SOLAR PUMPING
GUIDELINES FOR SUDAN
DRAFT 1-MARCH 2017
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Annex 3 - Solar Pumping Systems - Physical Control Installation and Maintenance checklist

References (available on request at solarquery@iom.int)

Reference 2 - Best Practice Guidelines Hybrid Solar PV systems - Kenya, draft 15 07 2015
Reference 3 - Solar PV water pumping study - FINAL REPORT (Single sided) - Namibia 2006
Reference 4 - Technical Assessment for Solar Powered Pumps in Lebanon 1.0.2015 (UNDP and SDC).
Why Solar Pumping.

Crashing of solar panel prices worldwide, an increase on reliability in solar products together with the high solar radiation in all areas of Sudan and the presence of incipient solar expertise at private sector companies in Khartoum, makes the use of solar energy for pumping water an adequate choice for water supply projects in a number of contexts.

Through providing water for potable use, irrigation, and livestock, solar water pumping brings obvious benefits, especially to rural areas and remote communities.

Using well-established technologies, solar energy empowers a water pump that moves water from wells, ponds, and other water sources to ground levels and to end use locations. Thus, as long as the sun is shining, water is being pumped and moved around either to a water storage location or directly to consumers.

When thinking of mechanizing a water point, solar pumping is considered a more economically feasible solution in off-grid areas of the country (or where grid is too unreliable for the intended purposes) due to the lower operating expenses related to fuel supply and maintenance costs and reduced carbon footprint as compared to diesel generators. Tens of thousands of solar water pumps are in operation all over the world, meeting consumption needs especially in regions beyond power lines and producing best during sunny seasons when the demand on water reaches its peak.

Technologies utilizing solar energy for electrically powering the water pump are becoming more common, offering competitive advantages over traditional fuel-driven generators.

<table>
<thead>
<tr>
<th>Type</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Pumping (stand alone)</td>
<td>• No fuel required</td>
<td>• High initial capital cost</td>
</tr>
<tr>
<td>(solar + battery)</td>
<td>• Little maintenance</td>
<td>• Uses unfamiliar technology</td>
</tr>
<tr>
<td></td>
<td>• Environmentally benign</td>
<td>• Parts may be hard to obtain</td>
</tr>
<tr>
<td></td>
<td>• Panel life is 20-30 years</td>
<td>• Requires regular cleaning</td>
</tr>
<tr>
<td></td>
<td>• Cost effective for small power demand.</td>
<td>• Theft of solar module and components</td>
</tr>
<tr>
<td>Diesel Engine driven pumping (Direct coupled or powered by a generator)</td>
<td>• Low initial capital cost</td>
<td>• Requires regular maintenance and fuel brought to site.</td>
</tr>
<tr>
<td></td>
<td>• Familiar technology</td>
<td>• Requires dependable operator and service support.</td>
</tr>
<tr>
<td>Hybrid Pumping (solar + diesel)</td>
<td>• Less maintenance</td>
<td>• Expensive when considering life cycle</td>
</tr>
<tr>
<td>(solar + grid)</td>
<td>• Minimum diesel consumption</td>
<td>• Pilferage of diesel</td>
</tr>
<tr>
<td>(solar + wind)</td>
<td>• All advantages of solar and diesel</td>
<td></td>
</tr>
</tbody>
</table>

Table: pro’s and con’s of solar vs diesel pumping.
Solar pumping is a pumping system that function totally or partially from solar energy converted into electricity.

Solar pumps utilize the photovoltaic effect to produce free electricity used for water pumping. Photons of light hit a collection of solar panels, exciting electrons into a higher state of energy, making them act as charge carriers an electric current. This is how Photovoltaic (PV) cells produce electricity.

DC electricity is therefore produced in a set of panels put together into arrays and connected to a pump that can be either surface or submersible. Solar schemes consists then of 1 or more solar panels, a pump controller with a DC pump, or an AC pump with an inverter. Both DC and AC pumps can be used; in the case of AC, the inverter is needed to convert DC to AC. The operation of the pump is controlled by a pump controller that assess the voltage output of the panels.

Storage can be done by the use of elevated water tanks or storage ponds where water is stored until it is demanded and delivered to end-users, or through the use of batteries that store electricity and save it until there is demand for water. The first is more feasible, more cost-effective and less maintenance-demanding as compared to battery storage systems, which should be avoided as much as possible.

