Capacity Enhancement of Micro Hydro Power Plant at Demodara Tea Estate for Net Metering

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Abstract–*In Sri Lanka, 30% of the total electrical energy requirement is supplied from hydro power generation, where 3.5% is met by non-dispatchable mini hydro and micro hydro (<10 MW) power plants. This research study is carried out for the existing run-of-river type micro hydro power plant installed at Demodara tea-estate with maximum generating capacity approximately about 66 kW. The introduction of net metering system to the tea factory demand is the main part of this study while looking at the possibility of enhancing the existing capacity.*
In net metering study, the total energy consumption of the tea factory is compared with the expected generation from the maximum possible enhanced plant capacity of 250 kW computed at 2 m^3s^{-1} flow rate. It is identified that most of the energy generated by the enhanced plant capacity, imported to the national grid owned by the Ceylon Electricity Board (CEB) is much higher than that of the factory energy requirement. Subsequently, the optimum plant capacity is found at 1.7 m^3s^{-1} flow rate and 200 kW is selected as the feasible capacity satisfying net metering concept. Finally, the paper discusses the techno-economic feasibility of the whole process.

Keywords: *Micro hydro power plant, Non-dispatchable, Capacity enhancement, Net metering, Run-of - river*

Nomenclature

η_t - Turbine efficiency
η_g - Generator efficiency
Q - Flow rate (m^3/s)
ρ - Density of water (kg/m^3)
PLC - Programmable Logic Controller

1 INTRODUCTION

Hydro power is attractive because of its renewable, non-pollution and environmental friendly nature. Hydro electricity generation plays a major role in power generation in Sri Lanka and around 30% of country's electricity requirement is supplied from hydro power industry out of which 3.5% of demand is being supplied by non-dispatchable mini hydro and micro hydro power plants (<10 MW) owned by the private sector(www.ceb.lk, 2016). This research is based on existing run of river type micro hydro power plant installed at

Demodara in Badulla district which is more than 75 years of age and its maximum generation capacity is around 66 kW, operated and maintained by the tea factory in Demodara Tea Estate.

The objective of this research study is to introduce net metering system for capacity-enhanced power plant to the tea factory and to propose an optimum feasible plant capacity for net metering system.

At the beginning of the study, enhanced power plant capacity is used to simulate net metering study with the stochastic behaviour of the load at the tea factory. Subsequently, feasible and optimum hydro power plant capacity for net metering is investigated.

Finally, a comprehensive techno-economic feasibility study is carried out and the payback period is calculated.

2 SELECTION OF DESIGN FLOW RATE FOR THE CAPACITY ENHANCED PLANT

In this study, drawbacks of the existing micro hydro power plant are observed. Insufficient fore-bay capacity during rainy seasons, water leaks in the channel, unable to handle plant under flood conditions and in-sufficient water for turbine during dry seasons are some of the problems that are identified in and around the power plant.

In order to address these issues, hydrological study is carried out to identify the possibility of capacity enhancement. It is observed that most of the time, stream flow of the river is greater than the channel inflow and existing power plant capacity is underrated. Therefore, there exist a high potential to enhance the capacity of existing micro hydro power plant.

To enhance the capacity of the micro hydro power plant, selection of flow rate is very essential. Hydrological analysis is carried out based on the past ten years stream flow data measured at Demodara gauging station obtained from Irrigation Department. In addition, location of existing micro hydro power plant is studied by using topographical map. Subsequently the design flow rate is selected using flow duration curve.

2.1 Selection of catchment area

In order to select design flow rate for the computation of new plant capacity, both topographical study and hydrological study are carried out, based on the plant location. Plant is located on upstream of the Badulu Oya which has 36.13 km^2 of catchment area at the point of channel intake, obtained from topographical map. In this study, the catchment area ratio is used to calculate flow rate at the channel intake since flow rate data at the stream diversion point (channel intake) is not available in the Irrigation Department. Topographical map is used to select relevant catchment areas at the gauging point and at the channel intake. Relevant catchment areas are shown in Figure 1.

