve the grid reliability of INPS and reduce the need for construction of additional fossil-fueled generation.

There seems to be a distinct relationship between hydropower generation and climate change. Studies have indicated that the generation of hydropower has contributed to the decreased use of fossil fuels and it has provided a substantial aid for the problem of climate change. Other studies have indicated how climate change has actually induced appreciable changes in hydroelectric production in different parts of the globe because it causes alterations in evaporation, river discharge, glacial melting, and changes in frequency of extreme meteorological events etc.
The next forty years promise to challenge energy and water resource management (Blackshear et al., 2011). In order to manage electrical energy, a method needs to be devised which can readily store electrical energy and supply when required. Pumped Storage hydropower plants seem to be the answer.

TECHNOLOGICAL ADVANCEMENT IN PUMPED-STORAGE HYDROPOWER SCHEMES

Various new technologies are being introduced in the sector of PSH all around the globe which is increasing the efficiency of operation of plants and bringing stability in the grid. For instance a major breakthrough in PSH technology was the introduction of the doubly-fed induction machine (DFIM) motor/generator with adjustable speed (AS) capability. The main advantages of AS plants are that they provide more flexibility in operations, as well as higher efficiency. In particular, the ability of AS plants to adjust power consumption while pumping enables provision of dispatch flexibility and regulation (i.e., respond to frequency deviations and short-term energy balancing needs in the system) in the pumping mode.

Internationally, more than 20 AS units have entered commercial operation since the 1990s, and several more are under design and construction. In particular, AS technology is seen as an important solution to grid reliability and renewable energy integration challenges. In recent years, a more flexible variation of the ternary PSH configuration with a hydraulic bypass has been developed. The hydraulic bypass allows for pumping and generation to occur at the same time, resulting in more pumped Storage Hydropower: Benefits for Grid Reliability and Integration of Variable Renewable Energy flexible operation than the FS (Fixed Speed) including the ability to provide regulation in the pumping mode.

In the traditional mode of operation, PSH follows a daily operational cycle. Electricity is used to pump water from the lower to the upper reservoir during low loads at night. Water stored in the upper reservoir is released during peak demand periods, delivering valuable electricity to the grid and reducing the need for peak load generation from other power plants. Because the deregulation of the bulk power electric system created separate products and prices for ancillary services, i.e., certain services required maintaining reliability in the power system, it is now possible to earn revenue for supplying such ancillary services. The rapid expansion of renewable energy (e.g., wind and solar) will likely increase the ancillary service requirements (Botterud et al., 2014).
CRITICAL NEED OF PSH IN NEPAL

In Nepal there is a considerable amount of gap between demand and supply of electricity. But even at this time of electrical crisis, Integrated Nepal Power System (INPS) is compelled to spill energy during off peak hours. Therefore it would seem obvious, given this situation, that one or two Pumped-Storage plant would be a major boon to grid operation.

Figure 1. Load Curve of Peak Load Day (Jan 13,2012) (NEA, Annual Report, 2012).

The analysis of daily load curve (Figure 1) of INPS showed that it has surplus energy during the night time and this surplus energy is superfluous because there is no demand at that instant. Almost all the countries around the globe faces same difficulty but they use different types of electrical energy storage technique to store the off peak surplus energy and use it at the time of demand. Among all the storage technique Pumped-Storage is the largest-capacity form of grid energy storage available, and, as of March 2012, Electric Power Research Institute (EPRI) reports that PSH accounts for more than 99% of bulk storage capacity worldwide, representing around 127,000 MW(Pumped-Storage Hydroelectricity, 2012). With the
increase in generation from other plant, Pumped-Storage plant will see increased usage and importance in upcoming years.

**PROSPECTS OF PSH**

The prospect of Pumped-Storage plant in Nepal is greatly dependent on the present and future energy status of Nepal. The result of the analysis of the daily load curve of INPS of year 2012 (Figure 1) assuming a constant power production of 400 MW (Dry period) and 680 MW (Wet period) is shown in Figure 2 below:

*Figure 2. Total Deficit Energy (1070.61 MWh).*

The result obtained showed that there is enough excess energy to overcome the deficit energy during wet season. However, this situation doesn’t hold true during dry periods for now. During dry periods very less amount of excess energy is available (Figure 2). Thus the Pumped-Storage scheme at present can only be thought for seasonal peaking (during wet season only). But, at present there are number of projects in pipeline and some are of huge capacity. In addition to this considering only 100000 Buildings in Kathmandu Valley that install grid connected PV systems of 1 kW capacity, a 100 MW of power could be generated for 6 hours daily that will be enough pump back the water from Rupa Lake to Begnas Lake.

![Total Excess Energy](image)

*Figure 3. Total Excess Energy (1460.76 MWh).*

Thus Pumped-Storage can be operated for daily peaking after implementation of those projects. However, the capacity of Pumped-Storage will vastly depend on the amount of excess energy available (Figure 3) from the run-off river projects or green energy sources or other sources to pump back the water.
POTENTIALITY OF DIVERSE PSH SCHEMES

The topography of Nepal is suitable for different types of PSH schemes such as pumping water from a lower natural reservoir to a higher natural reservoir or from river to a natural depression at an upper elevation (open loop type). It is also possible to pump water between two artificial reservoirs (closed loop type). This paper has included the open loop type PHS scheme with a case study of Rupa and Begnas lake PSH.

