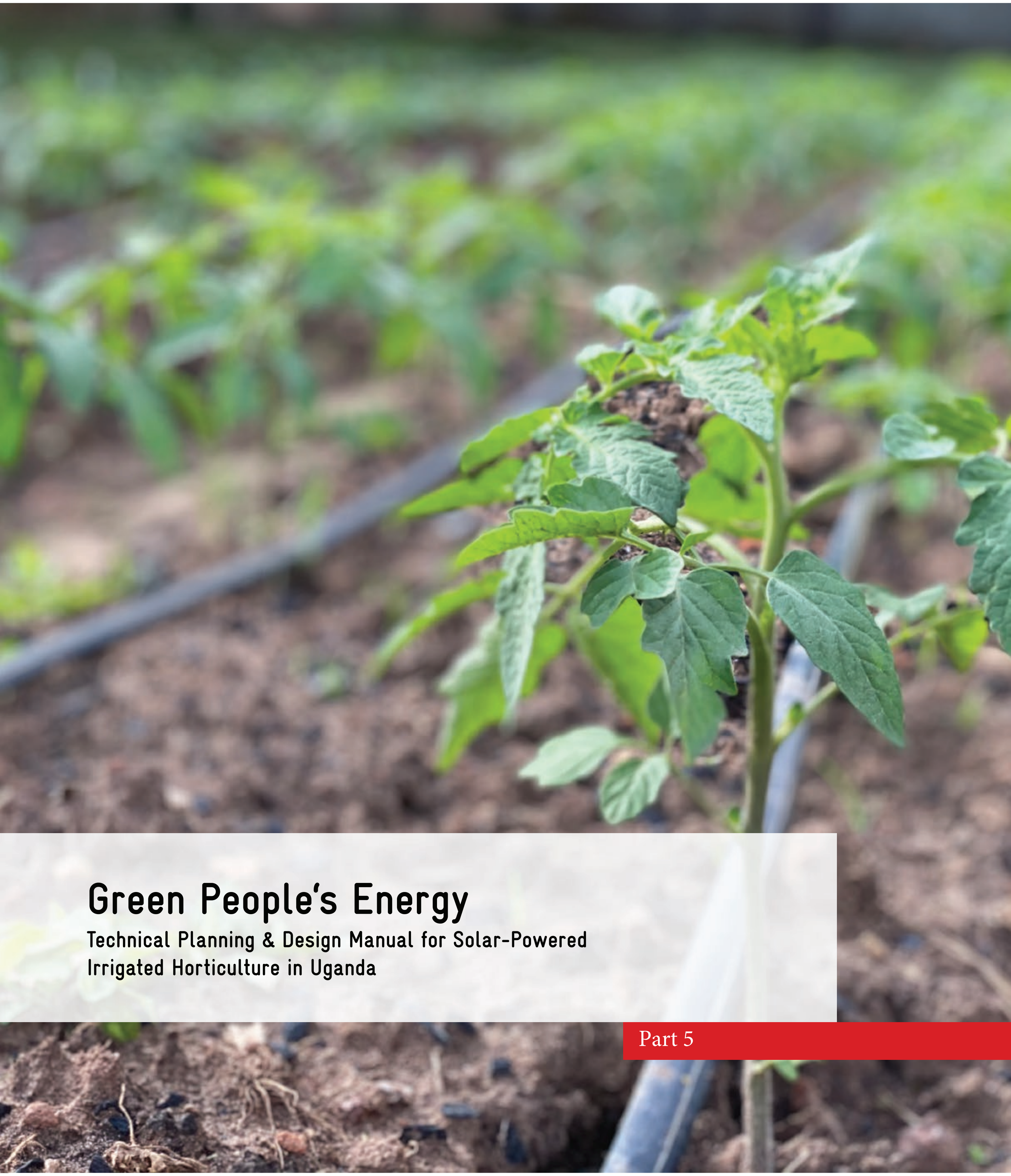

Green People's Energy

Technical Planning & Design Manual for Solar-Powered Irrigated Horticulture in Uganda

Part 5

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5.2. General Guidance

Figure 46 shows the major system components that technicians need to look at during system technical operation and maintenance. These components include the solar array and wiring, controller/inverter, well/pump, transmission line, storage tank, head unit, irrigation system. The operation, maintenance, common problems, diagnosis techniques and repair options of each of the components are explicitly explained below.