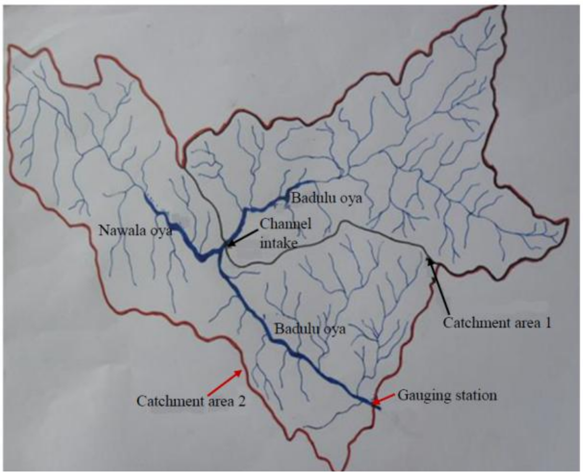


Figure 1: Catchment areas

Catchment area 1 is approximately about 36.13 km^2 and Catchment area 2 where stream flow is gauged by Irrigation Department, is selected from the map is about 82.2 km^2. Ratio of the catchment areas is obtained as 0.44 as follows.

$$Ratio = \frac{\text{Catchment area 1}}{\text{Catchment area 2}} = \frac{36.13\,\text{km}^2}{82.2\,\text{km}^2} = 0.44$$

Relevant stream flow data can be obtained by multiplying this ratio with data available at gauging station.

In hydrological study, stream flow data of Demodara gauging station are collected from Irrigation Department. Collected stream flow data is multiplied by the ratio established to obtain channel intake flow rates. Then the channel intake flow rate data is analysed to produce flow duration curve. Thereby suitable design flow rate is selected for enhanced hydro power plant by carefully examining the flow duration curve (Kunwor, 2012).

2.2 Flow duration curve and design flow rate

Flow duration curve is created using relevant stream flow data at the point of channel intake as shown in Figure 2. Maximum energy output can be taken through the selection of maximum flow rate. Therefore, design flow rate was selected as 2 m^3/s from the flow duration curve at 10% exceedance probability, which gives the maximum energy output throughout the year. Expected power produced from proposed plant can be calculated as follows (Penche, 1998).

$$P = 9.81\eta QH(kW)$$ ----------------- Equation (1)

Where;

P = electrical power produced, kW

ρ = density of water = 1000 kg/m^3

g = acceleration due to gravity= 9.81 m/s^2

H = elevation head of water= 15.3 m

Q = flow rate, m^3/s

η = overall efficiency ($\eta_t * \eta_g$)

Turbine Efficiency (η_t) = 0.85 (Selected turbine is Francis Type. Therefore, maximum turbine efficiency would be 0.85 and Generator Efficiency (η_g) = 0.9

Therefore, P =242 kW

The capacity of enhanced hydro power plant is taken as 250 kW. Since the capacity lies within the range of (100kW-1MW) capacity, this plant can be considered under the category of mini hydro power plant.