A CASE STUDY BEGNAS AND RUPA PUMPED-STORAGE HYDROPOWER

Rupa and Begnas Lakes are located in Sundaridanda, Kaski district, Nepal (Figure 4). The topographical survey at the site showed that the gross head between two reservoirs; Begnas Lake (upper reservoir) and Rupa Lake (lower reservoir) is 50 m (Mahesh et al, 2011).

Assuming a design head of 50 m, power generation capacity of 100 MW and efficiency of 70 %, the time period that the Begnas Lake can supply water as an upper reservoir is shown below in Table 3. The supply level is assumed only up to 5 meters deep as draining water beyond this depth might pose environmental disaster.
Table 1. Potential time of production of energy at different water levels in Begnas Lake.

<table>
<thead>
<tr>
<th>Depth(m)</th>
<th>Volume(MCM)</th>
<th>Potential hours</th>
<th>Cumulative Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 1</td>
<td>2.9</td>
<td>2.8</td>
<td>2.8</td>
</tr>
<tr>
<td>1 - 2</td>
<td>2.8</td>
<td>2.7</td>
<td>5.5</td>
</tr>
<tr>
<td>2 - 3</td>
<td>2.7</td>
<td>2.6</td>
<td>8.1</td>
</tr>
<tr>
<td>3 - 4</td>
<td>2.5</td>
<td>2.4</td>
<td>10.5</td>
</tr>
<tr>
<td>4 - 5</td>
<td>2.3</td>
<td>2.2</td>
<td>12.6</td>
</tr>
</tbody>
</table>

Table 1 shows that for a design power of 100 MW, Begnas Lake has ample capacity as upper reservoir. The time period for which Rupa Lake can supply water is shown in Table 4 below.

Table 2. Potential time of production of energy at different water levels in Rupa Lake.

<table>
<thead>
<tr>
<th>Depth</th>
<th>Volume(MCM)</th>
<th>Time(hours)</th>
<th>Cumulative time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>0.94</td>
<td>53.58</td>
<td>53.58</td>
</tr>
<tr>
<td>1-2</td>
<td>0.80</td>
<td>45.90</td>
<td>99.49</td>
</tr>
<tr>
<td>2-3</td>
<td>0.57</td>
<td>32.54</td>
<td>132.02</td>
</tr>
</tbody>
</table>

The capacity of Rupa Lake is too small to sustain the 100 MW pumped-storage hydropower. Hence, it necessitates making of dam for increasing the capacity of the Rupa Lake. However, dam would inundate land and few houses especially in the upstream area which is currently used for agricultural and resort purposes.

Figure 6. Cross-section of PSH showing geology and Tunnel Alignment.
A storage volume-elevation curve and area-elevation curve was obtained using survey data. Both the curves shown in Figures 7 and 8 respectively below are drawn as function of lower reservoir (Sah et al, 2013).

**Figure 7.** Graph of elevation vs inundation area.

A Bathymetric survey of Begnas and Rupa Lake as shown in figures below (Mahesh et al, 2011) was used to determine the reservoir capacity. The reservoir and plant capacity was determined using multi-disciplinary approach which encompassed reservoir capacity (Rupa Lake), excess energy available to pump back the water into Begnas Lake and operation hour of plant.

**Figure 8.** Storage volume elevation curve.

After performing several trials, the plant capacity was fixed to 100 MW that can be operated for five hours. A five hour operation of the plant will utilize 4.1 MCM (million cubic meters) of water i.e. drawdown of 1.5 m of Begnas Lake (Figure 9) at a design discharge of 227 m$^3$/s. This drawdown will inundate approximately 60 hectares of farmland at upstream of Rupa Lake (Figure 10). At downstream of Rupa Lake an 8.0 m high earthen dam is required to accumulate 7.0 MCM of water which is kept in order to incorporate pisciculture and irrigation. A reversible pump-turbine of 125 MW is required to pump back 4.1 MCM of water in 5.5 hours. However, other combinations of smaller capacities of pump can also be used to pump back the water using excess energy available from INPS at different time of day.
CONCLUSION

Optimized utilization of the electricity generated by run-off-river hydropower plants of Nepal is the key to solving the problem of power outages during peak hours. Pumped storage can be the solution not only because it is commercially successful but also it makes possible to manage the energy demand with supply. It takes CO$_2$ emissions and green-house gases out of the equation so that we have a more eco-friendly solution that is sustainable and does not contribute to climate change.

The future of electric grid systems is the addition of renewable energy sources like wind and solar energy, which are not only difficult to store but also poses serious trouble for transmission due to its instability caused due to its dependence on time and weather. Therefore, the need of balancing these plants becomes more necessary and pumped storage can be used for this purpose. The energy can be stored efficiently with pumped storage schemes and supplied as necessary. There might be argument about other technologies of energy storage available such as use of batteries and air compressors. However, nothing has proved to be as efficient and commercially successful on a large scale as pumped storage.

The new technologies like adjustable speed pump turbines being introduced in pumped storage schemes also makes it more efficient and also improves the quality of power, frequency and voltage with
time required for ramp up and ramp down. The system can be explained as a mechanism that can supply extra power when demand spikes and take in extra power when supply stays high while demand drops is extremely helpful.

There are problems (inundation of land, environmental impact etc.) associated with pumped-storage project but with technological advancements, sound policies and profound trans-boundary electrical connectivity and through the use of advantageously located natural lakes, it is possible to minimize and mitigate those problems and realize the pumped-storages project as shown in the case of Begans and Rupa Lakes in Nepal for enhancing Integrated Nepal Power System.

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