

TRANSFORMATION OF RURAL PV MARKET IN TANZANIA

UNDP/GEF/Government of Tanzania PROJECT - MWANZA

TECHNICAL TRAINING OF PV SUPPLIERS

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1.0. Basic Technical aspects of the PV Technology

The History of Solar Photovoltaic Technology

- The Photovoltaic effect was first noted by a French Physicist called Edmund Jacques Becquerel in 1839 who observed light dependent voltage between electrodes immersed in an electrolyte.
- In 1876 the same phenomena was observed in solid state selenium and cuprous oxide.
- Solar cells were used to power satellites and space crafts as early as 1958, and their use in space multiplied and become the major application in 1960's.
- The oil crisis of early 1970's taught the world of the importance of alternative energy sources including solar. This was followed by a major breakthrough in the production of silicon solar cells.
- By the end of 1970's terrestrial solar applications had far exceeded their use in space.
- The price of solar cells fell from USD100 per peak watt in 1974 to USD4 per peak watt in 1991 with expectation of further price drop in future (Figures refers to prices at supply sources in UK or US)
- During the 1980's many new cost cutting production methods were established and the result is the growing market for solar PV stand alone power systems.

What is Solar Photovoltaics (PV)?

- Is the direct conversion of sunlight into direct current electricity by using solid state semiconductor solar cells.
- Solar cells are made up of single crystal silicon cells with Boron or Phosphorus impurities/dopants added into it to increase efficiency.
- Solar electricity is nearly inexhaustible and depends upon two of the most plentiful natural resources on earth namely sunshine and sand.

How does the Solar cell work?

- A Photovoltaic device generally called a solar cell consists of layers of semiconductor materials with different electronic properties.
- In any typical solar cell the bulk of the material is Silicon doped with small quantity of Boron to give a positive or p-type character. A thin layer on the front of the cell is Silicon doped with Phosphorus to give it a negative or n-type character.
- The interface between these two layers contains an electric field and is called a p-n junction.
- Sunlight consist of tiny packets of energy called "Photons" which when sunlight hits the solar cell they are absorbed in the region of the junction hence freeing electrons from the crystal lattice.
- If the Photons have enough energy electrons will be able to overcome the electric field at the junction and are free to move through the silicon crystal and into an external circuit.

- When moving in the external circuit electrons give up their energy as useful work e.g. lighting lamps, turning motors etc.
- The Photovoltaic process is completely solid state and self contained, there are no moving parts and no materials are consumed or emitted in the process.

2.0. Types of Basic PV components

A Solar PV system will have the following basic components

- Solar module(s)
- Charge Regulator(s) or Charge Controller(s)
- Storage Battery(ies)
- DC-AC Inverter or Inverter Charger
- DC appliances
- AC appliances

The system will also have other support components like

- Cables and wires for interconnecting various parts and components
- Diodes, Fuses, Circuit breakers, grounding for safety operation
- Steel or Aluminium structures for supporting solar modules on the rooftop or on the ground.
- Switches and plugs for operation control
- Meters to know how much power is generated, being used, or is stored. Meters also protect and help in troubleshooting the system.

Installation of solar PV systems

Work tools

S/N	Tool / Equipment	Use of Tool
1	Hacksaw	Cutting metal frames and plastic conduits
2	Hammer	Nail works
3	Tape measure	Measuring length
4	Inclinometer	Angle measurement
5	Compass	Direction measurement, determine North direction
6	Level	Checking grade of mount and laid wires
7	Silicon sealant	Sealing module junction box and holes made on roof etc. during work
8	Spray paint	Spraying scrapes in the array support
9	Multi-meter	Measuring voltages, current, continuity, diodes etc.
10	Drill machine	Drilling holes for various purposes
11	Pliers / Wire cutter Wire cutter and stripper	Cutting and preparing cables Cable preparation
12	Electrician knife	Cable preparation and various cutting works
13	Set of screwdrivers	Tightening screws and terminals

14	Adjustable spanner sets	or	Tight and undo nuts
15	Align keys		Opening bolts
16	Crimp Tool		Attaching ring and spade terminals to wires
17	Solder iron & wire		Connecting wires to respective terminals
18	Hydrometer		Measuring Battery state of charge
19	Pencil and Paper		Taking notes on various measurements
20	Shovel / Hoe		Digging trenches
21	File		Smoothing rough surfaces after cutting
22	Product manuals		Guiding instructions for installing various components
23	Grease		Apply to Battery terminals
24	White Chalk		Marking parts for component mounting