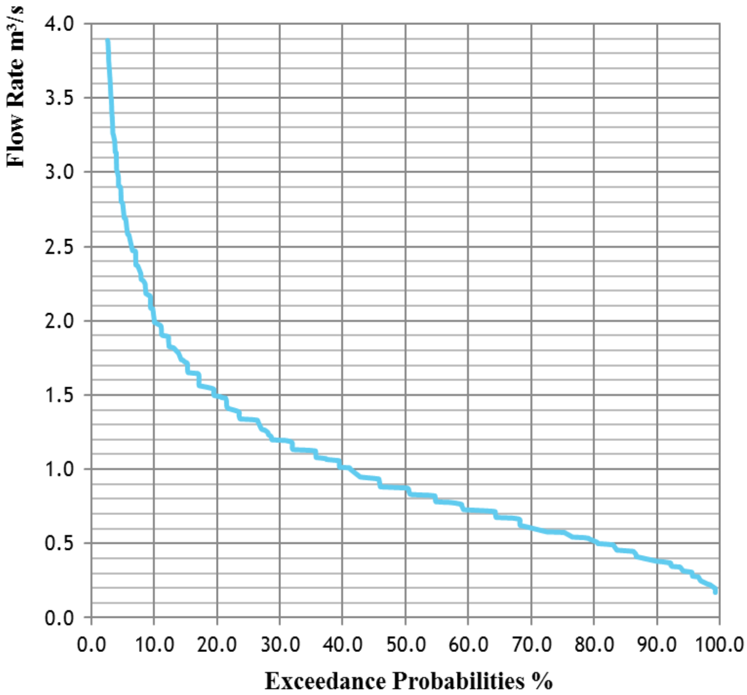


Figure 2: Flow duration curve for below 4 m³/s flow rate

3 NET METERING CONCEPT

The CEB consumer, who avails of this facility, energy meter needed to be replaced with an Import/Export meter. The electrical energy consumed from the grid is connected as import energy (energy debit) and the electrical energy generated and supplied to the grid is considered as export energy (energy credit). At the end of each billing period (typically one month), CEB will read the consumer's export energy meter and the import energy meter reading and the monthly electricity bill will be prepared charging the consumer for difference between the import and the export energy readings (NA, 2014).

If the export is more than the import in any billing period, the consumer will receive to carry forward export energy credit, and it will be credited towards his next month consumption. The key factor in this process is that there will be no payment made to the consumer for the excess energy exported by the consumer. All exports will be set off against consumer's own consumption, either in the current billing period or in future billing periods (NA, 2014).

Customer Category I-2 is the tariff plan of this tea factory and it is multi-tier tariff. If the tariff, applicable to the consumer/customer is multi-tier tariff, the energy credit is given only in the tier where credit is generated. This credit is carried forward to next billing period in the same tier. If the factory total energy consumption is less than the mini hydropower generator maximum output, factory can export excess energy to CEB side and at the end of billing period it can settle with the same tier energy consumption.

