Solar Pumping

For Village Water Supply Systems

TRAINING MANUAL
For technicians, designers and managers

PRACTICA FOUNDATION
Introduction

The elaboration of this manual is inspired by the need to support the professionalization of the departments, units, NGO’s and design bureaus that are directly involved in the design of solar water systems in developing countries.

Without being exhaustive, we aim to offer with this training manual practical guidelines for the design, exploitation, management, maintenance and financial analysis of off-grid solar pumped water systems.

This manual is part of a training package offered by Practica Foundation. Together with this manual, we developed a case study that takes the participants through all design steps, calculations and considerations, as well as a series of guiding questions for each module of this manual that can serve the purpose of examination, self-examination and exercise.

The manual and training are designed for people who are already active in the water supply sector and want to upgrade their knowledge and skills on designing and implementing solar water systems. It can be provided to, and adjusted to the needs of, governmental agencies, design agencies, NGO’s and water system managers. It will be a good resource for people who are charged with the elaboration or selection of design and tender documents, supervision of construction work, as well as for those in charge of operating and managing a solar pumped water system.

A second target group for this training are (teachers of) training centers who are charged with the provision of trainings to technical staff. These trainers can be trained by Practica Foundation, and equipped with training materials adjusted to the specific needs and characteristics of their country, to provide a training tailored to the needs of the water sector in their country.
Preface

Solar radiation is a perennial source of energy, available all over our planet, free of charge and entirely renewable. Photovoltaic systems, once installed, do not need any fuel input and do not emit greenhouse gases. They receive and automatically convert the solar radiation into electricity, do not contain any mobile parts and thus require very limited maintenance. Solar systems therefore have highly reduced running and maintenance costs compared to engine powered water systems.

This way, photovoltaic systems have the potential to drastically reduce the costs of water production, at the favor of the financial sustainability of water companies and service providers, as well as the water price to water users. They provide a great opportunity to respond to the needs and aspirations of people to upgrade hand pumped systems into small gravity water systems, thus improving service levels, accessibility and availability of water at affordable price.

Nevertheless, the initial investment costs of solar systems are quite high, and until recently constituted an obstacle for the application at scale. Thanks to the continuous price reduction of solar panels, this alternative has become more and more attractive, especially in areas where electric grid connections are not available.

Not in all situations, solar systems are applicable or even the best choice. As pumping hours are limited to the daily sunshine hours, a relatively high yielding water source is needed as water intake. Diesel aggregates or grid connected systems can pump 24 hours per day, thus producing a larger quantity of water at lower yielding water sources. Solar systems are less flexible, also from a financial management point of view. The relative weight of initial investment costs is high, whilst the operational costs of fuel pumped systems highly depend on their pumping hours.

Designing a water system is a process not limited to the technical and cost considerations as presented in this manual. In our view, all stakeholders including user groups (women, men, disabled people) and the (future) managers of the systems should be involved, and able to understand and influence design and management decisions according to their rights, needs and satisfaction. Technical and cost considerations are however an indispensable basis for this.
Summary of module content

Module 1 provides an introduction of the basic electric theory necessary to understand the functioning of solar systems. The concepts of voltage, current, resistance, losses, electric power and electric energy are presented, as well as the difference between direct current and alternating current.

Module 2 provides an introduction to the sun as power source. Not all energy of the sun can be captured and converted to be used for our energy needs. In order to maximize the utilization of this energy source, it is useful to understand more about sunshine and its characteristics.

Module 3 provides an explanation of the characteristics of solar cells and panels. The effects of irradiance level and temperature are presented. Attention is paid to how and where to place and locate a solar array in a water system, and what can be done against theft and vandalism. The effect of shadow is explained. As last subject, we introduce the electric losses and electric efficiency.

Module 4 is about the evaluation of water needs. Although not specific for solar systems, it is a crucial subject for the design of drinking water systems, and a basic input for all further calculations and system dimensions. We first introduce the general method and parameters for establishing the water consumption need of the target population of a community. After this, we introduce parameters for calculating the production requirements for a water system.

Module 5 treats with the borehole as water source. As the majority of small piped water supply systems make use of groundwater, this chapter describes means of access, construction aspects and quality requirements of boreholes.

Module 6 provides theory about Hydraulic Head and pump types, as next step in dimensioning the water and pump system.

Module 7 explains the dimensioning of the solar array. Although this is nowadays done by computer programs, it is important to have a good idea of how such dimensioning calculations are executed in order to avoid accepting offers from importers with inappropriate software. One also has to understand how dimensioning is done to be able to properly commission a system.

Module 8 goes into the aspects of determining the size of the storage tank, as the storage capacity requirement is related to the pumping hours and water consumption patterns.

Modules 9 treats a number of design considerations, and dilemmas are discussed, such as the choice between solar systems and grid connections; the options when the capacity of the borehole is insufficient to install a solar system. We explain why it is recommendable not to combine solar panels with different characteristics, the limitation of village size related to borehole and pump capacities, and go into pump capacity choices when pumps need replacement. Finally, we go into the quantitative effects of different combinations of design assumptions.

Module 10 presents the basic elements of financial analysis and planning that needs to take place to balance income from water consumption with the costs of water production. The unit water cost (UWC), cost elements, life cycle cost modelling and cash flow analysis are explained.
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ETUDE DE FAISABILITE « SOLAIRE » CONCERNANT LES AEV ET PEA DU BENIN, Ebo Roek, Practica Foundation, August 2014.


