A comprehensive study on the recent progress and trends in development of Small Hydropower projects

Teegala Srinivasa Kishore [1], Epari Ritesh Patro [2,*], V.S.K.V. Harish [3] and Ali Torabi Haghighi [2]

[1] Electrical & Electronics Engineering, GMR Institute of Technology, Rajam 532127, India; srinivasakishoret@gmail.com or kishore.ts@gmrit.edu.in
[2] Water, Energy and Environmental Engineering, University of Oulu, 90014 Oulu, Finland; ali.torabihaghighi@oulu.fi
[3] Department of Electrical Engineering, School of Technology, Pandit Deendayal Energy University
Gandhinagar, Gujarat 382481, India; vskvharish@ieee.org
* Correspondence: ritesh.patro@oulu.fi

Supplementary S2. Levelized cost of electricity determination (LCOE)

The life cycle costing methodology [1,2] for the Levelized cost of electricity determination is presented below.

$$Life\ cycle\ cost\ =\ PV_{L(ICC)}\ +\ PV_{L(OMC)}\ +\ PV_{L(RC)} \tag{1}$$

Where, $PV_L(ICC)$, $PV_L(OMC)$ and $PV_L(RC)$ represents the initial capital cost, O&M cost and replacement cost respectively which are levelized by Fixed Charge Rate (FCR).

$$PV_{L(ICC)} = ICC \times FCR \tag{2}$$

FCR is also referred to as the capital charge rate or capital recovery factor representing the fraction of the total capital cost that is paid each year to finance the plant.

$$FCR = \frac{r}{1-\frac{1}{(1+r)^N}} = \frac{r}{(1+r)^N-1} + r \tag{3}$$

where r is the real discount rate and N is the project life. The total present value of operation and maintenance (O&M) costs over different years are given by

$$PV_{OMC} = \sum_{i=1}^{N} \frac{OMC(i)}{(1+n)^i} = Annual\ OMC\ \times \frac{1-\frac{1}{(1+n)^N}}{n} \tag{4}$$

It is then levelized via FCR, therefore

$$PV_{L(OMC)} = PV_{OMC} \times FCR \tag{5}$$

where n is the nominal discount rate given by

$$n = r + 2.5\%\ inflation \tag{6}$$

The annual OMC is generally estimated as a percentage of total ICC. Electrical and mechanical equipment is prone to wear and tear over some years of operation, and the civil structures may require rehabilitation following years of operation. The periodic replacement and rehabilitation costs are to be levelized although the funds for the major repairs were paid to a reserve fund in the years before the replacement occurring in a specific year, given by,

$$Annual\ reserve\ payment = \frac{Replacement\ cost \times (1-D)}{T_R} \tag{7}$$

where D is the depreciation tax shield factor and T_R is the year of replacement and rehabilitation. The present value of Annual Reserve Payment (ARP) is given by,

$$PV_{ARP} = \sum_{i=1}^{T_R} \frac{ARP}{(1+n)^i} = ARP \times \frac{1-\frac{1}{(1+n)^{T_R}}}{n} \tag{8}$$

Using FCR, the levelized present value of ARP is given by,

$$PV_{L(RC)} = PV_{ARP} \times FCR \tag{9}$$

Finally, LCOE in Indian Rupees (INR) can be computed by

$$LCOE = \frac{Life\ Cycle\ Cost}{Lifetime\ \ Energy\ Production} \tag{10}$$

where lifetime energy production is computed as Annual Energy Production (AEP) in kW averaged over multiple years at busbar and is given by,

$$AEP = 8760 \times P \times \eta_T \times \eta_G \times P_{LF} \tag{11}$$

where P is the plant capacity in kW, η_T is the turbine efficiency, η_G is the generator efficiency and P_{LF} is the plant load factor.

B2. Cost determination based on correlation

The total cost of various SHP schemes based on the data obtained by correlations [3] has been computed by the following equations.

For run-off-river SHP scheme, the total civil cost is given by

$$C_{CIV} = C_{PHB} + C_{DW\&I} + C_{PC} + C_{DC} + C_{F\&S} + C_P + C_{TR} \tag{12}$$

For the dam toe SHP scheme, the total civil cost is given by

$$C_{CIV} = C_{PHB} + C_I + C_P + C_{TR} \tag{13}$$

For canal-based SHP scheme, the total civil cost is given by

$$C_{CIV} = C_{PHB} + C_S + C_{DW} \tag{14}$$

The components of electromechanical equipment cost are the same for all the SHP schemes and hence, the total cost is given by

$$C_{EM} = C_{TG} + C_{GE} + C_{AUX} + C_{T\&SY} \tag{15}$$

Based on the cost correlations of civil and electromechanical components, total SHP cost is given by

$$C_{SHP} = 1.13\ (C_{CIV} + C_{EM}) \tag{16}$$

where PHB is Power House building, DW is Diversion weir, I is Intake, PC is Power channel, DC is Desilting chamber, F is Forebay, S is Spillway, P is Penstock, TR is Tailrace, TG is Turbine governor system, GE is Generator & excitation system, AUX is Mechanical and electrical auxiliaries, T&SY is Transformer and switchyard. The factor 1.13 corresponds to establishment related cost including survey and investigations, preliminary expenses on report preparation, designs, audit & account, indirect charges, tools and plants, communication expenses, and cost of land were considered under miscellaneous and indirect costs.

References

1. Kishore, T.S.; Koushik, S.D.; Vidyabharati, I. Life cycle costing based LCOE method for economic analysis of low head small hydro power plants in India. *Water Energy Int.* **2017**, *59*, 43–48, Online ISSN : 0974-4711.
2. Zhang, Q.F.; Smith, B.; Zhang, W. *Small Hydropower Cost Reference Model*; 2012; Ornl/Tm-2012/501, Oak Ridge National Laboratory, (Available online: https://info.ornl.gov/sites/publications/files/pub39663.pdf)
3. Mishra, S.; Singal, S.K.; Khatod, D.K. Cost Optimization of High Head Run of River Small Hydropower Projects. *Water Resour. Dev. Manag.* **2018**, 141–166, doi:10.1007/978-981-10-6205-6_7.