Application of Pumped Hydroelectric Energy Storage for Photovoltaic based Rural Electrification

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Abstract: *Nowadays, due to the ever increasing demand of electricity and the rise of environmental concerns, renewable energies are becoming the best option for electrification especially for rural electrification. The biggest problem of wider use of renewable energy sources is energy storage. This research deals with the pumping storage system analysis. The water reservoir serves for daily and seasonal energy storage, thus basically solving the energy storage problem. The electrical energy produced in excess by the renewable energy system is converted in potential energy by pumping water to a higher elevation where it can be stored indefinitely and then released to pass through hydraulic turbines and generate electricity. The estimation of energy demand for day and night time, stored energy, reservoir dimension and parameters of hydroelectric plant are presented. Myanmar is richly endowed with renewable energy resources but it has the lowest level of energy access in South-East Asia with about 30% of the country's population having access to electricity. This research is aim to enhance the utilization of these renewable energy resources for rural electrification, especially with solar energy which is highly depending on energy storage. This study shows how pumped hydroelectric energy storage is suitable for this purpose.*

Key Words: *pumped hydroelectric, energy storage, rural electrification, renewable energy, photovoltaic.*

1. INTRODUCTION:

Electricity is an essential role to be comfortable for people in rural area. There are many difficulties without electricity, it can effect on modernize environment for rural area. A large increase in energy consumption was noted especially after the living standards were improved. Renewable energy generation is becoming more prevalent on today's electric grid. Part of the challenge of increasing the percentage of renewable energy beyond 20% will be dealing with the intermittent nature of renewable sources [1]. With renewable energy system, some difficulties appear by numerous network failures and a limitation of the renewable energy part due to the random nature of the solar source. The combination of renewable resources with energy storage can be a solution because it can increase the value of photovoltaic (PV) generated electricity, making supply coincident with periods of peak consumer demand. Energy storage systems have different application as to follow load, stabilize voltage & frequency, manage peak loads, improve power quality, defer upgrade investments, and support renewable. In this study, pumped hydroelectric energy storage is used for optimization of the capacity development of solar generation. The purpose of this study is to analyze the technical feasibility of a PV and PHES installation on the rural area.

The republic of the Union of Myanmar is a developing country with a population of about 53 million. Most geographical areas of Myanmar have a high solar energy potential. The average solar radiation of Myanmar is found to be 5.08 kW/m^2/day [3]. Comparison with neighboring countries reveals that Myanmar has nearly the same solar energy potential as Thailand and Cambodia but higher than Lao PDR [3]. A stand-alone PV system with energy storage will be excellent choice for Myanmar. In this study, Thaephyu village, Myanmar is selected as a site location for the hybrid PV and pumped storage system design. The proposed system can provide the much needed electricity in households in this village for basic loads as lighting.

2. PUMPED HYDROELECTRIC ENERGY STORAGE:

Using a pumped hydroelectric storage (PHES) allows to improve the quality of the provided electricity and to reduce the peak power of the other energy generating systems. This system flattens out the load variation on the power grid, and permits thermal power stations that provide base-load electricity to continue operating at peak efficiency while reducing the need for peaking power plants that use costly and polluting fuels. Moreover, a pumped storage system helps control electrical network frequency and provides reserve generation. Thermal plants are much less able to respond to sudden changes in electrical demand, potentially causing frequency and voltage instability. The pumped hydroelectric storage system can respond to load changes within seconds. These machines generate in synchronization with the network frequency, but operate asynchronously (independent of the network frequency) as motor-pumps. A new use for pumped storage is to level the fluctuating output of intermittent power sources. The pumped storage absorbs load at times of high output and low demand, while providing additional peak capacity.

For the stand-alone photovoltaic power system, PHES has another advantage. PHES can act as energy storage of the system instead of using battery bank which is required high capital cost and low life time. During day time, when solar energy is aviable, PHES is used to pump water from the lower reservoir to the upper reservoir (See Figure 2.1a). Water stored in the upper reservoir is then released during night time, when solar energy is unavaiable, delivering electricity to the grid (See Figure 2.1b).