3- System Design

A good solar pumping system is the one properly designed and sized to fit the job requirements. Various designs exist for a variety of applications, requiring research and technical design to avoid system insufficient performance or unnecessary cost incurrence.

During the design phase, system designers need to decide on whether the system is to be on-grid or off-grid, stand-alone solar or hybrid (solar together with another energy source such as diesel generator), with storage or without it and whether
storage is in batteries (discouraged) or in elevated water tanks (encouraged). They need to decide on the type of pump being used and whether the application requires a submersible or a surface pump, using AC or DC power. These all are factors that affect the system performance and feasibility of the proposed solution.

As opposed to diesel-generator systems, when thinking of going solar, systems will be designed considering water requirement per day (m$^3$/day as opposed to m$^3$/h).

**On-Grid vs Off-grid**

In solar pumping applications, when the grid is available, some systems are hooked into the grid allowing for a two-way exchange of power, working as such:

1. When solar energy is available, and there is demand for water, water is directly pumped to end use using solar power
2. When solar energy is available, and there is demand for water but not consuming all the electricity produced, excess electricity is fed into the grid
3. When solar energy is available, and there is demand for water but requiring more power than what is produced by the solar PV system, extra electricity provided from the grid
4. When solar energy is available, and there is no demand for water, electricity is fed into the grid
5. When solar energy is not available, and there is demand for water, water is directly pumped to end use using grid power

For applications where the utility grid is not available, mainly remote and not electrified regions, the solar system is installed as a stand-alone system, or as a hybrid system typically connected to a diesel generator (solar + generator) depending on the water requirement.

The diesel generator plays the roles (1), (3), and (5) of the grid mentioned above. It provides electricity when needed unless there is a storage system in place. This storage system allows to store electricity or water to offer availability during night times and winter seasons.

**Water Storage vs Battery Storage**

Solar energy is only available during the day, and can sometimes be absent during heavy winter days, which would require storage for some applications. In principle, batteries could be used storage method for electricity, but it is a major burden due to its high cost and maintenance and replacement requirements.

For this reason, a lot of solar pumping applications favor the use of water storage instead; here water is pumped whenever sufficient solar power is available and stored in an elevated tanks, form which water can be withdrawn whenever required.

Water storage is very practical when the system is properly sized. During sunny days, the system provides enough water more than the daily requirements, since pumping is free, this water can be stored in water tanks that should be sized to ensure sufficient storage volume depending on climatic conditions and water consumption patterns.
A photovoltaic (PV) water pumping system consists of the following components:

1. Pump/Motor
2. Solar photovoltaic (PV) array
3. Solar array mounting structure
4. Controller (MPPT, variable frequency drive etc.)
5. Hydraulic piping
6. Balance of system (BoS) components such as cables, switches, safety equipment etc.

A brief revision is made of components pump, controller and solar panel.

**Pump Type: Submersible vs Surface.**

There are two major types of pumps used in water pumping, the selection process depends on the type of water source, the flow requirements, and the site conditions. Surface pumps are used in shallow wells and surface water sources such as streams and ponds. It can only pump water from around 7 meters below ground level (or pump inlet). To maintain pump efficiency and increase system reliability it is recommended to keep the suction lift to a minimum.

There are three main types of surface pumps:

(1) **Delivery pump:** Moves water from a location to another, at both high or low pressure

(2) **Pressure pump:** Pressurize small water systems in homes and small buildings

(3) **Booster pump:** Maintain pressure or flow for towns and communities

Surface pumps are less costly than submersible pumps, and offered at larger variety, but submersible pumps are mainly used for deeper wells although they are also suitable for surface applications.

A submersible pump is usually positioned inside the underground well, normally located more than 7 meters below ground level. Some pumps can go as deep as 450 meters below ground level, with high durability characteristics and ability to tolerate water with relatively high levels of salinity. Recent technologies are developing floating submersible pumps where the pump is positioning in a floating unit on the top of the water. There are two major categories of submersible pump, the most common is centrifugal used for low head and high water volume and the other is positive displacement including helical rotor pumps and diaphragm pumps used for high head and low volume.
PV produces electricity in DC form, thus giving DC pumps an advantage over AC pumps due to the avoidance of additional costs for the use of an inverter (convertor of DC to AC) and the reduced efficiency caused. But DC pumps are only suitable for smaller applications, with power pump of 4kW or lower. Whenever the power of the pump in a given system is of 4kW or less, the choice of –brushless- DC pumps should be strongly favored over AC ones.

