Master Plan Study for Utilization of Solar Energy

in the Federal Republic of Nigeria

October 2006

Japan International Cooperation Agency (JICA)

Preamble

In response to the request of the Government of the Federal Republic of Nigeria (hereinafter referred to as “Nigeria”), the Government of Japan decided to conduct Master Plan Study for Utilization of Solar Energy in the Federal Republic of Nigeria (Hereinafter referred to as “Study”) in accordance with the relevant laws and regulations in force in Japan and entrusted the Study to the Japan International Cooperation Agency (hereinafter referred to as “JICA”), the official agency responsible for the implementation of the technical cooperation programs in the Government of Japan.

JICA sent the Master Plan Study Team (hereinafter referred to as “Team”) to Nigeria and conduct the Study in close cooperation with the authorities concerned in Nigeria. The Study includes a Pilot Project (hereinafter referred to as “Project”) using Photovoltaic (PV) systems, which is implemented in one (1) village each in Jigawa State, Ondo State, and Imo State.

The scope of the Project in Jigawa state includes the procurement, installation, and maintenance of the PV systems consisting of one (1) Battery Charging Station (BCS) including twenty (20) electrified households, one (1) Public Facility, forty (40) Solar Home Systems (SHSs), and ten (10) Street Lightings.

Meanwhile, the PV systems consist of one (1) Public Facility including one (1) PV vaccine refrigerator, sixty (60) SHSs, and ten (10) Street Lightings in Ondo state; the PV systems consist of one (1) Public Facility, eighty (80) SHSs, and ten Street Lightings (10) in Imo State,

The installation of the PV systems is completed late in June 2006, and the Project will be monitored up to February 2007 to evaluate the sustainability of PV systems in Nigeria.

The manual is specially prepared to instruct the concept and maintenance of PV systems of the Project and consists of three chapters: for users, for maintenance staff, and for engineers. The contents are as follows:

- For Users

  The chapter starts with the components of PV systems and illustrates what the users should do and should not do to keep the PV systems in good condition.

- For Maintenance Staff

  The chapter describes what the maintenance staff should do as a routine work. It also contains how to deal with the troubles of the PV systems.

- For Engineers

  The chapter starts with the general description of PV generation. For future reference, it also describes PV systems design.

PV Systems Manual

For Users

1.1 Components of PV Systems

JICA provides two kinds of PV systems for independent house use—Solar Home System (SHS) and Battery Charging Station (BCS). The SHS consists of the following components:

- PV Module: Getting the sunlight, the PV module generates electricity,
- Storage Battery: The electricity generated by the PV module during the daytime charges the storage battery. At night, the battery discharges and supplies electricity. JICA provides a sealed type battery which is maintenance-free,
- Charge Controller: The charge controller controls the charge/discharge of the battery and has a function to prevent the battery from over-discharge,
- Circuit Breaker: In case of short circuit, the circuit breaker automatically cuts off the circuit,
- Switch: The switch is used to turn on and off the lightings,
- Outlet: The outlet is used for DC appliances such as a radio, black and white television set, etc, and
- Lighting: The lighting, Compact Fluorescent Lump (CFL), is specially designed for DC use and is more efficient than an ordinary AC bulb.

Meanwhile, the BCS consists of the same components as the SHS except that the PV modules are not installed independently but aggregated at the station as a PV array. The Users of the BCS are required to take their batteries to the station every 4 or 5 days and charge them. Additionally, the battery is flooded type which is required to fill distilled water regularly.

Fig. 1-1 shows the configuration of PV systems.

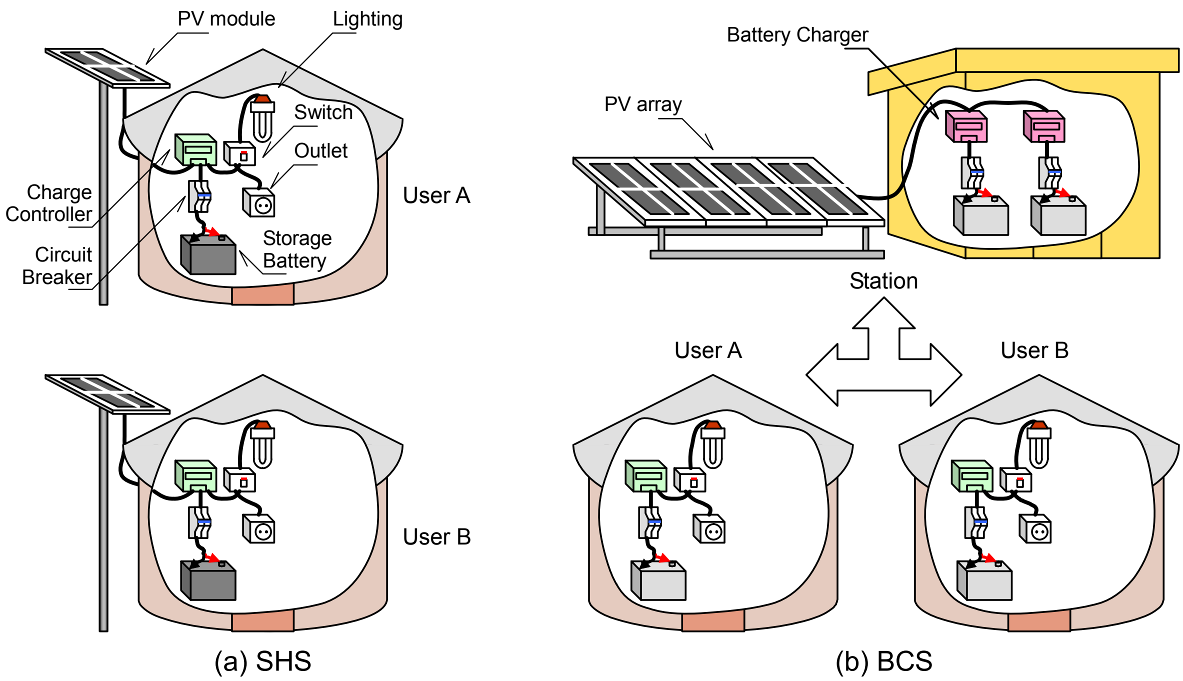
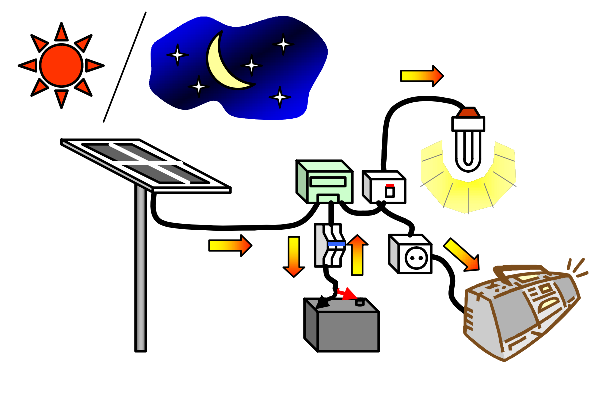
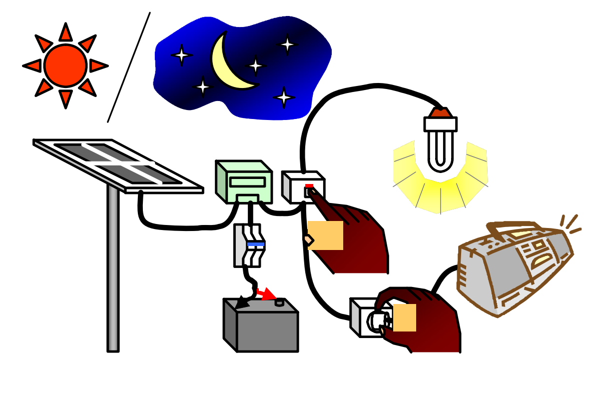
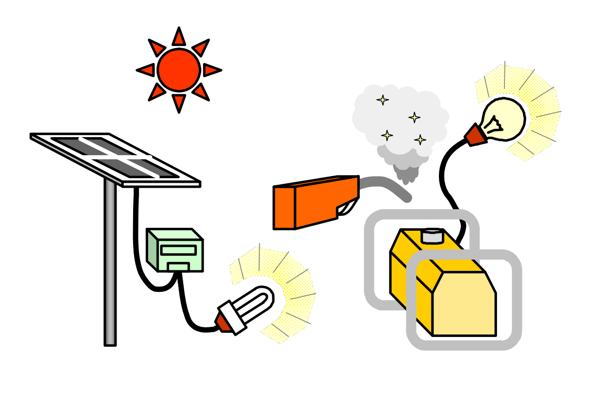
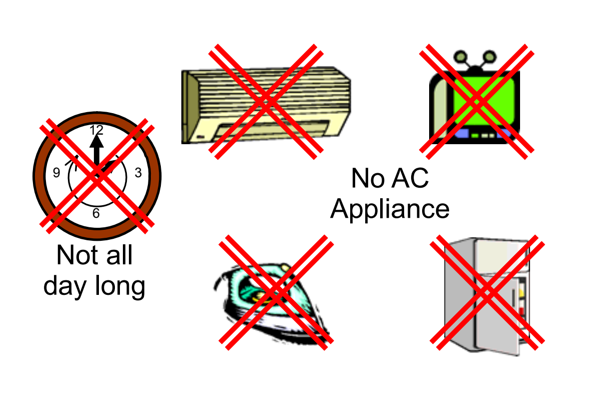


Fig. 1-1 Configuration of PV Systems

1.2 Feature of PV Systems

Table 1-1 illustrates the feature of PV systems.

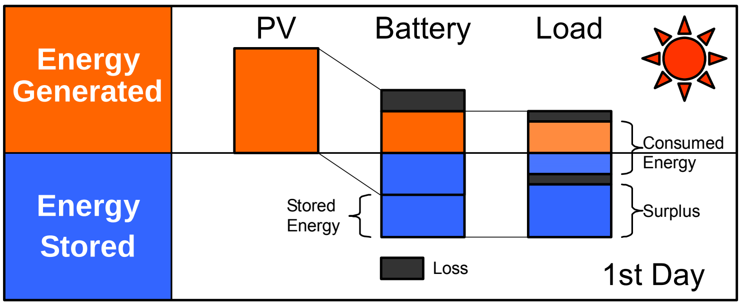
Table 1-1 Feature of PV Systems

Reliable You can use electricity whenever you need power.	***Simple*** When you need electricity, you just turn on the switch or plug in an appliance.
	
Ecologically Friendly During the generation, the PV systems do not produce any harmful substance.	***Having Limitations*** You can not use the PV systems all day long. In addition, AC appliances are not applicable.
	

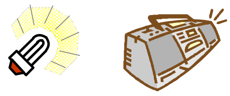
1.3 Concept of PV Systems

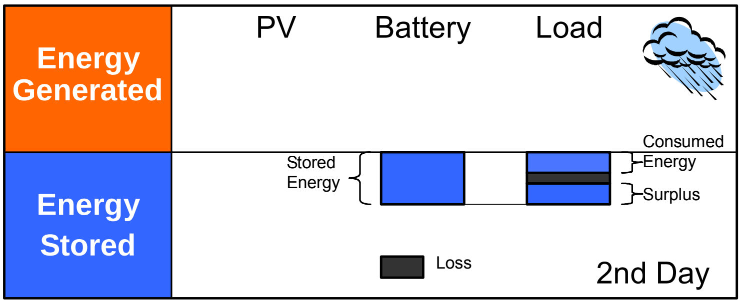
The output of the PV module totally depends on the weather. The more sunshine the PV module receives, the more electricity you can use. Meanwhile, the storage battery provides electricity at night. Even though you can not get any sunshine for a few days during the rainy season, the battery sustains the system and supplies you with electricity. However, the charge controller automatically disconnects the load when the battery voltage becomes too low to sustain the system.

Fig. 1-2 illustrates the concept of PV systems.

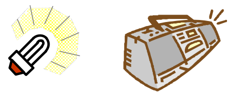


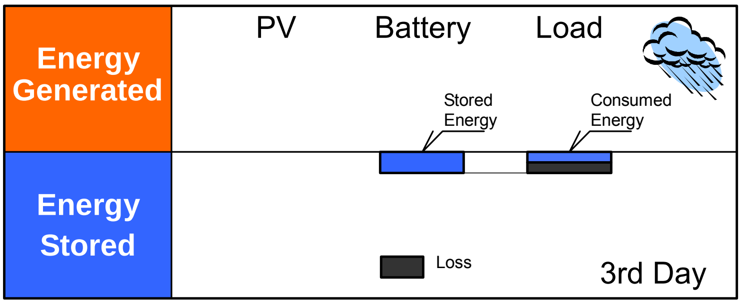
The PV module generates electricity, and surplus energy is stored in the battery.



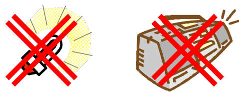


In case of rain, the PV module does not generate electricity at all, however, the battery supplies electricity.





When the battery runs out of the energy stored, the charge controller automatically disconnects the load.