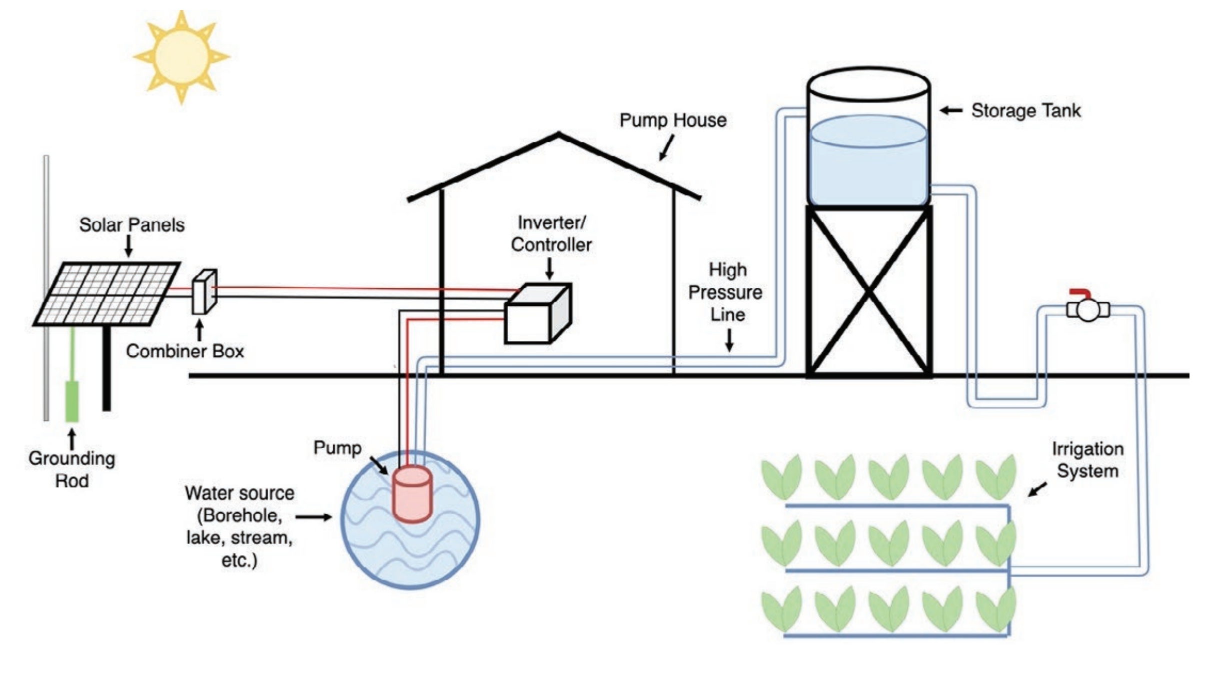

Figure 46: Major SPIS components

Six Major System Components:

i. Solar Panels/Array
ii. Controller/Inverter
iii. Well/Pump Motor/Pump
iv. Transmission Line
v. Storage Tank
vi. Irrigation system

The following section details the operations and maintenance tasks for each component of an SPIS for the Technician.

Typical notifications for Technician support will be when a failure occurs that renders the system non-operational and the Operator is unable to return the system to proper operation. In addition, it includes work that requires going inside of the equipotential barriers of the electrical system or modifying/repairing of the high-pressure line from the well to the storage tank or cleaning/repairing storage tank mechanical damage and when the pump/motor must be repaired/replaced. In most cases work on the irrigation system will be handled by the Operator. The role of the Technician starts when the problem cannot be resolved by the Operator

To accomplish these tasks the Technician is expected to have a technical certificate/diploma in Engineering from a recognized technical institute and at least two years of practical experience in the water supply sector.

