EFSE Annual Meeting 2012, Tbilisi

GGF Technical Workshop on Small Hydro Power

Financing hydropower

Introduction to the Specifics of Small Hydro Power Plants

01 June 2012
Introduction to the specifics of Small Hydro Power Plants (SHPP)

- Structure of the Presentation
  - 1. General Overview: Small Hydro Power Plants
  - 2. The major planning steps
  - 3. Hydrology: the basis for SHPP planning
  - 4. First approximation of SHPP layout and electricity generation
  - 5. Optimisation of SHPP
  - 6. Determination of budgetary investment cost
  - 7. SHPP bankable documents
  - 8. Environmental and Social Impact Assessment
1. General Overview: Small Hydro Power Plants

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Small Hydro Power (SHPP) scheme

- **Small Hydro Power Plant**
  - Usually < 10 MW installed capacity (under GGF financing SHPP projects < 30 MW are eligible)
- Run-of-river type SHPP
- Weir or low dam
- Electricity generation costs < EUR 96/MWh
SHPP Project: map segment
Hydro power is a mature technology – make use of the experience!

- A design solution has been realised for almost any specific condition: what has been published and which design solution has stood the test of time?
  - Use proven design solutions, study operating projects with similar head and design flow.

- One of its specifics: it requires the input from various fields of profession (hydrology, geology, ecology, civil- electrical- and mechanical engineering + economist).
  - It can be very costly to try to save on inputs from experts who’s task is to make the experience gained over decades available for the planning process.

- If planned properly, hydropower offers the lowest generation cost of all RE technologies at a very low risk and over an extremely long life time (>80 years)
  - Use high quality equipment (turbine/generator and gates!) able to withstand adverse conditions over the entire project lifetime.
2. The major planning steps

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Three major planning steps not to be missed

1. **Project formulation and layout**
   - Hydrological study (flow duration, flood conditions, dry/wet year conditions)
   - Basic topographical overview (possible head, access conditions, existing roads)
   - Preliminary assessment of slope stability and sediment loads
   - Basic project layout with first approximation of electricity generation

2. **Engineering design and layout optimisation**
   - Pre-design of hydraulic structures with cost estimations
   - Optimisation of sizing
   - Evaluation of layout alternatives

3. **Definition of project layout**
   - Detailed field investigations
   - Detailed engineering design and bill of quantities
   - Budgetary quotations for equipment
3. Hydrology: the basis for SHPP planning

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The hydrological study determines how much water will be available for electricity generation over the year. Hence, it provides the basis for the optimal sizing and the generation of the plant. The reliability of its result is crucial to the plant's financial viability. It requires a high degree of professional experience to interpret any available runoff data correctly.

Daily run-off data over several years is the core database the hydrological study needs to be meaningful. Supporting information includes precipitation data and geological formation of the watershed in question.

As the planning process of a SHPP can extend over more than a year, it is highly recommended to start immediately with automated discharge measurements at the intended intake site to obtain first-hand data. Appropriate data loggers are available (http://www.geoscientific.com/dataloggers/AquaRod_Freeze_Tolerant_Water_Level_Recorder.html)
Hydrological study - Deliverables

- **Average flow duration curve** as basis for the average annual generation and determination of the optimal design discharge

- **Flow duration curve of the driest year** for the sensitivity analysis to check whether the loan can be served even during dry spells

- **Correction factor** considering quality of data base to assess the sensitivity against variation of the water availability and the influence against missing or vague data

- **Residual flow** as a requirement from the ecological point of view

- **Estimated flood events and water levels** to design the hydraulic structures safely
Example of Flow Duration Curve, interpreted

**Shaded area:** flow available for power generation if maximum turbine capacity is 2.3 m³/s (104 kW)

**Optimum design discharge** (60 days → economic optimum)

**Residual flow**
4. First approximation of SHPP layout and electricity generation

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First approximation of the average annual electricity generation

1. Choice of $Q_{\text{design}}$ based on the flow duration curve ($Q_{60}$ for a start)

2. Choice of penstock diameter (5% head loss for a start) and determination of the net head as function of the turbine flow

3. Choice of turbine type and number of units

4. Total efficiency of conversion equipment as a function of the turbine flow (use supplier data)

5. With this information calculate annual generation (first approximation)
SHPP Intake
SHPP Penstock
Choice of Turbine for SHPP
Hydro Power Physics at a glance: calculation of electricity generation

\[ W_t = H_n \times Q \times g \times \eta_{tot} \times t \]

- \( W_t \) = electricity generation in time span “t” (kWh, MWh, GWh)
- \( H_n \) = net head (m) as f(Q)
- \( Q \) = average flow through the turbine in time span “t” (m³/s)
- \( g \) = gravity = 9,81 (m/s²)
- \( \eta_{tot} \) = \( \eta_{tur} \times \eta_{gen} \times \eta_{trans} \) all a f(size, type and \( Q/Q_{design} \))
- \( t \) = time span (hours) at which Q is available
**Example:**
annual production (1. approximation) with Qdesign = 3.6 m³/s

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<th>Available flow m³/s</th>
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<th>Q/Qd %</th>
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Average annual generation: 16.06
5. Optimization of SHPP

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Optimising the sizing of the SHPP

After the first approximation an optimisation of the sizing of the SHPP needs to be done to obtain the most economic installed capacity. This requires the following steps:

1. Based on the data from the flow duration curve the exceedance and the flow are listed.

2. The investment cost of the entire plant is determined as a function of $Q_{\text{design}}$. This requires that a formula is developed for the cost of each component in relation to the design flow (see example for E&M equipment later).