Installation accessories / materials

- **Module support structure comprising of steel or Aluminium pipes or flat bars, bolts and nuts.**
- **Module - Regulator cable usually 25 meters long or less.**
- **Regulator - Battery cable usually 3 meters long or less.**
- **Battery looping cable 50 or 70 sq. mm and 30 cm long or less per single loop pieces.**
- **Battery to Inverter cables 50 or 70-mm sq. and 2 metres long or less.**
- **Wiring cable 2.5-mm sq.**
- **Battery Acid**
- **Battery terminals**
- **Battery and stand**
- **Trunks and Conduits**
- **Main Switch**
- **Circuit Breaker**
- **Fuse and Fuse Holders**
- **Timer switch (where required)**
- **Clips and screws**
- **Cable ties / Fasteners**
- **Earth wire**
- **Earth rod**
- **Spray paint**
- **Silicon sealant**
- **Lighting switches and Switch sockets**

Voltage drops and cable size

- **This is a loss of voltage due to resistance in long runs of cable**
- **Occurs in all wires runs but is only a serious problem in low voltage systems with long cable runs.**

- Short thick cables have low voltage drops which thin long cables will have higher voltage drops.
- Voltage drop in cabling should not exceed 5% of the system voltage.
- It is determined by using Ohms law i.e.

$$\text{Voltage drop} = \text{Current carried} * \text{Resistance of cable}$$

$$\text{Resistance} = \text{Resistivity} * \text{Distance in metres of cable run in metres}$$

- Resistivity is the resistance per meter of a cable / wire run, it varies depending on the size in sq. mm of cable under consideration as shown in table2 below

Table1: Resistance factor for copper wires

Wire area in mm ²	Resistance Factor (Ohm per meter)
1.0	0.040
1.5	0.020
2.5	0.016
4.0	0.010
6.0	0.0068
10.0	0.0040
16.0	0.0026

- Cable sizes interconnecting various parts in the system are then calculated basing on the current they are expected to carry and the distance from power source to the point where power is delivered.

Array orientation and inclination

- Solar modules or arrays are installed in such a way as to face North in the Southern hemisphere and face South in the Northern hemisphere.
- Arrays are installed inclined at an angle equal to 10⁰ plus the latitude value of the site.

Parallel connection

- Modules or Batteries are connected in parallel when their positive terminals are connected together.
- Current capacity of modules add up when they connected in parallel
- Voltage of modules and Batteries are retained when connected in parallel

Series connection

- Modules or Batteries are connected in series the positive terminal of one is connected to the negative terminal of the next and so on.
- Voltages of modules / batteries add up when they connected in series.

- **Current capacity of modules and Batteries are retained when connected in series**

Fuse sizing and selection

- **Fuses are rated in Ampere according to the current demand of the circuit they are protecting**
- **They are sized to blow when the current is 20% greater than the maximum expected in the circuit.**

$$\text{Fuse size} = 120\% * (\text{Total load wattage in a circuit} \div \text{System voltage})$$

3.0. Different viable PV applications

- **Lighting in homes, schools, dispensaries, rural clinics, missionaries, tourist camps, and other institutions located in remote off grid areas**
- **Powering low consuming domestic appliances like TV/VCR, Satellite dishes, Radio sets, music systems, mobile phones etc.**
- **Street lighting**
- **Vaccine and Domestic refrigeration**
- **Telecommunication in repeater stations, radio links, radio calls, wireless local loop systems, ICT, weather monitoring equipment, etc.**
- **Water Pumping for domestic use, irrigation, or livestock**
- **Cathodic protection of underground pipes, tanks, bridges etc.**
- **Fence electrification e.g. in animal ranches**
- **Water purification and desalination**
- **Transport aid particularly in railway crossings and signaling, obstacle lights, navigational buoys, navigational lights, runway lights, highway signaling, tunnel lighting, emergency phones etc.**
- **Security systems by powering remote alarm systems**

Advantages of Solar PV systems

- **Have no fuel requirement removes hassles of erratic kerosene or supplies**
- **They are modular, each system can be sized to meet the particular demand**
- **Improves life quality by extending working hours to the night, allowing pupils to study at night, and enabling vaccination and medical services at night.**
- **PV systems are highly reliable; the sunlight energy supply is inexhaustible.**
- **PV systems are easy and less costly to maintain.**
- **PV modules have long life with very little degradation in performance over 15 years.**
- **They are friendly to the environment; there is no harmful pollution through the use of PV systems.**
- **Are economically viable for powering small power supplies if analysis is made on the Life Cycle Cost basis taking into consideration the reliability associated with it.**

4.0. Methods of PV system sizing

The following can be used

- **Computer design method – where ready computer design software are provided with the designer only required to key in data for the computer to work out all required results**
- **Calculation method**
- **Graph method e.g. nomograms**

For this particular training the “calculation method” will be discussed.

