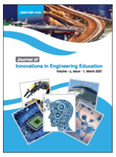

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Supply side management in microhydro using battery bank: A Case Study of Pinthali Microhydro Plant, Kavre, Nepal

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Abstract

Geographical difficulties and slow development of power generation, transmission and distribution, related activities have made many remote areas not assessable to national grids in Nepal. Electricity demand is increasing day by day in urban as well as rural areas but instant extension of national grid seems difficult in many remote places of Nepal. Thousands of Micro hydropower are being installed throughout the country where extension of grid is difficult. This paper presents the introduction of battery bank for the supply side management in the micro hydropower plants. Surplus power during off load time is stored in a battery instead of wasting in dump load. The system is designed in Matlab Simulink where system containing Electronic Load Controller (ELC), Battery Management System (BMS), three phase ac/dc converter were used. Synchronous Generator which generates constant power feeds the load, battery and dump load according to requirement. Battery uses the power for charging during off load hour and supplies deficit power during peak hour. Case study of Pinthali microhydro power of capacity 8.1 kW was carried out for load survey to calculate excess power. Simulated system successfully distributed the power to the load when load was higher than generation through the battery. Financial analysis of system showed the design is financially infeasible as Net Present Value (NPV) was negative and payback period was infinite.

Abbreviations and acronyms

AC : Alternating Current
Ah : Ampere hour
DC : Direct Current
DoD : Depth of Discharge
EMF : Electromotive Force
ELC : Electronic Load Controller
kW : kilo Watt
kWh : kilo Watt hour
LF : Load Factor
MHP : Micro Hydro Power
NPV : Net Present Value
NRs : Nepalese Rupees
SSM : Supply Side Management
USD : United State Dollar

1. Introduction

Micro Hydro Power (MHP) has history of about five decades in Nepal which comprises of installed capacity of about 23 MW. This has benefitted about 250,000 households around the country basically in rural areas where extension of grid is difficult [1]. The efficient use of microhydro can lead to advancement in the lifestyle and economic status of the people. Micro hydro power supplies electric power to the villages which are out of reach of the grid system. Villages are mostly small and scantly distributed and investment required for extension of grid is high. Per capita income of Nepalese people is USD 1034 per year and per capita electricity consumption is 245 kWh per year which is very low than average value [2]. Supply-side management (SSM) refers to actions taken to ensure the generation, transmis-

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sion and distribution of energy are conducted efficiently. This has become especially important with the deregulation of the electricity industry in many countries, where the efficient use of available energy sources becomes essential to remain competitive. SSM ensures the supply of electricity to consumer at reduced cost, reduces cost of investment on new plants to fulfil demand of increased loads and also help in improving plant use factor of any generating station [3]. For understanding the load pattern of microhydro plant study of Pinthali microhydro power situated at the distance of 70km east of the Kathmandu Valley was taken. It had total of 142 households who are benefitted from microhydro plants. Village was installed with microhydro of capacity 8.1 kW in 2001.

Battery based microhydro plant was found technically feasible for the usage of power in the communication channel in remote areas [4]. Battery based system could be a good option for the place where grid is not possible to be expanded in near future. Water resources may be limited in some places so it must be utilized properly and effectively. We should focus on the high plant use factor in the planning stage [5]. Also energy is dumped in electronic load controller or dump load when power generated is excess. Microhydro bears good socio- economic advantages but reliable and efficient power supply is always a challenge [6]. So microhydro needs to be modified with new available technology. Per unit cost of electricity generation in microhydro was found to be 3 cents in Pakistan whereas 10 cents in Tajikistan [7]. Cost of electricity generation can be reduced by coping with new technology, cost effective generators and turbine etc. Micro hydro power has capacity of electricity production throughout the day but communities tend to operate it for only about 6 hours a day [8]. This shows low productivity of plant and also a loss of probable energy that could be generated. This will also affect the financial issues of the plant as payback of the plant will be harder to obtain. If microhydro is unable to meet the peak load, battery may be an option to store power and supply at peak time [9]. During day time power is available as most of the lighting load are shut down in microhydro plant. So excess power can be used to iron cloth, charge battery and also for income generating activities [10]. So wasted energy can be utilized.