- **Stop using electricity for a day, and**
- **Wait till the battery voltage recovers and the charge controller automatically reconnect the load.**

Fig. 1-2 Concept of PV Systems

1.4 Plan of Energy Consumption

Generally, the northern part of Nigeria shows the better solar irradiation conditions, in other words, you can use the PV systems longer in the north if the systems are identical. However, the hour of use depends on the load you use. So you need to make a plan of energy consumption considering the load you use.

Table 1-2 shows the daily limits of energy consumption which are calculated based on the solar irradiation conditions and specification of PV systems. As you see, high solar irradiation in Jigawa state allow you to consume energy most. For the purpose of using the PV system for as long a time as possible, you shall use energy within the limitation.

Table 1-2 Limit of Energy Consumption at SHS

	Jigawa	Ondo	Imo
Minimum Average solar irradiation [kW/m^2-day]	5.34	3.50	3.73
Capacity of PV module [W]	60	60	62
Lighting [W]	15 x 2	15 x 2	11 x 2
Limit of energy consumption [Wh/day]	120	85	90

Table 1-3 shows a quick reference matrix of energy consumption. First you select a nominal input of the load you use in the column of Watt, and then you find out energy consumption in Watt-hour in the same row depending on the time of use.

Table 1-3 Quick Reference Matrix of Energy Consumption in Watt-hour

Time / Watt	10 min	20 min	30 min	1 hour	2 hour	3 hour	4 hour	5 hour
1	0.2	0.3	0.5	1.0	2.0	3.0	4.0	5.0
2	0.3	0.7	1.0	2.0	4.0	6.0	8.0	10.0
5	0.8	1.7	2.5	5.0	10.0	15.0	20.0	25.0
9	1.5	3.0	4.5	9.0	18.0	27.0	36.0	45.0
10	1.7	3.3	5.0	10.0	20.0	30.0	40.0	50.0
11	1.8	3.7	5.5	11.0	22.0	33.0	44.0	55.0
15	2.5	5.0	7.5	15.0	30.0	45.0	60.0	75.0
20	3.3	6.7	10.0	20.0	40.0	60.0	80.0	100.0

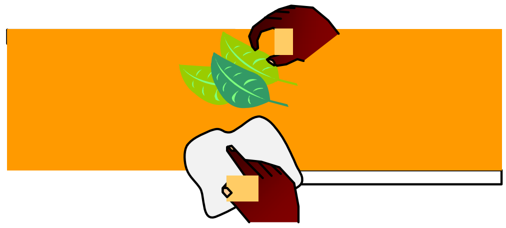
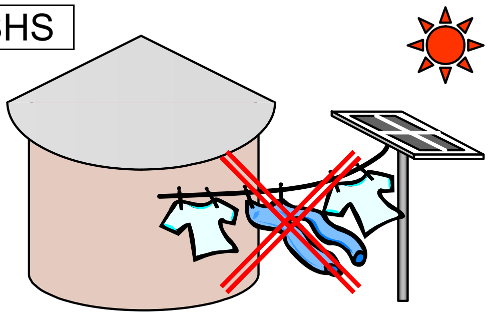
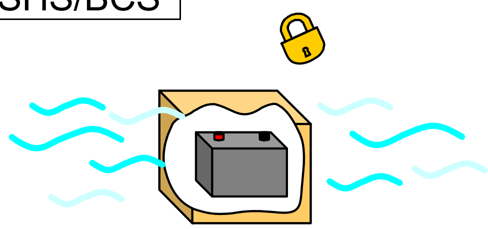
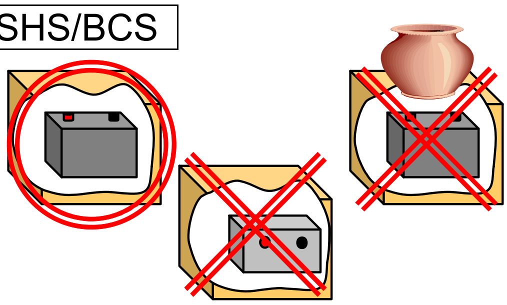
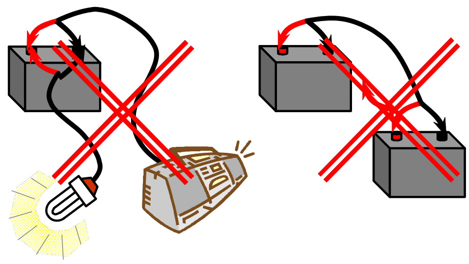
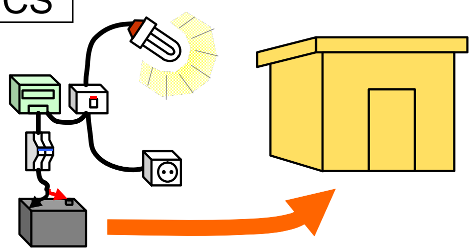
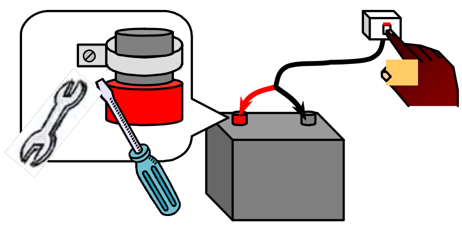
The following calculation shows an example of plan of energy consumption. In case of Jigawa, an nominal input of the two sets of lighting is 30 Watt. If you use them for 3.5 hours, the energy consumption yields 105 Watt-hour. Meanwhile, the energy consumption of radio for 3.0 hours is 15 Watt-hour, and we derive an accumulated energy consumption of 120 Watt-hour which meets the requirement of limit in Table 1-2.

Jigawa)	Light	30	Watt	x	3.5	hour	=	105.0	Wh
	Radio	5	Watt	x	3.0	hour	=	15.0	Wh
						Total		120.0	Wh

1.5 Points of Remember

In order to keep the PV systems in good condition, you should do and should not to do as illustrated in Table 1-4.

Table 1-4 Points of Remember

Should remove obstacles from the PV module to get as much sunshine as possible.	Should keep the PV module surface clean.
SHS 	SHS 
Should not hang the laundry on the cable to dry.	Should keep the battery in the battery box and lock it.
SHS 	SHS/BCS 
Should not put the battery sideways and leave any object on the battery box.	Should not connect the load to the battery terminal directly and connect the batteries in parallel.
SHS/BCS 	SHS/BCS 
Should take the battery to the station every 4 or 5 days and recharge it.	Should use a proper tool and be careful not to cause short circuit.
BCS  Take the batter to the station and recharge it	BCS Turn off the switch before connect/disconnect the cable 

PV Systems Manual

For Maintenance Staff

2.1 Components of PV Systems

JICA provides four kinds of PV systems—Battery Charging Station (BCS), Public Facility, Solar Home System (SHS), and Street Lighting. The components of the above PV systems are similar and have the following functions:

- PV Module/Array: Getting the sunlight, the PV module generates electricity,
- Storage Battery: The electricity generated by the PV module during the daytime charges the storage battery. At night, the battery discharges and supplies electricity. JICA provides sealed type batteries for SHSs and flooded type batteries for BCS households,
- Battery Charger: The charger is used to charge the storage batteries at BCS,
- Charge Controller: The charge controller controls the charge/discharge of the battery and has a function to prevent the battery from over-discharge,
- Circuit Breaker: In case of short circuit, the circuit breaker automatically cuts off the circuit,
- Switch: The switch is used to turn on and off the lightings,
- Outlet: The outlet is used for DC appliances such as a radio, black and white television set, etc,
- Lighting: The lighting, Compact Fluorescent Lump (CFL), is specially designed for DC use and is more efficient than an ordinary AC bulb, and
- PV Vaccine Refrigerator: The refrigerator is certified by the World Health Organization (WHO) and is specially designed for the purpose of preserving vaccines.

All the PV systems of the Project are operated at DC 12 V. Therefore, the Users are required to be careful when they choose the components of the system.

Fig. 2-1 illustrates the configuration of PV systems.

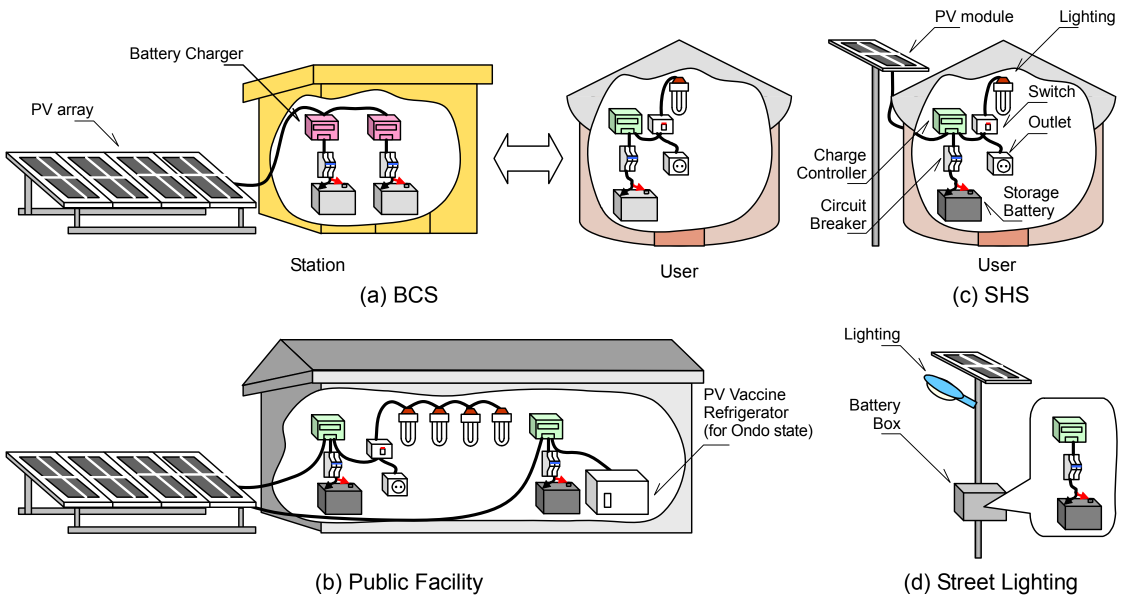


Fig. 2-1 Configuration of PV Systems

Table 2-1 to 3 illustrates the specification of the components in each state respectively.

Table 2-1 Specification of the Components in Jigawa State

Item	Specification
a. BCS	
i) Station	
PV Module	Polycrystal 60 W x 18 units
Charge Controller	12 V, 6 A x 1 unit
Battery Charger	12 V, 20 A x 5 units
Storage Battery	Sealed type for cycle use, 200 Ah x 1 unit
Lighting	12 V, 15 W Fluorescent Lamp x 2 units
ii) Household（per household）	
Charge Controller	12 V, 6 A x 1 unit
Storage Battery	Flooded type for trickle use, 88 Ah x 1 unit
Lighting	12 V, 15 W Fluorescent Lamp x 2 units
b. Public Facility	
PV Module	Polycrystal 60 W x 6 units
Charge Controller	12 V, 20 A x 1 unit
Storage Battery	Sealed type for cycle use, 200 Ah x 2 units
Lighting	12 V, 15 W Fluorescent Lamp x 12 units
c. SHS（per household）	
PV Module	Polycrystal 60 W x 1 unit
Charge Controller	12 V, 6 A x 1 unit
Storage Battery	Sealed type for cycle use, 65 Ah x 1 unit
Lighting	12 V, 15 W Fluorescent Lamp x 2 units
d. Street Lighting（per light）	
PV Module	Polycrystal 60 W x 1 unit
Charge Controller	12 V, 10 A x 1 unit, timer function
Storage Battery	Sealed type for cycle use, 65 Ah x 1 unit
Lighting	12 V, 18 W Sodium Lump x 1 unit

Table 2-2 Specification of the Components in Ondo State

Item	Specification
a. Public Facility	
i) Lighting	
PV Module	Polycrystal 60 W x 6 units
Charge Controller	12 V, 20 A x 1 unit
Storage Battery	Sealed type for cycle use, 200 Ah x 2 units
Lighting	12 V, 15 W Fluorescent Lamp x 10 units
ii) PV Vaccine Refrigerator	
PV Vaccine Refrigerator	38.7 liter x 1 unit
PV Module	Polycrystal 60 W x 4 units
Charge Controller	12 V, 15 A x 1 unit
Storage Battery	Sealed type for cycle use, 200 Ah x 1 unit, 100 Ah x 1 unit
b. SHS（per household）	
PV Module	Polycrystal 60 W x 1 unit
Charge Controller	12 V, 6 A x 1 unit
Storage Battery	Sealed type for cycle use, 65 Ah x 1 unit
Lighting	12 V, 15 W Fluorescent Lamp x 2 units
c. Street Lighting（per light）	
PV Module	Polycrystal 60 W x 1 unit
Charge Controller	12 V, 10 A x 1 unit, timer function
Storage Battery	Sealed type for cycle use, 65 Ah x 1 unit
Lighting	12 V, 18 W Sodium Lump x 1 unit