Key Component Preventative Care Measures Activity Sheet			
Frequency	Preventative Care and Maintenance	Activity	Remarks
As required/ Annually	Test SOLAR module output at array to ensure each panel/string is functioning properly	Perform a SOLAR Array test.	If any anomalies are found it may be necessary to replace a module or check wiring. Refer to trouble-shooting
	Check function of the tank float switch	Repair immediately in case of non-function	Failure can damage pump and well
	Check pump power consumption	Compare to previous month, report increase	Power consumption per m^3 pumped
	Check switch board and installations for corrosion	If corroded ask Technician for rehabilitation	Ensure good aeration in pump house
	Check Valves and Aeration	Cycle valves to ensure functionality Clean aeration screens	If valves are found to be tight, they may need to be lubricated. If they are found to be stuck, they may need to be replaced
	Monitor ground water (in the case of a borehole)	If level of ground water has changed a new well capacity test may be required	Recheck design and present demand to assure the well is still adequate for the user demand level

5.5. Routine Diagnostic Testing

To provide component preventative care and diagnostics, the system technician must be able to test each component of the solar pumping system and determine any changes from the most recent successful performance test. This step-by-step check is outlined in the following sections and a detailed example is provided in the attachments of this document.

5.5.1. Solar Module/String Output

Calculating the output power of a single SOLAR module at specific time can be used to compare the actual output power to the design output power expected from the module.

Use the process below to measure the current (actual) condition of the SOLAR Array. Using the data collected, calculate the expected solar array power output and compare to the expected output.

Expected / projected values compared against measured values

Start with the expected output based on measurements and STC ratings (found on the nameplate data) and the decrease in efficiency (.005-.01%/year). This will be done at each measurement time.

EG:

Measured solar irradiance (W/m2)	600 W/m2
STC Efficiency rating (%)	20%
Age of array (in years)	5
Decrease in efficiency over time (years) (%)	.01%
Expected Power Output = (measurement in plane W/m2) x (panel area m2) x ((Rated efficiency)) x (efficiency decrease)	
	((600*2)*.2)*(1-(5*.01)) = 228W
	Expected Output (STC): 228W / panel
	Adjust for ambient temperature (see example below) Expected output at ambient conditions: 223W/panel
Multiply the wattage output by the number of panels in the array for the total expected/projected output.	
	EG: 6 panels = Expected Output at ambient conditions: 1338W for array

Use the table below to compare the expected solar array power output and compare to the measured (actual) output.

Use the data collected below to measure the current (actual) condition of the SOLAR Array.

For measured solar array output, place the multimeter at the controller or combiner box.

	Test Condition	1	2	3	4	5	Average
	Time						
1	Solar Irradiance (W/m^2)						
2	STC Efficiency rating (%)						
3	Age of array (in years)						
4	Decrease in efficiency over time (years)(%)						
5	Sub-total						
6	STC rated Ambient Temperature (°C) (25 – or adjust for actual STC)						
7	Adjustment for ambient temperature (-.44 %/^{0}C – or adjust for actual STC)						
8	Total Expected output/panel						
9	Total number of panels in array						
10	Total expected output for array (W)						
11	Measured Solar Array Output (W)						
12	Difference (if more than 10% of expected, investigate problem areas)						

This direct diagnostic method of measuring and estimating operating power levels is key to the diagnostic process. Once the difference is determined, the cause of the differences must be identified. Very small differences 1 to 2 % can be measurement error in the calculation process estimation. Larger amounts of 40% to 60% can be related to dirt on panels and/or shading effects on the panels. In addition, aging of panels reduces the efficiency by .5% to 1% per year. If shading and dirty panels are not the cause of the discrepancy, then damaged panels and/or damaged wiring/connections should be checked. Replacement of the module/connectors may be required.