Installment of new plant for the generation of electricity involves investment of huge amount of capital. Generally, Micro Hydro Plants consists of ELC for dumping of excess power during of peak hours and these power are dissipated in the form of heat energy in most of the cases. Due to gradual increase in consumer power demand, during peak time demand becomes higher than supply. This will result in poor power quality as voltage and frequency drops on consumer end. In addition, if new generator is to be installed in existing plant for the capacity upgrade will also involves big capital. Plant use factor of the Micro Hydro Plant becomes low due to dissipation of large amount of power in dump load through ELC. Thus dumped power can be stored during off peak time and can be utilized later for maintaining reliable supply through Micro Hydro Plant. As battery is the power storing device, it can be used for the supply management in any Micro Hydro Plant.

2. Research Methodology

Issues identification on the need of battery based system for the effective running of the microhydro plant, supply side management, data collection, analytical model development, simulation setup, results with financial analysis was done and finally conclusion and recommendation was made. For development of this model energy consumption data was collected from the end user.

2.1. Basic Design

Microhydro plants are simple in construction with few of the major components involved such as turbine, synchronous generator, electronic load controller with consumer load as shown in the block diagram in Figure 1. Supply of power may be less than power demand by load during peak time. For addressing this issue, we have added the battery in the existing microhydro plant. After addition of battery in our system, we have new model with additional power source to supply power in peak time. Our new model has Pelton turbine, synchronous generator of 8.1 kW, battery and electronic load controller. As we have load varying up to 10 kW, we have battery system to supply power up to 2 hours. This will be obtained without decreasing the depth of discharge of battery beyond 50%. Also hybrid inverter is included in design for charging of battery and supply of power to the system.

2.2. Data collection and sampling

Battery incorporated micro hydro plant was developed in the Matlab and Simulink. This model helps in understanding how battery bank fulfills the peak demand by getting charged in the off peak time. This model was fed by the data collected from the case study of microhydro plant. Data included the information of appliances used by consumer, their consumption pattern, peak load time, plant outage time, load factor etc. Questionnaire was made to make date collection and analysis easier. Total 142 consumers were noted who are benefitted from the microhydro plant. Sample was considered when there's no more than 10% deviation in actual energy consumption of recent month and the energy consumption in

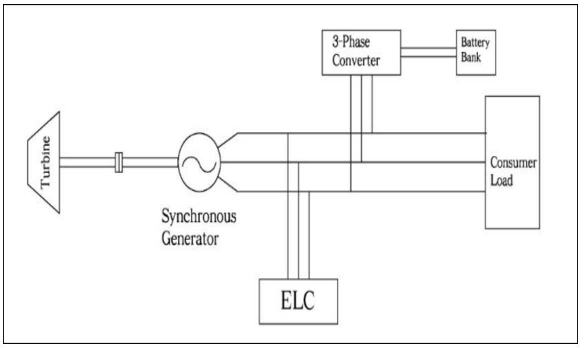

Figure 1: Block diagram of Microhydro with battery storage

survey data. Out of 142 consumers, 105 samples taken and they stay within deviation limit. of 105 samples there's the participation of different consumer class so as to represent proportionate stratified sampling as per the ratio of the population group. The sample size holds the 95% confidence level with 4.2% margin of error as per determined by the Slovin's formula given in Eq. 1. A number of research studies use the so-called Slovin's formula for obtaining the sample size n for N number of data [11].

$$n = \frac{N}{1 + Ne^2} \tag{1}$$

Where,

n : Sample size

N : Population size

e : Margin of error, which holds true for all 95% confidence level

2.3. Battery sizing

Battery needs proper rating according to the need when it needs to be used. Size of battery is directly linked with the financial issues. If battery is kept below the requirement it may get discharged up to lower value which reduces the battery life. In other hand oversizing may result in increased investment.