Table 2-3 Specification of the Components in Imo State

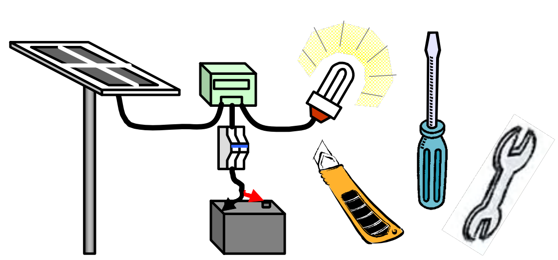
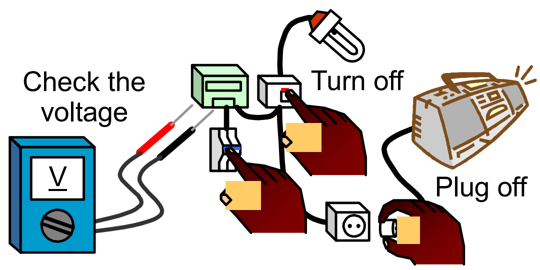
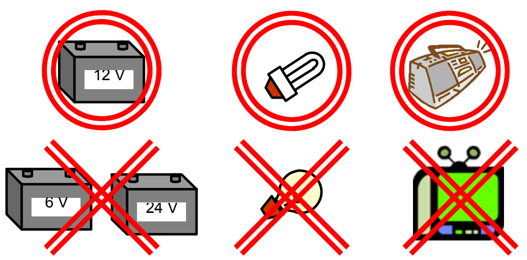
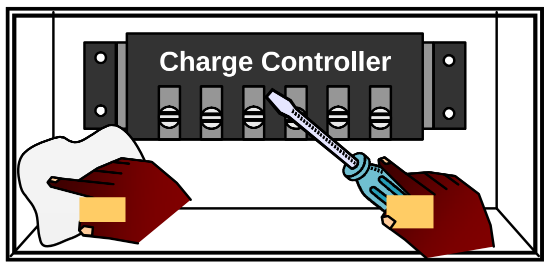
Item	Specification
a. Public Facility	
PV Module	Polycrystal 62 W x 8 units
Charge Controller	12 V, 30 A x 1 unit
Storage Battery	Sealed type for cycle use, 105 Ah x 4 units
Lighting	12 V, 11 W CFL x 12 units
b. SHS（per household）	
PV Module	Polycrystal 62 W x 1 unit
Charge Controller	12 V, 6 A x 1 unit
Storage Battery	Sealed type for cycle use, 60 Ah x 1 unit
Lighting	12 V, 11 W CFL x 2 units
c. Street Lighting（per light）	
PV Module	Polycrystal 62 W x 1 unit
Charge Controller	12 V, 10 A x 1 unit, timer function
Storage Battery	Sealed type for cycle use, 60 Ah x 1 unit
Lighting	12 V, 20 W CFL x 1 unit

2.2 Maintenance Works

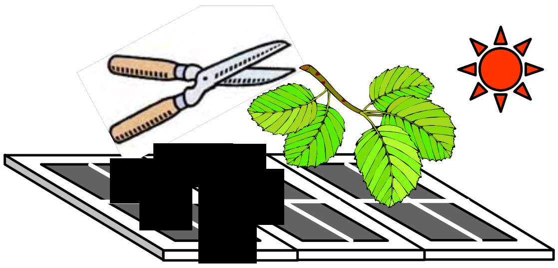
Generally, the PV systems do not need complicated maintenance works except filling distilled water in the flooded type batteries. You are required to check out the systems regularly and keep them in good condition.

The Points of remember are illustrated in the Table 2-4.

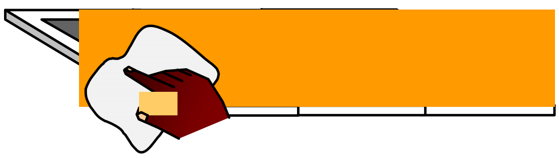
Table 2-4 Points of Remember

Should use proper tools during the maintenance work.	Should turn off the breaker and switch and check the voltage before the work.
	
Should use components which are designed for DC 12 V use.	Should fasten the screws if they are loose and clean the inside of the boxes.
	

Should remove obstacles from the PV arrays.

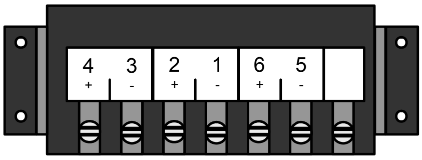


Should keep the PV arrays surface clean (Clean them up twice a month)



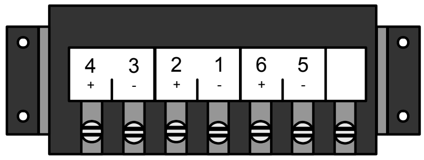
Clean up the surface twice a month

Should connect the cable in the order of the terminal number when you replace the charge controller.



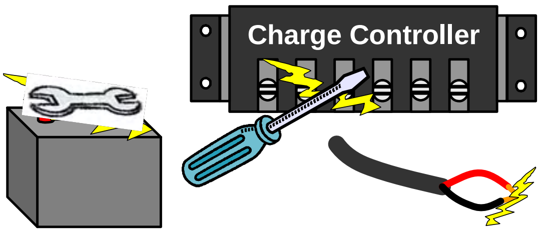
Turn off the switch/breaker and then connect the cables in the order of 1 ➔ 2 ➔ 3 ➔ 4 ➔ 5 ➔ 6

Should disconnect the cable in the opposite order of the terminal number when you replace the charge controller.

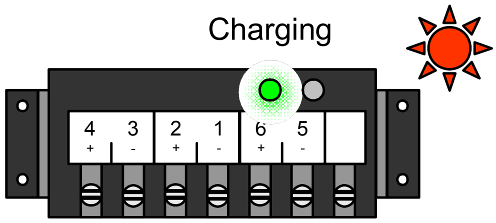


Turn off the switch/breaker and then disconnect the cables in the order of 6 ➔ 5 ➔ 4 ➔ 3 ➔ 2 ➔ 1

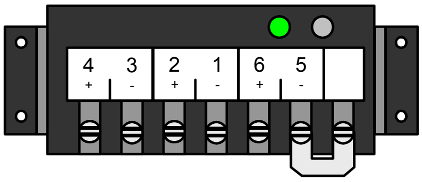
Should be careful not to cause short circuit.



Should confirm that the green light is on when the sunshine is present.

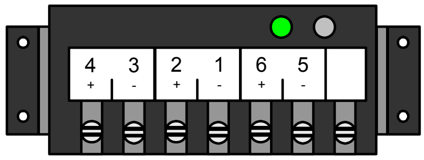


Should connect the jumper when a sealed type battery is used.

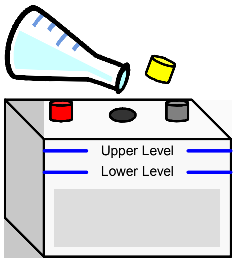
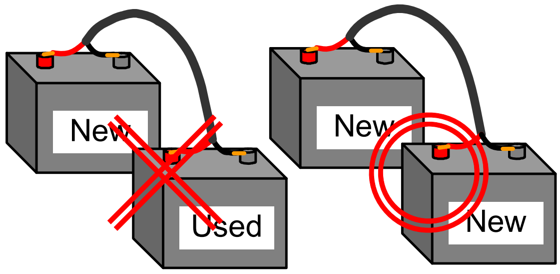


With the jumper, the charging voltage becomes 14.1 V for a sealed type battery.

Should remove the jumper when a flooded type battery is used.



Without the jumper, the charging voltage becomes 14.4 V for a flooded type battery.

Should confirm the level of electrolyte if a flooded type battery is used and fill distilled water up to the upper level.	Should replace the used batteries with the new ones at once.
 Do not use well water. Use only distilled water.	

2.3 Trouble Shooting

Most troubles can be checked at the terminals of the charge controller. In case that the User experiences a blackout, you shall check the system as follows:

a. Load Disconnection

- Check the indicator on the charge controller. If the red light is on, the charge controller has disconnected the load automatically because the battery voltage is too low to sustain the system.
- Make the User stop using electricity for a day and wait till the battery voltage recovers.
- When the battery voltage exceeds 12.6 V, the charge controller automatically reconnects the load.

b. Fault of Charge Controller

- Check the indicator on the charge controller. The green light is on during the daytime when the sunshine is present.
- Confirm that the breaker and switches are turned on.
- After turn off the breaker and switches, check all the wirings and their polarities. In addition, check all the terminal screws whether they are fastened tightly.
- Turn on the breaker and measure the voltage of each terminal.
- If the PV voltage—the voltage between the terminal 3 and 4—is close to the open voltage of the PV module and battery voltage—the voltage between the terminal 1 and 2—is low, the charge controller may be damaged. ➔ Replace the charge controller.
- If the battery voltage is too high, reconnect the cable on the PV terminals. The green light shall be off. If not, the charge controller may be damaged. ➔ Replace the charge controller.

c. Deterioration of Storage Battery

- The storage battery gradually deteriorates as the charge/discharge cycle goes by. Although the life cycle depends on how to use the battery, the expected lifetimes are approximately 5 or 6 years for a cycle use battery—a battery for PV generation application—and 1 or 2 years for a trickle use battery—a automobile battery, respectively
- If the load is disconnected quite often even though the User saves electricity, the battery will be replaced.

PV Systems Manual

For Engineers

3.1 Photovoltaic Power Generation

(1) Introduction

Photovoltaic (PV) power generation using solar energy which is clean and inexhaustible has great potential for supplying energy. Additionally, the generation will contribute to preventing global warming since it does not emit any carbon-dioxide.

PV systems consist of PV modules, inverters, batteries, and other components. To get needed voltage and current for a particular application, PV modules are connected in series and parallel to compose an array. The system is categorized either grid-connected system or stand-alone system. As is shown in Fig. 3-1, the grid-connected system can provide the load with electricity by both the PV module and grid. The system is used for a large system with capacity of a few kilowatts, and the surplus energy generated by the PV module will be sold to the utility company. Meanwhile, the stand-alone system is generally used in rural and remote areas where no distribution line exists. In order to provide power when the PV module generates no electricity, the system is equipped with the battery.

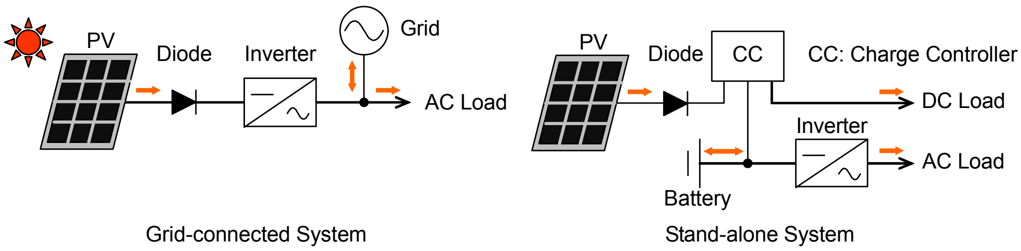


Fig. 3-1 Configuration of PV Systems

(2) Key Components of PV Systems

PV Module—A PV cell is a semiconductor device which converts light energy into electric energy by photovoltaic effect. Exposing the PV cell to light shown in Fig. 3-2, electron holes and electrons are generated around the p-n junction and transfer to p-type and n-type semiconductor respectively. Those electric charges cause an electric potential between the semiconductors. PV cells are categorized into three types: silicon semiconductor, compound semiconductor, and others. Among them, silicon semiconductor PV cells are only commercially available and categorized into crystalline and amorphous according to the materials. Table 3-1 shows their properties.

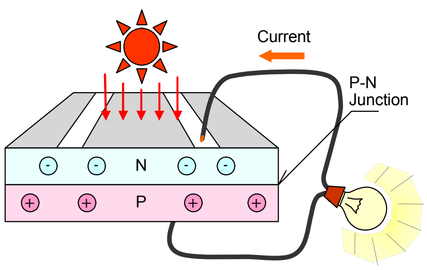


Fig. 3-2 Conceptual Diagram of Photovoltaic Effect

Table 3-1 Properties of Silicon Semiconductor PV Cells

Item \ Type	Monocrystal	Polycrystal	Amorphous
Conversion Efficiency	14 - 15%	11 - 13%	6 - 9%
Advantage	Widely used	High production volume	Cost reduction available
Disadvantage	High cost	High cost	Likely deteriorate

A PV module consists of tens of PV cells in series to get proper voltage for electrical appliances. As is shown in Fig. 3-3, PV cells are enclosed with Ethylene-Vinyl Acetate (EVA), and the semiconductors are connected with ribbon wirings. Furthermore, the cells filled with EVA resin are sandwiched between a front cover (reinforced-glass made) and back cover (film made), and rimmed with an aluminum frame.