Once the problem is identified and corrected the test is completed a second time and the performance level is documented and the mitigation of the cause is communicated to the SO for inclusion in the appropriate checklist.

It is important to apply this test at the middle output of the array between 10 am to 2 pm to eliminate the effects of early morning and late evening performance. In addition, if multiple panel arrays are used the same method is applied but the calculations are multiplied by the number of panels in the array. The more complicated calculations and diagnosing of the array is covered in the attached detail document. The purpose of this test is to diagnose if the problem lies within the solar SOLAR system and lead the System technician to the possible causes and required successful fix.

5.5.2. Controller/Motor/Pump Output

This test is performed after any problems with the solar panels have been resolved. The test consists of measuring the input power to the controller and the output power of the pump and determining the running efficiency of the combined controller/motor/pump system and comparing it to the calculated value of the output power based on the design efficiency of the controller and the efficiency of the pump/motor. Comparing the actual values to the calculated values will provide diagnosis of whether the system is running within design.

Output Test:

i. Measure the power input of the controller
ii. If the controller is not built into the motor/pump and is accessible, measure the output voltage, current, and power from the controller going to the motor. This is sometimes available on the controller display. Use the manufacturer's efficiency for the controller to calculate the design output of the controller and compare it to the measured efficiency to determine if controller has problems.
iii. Measure the water flow at the top of the well in M3/minute
iv. Measure the closest pressure to the output of the pump noting that there may be a pressure change from the output port of the pump to the top of the well for a submersible pump. If the pressure is measured at the top of the well, a calculation is done based on the depth of the well, the size of the pipe and the flow rate of the water to add the necessary static and dynamic pressure to document the outlet port pressure for the pump.

H [m] = (static + dynamic water head).
Q [l/s] = the flow rate of pumped water.
DC voltage V [V] and current I [A] are measured.
g = earth gravity = 9.81 m/s²:

$$\text{efficiency} = \eta = \frac{H \times Q \times g}{I \times V} = \text{output energy water/input energy electrical}$$

v. The measured efficiency is compared to the manufacturer's design efficiency at the measured flowrate to determine if these subsystems are performing as designed. A pump curve of the installed pump is required. If there is a significant difference the system must be removed from the well and the manufacture contacted to repair or replace the systems. In most cases the entire subsystem in the well will be replaced at one time especially if the system has been installed for a significant period of time.

vi. The diagnosis is made by comparing the measured values to the estimated design values for the inputs and outputs of the controller and the motor and pump. Examples are that if the input power to the motor is normal or high and the output pressure and flow are lower than normal and the corresponding efficiency is very low then there could be blockage in the intake, damage to a pump/motor, or problem with a partially closed valve in the well. All of these would require removal of the submersible component and identification of which one has failed. If the pressure is high and the flow rate is low at the top of the well and the controller, pump motor and pump efficiency are normal, it would imply that the valve or blockage problem is in the piping between the well head and the storage tank. Having this diagnosis information will greatly enhance the resolution of the performance issue. If the condition measured is low pressure and high flow at the well head and the subsystems are working properly it would indicate damage to the high-pressure line and possible leaks in the system.

EG:

	Measured input	Efficiency rating (on nameplate)	Expected output	Measured Output	Difference
Controller Input (W)	1040	97	1009	770	239W / 24%
Controller Input (V)	260		260	208	20%
Controller Input (A)	4		4	3.7	8%

Measure the actual output values and compare to the expected values. If there is a variance greater than 10%, further investigation is needed.

Test Condition	1			2			3		
Time	W	V	A	W	V	A	W	V	A
Input									
Efficiency loss									
Expected Output									
Measured output									
Difference									

The pump output testing is completed when the repairs are made and a final test is completed with documentation that the performance met or exceeded the design efficiency of the controller, pump motor/pump components.