Battery size in KWh is given by Eq. 2.

$$E_{batt}\ (\text{KWh}) = \frac{(1 + \text{ageing factor}) \times \frac{KWh}{\text{day}}}{n_{inverter} \times DoD} \tag{2}$$

Where,

Ageing factor : Reduced performance of the battery after being used for continuous time

$n_{inverter}$: Inverter efficiency

DoD : Depth of discharge

Battery capacity in Ah is given by Eq. 3.

$$E_{cap}\ (\text{Ah}) = \frac{E_{batt} \times 1000}{V} \tag{3}$$

Where,

E_{batt} : KWh rating of the battery

V : Voltage rating of the battery

2.4. Financial analysis of the system

A financial analysis is must before investing capital in the proposed project. Therefore, a financial analysis was done in order to know its financial feasibility. In this research, three key indicators of financial decision were considered to check whether the investing on the battery based microhydro system would be beneficial to utility as well as to consumer. The considered financial indicators were Payback period, internal rate of returns and Net present value of the proposed scheme [12].

$$DPP = \frac{ln\left(\frac{1}{1-\frac{I\times r}{A}}\right)^{-1}}{ln(1+r)} \tag{4}$$

$$NPV = -I + \frac{F_1}{(1+r)} + ... + \frac{F_n}{(1+r)^n} \tag{5}$$

Where,

DPP : Discounted payback period

NPV : Net present value

I : Initial investment

A : Annual return

F : Future values

r : Interest rate

3. Results and discussion

3.1. Analysis of existing load

The load profile of the model consisting of 142 users was found uneven, there appeared peak for two slots of time in a day. On the other time the demand is so less than that of peak loads. This load profile results a higher peak value with lower average value of Power demand. The system has been peaking in the evening and morning hour at which the residential works concentrate. Figure 2 shows that the demand profile of all seasons are uneven with multiple peaking and formation of valleys in a day. Power plant is kept close during day time i.e. from 10 a.m. to 5 p.m.

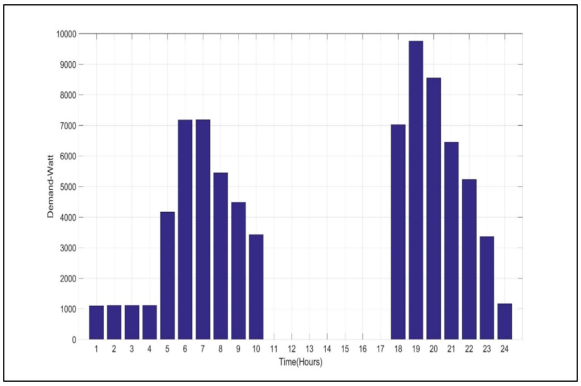

Figure 2: Load bar of consumer demand

From the load assessment and load curve calculation of the 142 consumers some conclusion was drawn. Load Factor(LF) of 0.3326 was obtained which shows the ratio of average load to the peak load. Higher the value of load factor more efficient the plant is. Average load of 3.245 kW was obtained and peak load of 9.757 kW was noted which was above the generating capacity of the plant as shown in Table 1.

Table 1: Load assessment findings

S.No.	Name	Value
1	Total consumers	142
2	Load factor	0.3326
3	Average load	3.245 KW
4	Peak load	9.757 KW

3.2. Operational modes

We have considered different modes for our study. The first priority of the power goes to the consumer load. Then if power remains it is used by battery. Finally, if power is left from usage by both then it is dissipated in ELC.

Surplus power = Power generated by source – Power used by load

Deficit power = Power used by load - Power generated by source

First mode : Surplus power is available after feeding load and battery is fully charged. So this power will be dissipated in ELC.

Second mode : Surplus power is available after feeding the load and battery in charging condition. Here, ELC doesn't get any power to dissipate. We have power available for load and battery only.