**Controller/ Inverter**

An impedance matching device (known as maximum power point tracker or MPPT) is provided to a solar pump to match the electrical characteristics of the motor-pump load and the PV array. In these conditions, both the motor and the array can function close to their efficiency over a range of conditions and light levels.

A DC motor driven water pump is directly coupled with solar array through a simple control box with an MPPT. The role of the control box in a DC solar system is:

- Show status of the pump & communicate the pump to sensors in the well or in the tank
- On/off switch / Soft starter
- Protect pump (over voltage/current/temperature)
- Track the MPP point to regulate power produced and match it to what the pump requires

CU200 control box from Grundfos manufacturer.
To drive a single or three-phase AC motor-pump system, a DC to AC invertor with variable frequency drive (VFD) is used. These VFDs control the frequency and hence voltage of an AC pump to best match the output of a PV system.

- Convert DC current from panels to AC for the pump
- All the other as for DC

**Solar Panels**

The solar PV array produces direct current (DC) power from sunlight. The capacity of the solar array in a solar pumping system is determined by the size of the pump, the daily water requirements and the solar energy available on site through the year.

There are different solar panels made with different materials although the ones made with Silicon mono or poly-crystalline are by far the most popular and used ones. A summary of main characteristics is shown below. Research to make panels more efficient is on-going and it is estimated that every year panels increase their efficiency by +0.5%.

![Image of Solar Panels](image-url)
Structure
Solar panels can be ground-mounted, roof-mounted, or post-mounted depending on the site conditions. Metallic structures are normally used to hold the panels, these structures are designed to withstand high winds and stormy weather. The structure itself needs to be properly coated and protected against environmental factors such as rain, humidity, and other conditions.

Orientation
In order to maximize the performance of solar panels in Sudan, it is essential to install them facing true south, with an acceptable tolerance of 15 degrees towards east or west that doesn’t significantly affect the performance (-0.2% of losses per degree of deviation from true South). For applications needing solar energy in the morning more than it does in the afternoon, a shift towards the east is practical to receive the solar rays as early as possible.

Tilt
The panel can get the best out of the solar radiation when its surface receives the solar rays at a perpendicular angle, allowing for a maximum solar ray density per unit area. But the sun path varies from day to another, being at higher levels during the summer and lower during winter in relation to the horizon.

Rule of thumb says that the tilt angle needs to be almost as much as the latitude of the location with a 5 degrees tolerance, and being no less than 15 degrees for allowing self-cleaning of panels when it rains.
The optimal solution would be changing the tilt angle on daily basis to match the solar radiation angle, but it is not a practical solution and sun trackers (devices that move panels to follow the sun track) are discouraged since they are high maintenance and expensive (due to the relative low cost of solar panels, a better solution to increase the energy yield is to increase the number of panels in the scheme).

**Pump Location**

The pump should be located in an enclosed room called a pump pit or a pump house. Surface pumps are not water proof and need to be kept away from water and protected from environmental conditions to prolong their lifetime and reduce maintenance requirements.

Distance between the pump and the PV panels should be kept to a minimum to reduce voltage drop in the cables. Increased distance causes harmonics and would require a harmonics filter to avoid damages to the pump and the inverter/controller.

**Other Considerations**

Some losses in the solar panel-box-pump system can be minimize if the scheme is well managed (for example: dirt of panels if cleaned regularly, using same model of panels in the scheme, avoiding shadows on the panels, having an optimum inclination and orientation) while others cannot as they are given by factors we cannot influence on. The table below details factor for losses and typical values.

<table>
<thead>
<tr>
<th>Losses due to:</th>
<th>Temperature</th>
<th>Dirt on panels</th>
<th>Inverter Performance/MPPT</th>
<th>Mismatching</th>
<th>Cabling</th>
<th>Reflectance of panels</th>
<th>Shadowing</th>
<th>Bad inclination or Orientation</th>
<th>Tolerance of panels</th>
<th>Other tolerances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Losses in %</td>
<td>3% to 20%</td>
<td>0% to 10%</td>
<td>3% to 10%</td>
<td>2% to 5%</td>
<td>1% to 2%</td>
<td>2% to 6%</td>
<td>0% to 2%</td>
<td>0%</td>
<td>0% to 5%</td>
<td>2%</td>
</tr>
</tbody>
</table>

Energy Production Typical Losses: Worst Case: -48% / Average Case: -29% / Best Case: -12%
Oversizing would incur unnecessary costs, and undersizing would lead to insufficient performance. This is why each component needs to be properly designed and sized to meet the specific requirements of the project. It is the only way to guarantee reliability and system durability, and achieve the desired performance.