Controller Output power (W)	770W
Pump (rated) efficiency %	80%
Expected pump water power (W)	616

Measure the actual Pressure and Flow Rate and calculate the Pump Power out:

Pump Power out = (Pump head in meters) *(flow rate converted from m^3/hr to l/sec) *(gravity calculated as 9.81 m/sec)

NB: One Bar is equal to 14.5 PSi, PSi*.72=pressure in meters

NB: 1m3/hour = 0.28L/sec

Discharge Pressure Gauge Reading (m head)	38*.72m = 27.4m head

Pump Flow Rate (m^3/hr)	7.5m3(2.1L/sec)
Actual Pump Power out	27.4*2.1*9.81= 564W

Test Condition	1	2	3	4	5
Time					
Controller Output power (W)					
Pump (rated) efficiency %					
Expected pump water power (W)					

5.5.3. Source/High Pressure Line/ Storage Tank

This is a simple test to determine (1) the pumping rate out of the well, (2) the storage tank water level, (3) the functionality of the storage tank float switch and (4) the margin between the well dynamic water level and the low water level for the pump. This test is completed with the following steps:

i. Turn off the main line water valve at the output of the storage tank.
ii. Measure the level of the water in the storage tank.
iii. Operate the solar pumping system while monitoring the water levels in the well and the storage tank until the storage tank switch operates and turns off the pumping system.
iv. Determine the well water depth between the cut off level of the pump and final dynamic well water level that was reached during the test.
v. Use the collected data to determine the capability of the dynamic level of the well to supply one day's usage plus one additional storage tank of water. Use the same calculation to determine if maximum expected pumping capacity for solar operation is less than the dynamic volume supply of the well in the required time period.
vi. Tank water volume in m^3 = $V = \pi r^2 h$

m = meters
r = radius of storage tank
h = height of water level in storage tank

This test provides a routine way of assessing the capability of the well supply for the continued normal operation of the well. This is important to track since both the capacity of the well and the production of the solar pumping system may be reduced over time. It is important to ensure that the well capacity and solar panel output continue to supply the user demand of the system to maintain a reliable water supply.

5.5.4. Low-water probe circuit

If the controller indicates "source low" when the pump is in the water, the low-water probe system may be at fault. When the water level is above the probe, the switch in the probe makes contact. That causes the applied voltage to drop toward zero. The systems "sees water" and allows the pump to run. If the voltage is greater than 3V, dry shut off is triggered. The low-water probe has an internal 1K resistor in series with the switch. When closed (in water), the normal resistance is around 1000 To bypass the low-water probe (and activate the pump), connect a small wire between the probe terminals in the junction box. Restart the controller. If the pump runs, there is a fault at the probe or in the probe wiring. The wires may be shorted (touching each other) or open (broken) or the moving part on the probe may be stuck with debris, or the probe may be out of its normal, vertical position.

Many submersible SOLAR pumps are equipped with dry-run protection built into the assembly. Consult with the manufacturer's O&M information for the installed pump.

5.5.5. Full-tank float switch

If the controller that the tank is either full or empty, but the signal differs from what can visually be observed the tank control switch may have failed or need service.

In general, there are two types of control switches, "normally open" and "normally closed". "Normally open" switches do not make an electrical connection until the switch is activated. Conversely, "normally closed" switches are capable of sending electrical signal until they are activated or opened.

When installing or inspecting switches and controls be sure to understand how the control system is designed by comparing the manufacturer's information on the switch to the design information on the system.

A simple diagnostic test for switches is connecting terminals with wire instead of running through the installed switch. If the switch is at fault, connecting or disconnecting the terminals directly should cause the pump to run when the system is turned back on. If not, other system components may be at fault.

This type of diagnostic testing should ONLY be done by a qualified electrician and should not be done while the system is under load.

5.6. Ground Water Monitoring

Ground Water Monitoring should be an ongoing proves to ensure that the well is not being over utilised and in risk of drying up. There are several ways the groundwater can be monitored, depending on the hardware installed. Some wells have remote digital monitoring which do not require manual inspection. Others may have a piezometer which will require manual monitoring. This should be done regularly to ensure the health of the well. This is also tested during the well/high pressure line/storage testing.