Calculation method of Solar PV system sizing

Following procedures are required

- **Establish quantity and power consumption rating of all appliances planned to be used on a solar system, examples are given in appendix1**
- **Establish the time in hours that every appliance is going to run off the system per day**
- **All such information are filled in a sizing form the format of which is shown in appendix2**
- **For every appliance multiply figures in Quantity, Watts, and Hours and fill the corresponding figure in the watt-hours column**
- **Get the total of all figures in the watt-hours column; this is the Daily system power requirement.**
- **For every AC appliance multiply figures in Quantity column with those in Watts column. The total for all appliances are then added together to get the system watt-rating which enables the designer to select the right inverter for the system.**
- **Select system voltage, this is 12, 24, 36, or 48 VDC depending on the total system wattage. Generally 12VDC is selected for system wattage below 1,500 Watts, 24VDC for wattage between 1500 and 5000 while 48VDC is for wattage exceeding 5000 Watts.**

After this stage the following table can be used to determine:

- **various system design parameters**
- **component type and specification**
- **component quantities**
- **cost of designed system**

Table2: Design parameter table.

Design Parameter	How obtained	Unit
Total daily energy consumption, E_t	Sum of all individual consumption	Wh
Selected system voltage, V_s	Selected basing on system wattage	V
Total daily system charge requirement, C_r	Calculated $C_r = E_t / V_s$	Ah
Average Peak sun hours at site, H_p	From near meteorological station	h
System charging Current, I_c	Calculated: $I_c = C_r / H_p$	A
Solar module nominal voltage, V_{nm}	Selected from available stock	V
Solar module Peak Current, I_p	From selected module data sheet	A
Number of solar modules in parallel, N_{pm}	Calculated: $N_{pm} = I_c / I_p$	-
Number of solar modules in series, N_{sm}	Calculated: $N_{sm} = V_s / V_{nm}$	-
Total number of solar modules, N_{tm}	Calculated: $N_{tm} = N_{pm} * N_{sm}$	-
Allowable Battery DoD, D_b	Selected basing battery type	%
Number of days of autonomy, N_{ad}	Decided basing on site weather	Day
Total Battery Bank capacity, B_t	Calculated: $B_t = C_r * N_{ad} / D_b$	Ah
Battery nominal voltage, V_{nb}	Selected from available stock	V
Selected Battery capacity, B_c	Read from Battery type selected	Ah
Number of solar batteries in parallel, N_{pb}	Calculated: $N_{pb} = B_t / B_c$	-
Number of solar batteries in series, N_{sb}	Calculated: $N_{sb} = V_s / V_{nb}$	-
Total number of Batteries, N_{tb}	Calculated: $N_{tb} = N_{pb} * N_{sb}$	-
Total system DC Power wattage, P_{dc}	Add power of all DC appliances	W
Total DC load current, I_L	Calculated: $I_L = P_{dc} / V_s$	A
Charge Regulator selection		
Total system AC Power wattage, P_{ac}	Add power of all AC appliances	W
DC – AC Inverter efficiency, η	Read from inverter name plate	-
System Inverter power rating, P_{inv}	Calculated: $P_{inv} = P_{ac} / \eta$	W

Component selection:

- **Solar Charge Regulator/Controller:** selected such that its voltage is the same as system voltage V_s . Both its charging current and load current should be greater than I_c and I_L determined from table1.
- **Inverter:** output voltage matching the standard domestic voltage e.g. 240VAC for Tanzania. Input voltage must match selected system voltage V_s and Power rating equal to P_{inv} as determined in table1.
- Other system components are selected in various steps in the parameter table above.

Obtaining a long-term performance from a PV system requires

- Consistent sizing calculations
- Knowledge of hardware availability, cost, and performance
- Use of good engineering practices when installing equipment, and
- Developing and following a complete operation and maintenance plan

5.0. Importance of system sizing

System sizing will enable us to determine correctly

- various system design parameters
- system component type and specification
- component quantities
- Component and material cost

6.0. Available PV market opportunities

According to 2001 UNDP/GEF study on Solar PV market transformation in Mwanza, the following findings were noted