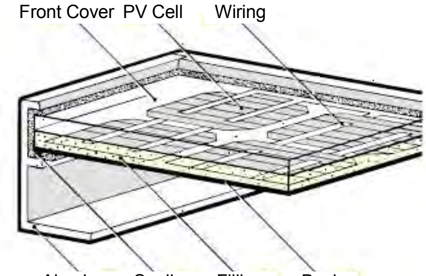


Fig. 3-3 Configuration of PV Module

The Fig. 3-4 shows a nameplate of PV module with capacity of 165 watt. The electrical characteristics is tested under the Standard Test Condition (STC) in accordance with IEC 60904-1—irradiance of 1000 W/m^2 with IEC 60904-3 reference solar spectral irradiance distribution, air mass (AM) 1.5 spectrum and cell temperature of 25 degrees. In addition, AM is defined as the ratio between the path length of perpendicular incidence and that of direct incidence as shown in Fig. 3-5. The electrical characteristics—Maximum power, open circuit voltage, short circuit current, maximum power voltage, and maximum power current—is greatly influenced by the condition of irradiance and cell temperature. As is shown in Fig. 3-6, the current I is maintained virtually constant against the voltage V until V gets at the maximum power voltage V_{pm}. In other words, PV modules function as constant current sources.

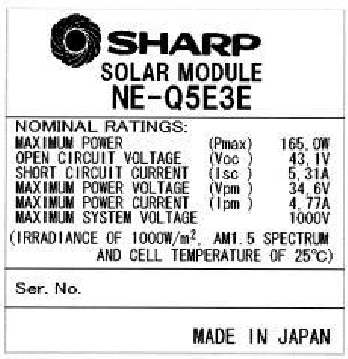


Fig. 3-4 Nameplate of PV Module

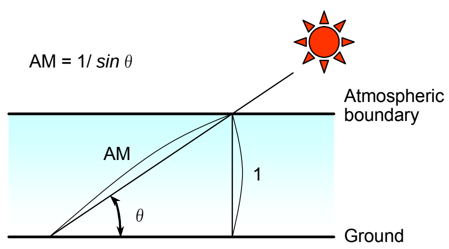
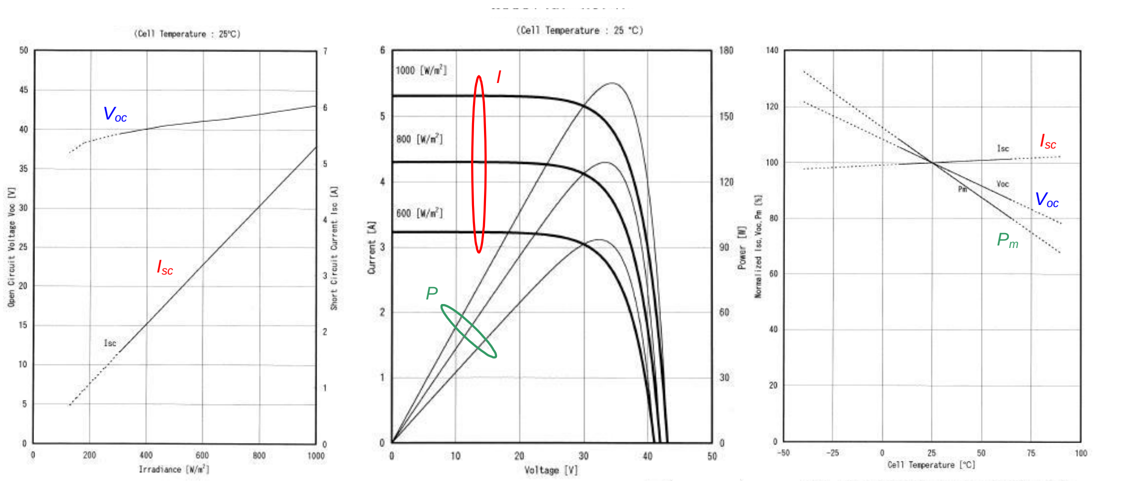


Fig. 3-5 Definition of Air Mass



V_{oc} and I_{sc} – irradiance characteristics *I and P – V characteristics* *P_m, V_{oc}, and I_{sc} – cell temperature characteristics*

Fig. 3-6 Electrical Characteristics of PV Module

Storage Battery—For PV system applications, lead batteries are widely used because they have a large capacity and are moderate-priced. Lead batteries are roughly classified into cycle and trickle use. A PV system repeats the cycles of charging electricity generated by the PV modules in the daytime and discharging it in the night. In general, batteries used for automobiles and Uninterruptible Power Supply (UPS) are float-charged at a constant voltage, and they are not appropriate for deep discharge—i.e. Depth of Discharge (DOD) * is large—and the repeating of charge and discharge. Consequently, in the event that batteries for trickle use are applied to the PV systems, there is possibility that the lifetimes of the batteries remarkably fall. Fig. 3-7 indicates the examples of battery discharge characteristics for trickle use with the depth of discharges as a parameter.

* Ratio of the amount of electric discharge against rated capacity

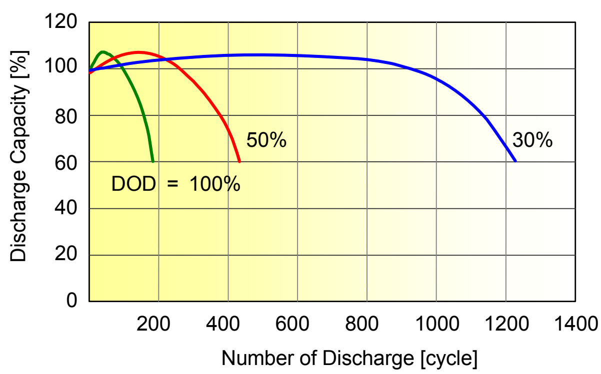


Fig. 3-7 Battery Discharge Characteristics

Fig. 3-8 shows a configuration of vented type battery. The negative and positive electrodes consist of expanded lead alloy filled with pasty lead powder. The active material for positive electrode is lead dioxide, while spongiform lead is used for the negative electrode. The separator prevents the electrodes from short circuit, and the glass mat is used to hold active materials on the electrodes.

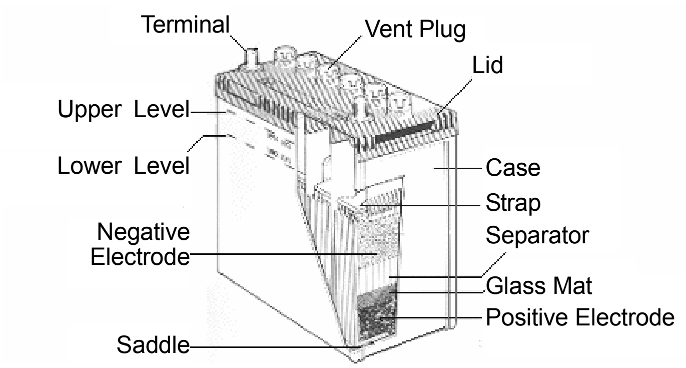


Fig. 3-8 Configuration of Vented Type Battery

Dilute sulfuric acid is used for the electrolyte. The chemical equation of the charge and discharge is expressed as follows:

$$\left.\begin{array}{l} PbO_2 + 2H_2SO_4 + Pb \;\rightarrow \text{discharge} \rightarrow\; Pb\,SO_4 + 2H_2O + Pb\,SO_4 \\ PbO_2 + 2H_2SO_4 + Pb \;\leftarrow \text{charge} \leftarrow\; Pb\,SO_4 + 2H_2O + Pb\,SO_4 \end{array}\right\} \quad (1)$$

The specific gravity of electrolyte indicates the State of Charge (SOC) of the battery. Using a hydrometer, the specific gravity can be measured as shown in Fig. 3-9. Using the following equation, the measured value can be converted to the standard value at 20℃.

$$SG_{20} = SG_t + 0.0007\,(t-20) \quad (2)$$

Where, SG_{20} : Specific Gravity at 20℃, SG_t : Specific Gravity at t℃, t : Electrolyte Temperature—using ambient temperature in practice. Finally, the converted value indicates the SOC of the battery as shown in Table 3-2. Note that the SG_{20} varies depending on the battery and electrolyte.

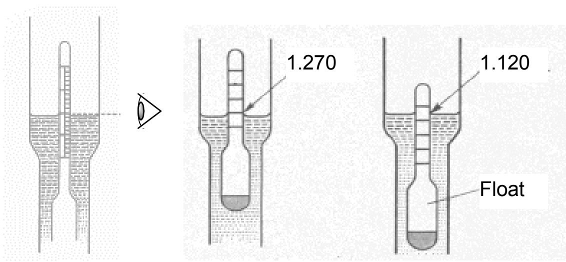


Fig. 3-9 Measuring Method of Specific Gravity

Table 3-2 Example of Specific Gravity-State of Charge Characteristics at 20℃

Specific Gravity	State of Charge [%]
1.280	100
1.240	75
1.200	50
1.160	25
1.120	0

Fig 3-10 shows a Valve Regulated Lead Acid (VRLA) battery—i.e. sealed type batteries. The VRLA battery contains small amount of electrolyte. Since the battery is sealed, it can be laid down. Fig. 3-11 shows the principal of the sealing means. Oxygen gas which is generated in the negative electrode at late stage of charge is absorbed by the spongiform lead of the electrode, and the gas is consumed inside the battery.

Fig. 3-10 VRLA Battery

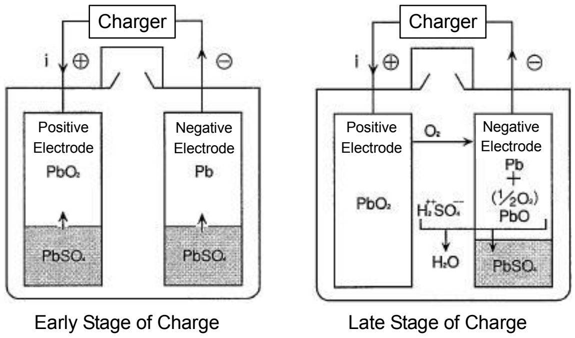


Fig. 3-11 Sealing Means of VRLA Battery

The capacity of a battery is a product of discharge current and time—Ampere-hour. When a battery is discharged at a constant current *I* for discharge time of *t* hours until the voltage *V* descends to the discharge termination voltage, the value of current is defined as an hour rate and expressed as *(1/ t) C* discharge. The hour rate capacities vary in accordance with the discharging currents. As shown in Fig. 3-12, the more discharge current becomes, the lower the discharge termination voltage turns out.

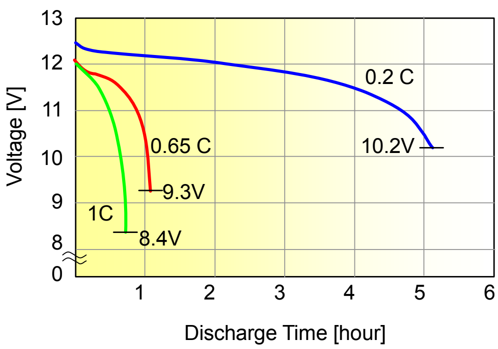


Fig. 3-12 Discharge Characteristics of Lead Acid Battery

Charge Controller and Inverter—A charge controller is used to control the battery charging by monitoring the battery voltage. Most controllers use Pulse-Width Modulation (PWM) control and automatically connect and disconnect the battery and load by semiconductor switches.

Fig. 3-13 Charge Controller

An Inverter is used to supply AC load with electricity. There are two types of inverters—one is sinewave type and the other is pseudo sinewave type as shown in Fig. 3-14. The sinewave type inverter supply the identical power frequency as the grid and can be used for any electrical appliances. Meanwhile, the pseudo sinewave type can not be used for the loads which operate depending on the wave form such as inverter type fluorescent lumps.

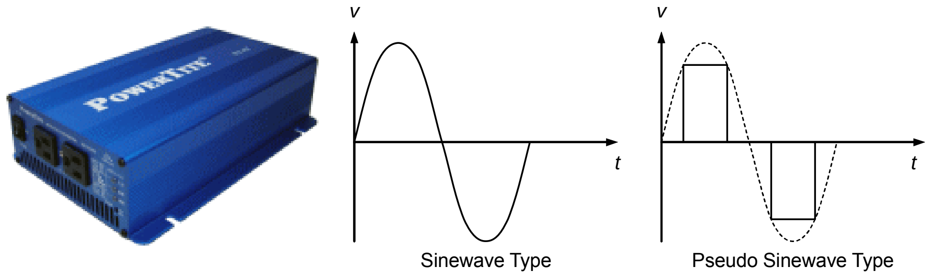


Fig. 3-14 Conceptual Diagram of Inver

Others—A fuse is used in main circuit of the PV system for preventing electrical appliances from the damage caused by short circuit. Especially, the fuse shall be connected between the battery and charge controller since the battery is easily broken by its short circuit current.

A Molded Case Circuit Breaker (MCCB) is used to switch on and off the circuit. In case of fault, it breaks the fault current after the certain time period in inversely relation to the percentage of fault current.

