Solar Pumping

For Village Water Supply Systems

TRAINING MANUAL

For techniciens, designers and managers

PRACTICA FOUNDATION

Author: Erik van de Giessen MSc

Co-authors and reviewers:

Ebo Roek MSc

Gertjan Bom MSc

Stéphan Abric MSc

Robert Vuik MSc

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.

Table of Contents

Introduction ... ii

Preface ... iii

Summary of module content ... iv

Table of Contents ... v

List of Figures ... vii

Module 1 Introduction into Electric units and Laws ... 1

1.1 Introduction ... 1
1.2 Electric Theory, Units and Laws ... 1
1.3 Electric Control Boxes in a solar pumping system ... 3

Module 2 The sun as power source ... 6

2.1 Introduction ... 6
2.2 Wave length and colors ... 6
2.3 Solar Irradiance and Irradiation ... 7
2.4 Weather conditions ... 9
2.5 The critical month ... 10

Module 3: The solar array as power source. ... 13

3.1 Introduction ... 13
3.2 The solar panel ... 13
3.3 Solar Arrays ... 14
3.4 Current-Voltage Diagram ... 16
3.5 Current-Power Diagram ... 17
3.6 Effect of Irradiation ... 17
3.7 Effect of temperature ... 18
3.8 Optimal position and location of a solar panel. ... 19
3.9 Location of the array ... 21
3.10 The enemy of the solar panel: Shadow! ... 24
3.11 Electric Efficiency and Losses ... 25
3.12 Optimization of electric efficiency ... 26

Module 4 Evaluation of water needs ... 27

4.1 Introduction ... 27
4.2 Calculating the water needs ... 27
4.3 Calculating the water production requirements ... 29
4.4 Data collection ... 30

Module 5 The borehole ... 31

5.1 Introduction ... 31
5.2 Groundwater access ... 31
5.3 Borehole drilling ... 31
5.4 Borehole siting ... 33
5.5 Drilling log ... 33
5.6 Borehole installation and completion ... 33
5.7 Borehole characteristics ... 35
5.8 Financial aspects ... 36

Module 6 Hydraulic Head, Pump types and choice ... 37

6.1 Introduction 37
6.2 Calculating the Hydraulic Head 37
6.3 Pump types 38
6.4 Borehole diameter and pump capacities 42
6.5 Borehole diameter and pump efficiencies 42
6.6 Pump maintenance and lifetime 42
6.7 Pump selection 43
Module 7 Dimensioning the solar array 44
7.1 Introduction 44
7.2 Calculating the power requirements of the solar array 44
7.2.3 Factoring in the electric and hydraulic efficiencies of the system 45
7.3 Configuration of the PV Array 46
Module 8 Storage capacity 47
8.1 Introduction 47
8.2 Reservoir size 47
8.3 Effect of Project Horizon 48
8.4 Fluctuations in solar radiation 49
8.5 Calculating the capacity of the storage tank 51
8.6 The height of the storage tank 51
8.7 Tariff structures 51
Module 9 Design considerations 52
9.1 Introduction 52
9.2 The choice between solar systems and grid connections 52
9.3 What to do if the capacity of the borehole is insufficient 52
9.4 Different water source alternatives 54
9.5 Can different solar panels be combined? 54
9.6 In what size of village is it more feasible to install a solar system, compared to a diesel generator pumped system? 55
9.7 Is it possible to change the pump into a larger pump, and more solar panels, after the first pump is worn-out? 55
9.8 Overdimensioning 56
Module 10 Financial Analysis, Management and Planning 58
10.1 Introduction 58
10.2 Costing 58
10.3 Life cycle cost modelling and analysis 59
10.4 Cash Flow Analysis 61
References and Further Reading 62

List of Figures

Figure 1 Two different examples of MPPT’s 3
Figure 2. The solar spectrum..... 6
Figure 3. Solar Radiation 7
Figure 4. Zenith angle and Air Mass (AM) 8
Figure 5 Ideal curve of daily irradiance 9
Figure 6 Conversion of irradiance into Peak sun hours..... 9
Figure 7 Average daily insolation on a horizontal surface each month. 10
Figure 8 Average daily insolation in Abomey, Kandi, Parakou and Djougou, Bénin. 10
Figure 9 Water demand and irradiation in Onigbolo, Benin. 11
Figure 10. Photovoltaic cell 13
Figure 11. Different cell types 13
Figure 12. Composition of a solar array 15
Figure 13 Series and parallel connections..... 15
Figure 14. Voltage-Current Diagramme 16
Figure 15. Current-Power Diagram 17
Figure 16. Relation between irradiance and PV output. 17
Figure 17. Relation between Temperature and Power 18
Figure 18. Tilt angle of a PV panel. 19
Figure 19. Incidence Angle effect..... 20
Figure 20 East-west tracking. 21
Figure 21 Simple North-South tracking 21
Figure 22 Manual adjustment of tilt position..... 21
Figure 23. Solar panels on top of a water tower 22
Figure 24. Solar panels on ground level plot..... 22
Figure 25 Control boxes installed under panel 23
Figure 26 Control boxes protected and locked 24
Figure 27. Summary of electric energy losses. 26
Figure 28. Lifetime of water system elements..... 27
Figure 29. Values of the multiplication factor for different project horizons and growth factors 28
Figure 30. Estimated growth of specific consumption in Benin. 29
Figure 31. A drilling machine..... 32
Figure 32 Hand drilling a borehole..... 32
Figure 33 Feasibility map for manual drilling in Benin 33
Figure 34. PVC screen pipes 34
Figure 35 Examples of Borehole head: design drawing and picture 35
Figure 36. Hydraulic Head Components..... 37
Figure 37. Schematic picture of single stage centrifugal pump 39
Figure 38. Multiple stage centrifugal pump (below)..... 39
Figure 39. Effective pumping hours of a centrifugal pump versus sunshine hours 40
Figure 40. Hourly and Daily Production of a solar pump 40
Figure 41. Schematic picture of a helical screw rotor pump..... 41
Figure 42. Daily curves of water production, water consumption and water stored 47
Figure 43. Water storage capacity as % of daily consumption, with a horizon of 20 years. 48
Figure 44. Yearly Fluctuations of Irradiation and August average in Abomey, Benin 49
Figure 45. Construction costs for a water storage tower and tank, price levels august 2014, Benin. 50
Figure 46. Daily curves of water production, consumption and water storage combining solar production with a diesel group 50
Figure 47. Table summarizing effects of Design Assumptions on Design Consumption..... 57
Figure 48 Water production cost comparison for solar, grid and diesel generator powered systems in Benin... 60

References and Further Reading

ETUDE DE FAISABILITE « SOLAIRE » CONCERNANT LES AEV ET PEA DU BENIN, Ebo Roek, Practica Foundation, August 2014.

LE POMPAGE PHOTOVOLTAIQUE Manuel de cours à l'intention des ingénieurs et des techniciens, Jimmy Royer et al. IEPF/Université d'Ottawa/EIER/CREPA, 1998.

Photovoltaic System Engineering, Roger Messenger and Jerry Ventre, 2004.

Solar Photovoltaic Systems Technical Training Manual, UNESCO TOOLKIT OF LEARNING AND TEACHING MATERIALS, Herbert A. Wade, 2003.

Solar Pumping Systems, Introductory and Feasibility Guide, Walt Ratterman, Jonathan Cohen and Anna Garwood, Green Empowerment, 2007.