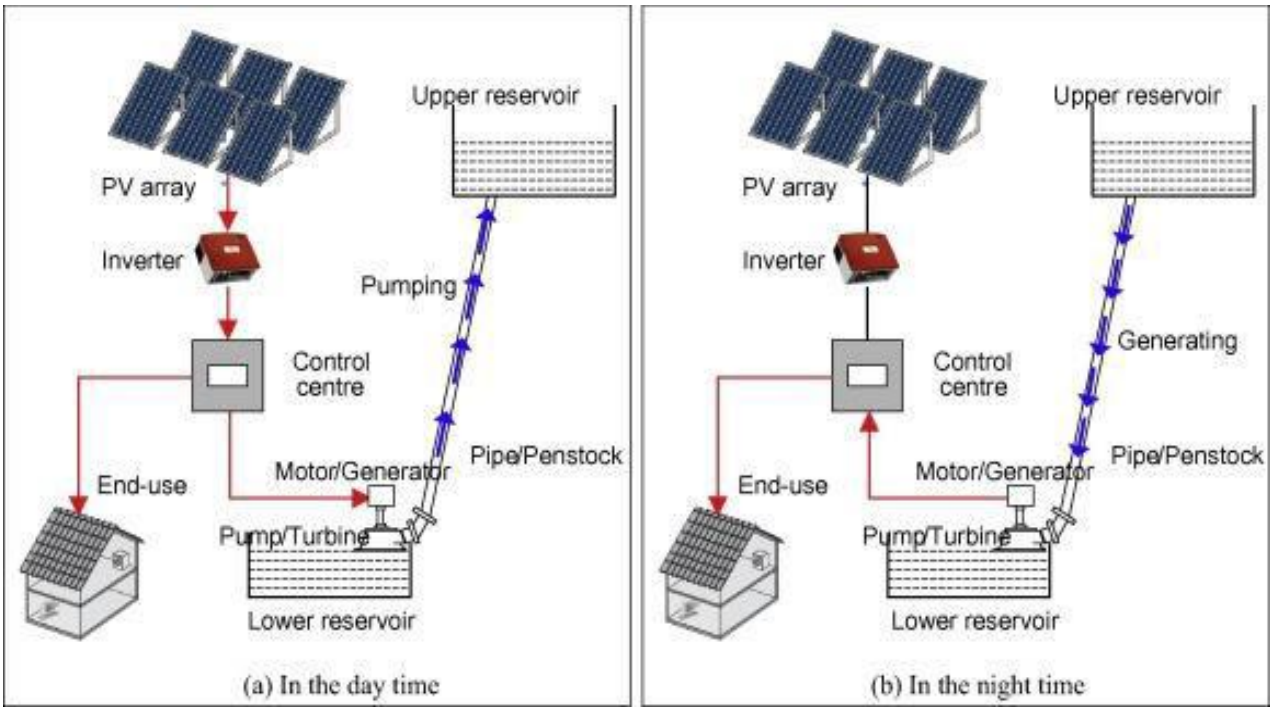

Figure 2.1. Operation of pumped hydro electric energy storage with photovoltaics power system.

3. PREDICTING ENERGY DEMAND AND SIZE OF PV STATION FOR STUDY AREA

In this research, the main system design is undetaken based on the data collected on Thaephyu Village, which is situated in Thayat Township, Magway Region in Myanmar. The village has no access to grid electricity for various reasons and its hybrid PV and PHES energy make to generate electricity. This work begins with the energy consumption estimation of Thaephyu Village and ends with the determination of the output of the hybrid PV and PHES. In Thaephyu village, there are total 137 household and one primary school. By the data surveying questionaries, the daily energy demand of Thaephyu vilage can predict as table 1.