While further below it is shown how to manually estimate solar array sizes for pumping schemes, due to the changing nature of several of the parameters involved in this calculation over the year, it is recommended to perform these calculations with software based tools, in order to estimate the best and most cost effective solutions.

Similarly when sizing a solar system, it is recommended to use the ‘worst month method’. By sizing the systems for the month with most adverse conditions in the year, it will be ensured that water supply will be enough for all the other months.

The worst month in the year will be that in where the gap between the energy required to supply water and the energy available from the Sun is higher. In case the daily water requirement is the same all the year round (meaning too that the energy required is the same all the year round since pump will run for the same number of hours any day), the worst month will be that with least solar radiation (for example, July for the case of Khartoum).

The steps that need to be followed in the manual sizing process of a new water pumping system powered by solar are presented in the table below.

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Variables</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water source</td>
<td>(a) Water depth</td>
<td>- Pump type</td>
</tr>
<tr>
<td></td>
<td>(b) Water level</td>
<td>- Capacity of water available</td>
</tr>
<tr>
<td></td>
<td>(c) Delivery capacity</td>
<td></td>
</tr>
<tr>
<td>Water demand</td>
<td>(a) Consumption profile</td>
<td>- Storage size</td>
</tr>
<tr>
<td></td>
<td>(b) Storage capacity</td>
<td></td>
</tr>
<tr>
<td>Total head</td>
<td>(a) Static head</td>
<td>- Pump size</td>
</tr>
<tr>
<td></td>
<td>(b) Dynamic head</td>
<td></td>
</tr>
<tr>
<td>Solar resources</td>
<td>(a) Solar radiation</td>
<td>- PV size</td>
</tr>
<tr>
<td></td>
<td>(b) Sun peak hours per day</td>
<td></td>
</tr>
<tr>
<td>Flowrate</td>
<td></td>
<td>- Pump size</td>
</tr>
<tr>
<td>Sizing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pump</td>
<td>(a) Flowrate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(b) Total head</td>
<td></td>
</tr>
<tr>
<td>Solar array</td>
<td>(a) Pump size</td>
<td></td>
</tr>
</tbody>
</table>

(1) Water source

(a) The depth of the well decides on whether a surface pump can be used or not. For wells deeper than 7 meters below ground level, it is demanded to use a submersible pumps.

(b) The water level decides on the position of the submersible pump. Clearance needs to be kept between the bottom of the borehole and the pump.

(c) Delivery capacity or Safe Yield (determined through 72h pumping test) measures the capacity of water source to provide water in a sustainable manner. Withdrawing more than the tested delivery capacity leads the borehole to become a dry well.
as the discharge rate exceeds the water resource replacement rate. No mechanization of borehole should occur without having clear beforehand the Safe Yield of the given water point.

**IMPORTANT: The pump peak flow rate must be lower than the safe yield of the borehole**

(2) Water demand

(a) Water demand is the major factor affecting the size of the pumping system. For solar systems it is calculated as a daily consumption rate (m3/day).

(b) The storage capacity is the volume of water that need to be stored to ensure sufficient and continuous supply of water to end users. Storage tanks usually range in a volume of between 1 to 5 days of daily water requirements, depending on the location and the usage patterns (this is further discussed below).

(3) Total dynamic head (TDH)

The total dynamic head is the distance between the storage delivery points to the submerged depth of the pump in addition head losses through the piping system. It is the summation of elevation head, major losses head, and minor losses head.

(4) Solar Resources

(a) Sudan is blessed with good solar radiation levels, varying from a yearly average of 2,000 kWh/m2 (or 5.5 Peak Sun Hours) in the least irradiated regions to 2,500 kWh/m2 (or 6.9 Peak sun Hours) in those regions with best solar irradiance.