3.1 Typical arrangement of net metering

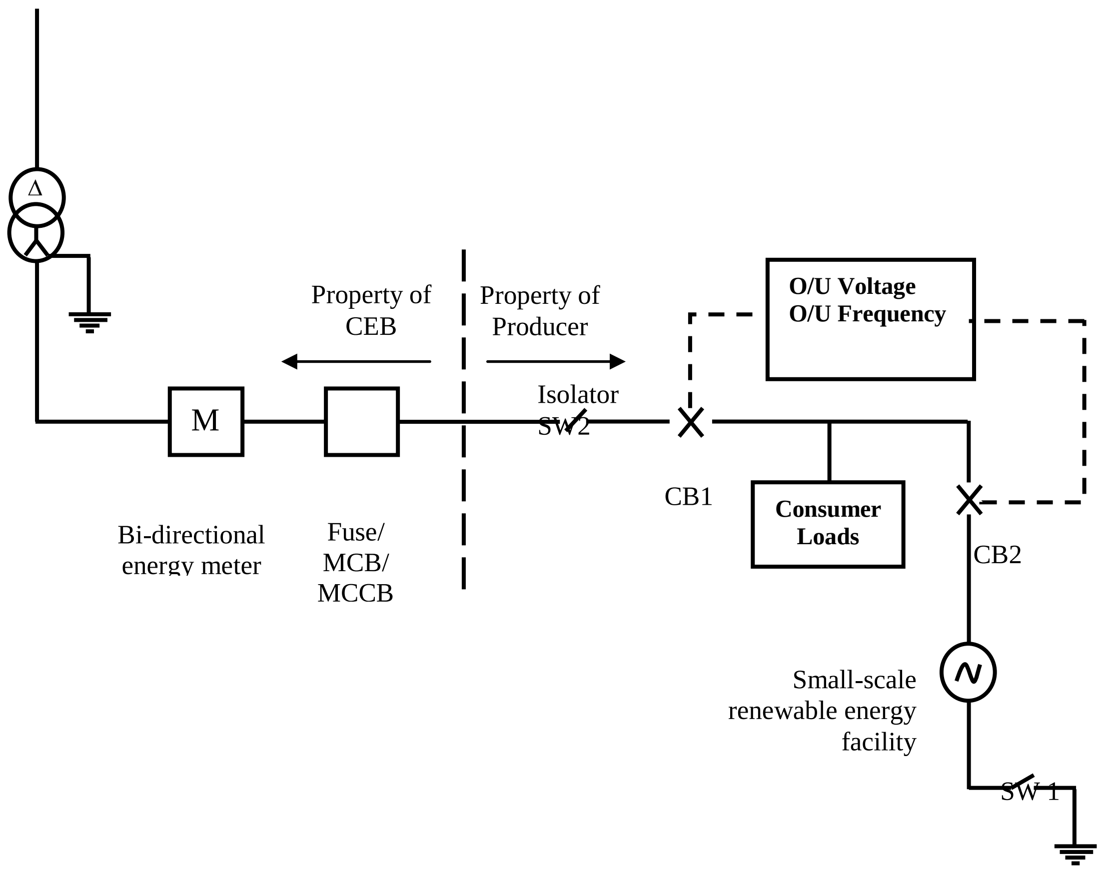


Figure 3: Net metering arrangement for parallel operation of small-scale renewable energy facility

Figure 3 shows only the required interconnection protection. Interconnection protection may operate either CB1 or CB2. SW2 isolator need to be kept at an easily accessible place to CEB and the switch should be locked and kept protected against unauthorized operation. SW1 should keep "Open" during all times of parallel operation with CEB system (NA, 2014).

3.2 Net metering study for enhanced power plant capacity

In net metering study, tea factory energy consumption is compared with the maximum possible capacity that could be harnessed from the entire flow duration. Correspondingly 2 m^3/s flow rate is being selected as the design flow rate. Maximum generation capacity of enhanced power plant is computed as 250 kW according to the said flow rate. Factory's real energy consumption data and the monthly expected energy generation at the flow rate of 2 m^3/s are used to simulate behavioral pattern of the net metering concept to the tea factory.

Net metering analyzing study is carried out by using factory real energy consumption data since 2008 January. In addition, it is assumed that 250 kW of mini hydro power plant is available and operated since 2008 January 1st. CEB billing period is selected as 30 days (one month).

In this analysis, the electrical energy consumed from the grid is considered as import energy and the electrical energy generated and supplied to the grid is considered as export energy (NA, 2014). At the end of each billing period (typically one month) total export or import energy is considered. In the net metering concept in Sri Lanka, there is no payment for excess exported energy as mentioned earlier. The consumer will be received a carried-forward export energy credit, and it will be credited towards consumer's next month energy consumption.

4 ANALYSIS OF NET METERING

4.1 Net metering analysis for enhanced power plant capacity

Analysis of the net metering concept in 2008 is shown in Table 1.

Table 1: Analysis of net metering behavior at 2 m^3/s flow rate in 2008

Month	Factory's total energy consumption (kWh/Month)	Expected mini hydro power plant generation (kWh/month)	Import energy from CEB (kWh/month)	Export energy to CEB (kWh/month)
2008 January	49,935	56,677	-	6,742
2008 February	67,500	34,578	26,180	-
2008 March	100,130	93,496	6,634	-
2008 April	83,880	129,215	-	45,335
2008 May	100,832	100,458	-	44,961
2008 June	65,710	68,603	-	47,854
2008 July	46,890	42,499	-	43,463
2008 August	54,640	43,707	-	32,530
2008 September	95,434	57,269	5,635	-
2008 October	69,058	89,663	-	20,605
2008 November	69,784	58,227	-	9,048
2008 December	60,236	97,331	-	46,143
Total energy import from CEB end of year 2008			38,449	

As per the above analysis, toward the end of year 2008, the factory had to be paid for 38,449 kWh of energy and carried forward 46,143 kWh of export energy as a credit. Similarly, it had been analyzed net metering behavior of the factory since 2008 to 2012 and simulated results are shown in Table 2.

Table 2: Analysis of net metering behavior at 2 m^3/s flow rate since 2008 to 2012

Year	Factory's total energy consumption (kWh/year)	Expected mini hydro power plant generation (kWh/year)	Import energy from CEB (kWh/year)	Export energy to CEB end of year (kWh)
2008	864,029	871,723	38,449	46,143
2009	693,761	541,870	189,922	84,174
2010	816,328	804,484	-	72,330
2011	678,328	863,770	-	257,772
2012 up to September	510,381	409,195	228,371	

According to Table 2, it is identified that the energy exported to CEB in each year is much higher than that of the factory requirement. Exporting that much of higher energy to CEB through net metering is not economical for mini hydro power plant since it will not gain any profit. Therefore, to take better advantage of net metering, an optimum flow rate is recognized to match with net metering system thus, feasible hydro power plant capacity for net metering is proposed.