Fig. 3-15 Fuse for Low Voltage Circuit

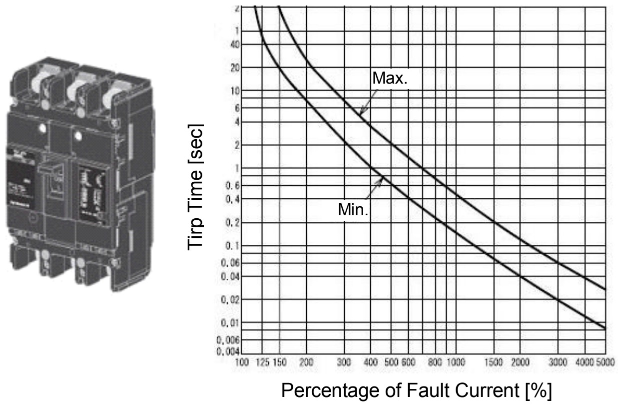


Fig. 3-16 Operating Characteristics of MCCB

3.2 PV Systems Design

(1) Introduction

Meteorological conditions greatly affect energy outputs of PV systems; however, the detailed data nearby project sites are often not available. In addition, since the installation conditions also have an effect on the energy outputs, the prediction of the energy is hard and difficult. In practice, a PV systems design is carried out by reference to the design of similar systems. Fig. 3-17 shows the flow chart of PV systems design

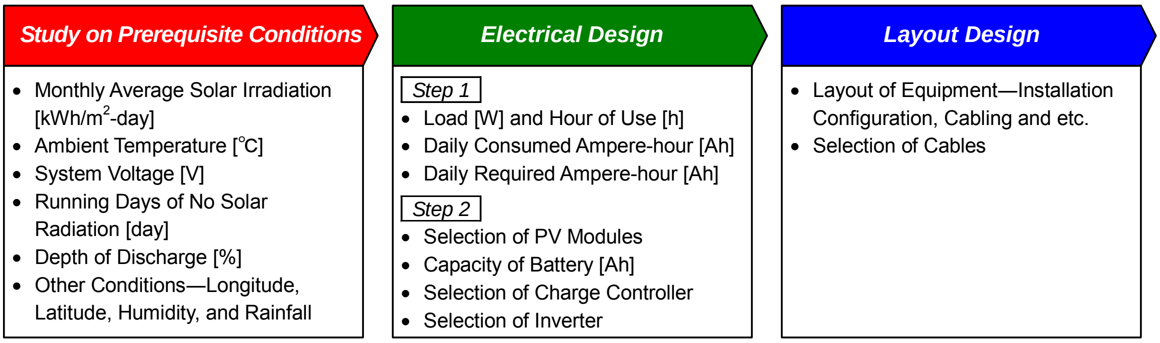


Fig. 3-17 Flow Chart of PV Systems Design

(2) Design Parameters

Direction and Tilt angle of PV modules—Since the earth rotates with axial inclination of 23.45 degree, solar irradiances on the ground have seasonal and location variations. Fig. 3-18 illustrates the orbit of the sun in the northern hemisphere. In midsummer, the sun orbits the highest path, while it takes the lowest path in midwinter. Fig. 3-19 shows the solar irradiance variation observed at Hamamatsu city, Japan, with latitude of 34.5 degree. The four curves represent the solar irradiance northward (N), southward (S), eastward (E), and westward (W). As is shown the figure, the southward irradiance becomes the highest. Thus the PV module shall face south to get the maximum solar irradiation. Additionally, the PV module shall be installed considering that no obstacle will shade the modules in midwinter.

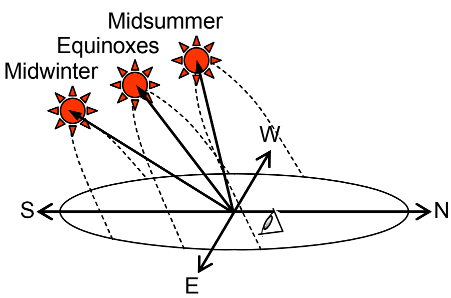


Fig. 3-18 Orbit of the Sun

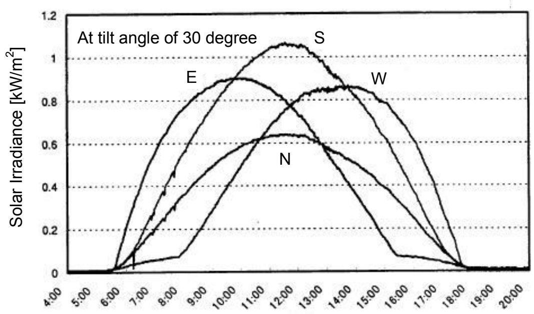


Fig. 3-19 Solar Irradiance Variation

According to the study in Japan, the optimum tilt angle which provides the maximum annual solar irradiation is slightly smaller than the latitude of the location. In addition, the PV module shall be set up at the tilt angle between 10 and 15 degrees at least to prevent rain water from remaining on the difference in level between their front cover and aluminum frame. Consequently, 15 degrees is recommended as the tilt angle in Nigeria because the country is located between the latitudes of 4 and 14 degree.

Solar Irradiation—Once you obtain the monthly average solar irradiation nearby the site, you have to determine the design value among the data. Being on the safe side, the minimum solar irradiation is recommended to use as the design value.

Ambient Temperature—Since the output of PV modules is greatly affected by the cell temperature, you have to carefully take ambient temperature into consideration. Typically, the output of PV modules will decrease approximately by 20% if the temperature rises by 50 degrees. If any average temperature over 45 degrees is expected at the site, you shall take it for the design value. Otherwise, assume 45 degrees as the design ambient temperature.

System Voltage—For the purpose of reducing the loss caused by the circuit current, the higher system voltage is preferable; however, most commercially available PV system products are designed for 12 V or 24 V use according to the rated voltage of batteries. For Solar Home Systems (SHSs) application, 12 V is suitable as the system voltage because rated power of SHSs is generally in the rage of 100 W. For the lager systems, 24 V or more is recommended as long as the products are available.

Running Days of No Solar Radiation and Depth of Discharge—The batteries supply the loads with electricity while the PV modules do not generate. The required capacity of the batteries is subjected to the running days of no solar radiation and DOD. Typically, 3 days are expected for no solar radiation, while DOD is assumed 50% as the design value.

(3) Design Methods

Study on Prerequisite Conditions—Firstly, determine the following design values:

- Monthly average solar irradiation SI_A [kW/m^2-day]—the minimum value of monthly average solar irradiations is recommend to use for the design,
- Ambient temperature T [degree]—45 degrees as long as the higher temperature is not expected,
- System voltage V_S [V]—12 V or 24 V,
- Running days of no solar radiation D_{NSR} [day]—3 days, and
- Depth of discharge *DOD* [%]—50%

And then, collect the other information such as the longitude, latitude, humidity, and rainfall. The information does not directly affects the electrical design of the PV systems; however, you have to confirm whether the rainfall which contributes to the self-cleaning of PV modules is expected or not at the site.

Electrical Design

- Daily Consumed Ampere-hour

Assume the loads and their hour of use. For AC loads, you have to take a conversion efficiency of inverter into consideration and assume it to be 90%. Dividing the loads by the system voltage, you derive the daily consumed ampere-hour AH_C from the quotient.

- Daily Required Ampere-hour

Find out the daily required ampere-hour AH_R considering the following correction coefficients:

- Correction coefficient of contamination K_D
- Correction coefficient of temperature K_T
- Correction coefficient of battery circuit K_B, and
- Other correction coefficient K_O

K_D represents the decrease of PV module outputs caused by the dust on their surface. According to the result of five-point observations in Japan, we assume K_D to be 0.98.

K_T represents the decrease of PV module outputs caused by the cell temperature rise. Define K_T as follows:

$$K_T = 1 + \alpha \; (T + \Delta T - 25) \qquad (3)$$

Where, α [degree^{-1}] : Coefficient of temperature, T [degree] : Ambient temperature, and ΔT [degree] : Temperature rise of PV modules. Assume PV modules outputs decrease by 20% when the temperature rises by 50 degrees and derive α to be - 0.4%/degree. ΔT varies according to the installation configuration of PV modules and is in the range of 18 to 25 degrees. Being on the safe side, assume that ΔT is 25 degrees. When T is 45 degrees, the K_T yields 0.82.

K_B represents the loss caused by charging and is generally to be 0.80 for lead acid batteries. K_O represents the other losses caused by wiring and charge controllers. Assume that it is 0.90.

Define the product of the above coefficients as the design coefficient as follows:

$$K = K_D \cdot K_T \cdot K_B \cdot K_O \qquad (4)$$

When T is 45 degrees, K yields 0.58. Dividing the AH_C by K, and derive the AH_R.

- Selection of PV Module

Determine the number of PV modules needed for the system. The PV output current I_{PV} is given by:

$$I_{PV} = AH_R \,/\, H_{SR} = AH_R \,/\, (SI_A \,/\, 1000) \qquad (5)$$

Where, AH_R [Ah/day] : Daily required ampere-hour, SI_A [kWh/m^2-day] : Average monthly solar irradiation, and H_{SR} [hour/day] : Hours of solar radiation—1000 W/m^2 represents the ideal solar irradiance on the ground.

Meanwhile, the PV output voltage V_{PV} is given by:

$$V_{PV} = V_S \cdot K_C + \Delta V_D + \Delta V_L \quad (6)$$

Where, V_S [V] : System voltage, K_C : Coefficient of full-charging, ΔV_D [V]: Voltage drop of diode, and ΔV_L : Voltage drop of wiring. K_C is generally to be 1.24 for lead acid batteries. ΔV_D is typically to be 0.7 V, while ΔV_L is determined according to the users' criteria. Referring to standard electrical characteristics of PV modules, you will decide the number and connection of PV modules so as to the PV array output meets the above requirement.

- Selection of Battery

The capacity of battery C_B is give by:

$$C_B = AH_C \cdot D_{NSR} / (K_L \cdot DOD / 100) \quad (7)$$

Where, AH_C [Ah/day] : Daily consumed ampere-hour, D_{NSR} [day] : Running days of No solar radiation, DOD [%] : Depth of discharge, and K_L: Coefficient of wiring and controller loss. Assume that K_L is 0.9.

- Selection of Charge Controller

Considering the charge controllers which are commercially available, decide the number of charge controllers N_C first, and then determine the rated input current of I_{IC} and output current I_{OC} as follows:

$$I_{IC} = I_{PV} / N_C \quad (8)$$

$$I_{OC} = P_M / (V_S \cdot N_C) \quad (9)$$

Where, I_{PV} [A] : PV output current , P_M [W] : Maximum Load input, V_S [V] : System voltage. Confirm that the rated currents of the charge controller meet the above requirement.

- Selection of Inverter

Determine the rated output current of I_{OI} and input current I_{II} as follows:

$$I_{OI} = P_{AC} / V_{AC} \quad (10)$$

$$I_{II} = I_{OI} \cdot V_{AC} / (V_S \cdot \eta) \quad (11)$$

Where, P_{AC} [W] : AC load input, V_{AC} [V] : AC load voltage, V_S [V] : System voltage, and η : conversion efficiency of inverter. We will select the inverters among commercially available product which meet the above requirement. The inverter shall be directly connected to the battery.

According to the type of the AC load, the higher power is required to start up the loads. For example, a color television consumes as 5 times higher power as the rated power when it stars, and a refrigerator needs as 10 times higher power as the rated power when its compressor starts. To determine the rated output of inverters, the above conditions have to be considered. A maximum load input P_{mI} is given by

$$P_{ml} = C_m \cdot P_{AC} \qquad (12)$$

Where, C_m : Multiple number between maximum load input and rated load input. The output power of the inverter shall meet the above requirement.

- Layout Design

Table 3-3 shows rated current associated with voltage drops for PVC cables regulated in Nigeria. In the regulation, total voltage drops between the consumer's terminals and any points in the installation shall not exceed 2.5% of the nominal voltage. Using the table, you will easily find out the voltage drops which are caused by the current.

Table 3-3 Rated Current associated with Voltage drops for PVC cables

Conductor		Enclosed in cable conduit		Unenclosed	
Cross-sectional area [mm^2]	Number / diameter of wires	Rated current [A]	Voltage drop [mV/A·m]	Rated current [A]	Voltage drop [mV/A·m]
1.0	1/1.13	11	40	13	40
1.5	1/1.38	13	27		27
	7/0.50		30	16	30
2.5	1/1.78				
	7/0.67	18	16	23	16
4	7/0.85	24	10	30	10
6	7/1.04	31	6.8	38	6.8
10	7/1.35	42	4.0	51	4.0
16	7/1.70	56	2.6	63	2.6
25	7/2.14	73	1.6	89	1.6
35	19/1.53	90	1.2	109	1.2

Source: 1996 Electricity Act. Electrical Installation Regulations, Nigeria

(4) Design Example

Table 3-4 shows an example of PV system design. In this example, the stand-alone system having both DC and AC loads is designed.