5.7. Valve Maintenance

Check pressure and pressure relief valves periodically but never when the collectors are stagnating. Manually operate the valves using the lift lever. Replace any valves that are stuck (frozen) shut or leaking.

Check automatic air vent valves periodically by: (1) removing cap, (2) depressing valve stem until small amount of fluid is released, and (3) replacing cap, taking care to only tighten two turns to allow proper venting.

Inspect check valves. The inspection should include, if possible, opening the valve (after isolating it from the system) to verify that there has been no erosion or corrosion, that the seat is not damaged, and that the valve operates freely (does not stick), and that the flapper or plunger is not pitted or scaled.

Cycle all manual valves (i.e., opened, closed, and returned to design position) periodically. This prevents freeze-up of the valves. Consult manufacturer's literature for any lubrication requirements.

Check aeration and overflow. Clean aeration screen and make sure the overflow flip valve is working.

5.8. System Performance and Diagnostic Check

The goal of the annual system performance check is to evaluate the deterioration of the system over time. It is simpler than the commissioning tests, which are more detailed and are specific to the design capability of the system components at multiple solar power outputs as outlined in IEC - 62253 Photovoltaic pumping systems – Design qualification and performance measurements. Data from the annual system performance check should be compared to data from the previous year's check as well as the commissioning tests.

The same testing method is used to perform a diagnostic check of the system to determine if the performance of the system elements has changed and allow the system technician find the cause of the change and plan the repair of the system to return it to normal. The annual system performance check has one clear difference; it is done over a full cycle of the operation of the solar pumping system for one complete day's operation from just before pump start until just after pump stopping. It is usually hourly values. Note that the process is identical to the as needed routine testing and diagnostic procedure in the section above and will not be repeated here.

Table 31: System Performance Table

Test Condition			**Comments:**
Solar Array	Expected Output_______	Measured Output_________	
Controller/Charge Controller/Inverter	Expected Output power_________ Input Power_________	Measured Output power_________ Input Power_________	
	Input Voltage_________ Current_________ Power_________	Maximum Power Point Level Voltage_________ Current_________ Power_________	
Pump and Pump Motor	Expected Pump Power Output_______	Measured Pump Power Output_________	
Storage Tank Level	Flow rate from pump:	Measured tank level increase:	
Irrigation system	Minimum expected flow ________	Measured emitter/lateral flowrate Emitter/lateral 1: ________ Emitter/lateral 2: ________ Emitter/lateral 3: ________ Emitter/lateral 4: ________ Emitter/lateral 5: ________	

5.9. Trouble Shooting and Repair

The lists of problems and causes below are NOT meant to be comprehensive lists of all possible problems and causes. Rather, they provide a sampling of commonly encountered issues. Tailor the guidelines, through deletions and additions, to each specific site. List the probable causes for each problem in the order of priority in which they should be evaluated to minimize expensive or unnecessary repair work.

ALWAYS SHUT THE SYSTEM DOWN STARTING WITH THE CONTROL PANEL, ALWAYS FOLLOW MANUFACTURER'S RECOMMENDED SHUTDOWN PROCEEDURE.

Table 32: System Trouble shooting and Repair

Component with Apparent Issue	Issue	Possible Causes	Suggested Operator Action	Suggested Technician Action
Solar Panels	Panels Appear Broken	Damage to panels	Notify Technician	Inspect and Repair Panels
	System not producing power or producing reduced power	Panels shaded or dirty	Clean panels as part of regular maintenance Check for panel shading throughout the day, trim trees and clear shading as part of regular maintenance. Notify ST if problem persists.	
		Panels are disconnected	Notify Technician	Inspect and reconnect panels according to design schematics.
		Array wiring is frayed or broken	Notify Technician	Repair wiring according to good practice.
Other Panel Array and Electrical Components	Array disconnect, or transfer switch is over-heating		Notify Technician	Inspect Transfer switch for contact damage, rodent infestation, loose contacts or conductors, heat damaged wires. Resolve the problem found. Confirm wire connections & terminals are properly tightened. If they are, confirm switch is appropriately rated for DC, proper maximum system voltage, and array short circuit current. If not, consult with designer/ contractor regarding replacement with proper equipment.