(b) Peak Sun Hours (PSH) indicates the average equivalent hours of full sun energy received per day, this varies based on the location and the tilt angle, with 1 PSH equals to 1 kWh/m2/day. These data can be retrieved for any location in Sudan from any of these 2 databases:
Table: PSH for Khartoum, for different tilt angles.

<table>
<thead>
<tr>
<th>Lat 15 Lon 32</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Annual Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tilt 0</td>
<td>5.31</td>
<td>6.03</td>
<td>6.76</td>
<td>7.17</td>
<td>6.79</td>
<td>6.82</td>
<td>6.47</td>
<td>6.31</td>
<td>6.29</td>
<td>6.03</td>
<td>5.55</td>
<td>5.06</td>
<td>6.22</td>
</tr>
<tr>
<td>Tilt 15</td>
<td>6.14</td>
<td>6.64</td>
<td>7.03</td>
<td>7.03</td>
<td>6.82</td>
<td>6.94</td>
<td>6.54</td>
<td>6.09</td>
<td>6.38</td>
<td>6.5</td>
<td>6.35</td>
<td>5.93</td>
<td>6.53</td>
</tr>
<tr>
<td>Tilt 90</td>
<td>4.88</td>
<td>4.25</td>
<td>3.16</td>
<td>1.88</td>
<td>2.39</td>
<td>2.76</td>
<td>2.52</td>
<td>1.67</td>
<td>2.48</td>
<td>3.76</td>
<td>4.81</td>
<td>4.98</td>
<td>3.29</td>
</tr>
</tbody>
</table>

(5) Required flowrate

The flow rate can be estimated from the water demand and the peak sun hours per day (taking into account demand not only in present but also in future times). Calculated in m³ per hour, the flow rate is the result of the demand in cubic meters divided by the peak sun hours in hours.

\[
\text{Flowrate} = \frac{\text{Demand}}{\text{PSH}}
\]

\[
m³/h = \frac{m³/day}{h/day}
\]

Otherwise, Safe Yield of the given water point could be taken as the desired flow rate; in this way that the resulting solar scheme will exploit the water point as its maximum capacity.

(6) Pump size (refer to existing WESS Guidelines)

The pump power required can be calculated as usual by using the pump sizing chart provided by the pump manufacturer and requiring two variables only that are the total dynamic head –TDH- (3) and the flow rate (5).

(7) Solar Array

Once the pump has been determined, the size of the solar array can be defined through different methods.

\[
\text{Power Pump (W)} \times \text{hours pump running (h)} = \text{Solar Array Power (W)} \times \text{PSH (h)} \times \text{PR}
\]

Where:

- Power of the pump, is power in Watts of the pump motor.
- Hours of pump running, is number of hours the pump needs to be running to supply the daily demand
- Power of solar panels, is the combined power of all solar panels need to run the pump for the hours required
- PSH, is Peak Sun hours for the particular location,
PR, is the Performance Ratio of the system that, has seen above, expresses reduction in generation of solar energy due to Temperature and other factors and can vary between 0.4 and 0.9 depending on losses in the system. The lower Performance Ratio is, the more panels will be needed to compensate losses.

Another way to calculate the power of the solar array for the same example would be through the calculation of energy required:

The hydraulic energy required (kWh/day)

\[= \text{volume required (m}^3\text{/day}) \times \text{head (m)} \times \text{water density} \times \text{gravity} / (3.6 \times 10^6)\]

\[= 0.002725 \times \text{volume (m}^3\text{/day}) \times \text{head (m)}\]

The Daily Energy Demand

\[= \frac{\text{Hydraulic Energy Required}}{\text{Pump efficiency, with Pump Efficiency normally between 0.4 to 0.6}}\]

The solar array power required (kWp)

\[= \frac{\text{Daily Energy Demand (kWh/day)}}{\text{PSH} \times \text{PR}}\]

where PSH = Peak Sun Hours for the given location

and PR = Performance Ratio, typically between 0.4 and 0.9 as explained earlier.

Examples for calculating solar arrays can be found at Annex 0.

The final stage is deciding on the solar array connections and how to make the interconnections in order to achieve the desired voltage and current.

Connecting the panels in series adds up the voltages of the panels while keeping the current fixed. While parallel connections add up the current while keeping the voltage fixed.