Table 3.1. Daily energy demand of Thaephyu Village

Consumer	Consumption/House (Wh/day)	Housing No.	Day Time Total Consumption (Whr)	Night Time Total Consumption (Whr)
High Income	5515	30	68550	96900
Normal Income	2577	70	66290	114100
Low Income	734	37	10693	16465
School	1278	1	423	846
Total			145956	228311

In table 1, ther required amount of energy for day time is 146 kWh and the required amount of energy for night time is 228 kWh. The daily total energy consumption of the ThaePhyu village is 375 kWh per day. For the condition of weather changes and another losses, the extra power is considered about 394 kWh per day. In this case, it is assumed that the solar irradiance for ThaePhyu village is symmetric for before noon and afternoon and also assume that PV power is abaiable from 6AM to 6PM. According to the avaiabality and time dependent of solar irradiance, We have to choose 60kW PV power plant to supplied 394 kWh per day.

The comparing of power from PV power plant (red line) and daily energy consumption of ThaePhyu village (blue line) is shown in Figure 3.1.

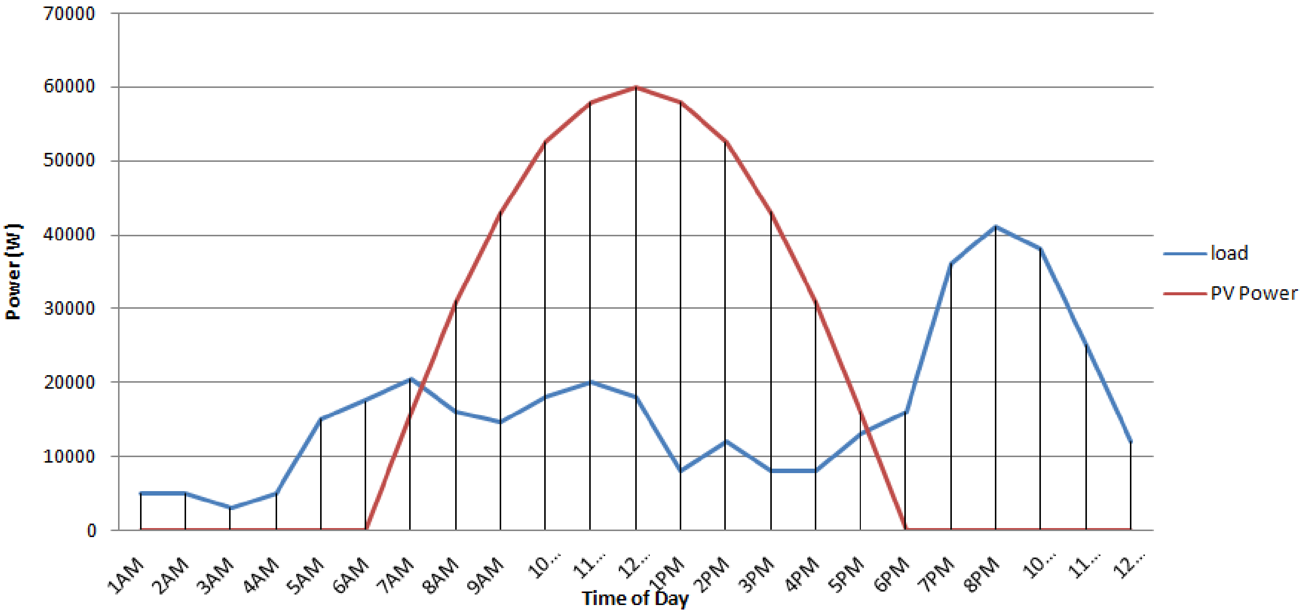

Figure 3.1. Comparing of power from PV power plant and daily energy consumption of ThaePhyu village