Therefore, optimum and feasible plant capacity for net metering needed to be investigated. In hydro power plant capacity investigation study, import energy from Ceylon Electricity Board (CEB) within a specified time is considered as the key factor. Therefore, expected plant generation capacities at different flow rates were considered and simulated to find out feasible plant capacity for net metering.

4.2 Study results with the different flow rates using net metering concept

In this study, real energy consumption data has been used for past five years i.e., up to September 2012. The design flow rates of the plant is considered in between 0.9 m^3/s and 2.0 m^3/s. Annual import energy from CEB from January 2008 to September 2012 at different flow rates are also recorded and are shown in Table 3.

Table 3: Total expected import energy with different flow rates within past five years

Design flow rate (m^3/s)	Total energy import from CEB(kWh) within past 5 years
0.9	549,074
1.0	445,974
1.1	375,466
1.2	375,525
1.3	286,842
1.4	329,340
1.5	267,690
1.6	145,341
1.7	144,950
1.8	145,915
1.9	158,123
2.0	228,371

According to the data shown in Table 3, it is observed that the minimum imported energy from the CEB occurs at a flow rate of 1.7 m^3/s. Therefore, 1.7 m^3/s flow rate is selected as the optimum flow rate under net metering concept [Appendix-1].
As such, and at this flow rate, optimum feasible generation capacity can be established as 200 kW by using equation (1). Therefore, plant capacity of 200 kW is selected as the most suitable hydro power plant design capacity for net metering system for Demodara tea estate.

5 TECHNO ECONOMICAL ANALYSIS

Once the optimum design capacity of the mini hydro power plant is established, a gross cost estimation can be tabulated as presented in Table 4. It can be observed that the main contributions are the construction cost of civil structures and the installation costs of electrical equipment's. In addition, it is expected to cover capital cost of the project through a bank loan with interest (Fraenkel, *et. al.*, 1999). Plant operation and maintenance costs are also considered when computing the payback period using discounted cash flow analysis.

Table 4: Estimation of gross capital cost of the project

Description	Cost (MLKR)
Civil Constructions – Weir ,intake ,channel, settling basin , fore-bay , spillway , power house, tailrace and penstock pipes supporters(including labour cost)	29.246
Electro mechanical equipment cost – Turbine, synchronous generator, butterfly valve, governor, Control panel, switchgears and installation cost.	15.500
Penstock Material -Mild steel, Thickness -13mm, Diameter - 1m, Length - 60m	2.758
Transmission line 4 Core, Line Length-1.5km, Conductor -Arial Bundle Conductor	2.321
Transportation cost Electro mechanical equipment brings from China to Demodara & material transport cost for civil works	1.500
Cost of consultation	6.480
Total cost	57.805
Contingency 10%	5.781
Total capital cost	63.586

In this net metering study, net-present value (NPV) is considered using discounted cash flow analysis. Result of the NPV analysis is shown in Table 5.

Table 5: Net Present Value calculation

Year	PV Value (MLKR)		Annual Bank Payment (MLKR)	Other Expenditures (MLKR)	Annual Income (MLKR)	Present Value of annual Income (MLKR)	Net Present Value (MLKR)
	Annual Saving (MLKR)	O & M Cost (MLKR)					
0						-63.586	-63.586
1	8.298	1.156	13.353	15.897	-22.108	-20.098	-83.684
2	15.842	2.208	13.353		0.281	0.233	-83.452
3	22.700	3.163	13.353		6.184	4.646	-78.806
4	28.935	4.032	13.353		11.549	7.888	-70.917
5	34.602	4.822	13.353		16.427	10.200	-60.717
6	39.755	5.540			34.215	19.313	-41.404
7	44.439	6.193			38.246	19.626	-21.777
8	48.697	6.786			41.911	19.552	-2.226
9	52.568	7.325			45.243	19.187	16.962
10	56.088	7.816			48.272	18.611	35.573

It can be observed from the NPV analysis from Table 5 that the simple payback period can be taken as nine years since the total benefits from the hydro power plant covers its investment cost during the period concerned.