Third mode : Power demand by load is greater than power generated by source. So demand will be met by addition of the power from battery into the system.

3.3. Simulation results

Battery based microhydro system was tested in the Matlab and Simulink and some results were drawn. Simulation results shows improved performance of Microhydro after implementation of Microhydro powered batteries.

When battery is fully charged and power generated by microhydro is greater than power demanded by load, excess power will be dissipated on the Electronic Load Controller as shown in Figure 3.

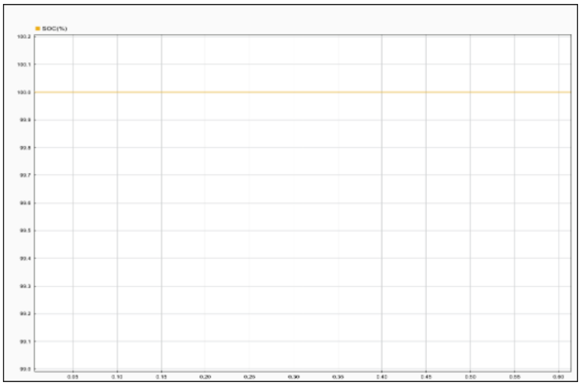

Figure 3: State of charge of battery after being fully charged

Here, state of charge is maintained at 100% and excess power is dumped in ELC.

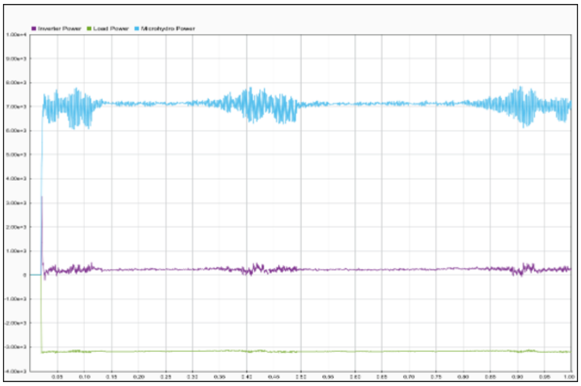

Figure 4: Power generation and distribution after battery is fully charged

After battery is fully charged power distribution is shown as in Figure 4. Here blue curve shows power generated by plant, purple line shows power demanded by battery which is nearly zero and green curve is the power demanded by load. Excess of power will be dumped in ELC.

When load demand is less than the power generated by the source and battery is on charging process. Load will take the power needed from the main source and battery will take the power required for the charging. Remaining power after being used by load and battery will be consumed by the ELC.

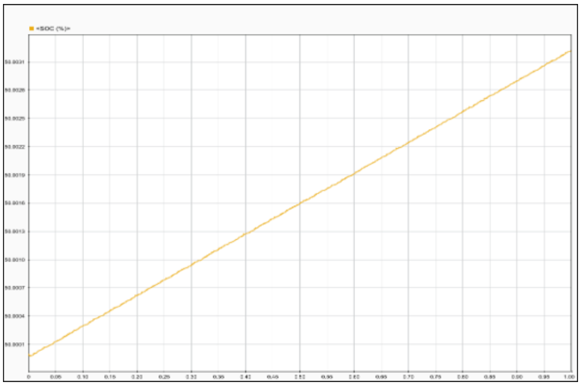

Figure 5: State of charge on charging condition of battery

State of charge when it is in charging condition as shown in Figure 5, shows the charge is gradually increasing.