Table 3-4 Example of PV system Design

1. Prerequisite Conditions

- Site: FCT, Nigeria
- Average Solar Irradiation [kWh/m²-day]: 4.18 on Aug.
- Ambient Temperature [°C]: 45.0 No information
- System Voltage [V]: 12.0 12V products prevail.
- Running Days of No Solar Radiation [day]: 3.0

Depth of Discharge [%]: 50.0

2. Daily Consumed Ampere-hour

- Daily Consumed Ampere-hour [Ah/day]: 29.5

Load	Power (W)	Hour of use (h/day)	Efficiency	Consumed Ah (Ah/day)
DC Load, Fluorescent light (11W x 4)	44.0	6.0	1.0	22.0
AC Load, Color TV (40W x 1)	40.0	2.0	0.9	7.5
			Total	29.5

3. Daily Required Ampere-hour

- Daily Required Ampere-hour [Ah/day] = Daily Consumed Ampere-hour / Design Coefficient
  51.0

Correction Coefficient of Contamination	0.98	PV output decreases due to the contamination.
Correction Coefficient of Temperature	0.82	Output decreasing rate is -0.4%/deg
Correction Coefficient of Battery Circuit	0.80	Loss due to chargeing
Other Correction Coeffient	0.90	Loss due to wires and controllers
Design coefficient	0.58	

4. Selection of PV module

- Hours of Solar Radiation [h/day] = Average Solar Irradiation / 1000
  4.2
- PV output current [A] = Daily Required Ampere-hour / Hours of Solar Radiation
  12.2
- PV output voltage (V) = System voltage x charging coefficient + voltage drop
  15.9

Coefficient of Ful-charging	1.24	for lead acid battery
Voltage Drop of Diode [V]	0.70	for preventing adverse current
Voltage Drop of Wiring [V]	0.30	2.5% of system voltage (Nigeria standard)

- PV module specification

Maximum power rating (W)	55	Refer to Shell SM55 (55W)
Rated current (A)	3.15	ditto
Rated voltage (V)	17.4	ditto

- Noumber of Modules in Series

Since the rated voltage 17.4V > PV output voltage 15.9V, Number of modules in series shall be 1.

- Noumber of Modules in Parallel

PV output current (A)	12.20	
Rated current (A)	3.15	
Number of modules in parallel	4	

5. Capacity of Battery

・Capacity of Battery [Ah] = Daily Consumed Ah x Running Days of No Solar Radiation / (Coefficient of Wiring and Controller Loss x DOD / 100)

196.7	== >	200	Round up

Daily Consumed Ampere-hour [Ah/day]	29.5	
Running Days of No Solar Radiation [day]	3.0	
Depth of Discharge [%]	50.0	
Coefficient of Wiring and Controller Loss	0.9	loss due to wires and controllers

6. Selection of Charge Controller

・Input Current [A] = PV output current / Number of controllers

12.20	== >	13	Round up

PV Output Current [A]	12.20	
Number of Charge Controllers	1	4 modules/controller

・Output Current [A] = Maximum Load input / System Voltage / Number of controllers

3.67	== >	4	Round up

Maximum Load Input [W]	44.0	DC Load
System Voltage (V)	12.0	
Number of Controllers	1	

Being on the safe side, both the input and output current shall be 20A.

7. Selection of Inverter

・Output current [A] = Maximum Load Input / AC Load Voltage

0.17	== >	1	Round up

Maximum Load Input [W]	40.0	AC Load
AC Load Voltage[V]	230.0	

・Input Current [A] = Output Current x AC Load Voltage / System Voltage / Conversion Efficiency

3.70	== >	4	Round up

Output current [A]	0.17	
AC Load Voltage [V]	230.00	
System Voltage [V]	12.00	
Conversion Efficiency	0.9	

・Output Power [W] = Maximum Load Input X Multiple Number

200.00	== >	200	Round up

Maximum Load Input [W]	40.0	AC Load
Multiple number	5.0	The load is color TV.

8. Specification

System Voltage [V]	12	
PV Array Output [W]	220	55W x 4 modules
Battery [A]	200	
Charge controller [A]	20	1 unit
Inverter [W]	200	1 unit

The Federal Republic of Nigeria
Master Plan Study for Utlization of Solar Energy

Log Book
on the
Operation and Maintenance
of
the Pilot Project for Solar PV System

Village: Garkon Alli
Local Government Area: Kiyawa
State: Jigawa

Project Funded by

Japan International Cooperation Agency (JICA)

Log Book on the Operation and Maintenance
of
the Pilot Project for Solar PV System

Village: Garkon Alli **Local Government Area: Kiyawa** **State: Jigawa**

Name of Lessee: ______________________ **ID:** ______________

Type of Solar PV System(Tick as appropriate):
1) **Solar Home System** ☐
2) **Battery Charging System** ☐

Note: "0" denotes sample writing.

No.	Payment			Record on Maintenance Works											Security
	Date	Amount(₦)	Received by	Date of Breakdown	Lamp	Wiring	Switch	Battery	Charge Controller	Solar Panels	Description	Date of Action Taken and Its Contents	Result	Payment Made for Repairing Works	
0	2007/1/1	850	(Signature)	-	x	x	-	-		-	Broken during the renovation of the house	Assistance asked to the State Government for repairing	After 5 days, State Gov. sent engineer	Wiring: 500 Naira, Lamp: 400Naira	Solar panel was stolen on April/xx/20xx
Jan															
Feb															
Mar															
Apr															
May															
Jun															
Jul															
Aug															
Sep															
Oct															
Nov															
Dec															

Conditions of the Households and Life Stype that Affect the Use of Solay PV System, Complaints and Comments:

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Recorded by: ______________ **Reviewed by:** ______________ **Approved by:** ______________

Monthly Record of SHS Year:___________ Village: Garkon Alli   Local Government Area: Kiyawa   State: Jigawa

No.	No. of Payment			Area of Repairing Works						No. of Maintenance Works		Security of the Solar PV System
	Made	Not Made	Total Amount of Payment (N)	Lamp	Wiring	Switch	Battery	Charge Controller	Solar Panels	No. of Works	No. of Responses made by the State Government	
0	56	4	1590	-	2	1	-	-		3	3	No vanadalism this month.
Jan												
Feb												
Mar												
Apr												
May												
Jun												
Jul												
Aug												
Sep												
Oct												
Nov												
Dec												

Recorded by: ______________________   **Reviewed by:** ______________________   **Approved by:** ______________________

Revenue: **Year**____________________ **Village: Garkon Alli** **Local Government Area: Kiyawa** **State: Jigawa**

No.	Revenue				Spending		Balance to Date (₦)	Description
	Made	Not Made	Total Amount Collected this month (₦)	Total Cumulative Amount to date (₦)	Total Amount Spent for Maintenance Works (₦)	Remuneration (₦)		
0	56	4	36,400	36,400	1,590	10,000	10,000	
Jan								
Feb								
Mar								
Apr								
May								
Jun								
Jul								
Aug								
Sep								
Oct								
Nov								
Dec								

Recorded by: ____________________ **Reviewed by:** ____________________

Monthly Record of BCS: Month____________________, 2006 Village: Garkon Alli Local Government Area: Kiyawa State: Jigawa

BCS House No.	Individual Battery Charging Works					Maintenance Works of Battery Charging Station						Descriptions
	Serial No. of Battery	Conditions of Battery (water, etc.)	Date. of Charging	Total No. of Battery Charging of the Month	Extra Payment (₦) *	Charging Plug	Wiring	Switch	Battery	Charge Controller	Solar Panels	
Sample Writing	(No.)	Good	Jan/5, 15, 25	3	-	-	-	Getting loose	-	-	-	
BCS 01												
BCS 02												
BCS 03												
BCS 04												
BCS 05												
BCS 06												
BCS 07												
BCS 08												
BCS 09												
BCS 10												
BCS 11												
BCS 12												
BCS 13												
BCS 14												
BCS 15												
BCS 16												
BCS 17												
BCS 18												
BCS 19												
BCS 20												

Note: * - Payment imposed on excessive charging.

Recorded by: ____________________ **Reviewed by:** ____________________ **Approved by:** ____________________

Data Sheet for Charging Record

BCS Charging Record Month ______

No.	Date / Voltage	Record 1	Record 2	Record 3	Record 4	Record 5	Record 6	Record 7	Record 8	Remarks
1	Before Charging	/	/	/	/	/	/	/	/	
	After Charging	/	/	/	/	/	/	/	/	
2	Before Charging	/	/	/	/	/	/	/	/	
	After Charging	/	/	/	/	/	/	/	/	
3	Before Charging	/	/	/	/	/	/	/	/	
	After Charging	/	/	/	/	/	/	/	/	
4	Before Charging	/	/	/	/	/	/	/	/	
	After Charging	/	/	/	/	/	/	/	/	
5	Before Charging	/	/	/	/	/	/	/	/	
	After Charging	/	/	/	/	/	/	/	/	
6	Before Charging	/	/	/	/	/	/	/	/	
	After Charging	/	/	/	/	/	/	/	/	
7	Before Charging	/	/	/	/	/	/	/	/	
	After Charging	/	/	/	/	/	/	/	/	
8	Before Charging	/	/	/	/	/	/	/	/	
	After Charging	/	/	/	/	/	/	/	/	
9	Before Charging	/	/	/	/	/	/	/	/	
	After Charging	/	/	/	/	/	/	/	/	
10	Before Charging	/	/	/	/	/	/	/	/	
	After Charging	/	/	/	/	/	/	/	/	
11	Before Charging	/	/	/	/	/	/	/	/	
	After Charging	/	/	/	/	/	/	/	/	
12	Before Charging	/	/	/	/	/	/	/	/	
	After Charging	/	/	/	/	/	/	/	/	
13	Before Charging	/	/	/	/	/	/	/	/	
	After Charging	/	/	/	/	/	/	/	/	
14	Before Charging	/	/	/	/	/	/	/	/	
	After Charging	/	/	/	/	/	/	/	/	
15	Before Charging	/	/	/	/	/	/	/	/	
	After Charging	/	/	/	/	/	/	/	/	
16	Before Charging	/	/	/	/	/	/	/	/	
	After Charging	/	/	/	/	/	/	/	/	
17	Before Charging	/	/	/	/	/	/	/	/	
	After Charging	/	/	/	/	/	/	/	/	
18	Before Charging	/	/	/	/	/	/	/	/	
	After Charging	/	/	/	/	/	/	/	/	
19	Before Charging	/	/	/	/	/	/	/	/	
	After Charging	/	/	/	/	/	/	/	/	
20	Before Charging	/	/	/	/	/	/	/	/	
	After Charging	/	/	/	/	/	/	/	/	
	Before Charging	/	/	/	/	/	/	/	/	
	After Charging	/	/	/	/	/	/	/	/	
	Before Charging	/	/	/	/	/	/	/	/	
	After Charging	/	/	/	/	/	/	/	/	
	Before Charging	/	/	/	/	/	/	/	/	
	After Charging	/	/	/	/	/	/	/	/	

Example of filling out the data sheet

No.	Date / Voltage	Record 1	Record 2	Record 3	Record 4	Record 5	Record 6	Record 7	Record 8	Remarks
1	Before Charging	1 / 12.0 V	6 / 12.5 V	10 / 12.0 V	17 / 11.8 V	22 / 12.0 V	27 / 12.5 V	/	/	Filling the battery with
	After Charging	2 / 14.5 V	7 / 14.0 V	12 / 14.5 V	18 / 14.5 V	23 / 14.0 V	28 / 14.5 V	/	/	distilled water on 22nd.

Data Sheet for Charging Record

BCS No. ______ Month ______

Weather 1. Sunny, 2. Cloudy, 3. Rainy, 4. Occasionally rainy, 5. Occasionally Cloudy

Load 1. Lighting 1, 2. Lighting 2, 3. Radio, 4. Others (Indicate it in the remarks)

Date	Weather	Energy Consumption Record															Remarks
		Record 1			Record 2			Record 3			Record 4			Record 5			
		Load	From	To	Load	From	To	Load	From	To	Load	From	To	Load	From	To	
1																	
2																	
3																	
4																	
5																	
6																	
7																	
8																	
9																	
10																	
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24																	
25																	
26																	
27																	
28																	
29																	
30																	
31																	

Example of filling out the data sheet

Date	Weather	Energy Consumption Record															Remarks
		Record 1			Record 2			Record 3			Record 4			Record 5			
		Load	From	To	Load	From	To	Load	From	To	Load	From	To	Load	From	To	
1	1	3	10:00	12:00	1	19:00	21:00	2	19:00	22:00							
2	4	4	12:00	14:00	1	15:00	16:00	1	19:00	23:00							B/W TV, 30W

Data Sheet for Charging Record

Public Facility Month ______

Weather 1. Sunny , 2. Cloudy , 3. Rainy , 4. Occasionally rainy / , 5. Occasionally Cloudy /

Load 1. Lighting 1 x 4 , 2. Lighting 2 x 4 , 3. Lighting 3 x 4 , 4. Radio , 5. Others (Indicate it in the remarks)

Date	Weather	Energy Consumption Record															Remarks
		Record 1			Record 2			Record 3			Record 4			Record 5			
		Load	From	To	Load	From	To	Load	From	To	Load	From	To	Load	From	To	
1																	
2																	
3																	
4																	
5																	
6																	
7																	
8																	
9																	
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23																	
24																	
25																	
26																	
27																	
28																	
29																	
30																	
31																	

Example of filling out the data sheet

Date	Weather	Energy Consumption Record															Remarks
		Record 1			Record 2			Record 3			Record 4			Record 5			
		Load	From	To	Load	From	To	Load	From	To	Load	From	To	Load	From	To	
1	1	1	19:00	21:00	2	19:00	21:00	3	19:00	21:00							
2	4	4	12:00	14:00	5	15:00	17:00	1	19:00	21:00							B/W TV, 30W