4. ENERGY REQUIREMENT CALCULATION

Power supply scheme for ThaePhyu village is shown in figure 4.1. In these supply scheme, we can devided into three different supply schemes. The first one is PHES only power supply scheme and it will supply from 6PM to 6 AM. The second one is PV only power supply scheme and it will supply from 8 AM to 5 PM. The last one is PV + PHES scheme and it wil supply from morning 6AM to 8 AM and from evening 5 PM to 6 PM. Total energy requirement for each scheme are needed to decide. In this case, we assume that the avaiable solar energy can get from 7AM to 5PM. So we can calculate energy requirement for each source as follow;

Total Avaiable Energy from PV Power Station per day= 461 kWh
Total Energy Requirement for Day Time (7AM to 5PM) = 156kWh
Excess Energy from PV Power Station = Total Energy – Energy Requirement
= 470 – 156 = 305 kWh
Total Energy Requirement for Night Time (5PM to 7AM) = 233.5 kWh
Assuming that The efficiency of PHES is 80%
The required energy amount of PHES for pumping = 233.5/ 80% = 292 kWh
From these results, the excess energy from PV power station is enough for the pumping process of PHES.

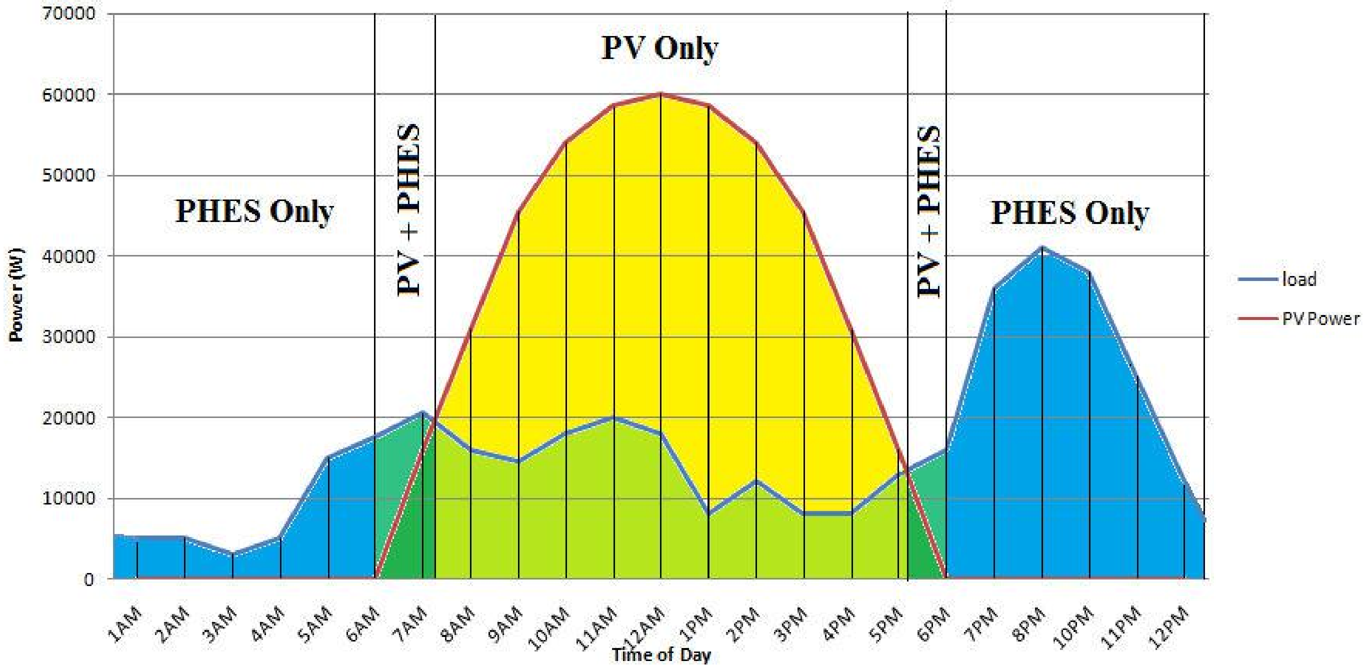

Figure 4.1. Power supply scheme for ThaePhyu village

5. DESIGN CALCULATION OF PUMPED HYDRO ENERGY STORAGE SYSTEM:

Ther upper reservior of PHES system is proposed at the top of Htone Mountain (located near ThaePhyu village) which has 150m hight above sea level. Ther lower reservior is proposed at the bottom of Htone Mountain, by flowing into Arrawaddy river (It is considerable as an economical point of view).