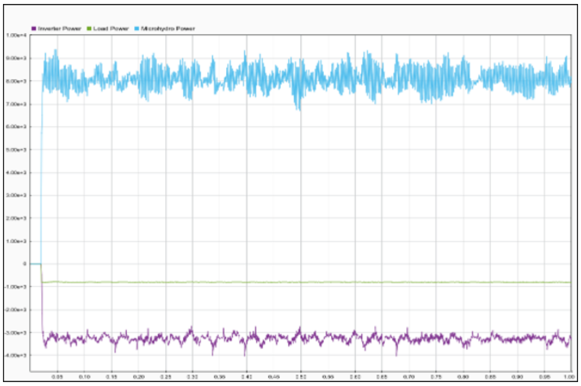

Figure 6: Power generation and distribution during underload condition

In Figure 6, upper curve on positive part with blue color denotes the power generated by the main source. Curve on the negative part is the power consumed by consumer load and battery for charging. In this mode battery gets charged from the excess power from the source and further excess load is dumped in ELC.

When the system runs in the overload condition, the power demand by the load is greater than the power generated by the plant. In this case the deficit power to the load is supplied by the auxiliary source i.e. from battery. Plant will be running in the full capacity in this condition and tends to under speed due to demand of high power from the load. As auxiliary source adds up the power in the system, again rotor speed tends to fluctuate. In this way rotor speed tends to settle with respect to the time.

Figure 7: State of charge of battery during overload condition

The state of charge of battery slowly decreases when it supplies power to the load in overloading condition as shown in Figure 7.

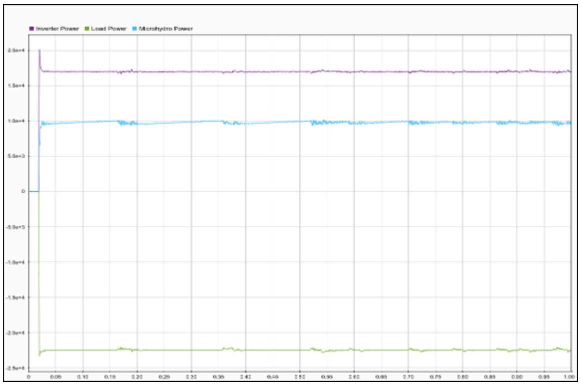

Figure 8: Power generation and distribution during overload

When there is over load in the plant, battery supplies power into the system here demand is high then power generated by plant shown by green curve in Figure 8. Here total power demanded by load is supplied by battery and power plant together.

3.4. Mode switching

System operates in the different modes on the basis of the power consumed by battery, consumer load and

ELC. When battery is charged completely we have one mode of operation whereas when battery is in charging condition we have another mode of operation. Also when load demand is higher than generated power, we have another operational mode. In this way we have to switch the operation according to the mode.

For transition of mode dc link voltage is compared to dc bus voltage as shown in Table 2. DC link voltage is maintained at 800V. DC link voltage is compared with dc bus voltage and reference signal is obtained from the comparison. Thus obtained reference signal triggers the different modes of operation of the inverter.

Table 2: Mode transition

S.No.	DC Link Voltage	DC Bus Voltage	Mode
1	800V	800V	1 (Fully charged)
2	800V	$<$ 800V	2 (Charging)
3	800V	$>$ 800V	3 (Discharging)

A 8.1 kW generator generates the power and supplies to the load of 3kW, if battery is fully charged then system will operate in mode 1. And DC link voltage and DC bus voltage is maintained at 800V. The excess of load is dumped on the ELC. If DC link voltage is less than DC bus voltage, then system will operate in mode 2 i.e. the battery will continue to charge and if excess power is left it will be dumped in ELC.

Finally, if DC link Voltage is greater than DC bus voltage then the system will operate in mode 3 i.e. battery will supply power to the load and battery will start to discharge. In this way different modes of operation are obtained from comparison of DC link voltage and DC bus voltage.

3.5. Selection of battery

For the incorporation of battery in the existing microhydro plant, sizing of the battery is important. The size of battery should be chosen in such a way that it covers the excess load in the system. Power deficit in the peak load time is covered by the battery bank.

For the sizing of the battery we have to consider different factors such as depth of discharge(DoD), battery ageing, operating temperature, inverter efficiency etc. We have used the operating temperature of 25°C, and battery ageing factor is considered 15% [13]. Hence capacity of battery needs to be increased by 15%.