Data Sheet for Charging Record

SHS No. ______ Month ______

Weather 1. Sunny, 2. Cloudy, 3. Rainy, 4. Occasionally rainy, 5. Occasionally Cloudy

Load 1. Lighting 1, 2. Lighting 2, 3. Radio, 4. Others (Indicate it in the remarks)

Date	Weather	Energy Consumption Record															Remarks
		Record 1			Record 2			Record 3			Record 4			Record 5			
		Load	From	To	Load	From	To	Load	From	To	Load	From	To	Load	From	To	
1																	
2																	
3																	
4																	
5																	
6																	
7																	
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28																	
29																	
30																	
31																	

Example of filling out the data sheet

Date	Weather	Energy Consumption Record															Remarks
		Record 1			Record 2			Record 3			Record 4			Record 5			
		Load	From	To	Load	From	To	Load	From	To	Load	From	To	Load	From	To	
1	1	3	10:00	12:00	1	19:00	21:00	2	19:00	22:00							
2	4	4	12:00	14:00	1	15:00	16:00	1	19:00	23:00							B/W TV, 30W

Data Sheet for Charging Record

Spare Parts and Lending Goods

No.	Item	Specification	Unit	Remaining Quantities													Remarks
				Initial	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	
1. Spare Parts for BCS																	
1.1	Battery Charger	12 V, 20 A	pcs	1													
1.2	Charge Controller	12 V, 6 A	pcs	1													
1.3	Storage Battery	88 Ah, vented type, trickle use	pcs	2													
1.4	Circuit Breaker	Bipolar, 30 A	pcs	1													
1.5	ditto	Bipolar, 20 A	pcs	1													
1.6	ditto	Bipolar, 10 A	pcs	2													
1.7	Lighting	12 V, 15 W, fluorescent lamp	pcs	22													
1.8	Switch	Bipolar, DC 12 V	pcs	10													
1.9	Outlet	DC 12V	pcs	5													
1.10	Distilled Water	20 liter	pcs	1													
2. Spare Parts for Public Facility																	
2.1	Charge Controller	12 V, 20 A	pcs	1													
2.2	Circuit Breaker	Bipolar, 20 A	pcs	1													
2.3	Lighting	12 V, 15 W, fluorescent lamp	pcs	6													
2.4	Switch	Bipolar, DC 12 V	pcs	1													
2.5	Outlet	DC 12V	pcs	1													
3. Spare Parts for SHS																	
3.1	Charge Controller	12 V, 6 A	pcs	2													
3.2	Circuit Breaker	Bipolar, 10 A	pcs	2													
3.3	Lighting	12 V, 15 W, fluorescent lamp	pcs	40													
3.4	Switch	Bipolar, DC 12 V	pcs	20													
3.5	Outlet	DC 12V	pcs	10													
4. Spare Parts for Street Lighting																	
4.1	Charge Controller	12 V, 10 A	pcs	2													
4.2	Circuit Breaker	Bipolar, 10 A	pcs	2													
4.3	Lighting	12 V, 18 W, Sodium lamp	pcs	5													
5. Lending Goods																	
5.1	Radio	12V, 5W with DC plug	pcs	4													
5.2	Digital Multimeter	Portable	pcs	1													
5.3	Maintenance Tool	Driver, wrench, etc.	lot	1													

Example of filling out the inventory

No.	Item	Specification	Unit	Remaining Quantities													Remarks
				Initial	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	
1. Spare Parts for BCS																	
1.7	Lighting	12 V, 15 W, fluorescent lamp	pcs	22			22	20	19	15	10	20	19	18	18	17	Purchase 10 sets of FL in Aug.
5. Lending Goods																	
5.1	Radio	12V, 5W with DC plug	pcs	4			4	4	4	4	4	4	4	4	4	4	

Questionnaire about the Pilot Project State: Jigawa/Ondo/Imo, User: SHS/BCS No. _____

1. Attribute
a. Name: ________________ b. Age: _____ c. Number of family members: Male _____, Female _____
d. Occupation: ☐ Employed worker ☐ self-employed worker ☐ Farmer ☐ Others ( )
e. Yearly income ___________ f. Number of rooms _____
2. General
2.1 Are you satisfied with the PV systems? Tick one (1) choice.
☐ Yes, very much ☐ Yes, moderately ☐ No, not much ☐ No, not at all
2.2 What is the reason of the above answer? Tick one (1) choice.
☐ Expensive tariff ☐ Reasonable tariff ☐ Reliable/Easy to use ☐ Environmentally friendly
2.3 Do you understand how to use the PV systems? Tick one (1) choice.
☐ Yes, very well ☐ Yes, moderately ☐ No, not well ☐ No, not at all
2.4 Do you understand that the PV systems have the limitations? Tick one (1) choice.
☐ Yes, very well ☐ Yes, moderately ☐ No, not well ☐ No, not at all
2.5 Who use the PV systems often? Tick one (1) choice.
☐ Husband ☐ Wife ☐ Children ☐ Visitors
2.6 From a husband point of view, what did the PV systems improve? Mark the number in order.
( ) Household work ( ) Child care ( ) Reading/ Studying ( ) Security
( ) Income ( ) Saving expenses ( ) Information ( ) Having fun
2.7 From a housewife point of view, what did the PV systems improve? Mark the number in order.
( ) Household work ( ) Child care ( ) Reading/ Studying ( ) Security
( ) Income ( ) Saving expenses ( ) Information ( ) Having fun
2.8 Did you start any business after you started using the PV systems? Tick one (1) choice.
☐ house industry ☐ Sewing ☐ None ☐ Others ( )
2.9 How much did you spend for energy (kerosene, battery, etc.) before you started using the PV systems? Write the monthly amount. __________
2.10 How much do you spend for energy (kerosene, battery, etc.) now? Write the monthly amount. ______
2.11 If possible, how may lighting points do you need? Write the number.__________
2.12 Which system do you like best? Tick one (1) choice.
☐ 55 W SHS for two (2) sets of lamps and one (1) radio at the rate of N500/month.
☐ 110 W SHS for four (4) sets of lamps, one (1) radio, and one (1) TV set at the rate of N750/month.
☐ 165 W SHS for six (6) sets of lamps, one (1) refrigerator, and one (1) TV set at the rate of N1,000/month.
☐ BCS for two (2) sets of lamps and one (1) radio at the rate of N50/charge.
2.13 If possible, which appliances do you want to use? Mark the number in order.
( ) Fan ( ) TV set ( ) Refrigerator ( ) Lighting ( ) Others ( )
2.14 Do you own a generator? Tick (1) one choice and write the output.
☐ Yes. Output:_______W ☐ No
2.15 What appliances do you own? Tick as many as you own.
☐ Radio ☐ Fan ☐ TV set ☐ Lighting ☐ Others ( )
3. Public Facility/Street Lighting
3.1 What do you think Public Facility/Street Lighting? Tick one (1) choice.
☐ Beneficial ☐ Not beneficial ☐Others ( )
3.2 If possible, how long do you want to use Street Lighting? Tick one (1) choice.
☐ 4 hours ☐ 6 hours ☐ 8 hours ☐ 10 hours ☐ 12 hours
3.3 Are you willing to pay tariffs for Public Facility/Street Lighting? Tick one (1) choice.
☐ Yes, very much ☐ Yes, moderately ☐ No, not much ☐ No, not at all
3.4 What is the reason of the above answer? Tick one (1) choice.
☐ Beneficial ☐ Not beneficial ☐ L.G. shall pay for them ☐Others ( )

Questionnaire about the Pilot Project State: Jigawa/Ondo/Imo, User: SHS/BCS No. _____

4. SHS *SHS users only
4.1 What do you think the monthly tariff of SHS? Tick one (1) choice. ☐ Inexpensive ☐ Reasonable ☐ Expensive
4.2 Considering the charging fee at BCS, which do you prefer, SHS or BCS? Tick one (1) choice. ☐ SHS ☐ BCS
4.3 What is the reason of the above answer? Tick one (1) choice. ☐ Expensive tariff ☐ Reasonable tariff ☐ Reluctant to carry the battery ☐Others ( )
5. BCS *BCS users in Jigawa state only
5.1 What do you think the charging fee at BCS? Tick one (1) choice. ☐ Inexpensive ☐ Reasonable ☐ Expensive
5.2 Considering the monthly charge of SHS, which do you prefer, SHS or BCS? Tick one (1) choice. ☐ SHS ☐ BCS
5.3 What is the reason of the above answer? Tick one (1) choice. ☐ Expensive tariff ☐ Reasonable tariff ☐ Reluctant to carry the battery ☐Others ( )
6. Village Committee
6.1 Does the committee manage the Pilot Project? Tick one (1) choice. ☐ Yes, very well ☐ Yes, moderately ☐ No, not well ☐ No, not at all
6.2 Does the maintenance staff maintain the PV system properly? Tick one (1) choice. ☐ Yes, very well ☐ Yes, moderately ☐ No, not well ☐ No, not at all
7. Local Government and State Government
7.1 Do you think the L.G./S.G. contribute to the Pilot Project enough? Tick one (1) choice. ☐ Yes, very much ☐ Yes, moderately ☐ No, not much ☐ No, not at all
7.2 What do you expect the L.G./S.G. to do? Tick one (1) choice. ☐ Financial support ☐ Technical support ☐Others ( )
8. Comments on the Pilot Project, if any
Thank you for your cooperation.

Signature: ____________________

Result of Questionnaire about the Pilot Project

1. Attribute

Table 1-1 Number of answers

State	Number of objectives	Number of answers	Ratio of respondents	Remarks
Jigawa	58	58	100%	Excluding 2 systems for schools
Ondo	51	46	90%	Excluding 9 systems for schools, church, etc.
Imo	80	68	85%	
Total	189	172	91%	

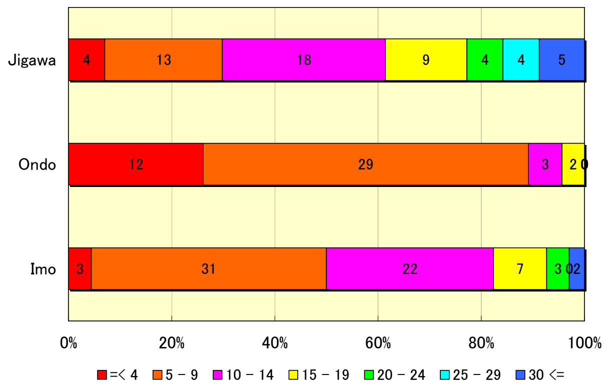

Fig. 1-1 Number of family members

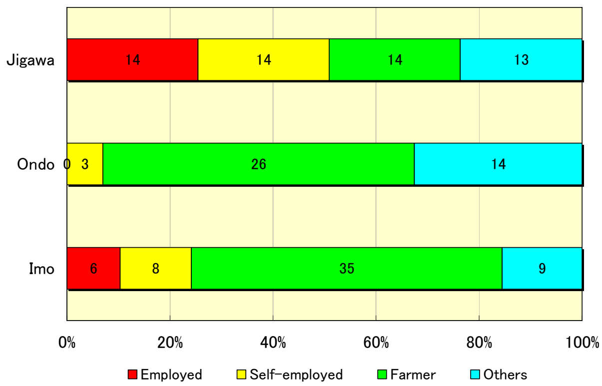

Fig. 1-2 Occupation

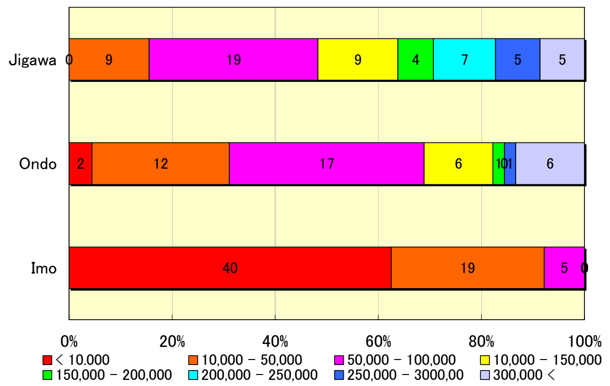

Fig. 1-3 Yearly income (Naira)

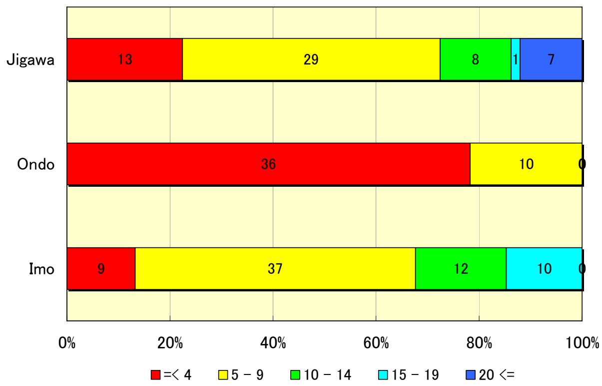

Fig. 1-4 Number of rooms

2. General

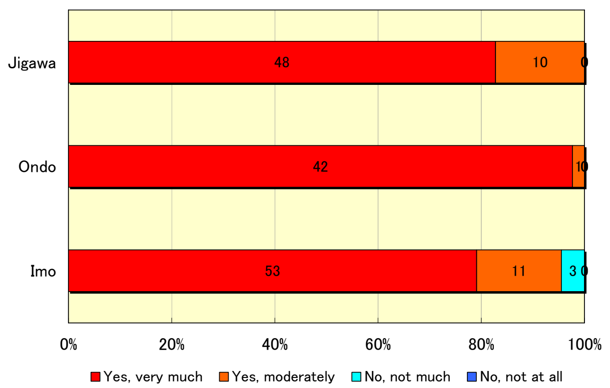

Fig. 2-1 Degree of satisfaction

"Are you satisfied with the PV systems?"