5.1 Upper Reservior Design

According to daily energy consumption curve, total energy requirement for night time (from 5PM to 6AM) is 233.5 kWh. Assuming that the efficiency of PHES is 80%, so total energy requirement for PHES is 292 kWh. Considering evaporation loss, required energy storage capacity for upper reservisor is 300kWh.

Energy Storage Capacity = $300 \times 3600000 = 10.8 \times 10^8$ joules ($1\text{kWh} = 3.6 \times 10^6$ joules)

High difference (elevation) = 150 m -50 m (Assuming that power house at 50 m asl)

Mass of Water = $10.8 \times 10^8/100\text{m} \times 9.81$ (PE = mgh)

$= 11.00 \times 10^5$ kg

$\simeq 1100\ \text{m}^3$ (Water density = $1000\ \text{kg/m}^3$)

A reservior with a dimension of length of 20m, width of 11m and depth of 5m is proposed to be constructed. This would require excavating the land surface to get a depth of 5m. The upper reservior will have a gross storage capacity of 850 cubic meter of water.

5.2 Penstock Design

Penstock (pipes) are used to conveying water from intake to the power house. We can consider the flow rate for pumping mode and generating mode. For pumping mode, the water is pumped from river to upper reservior for 1100 m^3 during 8 hours. From figure.4.1, maximum avaiable solar energy for pumping is 45kW at 1 PM. Power is the product of the specific weight of water, the discharge, and the change in hydraulic head ΔH[2]. We can define as;

$$P = \gamma Q \Delta H \tag{5.1}$$

Where,

γ = Specific weight of the fluid [lb/ft3;N/m3]

Q = Flow rate [ft3/s; m3/s]

ΔH = Change in head [ft; m]

For a pumped storage hydropower project during pumping mode, ΔH is energy/weight applied to the pump water uphill, and during turbine operation ΔH is energy/weight applied by fluid. The power required to pump the water uphill is calculated as:

$$P_{pumping} = \frac{\gamma Q \Delta H}{\eta} \tag{5.2}$$

The power generated during turbine operation is calculated as:

$$P_{generating} = \eta \gamma Q \Delta H \tag{5.3}$$

From equation (5.2), pumping flow rate can be calculated;

$$Q = \frac{45kW \times 0.98}{1000\ kg/m^3 \times 100m} \times \frac{1kg-m/s}{9.81W} \times \frac{1000W}{1kW},\ Q_{pumping} = 0.045\ m^3/s$$

From figure 4.1, for the night time generating mode, peak power demand is 40kW at 8 AM turbine efficiency is assumed as 92%.

From equation (5.3) generating flow rate can be calculate ;

$$\text{Q} = \frac{40\text{kW}}{1000\ \text{kg/m}^3 \times 100\text{m} \times 0.92} \times \frac{1\text{kg}-\text{m/s}}{9.81\text{W}} \times \frac{1000\text{W}}{1\text{kW}}, \quad \text{Qgenerating} = 0.044\ \text{m3/s}$$

5.3 Penstock Design

The power house is located at 50m asl. So the gross head between upper reservior and power house is 100m. The power house is located 112 m away from the bottom center of Htone mountain. By Pythagora's Theorm, total penstock length is calculated as 150m. One common penstock is used for pumping and generating. So the flow rate is taken as 0.035 m^3/s.

$$\text{Internal Penstock Diameter} = 2.69 \times \left(\text{n}_\text{P}^2 \times \text{q}^2 \times \frac{\text{L}_\text{P}}{\text{H}_\text{g}}\right)^{0.1875} (\text{m}) \tag{5.4}$$

$$= 0.167\ \text{m} = 6.6\ \text{inches}$$

Where, np = Meaning's coefficient (0.011), q = water flow rate (0.035 m3/s), Lp = penstock length (200 m), Hg = gross head (130m).