- There is a great potential of Solar PV use in the fishing industry where about 2,300 fishing vessels in Lake Victoria
- Only 5.3% of the population in Mwanza are connected to the National grid. The remaining population of about 95% remains as a potential market for Solar Home Systems and Institutions.
- About 249 Health centres in Mwanza Region are far from the national grid and solar PV is the most feasible power option at the moment.
- About 26 Health centres use solar PV for lighting and vaccine fridge with a combined installed capacity of 5.72 kWp.
- Solar water pumping is not popular in Mwanza, the potential of such technology exist around Lake Victoria.
- Apart from lack of capital there are no serious barriers to entry into the solar PV business in Mwanza. Joint procurement arrangement can reduce unit cost of solar PV component but is not yet practise since every company is striving for market leadership.
- Institutional support from MEM, UNDP/GEF Mwanza PV project, Government plan to remove duties, Growth of micro-financing institutions, and down trend in module prices were noted in the study as additional opportunities available to Solar PV business / dealers to develop and grow business.
- Neighbouring regions of Kagera, Mara, and Shinyanga are also seen as a viable and potential market for Mwanza based Solar PV dealers.

Following weakness were pointed out in the study

- Lack of necessary skills in Solar PV system sizing and installation
- Lack of general business education
- Lack of Capital for expanding existing investments
- High interest rates of loans.

Basing on above study, the following conclusion can be made

- If national grid is not extensively carried out in the near future, solar PV electrification for remote locations still remains to be an attractive option and is considered to form medium to long term interventions.
- High up-front cost of solar PV and lack of awareness are considered to be more critical amongst the business community and potential users hence the need to be properly addressed. Strategies could include identification of the most appropriate financing mechanism model for each market segment.
- The market potential for lighting and powering electronic systems in remote areas is quite significant, and hence it should be tapped
- Potential market segments include rural households, educational institutes, health facilities, NGO's, Government and Donor projects, Police posts, Prisons, ICT projects/centres, Mining, Fishing, Tourism, and Telecom Industries.

7.0. Case studies of well sized PV systems

Three examples of sizing are given whereby the consultant will go step in step to size them with the supplier/dealer basing on the procedures detailed in table1.

Example1

Appliance	Qty	Voltage (Volts)	Power (Watts)	Time (Hours)	Energy used (Watt-hours)
Lights bedrooms & kitchen	4	12VDC	9W	1h	36
Lights in toilets & bathroom	2	12VDC	7W	0.5h	7
Lights in sitting room	1	12VDC	11W	3h	33
Radio	1	6VDC	8W	5h	40

Daily Energy requirement 116 Wh

Selected system voltage is 12VDC

Total DC wattage is 62 W

Total AC wattage is 0 W

Example2

Appliance	Qty	Voltage (Volts)	Power (Watts)	Time (Hours)	Energy used (Watt-hours)
Lights in bedrooms	4	240VAC	11W	2h	88
Light in Kitchen	1	240VAC	11W	2h	22
Lights in toilets & bathroom	3	240VAC	9W	0.5h	13.5
Lights in sitting room	1	240VAC	15W	4h	60
Outside Lights	1	240VAC	9W	10h	90
Radio cassette	1	240VAC	50W	3h	150
Color TV 14"	1	240VAC	80W	3h	240

Daily Energy requirement 663.5 Wh

Selected system voltage is 12VDC

Total DC wattage is 0 W

Total AC wattage is 138 W

Example3 - Office in a remote rural area

Appliance	Qty	Voltage (Volts)	Power (Watts)	Time (Hours)	Energy used (Watt-hours)
Lights inside office	5	240VAC	15W	3	225
Lights outside office	2	240VAC	11W	12	264
Toilet Lights	2	240VAC	11W	0.5	11
Color TV 21"	1	240VAC	100	1	100
VCR	1	240VAC	50	1	50
Laptop computers	1	240VAC	90	2	180
Desktop computers	1	240VAC	180	3	540
Printer	1	240VAC	100	0.5	50
Photocopier	1	240VAC	1,000	0.25	250
Radio –call (transmit)	1	12VDC	240	1	240
Radio-call (receive)	1	12VDC	24	1	24
Radio-call (idle)	1	12VDC	5	6	6

Daily Energy requirement 1,940 Wh

Selected system voltage is 12VDC

Total DC wattage is 240 W

Total AC wattage is 1,539 W

8.0. Existing Local PV suppliers

BP Tanzania Limited (BP Solar)

P.O. BOX 9043 Dar Es Salaam

Tel: 022 2 111269

Fax: 022 2 112723

E-mail: john.mwera@tz.bp.com

Website: www.bp.com

Contact person: John Mwera (Mob: 0744 467862)

Rex Investment

P.O. BOX 76578

Dar Es Salaam

Tel: 022 2 180 109

Fax: 022 2 180 109

E-mail: solaenergy@cats-net.com

Contact person: Francis Kibhisa (mob: 0741 607533)