Component with Apparent Issue	Issue	Possible Causes	Suggested Operator Action	Suggested Technician Action
	Inverter is overheating		Notify Technician	Inspect inverter for fan operation, loose contacts or conductors, heat damaged wires, rodent infestation and resolve problems found. Confirm inverter is properly rated for input and output voltages and currents.
	Inverter isolation fault		Shut down system and contact Technician	Inspect inverter for loose connections, heat damaged wires, rodent infestation, burnt areas from arcing and resolve issues found If no problems found, disconnect motor/pump from inverter and restart system. If system starts then shut inverter down and check wiring and contacts from the inverter to the motor. If no problems are found, then try to restart system. If inverter isolation fault occurs, then motor and pump must be checked to determine failure and replace equipment as needed.
	Inverter does not restart (after grid fault)		Contact Technician	Check input voltage and frequency to the inverter and make sure proper starting voltage (s) is available. If not review connection to resolve voltage issue from power source. If proper voltage and current is present, turn inverter completely off, then on again. If proper voltage is available and the inverter still does not start, review inverter trouble shooting guide in equipment manual. Contact supplier for support as needed.
Surface Water Source	The source has over flooded or been filled with sediment	Heavy rainfall/storm Poor management	Contact an experienced person	De silt the source

Component with Apparent Issue	Issue	Possible Causes	Suggested Operator Action	Suggested Technician Action
Pump	Pump won't start	All causes	Check the pump control panel display (if used) for any information on system faults. Refer to the manufacturer's information to troubleshoot.	
		No power to the pump	Check that pump control panel or switch is in the 'ON' position. Check that main disconnect arm (main switch) is in the 'ON' / energized position. Check that there is no visible damage to wiring or power system.	Refer to the manufacturer's troubleshooting information Check voltage and current across each system component.
		Pump dry run sensor was tripped	Wait a minimum of 5 minutes for the switch to reset. Refer to the manufacturer's instructions.	
		Circuit Breaker or overload relay was tripped.	Reset once. If it trips again, contact Technician.	Review connections from the circuit breaker to the pump to identify bad connections, points of arcing faults within equipment, and any abnormal operating conditions which may have overloaded the system. If none are found, then wiring from inverter/controller should be inspected for faults. Check if breaker or relay are appropriately rated for AC or DC, voltage, and current. If no problems are found then the pump/motor should be removed and inspected for equipment failures. Refer to pump/motor manual trouble shooting

Component with Apparent Issue	Issue	Possible Causes	Suggested Operator Action	Suggested Technician Action
		Fuse is burned out.	Contact Technician.	Review connect equipment between the fuse and the next protective device checking for bad connections, points of arcing faults within equipment and any abnormal operating conditions which may have overloaded the system. If none are found, then wiring from inverter/controller should be inspected for faults. Confirm wire connections & terminals are properly tightened. If they are, check if fuses were appropriately rated for AC or DC. If no problems are found then the equipment should be removed and inspected for failures. Refer to equipment manuals trouble shooting
		Wiring is loose, broken, frayed, disconnected	Notify technician	Have a qualified electrician make repairs as needed.
		None of the above	Notify technician	
	Pump is starting and stopping too frequently	Pump control switches are at fault or incorrectly installed	Inspect tank level switch or any other pump control switches.	Disconnect switch and bypass at the controller to test the system and pump with the switch removed. Refer to manufacturer's information
		Leakage between the pump discharge and tank	Visually inspect the pressure line and tank for leakage. Check the pressure line and flowmeter for signs of backflow. These include the flowmeter running backwards and sounds of flowing water in the pressure line when the pump is off.	