For the Pinthali microhydro plant we have generated capacity of 8.1 kW, so synchronous generator constantly generates the power of 8.1 kW. When power demand by load is less then power generated power is used for battery charging and further excess power will be dumped in ELC. In case of power demand by load is greater than the power generated it is supplied by battery bank to the system. From our load survey we have noted the peak demand of 9.575 kW which is approximately 20% greater than the generated capacity of the plant. Over discharging of battery may reduce battery life so it is not discharged beyond 50% and battery supplies the system for two hours.

The addition of battery bank in the microhydro plant doesn't add up any additional income in the microhydro plant but addition of the system would add up the capacity of the plant in peak hours. The battery bank is able to supply up to 3 kWh of energy per day which could be monetized according to the electricity standard rates for the purchase of power from power producer. Nepal Electricity Authority has two different rates of tariff varying on dry and wet season. Dry season indicates from month of Poush to Chaitra (16^{th} of December to 15^{th} of April) with tariff rate of NRS 8.4 per unit and wet season indicates from month of Baishakh to Mangsir (16^{th} of April to 15^{th} of December) with tariff rate of NRS 4.8 per unit. This could generate revenue of 6,480 in one year.

For financial analysis of the system only NPV could be calculated. Discounted payback period couldn't be calculated as return is very small as compared to the investment. Discount rate is considered 10% for our financial analysis. Discounted payback is obtained in infinity time as high initial investment couldn't be compensated by small revenue from the investment. Life of the battery is generally considered 5 years for solar tubular battery, so we have calculated the net present value of the project after 5 years. the NPV value is NRS -184245.7, and when NPV value is negative, we reject the project from the financial aspects.

4. Conclusions

The use of battery based system improves the load factor of the plant. The productivity of power was improved and this will certainly support on sustainability, reliability and efficiency of Microhydro power. Microhydro produces constant power as it is equipped with synchronous generator. The power demand by the load varies as consumption pattern of the consumer differs from each other and load also varies with respect to time. During off peak time power is dumped in the ELC as generated power is not fully consumed by load but on the other hand there is power deficit in the peak time. So power can be stored in the battery during off peak hours and can be delivered to load on peak hours. Case study of microhydro plant gave different parameter for our study. Some conclusion was drawn from those data like,

Table 3: Different parameters for battery sizing

S.No.	Parameter	Calculated Rating	Design Rating
1	KWh Battery size	7.66 KWh	-
2	Ah Battery size	639 Ah	700 Ah
3	Battery voltage	-	12 V
4	Inverter size	1.84 KVA	2 KVA

Table 4: Costing for battery based system

S.No.	Items	Rating	Rate(NRS)	Quantity	Total cost(NRS)
1	Battery (solar tubular)	100 Ah	21,180	7	148,260
2	Inverter	2000 VA	60,550	1	60,550
	Total			208,810	

load factor was found to be 0.3326, average load was found as 3.245 kW and peak load was calculated to be 9.757 kW. Peak load was noticed on 7pm on the evening. In this way battery based microhydro seems effective in supplying peak load by being charged from the excess power during off load period. Cost analysis done for the instalment of battery based microhydro system for the supplement of additional power during peak hour showed the cost of investment of NRs 208,810. Peak load exceeds the generated load by 1.475 kW and system was designed to supply the deficit power which include total cost of battery and inverter inclusive of installation cost, VAT and transportation cost. Financial analysis of the system was not found feasible. Discounted payback period of the project was not found as financial benefit earned from the project is very low as compared to the initial investment. Annual cost of electricity generated was only NRs 6,480. In addition, net present value for the project is negative which implies that project is financially infeasible. Installation of microhydro is done for the improving the socio-economic aspect of the local people. It is not used for purpose earning the profit in our context. Installation of the battery based system definitely provide the quality power to the consumer by meeting the demand in the peak hours. So this system may be feasible from socio-economic aspect but is financially infeasible.

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