According to the calculated result, we can choose 8 inches diameter PVC pipe for penstock.

5.4 Electromechanical Equipments Selection

The gross head between upper reservior and power house is 100m and the discharge rate is 0.045 m3/s. So, cross flow turbine is suitable for this research.

In this work, overall motor rating is considered about 40 kW according to daily energy consumption curve. Generator rating is considered as 50 kVA because the peak demand

5.5 Calculated Parameter for Pumped Hydroelectric Storage for Thaephyu Village

In this research, system parameters for pumped hydroelectric storage system are calculated. The calculated results are show in table 5.1.

Table 5.1 Calculated Results

No	Parameter	Value	Unit
1	Energy Production	470	kWh/day
2	Energy Requirement (Day Time)	156	kWh/day
3	Energy Requirement (Night Time)	233.5	kWh/day
4	Water Storage Capacity	1100	m3
5	Size of Upper Reservior	11 × 20 × 5	m
6	Water Flow Rate (Pumping)	0.045	m3/s
7	Water Flow Rate (Generating)	0.044	m3/s
8	Penstock Diameter (Inner)	8	in
9	Gross Head	100	m
10	Pump Motor Rating	40	kW
11	Generator Rating	50	kVA

6. CONCLUSION:

This work investigates the design considerations of a Hybrid PV and Pumped Hydroelectric Energy Storage for ThaePhyu village. Hybrid PV and PHES system sizing design depends on many variables such as solar PV module, Upper and Lower reservior design, Penstock design, Pump motor and generator rating. After calculation of overall system based on collected parameter of target area, 60kW PV system, 40kW pump motor and 50kVA generator of pumped hydroelectric energy storage system is selected to get 470 kWh/day. The variation of variables will have direct impact towards the system reliability, the expected life cycle cost. The results show that the design parameters of required impementation of purposed rural areas using of hybrid PV and PHES system. The purposed system design can supply enough power to consumers who live in Thaephyu Vollage. Finally, the proposed hybrid PV and PHES system design was evaluated technically, economically and enviromentally to achieve reliability.

REFERENCES:

1. G. Notton, V. Lazarov, L. Stoyanov, " Analysis of Pumped Hydroelectric Storage for A Wind/PV System for Grid Integration", *Екологично инженерство и опазване на околната среда*, No 1, 2011, c. 64-74
2. Brandi A. Antal, "Pumped Storage Hydropower: A Technical Review", *Master of Science Report, University of Colorado-Boulder*, 2004
3. Soe Moe Aung, Prapita Thanarak, "Renewable energy potential and its utilization for rural electrification in Myanmar" *International Journal of Renewable Energy*, Vol. 10, No. 1, January - June 2015
4. Khaled Bataineh, Doraid Dalalah, "Optimal Configuration for Design of Stand-Alone PV System", *Smart Grid and Renewable Energy*, 2012, 3, 139-147
5. ESHA, "*Guide on How to Develop a Small Hydro Power Plant*", Europian Small Hydropower Association – ESHA 2004
6. Getnet Zewde Somano, Getachew Shunki, "Design and Modelling of Hybrid PV-Micro Hydro Power Generation Case Study Jimma Zone", *American Journal of Electrical Power and Energy Systems*, 2016; 5(6): 91-98
7. Abd El-Shafy A. Nafeh, "Design and Economic Analysis of a Stand-Alone PV System to Electrify a Remote Area Household in Egypt", *The Open Renewable Energy Journal*, 2009, 2, 33-37