Table 10 shows the effect of parallel and series connections on the voltage and current of PV modules. Each module is assumed to have a voltage of 40V and current of 3A.
An on-line tool to size solar pumping can be found at www.grundfos.com

Other software based tools can be send for free upon request by writing to solarquery@iom.int

### 7 - Economic Analysis

**Cost of solar schemes versus grid connected schemes**

Solar pumping is most practical and financially feasible when the power line is more than 1-2 km away from the pump location (distance depending on cost of extending power lines for the specific location). The investment that would be made to have a solar-powered water pump makes more sense than that made to extend power lines.

From the economic point of view, Solar pumping is more cost effective in applications that can be solely powered with solar energy (stand-alone solar versus hybrid ones). Except for small systems, capital cost for solar schemes will be always higher than capital cost for diesel run schemes. What it is important then when talking about costs, it is to look at the cost over the life cycle of the equipment, and this should be remembered specially when approaching donors.

There are two concepts to be understood before taking an economic assessment:

1. **Payback period**: Time period when initial investment is equal to benefits gained.

2. **Life Cycle Costs**: The sum of all costs and benefits associated with the pumping system over its lifetime (or over a selected period of analysis), expressed in present day money. This is called the Present Worth or the Net Present Value of the system. For the system to be worthwhile, the benefits must be greater than the costs.
A typical graph showing the costs of a solar system vs a diesel one would typically look like the one below.

A methodology to calculate those costs over the life cycle of equipment is provided in Annex 1.

8 - Sizing of Water Storage.

The storage tank should have enough volume to account for peak demands, to compensate for nights and cloudy days, especially for stand-alone solar systems (systems with no other source of energy connected).

Storage tank for stand-alone solar systems is calculated having into account the Equivalent number of NO-SUN or black days in a month for the particular location. This data is openly available in the NASA database in internet. If, for example, the number of black days for the worst month of the year is 2.5, storage tank should be 2.5 times the daily water requirement for the given location. If the systems is Hybrid (solar + diesel) storage tank volume can be made smaller, as it will be always possible to pump with the generator if needs come.

As a general rule:

- Storage capacity of stand-alone solar system = Maximum Number of No Sun Days x Daily Water Demand
- Storage capacity for hybrid system = Minimum or Average Number of No Sun Days x Daily Water Demand

Example of non-sun days in a month for different locations in Sudan.
Sometimes it won’t be possible and/or cost-effective to oversize the water tank just to meet worst case scenarios and a reflection on each particular context and situation will have to be made when deciding the size of water tanks.

### 9 - Preventing Theft of solar panels.

Theft ought to be a concern where there is a lack of ownership, where there is a lack of correct application (e.g. institutional PV installations where the users have not been consulted in terms of their needs and the energy systems that are installed do not provide the services needed), where systems fall into disrepair (and the energy service ceases) and where the systems are installed at remote locations and near public places.

Theft of panels is an issue especially for schemes at community level (not that much at camp level since there is normally a 24h guard by the water point). The single most effective measure to avoid theft is mounting panels on elevated poles, fencing and providing watchman overnight.

Other measures documented to minimize this problem are:

1) For new boreholes: Try to find a drilling location which is close to the users/beneficiaries or remote from roads,

2) For community water supply, ensure that there is ownership of the water supply system,

3) Mark the modules with the owners name in non-removable paint,

4) Engrave the name of the owner on the frame,

5) Note the serial numbers of all the modules,

6) Inform the police of the installation if sensible,

7) Make use of high voltage modules and put up a sign at the installation in the local languages that these modules are not usable in other installations,

8) Put up a sign anyway, even if not high voltage modules,

9) Put a fence around the solar array installation,

10) Electrify the fence if sensible (large installation),

11) Electrify the fence with interrupt/shorting alarm if sensible,

12) Use a siren if feasible,

---

<table>
<thead>
<tr>
<th>Location</th>
<th>Equivalent number of NON-SUN hours or black days in a month</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jan</td>
</tr>
<tr>
<td>Khartoum</td>
<td>2.60</td>
</tr>
<tr>
<td>Nyala</td>
<td>2.56</td>
</tr>
<tr>
<td>Kassala</td>
<td>3.27</td>
</tr>
</tbody>
</table>

Source: [https://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi?email=skip@larc.nasa.gov](https://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi?email=skip@larc.nasa.gov)
13) Take out insurance on the installation

14) If sensible have somebody live at that water supply point,

15) Organize for security personnel in large applications,

16) Place the modules into the center of the reservoir if near borehole and feasible,

17) Use one-way bolts or security screws to fix the modules on the frame,

18) Weld the solar panels to the frame (but take into account that it will be difficult to replace them in case of need)

19) Install the modules on six meter steel poles with a large concrete block as foundation,

20) Fit razor wire underneath the modules,

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10 - Tender Process for Solar Equipment.