Component with Apparent Issue	Issue	Possible Causes	Suggested Operator Action	Suggested Technician Action
	Pump discharge pressure has increased from normal value	Pressure line is obstructed	Check that valves are not closed, preventing normal flow. Check for any obvious damage or obstruction to the piping or discharge at the tank. Notify Technician.	Inspect piping system. Notify qualified technician or manufacturer's representative if needed.
	Pump discharge pressure has decreased from normal value	Pressure line has a breakage or leak	Check that no valves are open allowing flow to bypass the tank. Inspect the pressure line and check for obvious signs of leakage. Notify Technician.	Inspect piping system. Notify qualified technician or manufacturer's representative if needed.
		Pump wiring is connected incorrectly	Check manufacturer's information. Notify Technician.	Notify qualified technician or manufacturer's representative if needed.
		Pump is damaged	Notify Technician	Notify qualified technician or manufacturer's representative if needed.
Supply Piping (Pressure Line)	Leaking or cracked pipe	Piping is exposed	SOLARC piping will become brittle when exposed to sun. Check that all SOLARC pipes are properly buried or covered. Fix minor leaks. Notify Technician.	
		Piping has been damaged	Fix minor leaks and Notify Technician.	
	Piping is vibrating excessively	Piping is not properly secured	Notify Technician	Fasten and anchor the piping appropriately.
Valving	Valve will not open or close	Valve is stuck	Attempt to gently actuate valve. Do not use excessive force. Notify Technician.	Stop the system if necessary. Isolate the valve and remove to service.
		Debris is clogging valve	Attempt to gently actuate valve. Do not use excessive force. Notify Technician.	Stop the system if necessary. Isolate the valve and remove to service.

Component with Apparent Issue	Issue	Possible Causes	Suggested Operator Action	Suggested Technician Action
Tank	Tank is overflowing	Pump control switch is not functioning properly	Visually inspect pump control (tank level or pressure) switch. Inspect piping downstream of tank for blockage.	
	Tank is leaking	Failure of tank structure	Turn off system if leakage is severe. Notify Technician.	
	Float switch fault	Float switch is disconnected, broken, or snagged.	Visually inspect float switch. Notify Technician.	Test switch. Test system without switch connected. Replace switch.
	Sediment accumulating in tank	Sediment from well is being pumped into the tank	Notify Technician. Tank may need to be cleaned. Pressure line piping, pump and borehole should be investigated for issues.	
Irrigation System	Leakage on submains and laterals	Exposed or broken piping	Visually investigate piping. Wet spots or unusual plant grown may indicate a leak. Notify Technician of major leaks and breakages.	Inspect and repair piping.
	Exposed piping		Bury piping appropriately.	
	No discharge at the emitter Non-Uniform application rates at the emitters	Clogged emitters Low flowrates and pressures at some emitters	Clean or replace the filter Flush the drip lines Make sure the drip lines are laid with emitters facing up.	

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ANNEX

Table 33: Printable data collection table

Parameters	Observation/Finding	Notes
WATER SUPPLY		
Water source		
Current status		
Shared / private?		
Distance of water from plot		
Land ownership at water source location		
Quantity of water available		
Water quality		
PLOT CHARACTERISTICS		
Plot size		
Shared/private		
Current usage		
Terrain – flat/hilly, etc		
Soil type		
CLIMATE		
Altitude		
Climatic zone		
CROP SELECTION		
Crop type		
Production time		
Expected yield		
Market Value		
Number of harvests per year		
Water required	High/low	
Varied crops?		More than one crop type for area?
FERTILIZATION		
Fertilizer required?		
Type of fertilizer		
IRRIGATION		
Irrigation Type selected		
IRRIGATION SCHEDULING		
Water Demand		
Irrigation Schedule		
WATER SUPPLY DEVELOPMENT		
Water supply solution estimated cost		

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