3. Varying the $Q_{\text{design}}$ and the penstock diameter will vary the investment cost but at the same time the generation and with this the revenue. That $Q_{\text{design}}$ which yields the highest NPV will result in the most economic size, the plant should be designed for.

→ This optimisation step is very often omitted resulting in SHPP too big for the river or the available potential is under-utilised.
The planning process and its optimisation

- Project idea
  - Energy Resource investigation
  - Site definition
  - Technology definition

- Formulation
  - Sizing of equipment
  - Arrangement of buildings and structures
  - Transmission line routing
  - Mitigation of environmental disturbances

- Layout
  - Layout Design of equipment and structures
  - Planning of implementation
  - Planning of operation + management

- Engineering Design
  - Budget quotations from suppliers
  - Bill of quantity for civil works and unit costs
  - Planning + implementation cost
  - Operation + maintenance cost

- Cost estimate

- Economic and financial analysis
  - Definition of annual cost and income
  - Calculation of IRR, NPV, DSCR
  - Comparison with opportunities

- Bankable Project

Optimisation of project layout
- Assessing the economics of alternatives
- Variation of sizing and layout until economic optimum is reached
As first approximation the cost for the electro-mechanical equipment can be expressed by the formula below:

The formula includes a scope of delivery of all components needed from end of penstock to 35 kV feed in i.e turbine inlet valve, turbine, generator, governor, LV control, transformer, MV switchgear, reflecting 2010 prices.

\[
I_{E+M} \text{ (Euro)} = 50,000 \times H^{0.529} \times Q^{0.74}
\]

Where:

- \( H \) = net head (m)
- \( Q \) = design flow (m³/s)
6. Determination of budgetary investment cost

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Determining the budgetary investment cost as a basis for seeking appropriate financing of the SHPP

Once the optimum $Q_{\text{design}}$ is determined the investment cost can be determined in more detail:

- The engineering design of the civil works component will yield a **bill of quantity** (quantities of excavation, concrete, reinforcement steel, back filling etc).
  - With the help of **unit costs** for these quantities the cost for the civil works components can be determined to a high degree of accuracy.

- For all items which will be purchased, like gates, penstock and E&M equipment, **budgetary quotations** need to be requested from renowned suppliers. These kind of quotations can be received rather easily as they are not binding for the supplier. It is accepted practice that the price quoted can fluctuate ±15%

- For planning and construction supervision use for first approximation $I_{\text{consult}} = 1.8 \times I_{\text{tot}}^{0.77}[\text{Euro}]$

- To consider any contingencies account for 10% of total investment at this stage
Such a budgetary investment cost should be sufficient to approach FI’s to investigate the possibility of financing the project.

It forms an integral part of the bankable document and could look like this:

**Note:** cost items are backed by budgetary quotations!
7. SHPP bankable documents

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The documents accompanying any loan application should contain at least:

- **Feasibility study:**
  » This study determines the final technological choice and scope and proves its technical, economic and environmental feasibility,

- **Financing strategy / business plan:**
  » This is the presentation of the financing strategy, availability of project sponsors equity participation and debt service coverage capacity,

- **Legal documentation:**
  » All project related permits, licenses and contracts, including the budgetary quotations.
  » Documentation on the project sponsor
An expert analysis of the likelihood of success of the project in a technical and economical sense.

» presents the **project layout** as a result of the evaluation of design alternatives

» calculates the **average annual electricity generation and the revenues**

» gives information how the **budgetary investment cost** was determined

» evaluates the **economic and financial profitability and its sensitivity** against changes in the assumptions

» assesses the **environmental and social impacts**
1. General Description of the Project (location and layout, activities done so far)
2. Field investigations (topographical, hydrological, geological studies)
3. Design Flow and Annual Electricity Generation
4. Engineering Design and budgetary investment cost (Project layout, and specifications, investment and operating cost, annual generation)
5. Implementation Plan
6. Economic Project Evaluation
7. Financial Project Evaluation
8. Sensitivity Analysis
9. Assessment of the Expected Environmental and Social Impacts
Results of the Economic Evaluation

- Calculation of the **net present value (NPV)** obtained by calculating at a constant interest rate and separately for each year the differences of all economic costs and benefits of the project.

- Calculation of the **internal rate of return (IRR)** defined as the interest rate at which the present value of inflows is equal to the present value of outflows.

- Calculation of the **dynamic unit electricity generation costs** obtained by dividing the present value of costs by the present value of electricity production.
The Business Plan

- Projection of the **revenues, expenses, and cash flows** to be generated by the project along with supporting assumptions.

  - The Business Plan complements the feasibility study by outlining the retained **financial strategy and demonstrating that the project will generate sufficient cash for the debt service** and the remuneration of equity capital and envisaged investment

  - Financing plan

  - Projection of the financial statements for the project
Delivery models of SHPP implementation

- **Turnkey:**
  - Common approach: single contractor takes care of plant design, civil construction tendering for E&M equipment

- **Partnership:**
  - Combination of capabilities and shared risk

- **BOO (Build own operate)**
  - SHPP owner sells rights to the project to a developer who pays annual royalty
8. Environmental and Social Impact Assessment

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For all SHPP projects an ESIA is obligatory covering the expected positive and potential negative **environmental and social impacts** of the proposed project and the related mitigation activities.

» This regards the construction and the operation of the SHPP

» Emphasis will have to be put on the following parameters:

  - **Residual flow** of the river safeguarding functioning of flora and fauna (particular fish population)
  - Proper **construction and operation procedures** assuring work safety
  - Proper awareness of the **potential impact of the SHPP project on potentially endangered species** and the development and implementation of adequate mitigation activities
  - Development and implementation of an adequate **Environmental and Social Action and Monitoring** plan
Thank you for your attention