Unless your organizations counts with a solid expertise in solar pumping schemes and so you are confident to ask precisely and confidently for the equipment you want, it is recommended to provide information about water required at the site and let the different contractors to propose the necessary equipment and its design to meet the requirements.

It is especially recommended to ensure availability of specialized technical support during the first 12-24 months after installation, and to clearly state and define such support during the tender process.

*In Annex 2 an example is provided of a complete Solar Tender document.*

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11 - Physical Installation and Maintenance of Equipment.

During the installation of the equipment in the field location, a number of steps should be checked/ followed to ensure equality assurance of the installation made. 4 basic principles should be followed during the installation phase:

1) Check the references of all components of the system to ensure that the installed components are those provided in the design.

2) Check orientation and the inclination of the panels, and shadow on the Solar PV generator. The orientation and inclination must have enough values close to those that were determined during calculations sizing. The acceptable variations will be less than 5° for the inclination and 15° with respect to the geographic south orientation.

3) Check the cleanliness and protection of the wiring, and its compliance with the standards.

4) Finally, inspect civil works (castle, basin, trough, fixing the solar generator supports ...), piping, valves and all other important elements that can compromise the operation sound of the station.

*A detailed checklist referring to all these 4 aspects is given in Annex 3.*
The private market is flooded with solar products of many different manufacturers and many different qualities. Since the solar technology makes more sense when thinking in the medium and long term, it is strongly recommended to use products that are of good quality, in order to ensure they will last for long years.

A recommendation is made to use **Solar panels approved to IEC/EN 61215 and 61730 or UL 1703 certified and listed**. All modules must be of a robust design. In case the solar panels are to be mounted elevated on poles, a design of this would be provided by the bidders.

**Control equipment (control box and DC to AC invertors) must meet EN 61800-1, EN 61800-3, EN 60204-1 or internationally recognized equivalent standards.** Moreover control equipment must be housed in a suitable enclosure of robust design for mechanical and environmental protection to at least IP54 or higher.

**As for the pump, the recommendation is that the pump must meet EN 809 and EN 60034-1 or internationally recognized equivalent standards. The pump should be of a design where rotors and impellers are made of stainless steel with a minimum grade of AISI 304 or higher** (unless the chemical nature of the water is so corrosive that plastic or other materials are better suited).

**Besides the electrical protection of any solar scheme is of paramount importance to ensure long life. The system must have dry run protection to protect the system in event of low water levels. Other protection systems should at least include Surge Protection Units (SPUs) and over/ under voltage protection. Each array structure of the PV yard should be grounded properly. All metal casing/shielding of the plant should be thoroughly grounded in accordance with applicable electricity rules.**

### 13 - Solar Pumping at Host Communities vs IDP/Refugee Camp settings – social aspects

As this is a long term measure, that can have a lifespan of 25 years, it is vital that the community is involved from the start in the planning, siting, management and operation and maintenance of the solar water supply. A survey and assessment should be conducted among the village health committee (VHC), leaders and households to determine if the villagers will be willing to embrace the technology. The assessment should consider local skills, materials, and labour in order to estimate how the community could be involved in the installation, operation, and maintenance of the system. It is also generally a good idea for the community representatives such as the VHC to visit an existing community with a solar supply to discuss how an existing system is operated, managed and paid for. It is vital to plan this with the local WES/SWC officials so that the system relies on technologies that WES/SWC agrees with.

Solar-powered water supply systems are gaining ground in developing countries. There are significant upfront costs and community training required for the successful implementation. NGOs or government offices will usually be involved in the initial phases of the project including design, installation, and training needed to operate and maintain the systems.

Community ownership is key to the longevity of the system. The community should have a strong sense of ownership in it. There needs to be a tariff system set up to pay a water system manager in the village and to maintain and upgrade the system as needed. The NGO needs to arrange the training of villagers, such as representatives from the VHC to install the system and to understand its basic operation and maintenance.