Chloride Exide Solar
P.O. BOX 76578
Dar Es Salaam
Tel: 022 2 182 209
Fax: 022 2 182 313
E-mail: cexidetz@africaonline.co.tz
Website: www.chloride-exide.com
Contact person: Louis Nyamwaya (mob: 0745 860 556)

Umeme Jua Limited
P.O. BOX 26
Dar Es Salaam
Tel: 022 2 135 661
Fax: 022 2 135 663
E-mail: sales@umemejua.com
Contact person: Caroline (mob: 0748 550 550)

Mona Mwanza Electrical & Electronics
P.O. BOX 110
Mwanza
Tel: 028 2 502 337
Fax: 028 2 502 910
E-mail: totomona@hotmail.com
Contact person: Nizarihussein Parpia (mob: 0744 487 183)

9.0. Existing International PV suppliers

List shown as appendix4

10.0. Service delivery models - Contracts

Contracts

Details signed and stamped terms and conditions of agreement governing supply or project execution process between supplier or service provider and the client. Agreement is done well before work or supply commencement and is witnessed by two lawyers each representing one part. Among other things the contract will include agreements on

- Type, source and specification of material or service to be supplied by the supplier to the client.**
- Quantities of each type of materials to be supplied.**
- Cost per unit of each material component to be supplied**
- Total Supply or Project value indicating provisions for currency fluctuation and contingencies.**
- Financial and Technical capacity of supplier.**

- **Security to the supplier or service provider in case the Client goes bankrupt or Project disrupted by political instabilities etc.**
- **Delivery time (for materials) or schedule of work for service e.g. installation.**
- **Mode of Payment (How and When)**
- **Percentage interest billed per day of delay in delivery expressed as a percentage of the contract value.**
- **Percentage interest billed per day of delay in payment expressed as a percentage of the contract value.**
- **Overall project management and supervision by Project Engineer/Manager (from supplier side) and Consultant (from Client's side).**
- **Duration of notification for changes one part wish to make to another part on any contract clause.**
- **Warranty of materials supplied or service rendered and any conditions governing the warranty.**
- **Maintenance requirement of plant or machine supplied / installed**
- **Spares required and availability.**
- **Termination of contract by either part.**
- **Dispute settling.**

For Solar PV systems warranties vary depending on the type of component and the manufacturer. It is usually 10 years for solar modules, one year for small batteries, three years for bigger batteries, and one year for inverters, charge regulators, lights etc. Maintenance requirement is attached as appendix5.

Appendix1: Power consumption of commonly used appliances

DC Appliances		
S/N	Appliance	Power consumption (Watts)
1	Submersible Pump	150
2	Ceiling Fan	25
3	Refrigerator	65
4	Television color 10"	60
5	Radio Tape player	35
6	Blender	80
AC Appliances		
S/N	Appliance	Power consumption (in Watts)
1	Energy saving lamps, ranges of	5,7, 9, 11, 13, 15, 18,25
2	Sewing machine	80
3	Color TV 14"	80
4	B&W TV 12"	13
5	B&W TV 14"	33
6	B&W TV 20"	60
7	Radio	5 – 30 depends on volume set
8	Cassette player	20 – 60 depends on volume set
9	Small iron (30 minutes)	300
10	Soldering iron (10 minutes)	200
11	Electric drill (5 minutes)	300
12	Lap top computer	40
13	Desk top Computer	100 - 200
14	Fan	60
15	Water Pump	450
16	Refrigerator	300 (runs 1/3 of time per day)
17	Blender	350
18	Dishwasher	1,200
19	Freezer	450
20	Refrigerator	330
21	Electric Iron	1,000
22	Micro-wave oven	800
23	Toaster	1,190
24	Washing machine	450
25	Coffee maker	1,200
26	Electric water Heater	5,000

Appendix3: List of Abbreviations and symbols used

	Abbreviation / Symbol	Description
	A	Ampere
	AC	Alternating Current
	Ah	Ampere-hours
	DC	Direct Current
	DoD	Depth of Discharge
	E	Energy
	GEF	Global Environmental Facility
	h	Hours
	I	Current
	ICT	Information and Communication Technology
	MEM	Ministry of Energy and Minerals
	NGO's	Non-Governmental Organizations
	P	Power
	PV	Photovoltaic
	Qty	Quantity
	TV	Television
	UK	United Kingdom
	UNDP	United Nations Development Program
	US	United States
	USD	United States Dollar
	V	Volt or Voltage
	VAC	Alternating Current Voltage
	VDC	Direct Current Voltage
	VCR	Video Cassette Recorder
	W	Watt
	Wh	Watt-hours

Appendix4

Existing International Solar PV suppliers

Appendix5

Maintenance requirement of Solar PV systems

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