6 CONCLUSION

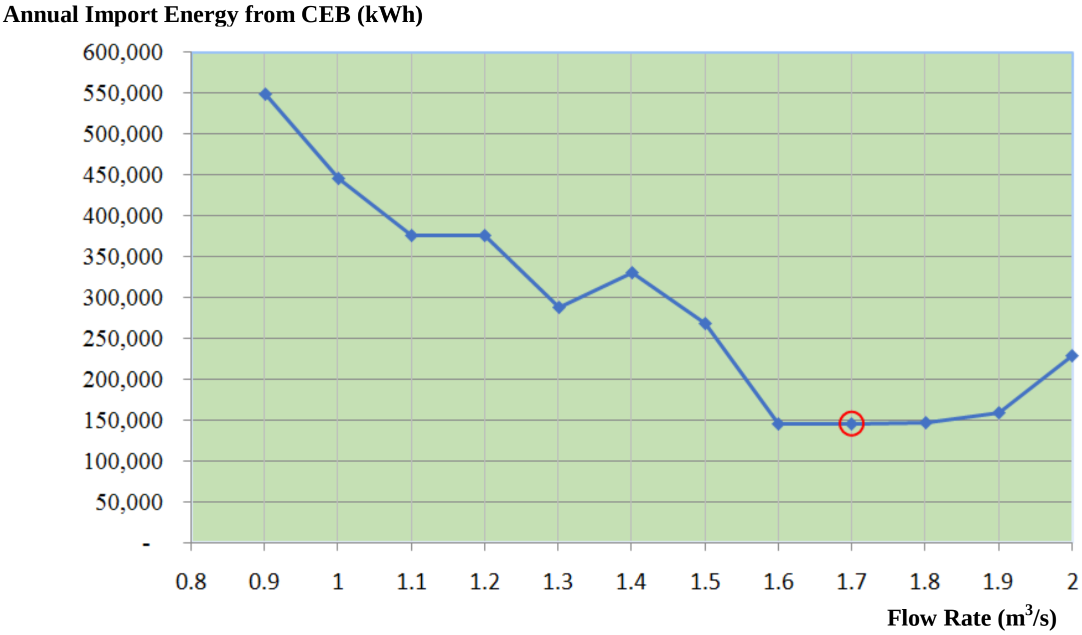
Most of the time, it can be seen that the water is spilling from the weir at existing micro hydro power plant. It is found that the existing micro hydro power plant capacity of 66 kW is underrated and can be upgraded to mini hydro plant (100 kW<capacity<10 MW)having capacity of 250 kW.

Initially a hydrological study was carried out and flow rate data are analyzed to obtain the channel intake flow rate. However, it is found that the hydrological head of the existing micro hydro power plant cannot be altered and only the flow rate can be regulated as per the geographical and practical limitations of the site. Therefore, to obtain maximum possible energy output, flow rate of 2.0 m^3/s is selected for the proposed power plant using flow duration curve. However, since the imported energy to CEB with the enhanced capacity is more than the requirement by the tea factory, the optimum plant capacity for the net metering requirement of the tea factory is established. Finally, 1.7 m^3/s flow rate is selected as the optimum design flow rate for the hydro power plant which gives the plant capacity of 200 kW.

Existing factory load installation consisting of main and sub-panel designs are considered as a secondary requirement of this study. Improvement for main panel and sub-panels with prevailing recommended standards are proposed. PLC program is developed for controlling the main panel to achieve most reliable and a stable electrical supply to the tea factory. Also, the flexibility is there at any moment to the factory maintenance crew to change PLC program as per the demand of the factory. Finally, the economic feasibility study is carried out to obtain the payback period for the net metering system. Discounted cash flow analysis using net present values showed that the simple payback period is about nine years.

7 APPENDIX

Appendix 1- Annual Expected Import Energy with Different Flow rates



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