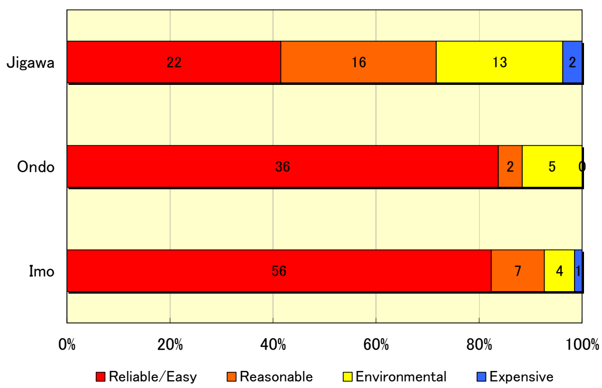

Fig. 2-2 Reason of the degree of satisfaction

"What is the reason of the above answer?"

Result of Questionnaire about the Pilot Project

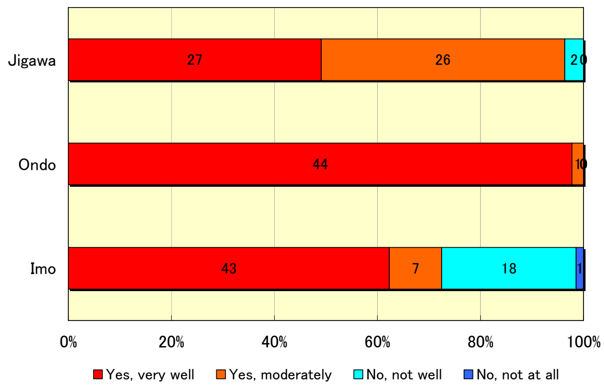

Fig. 2-3 How to use the PV systems

"Do you understand how to use the PV systems?"

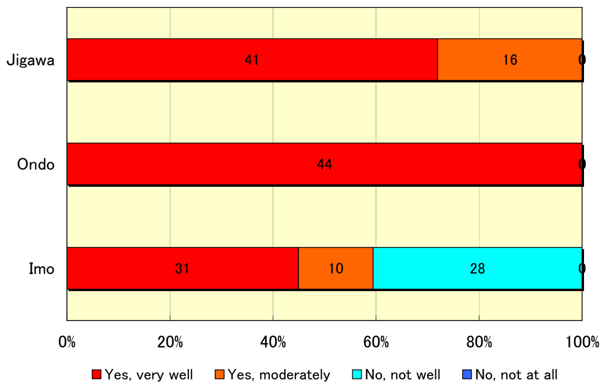

Fig. 2-4 Limitation of the PV systems

"Do you understand that the PV systems have the limitations?"

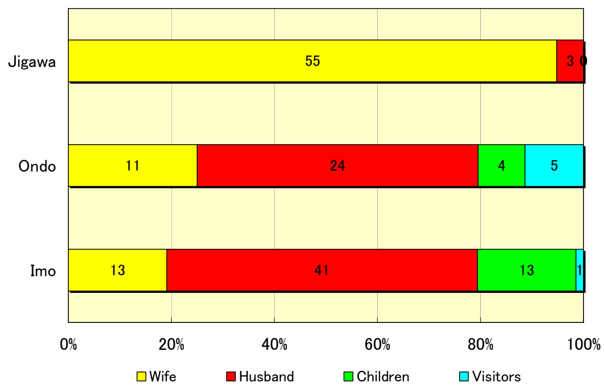

Fig. 2-5 Frequent user of the PV systems

"Who use the PV systems often?"

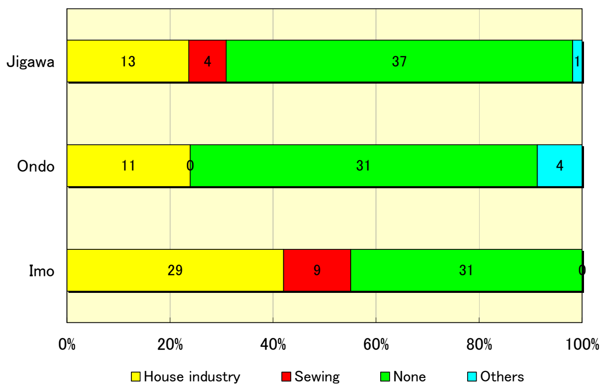

Fig. 2-6 Business using the PV systems

"Did you start any business after you started using the PV systems?"

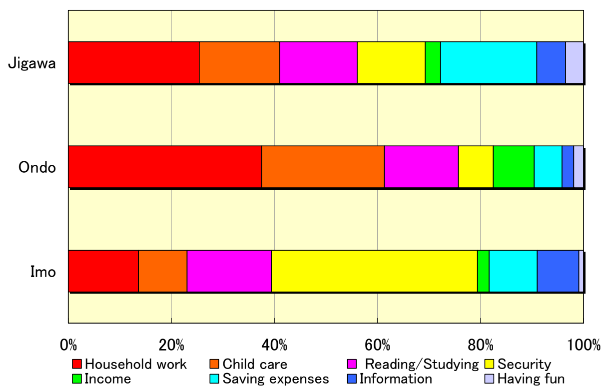

Fig.2-7 Improvement of living as a husband

"From a husband point of view, what did the PV systems improve?"

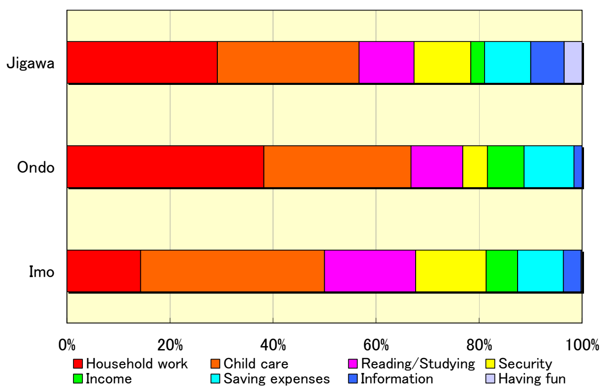

Fig.2-8 Improvement of living as a housewife

"From a housewife point of view, what did the PV systems improve?"

Table 2-1 Reduction of energy expense

State	Average reduction in Naira	Average reduction ratio
Jigawa	388	64%
Ondo	458	58%
Imo	204	45%
Average	359	57%

"How much did you spend for energy (kerosene, battery, etc.) before you started using the PV systems? How much do you spend for energy now?"

Table 2-2 Number of owners of generator

State	Number of owners
Jigawa	2 out of 58
Ondo	2 out of 46
Imo	9 out of 68
Total	13 out of 172

"Do you own a generator?"

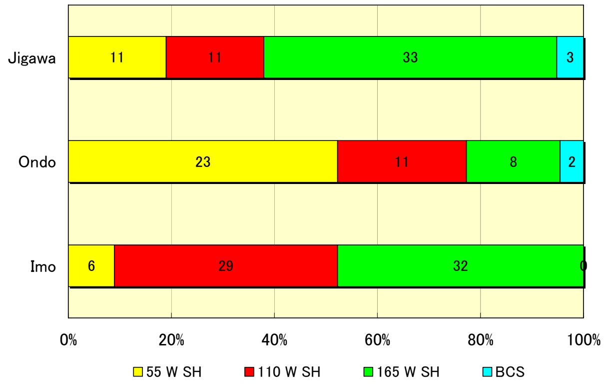

Fig. 2-9 Preferred PV systems

"Which system do you like best?"

Description of PV systems

- 55 W SHS for two (2) sets of lamps and one (1) radio at the rate of N500/month.
- 110 W SHS for four (4) sets of lamps, one (1) radio, and one (1) TV set at the rate of N750/month.
- 165 W SHS for six (6) sets of lamps, one (1) refrigerator, and one (1) TV set at the rate of N1,000/month.
- BCS for two (2) sets of lamps and one (1) radio at the rate of N50/charge.

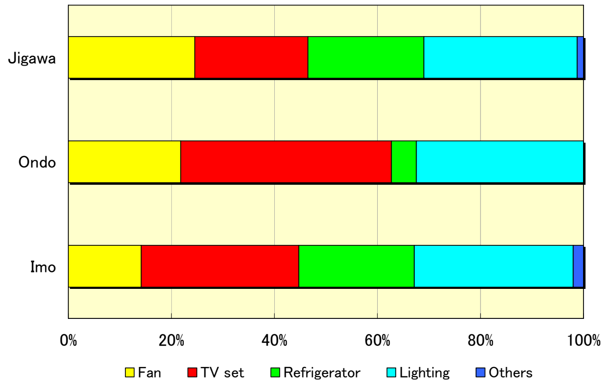

Fig. 2-10 Preferred electrical appliances

"If possible, which appliances do you want to use?"

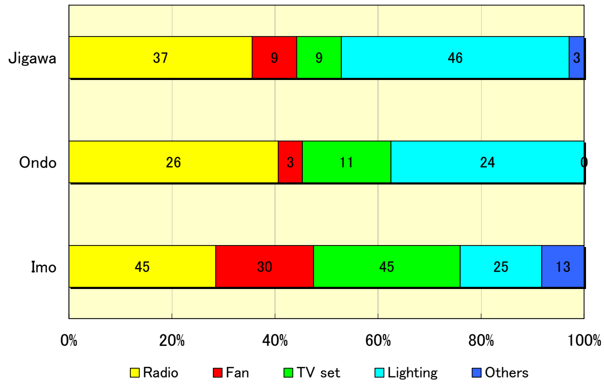

Fig. 2-11 Owned electrical appliances

"What appliances do you own?"

Table 2-3 Number of needful lighting points

State	Number of lighting points
Jigawa	7
Ondo	3
Imo	7
Average	6

"If possible, how may lighting points do you need?"

3. Public Facility/Street Lighting

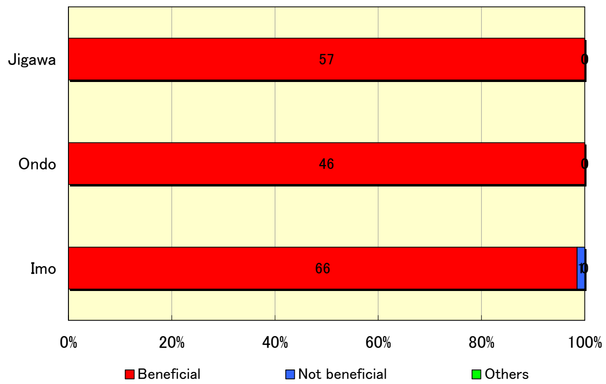

Fig. 3-1 Benefit of Public Facility/Street Lighting

"What do you think Public Facility/Street Lighting?"

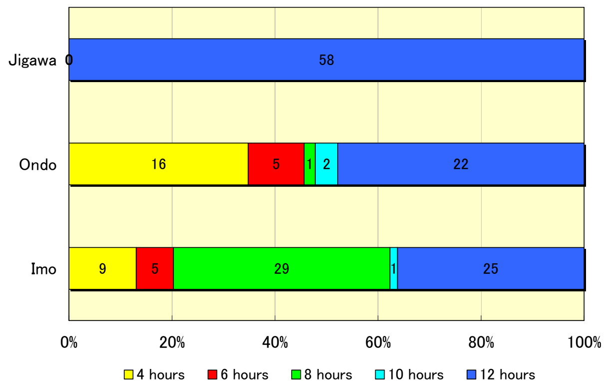

Fig. 3-2 Hour of use of Street Lighting

"If possible, how long do you want to use Street Lighting?"

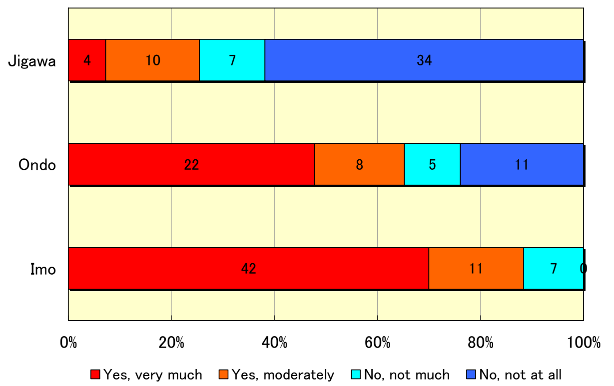

Fig. 3-3 Willing to pay for Public Facility/Street Lighting

"Are you willing to pay tariffs for Public Facility/Street Lighting?"

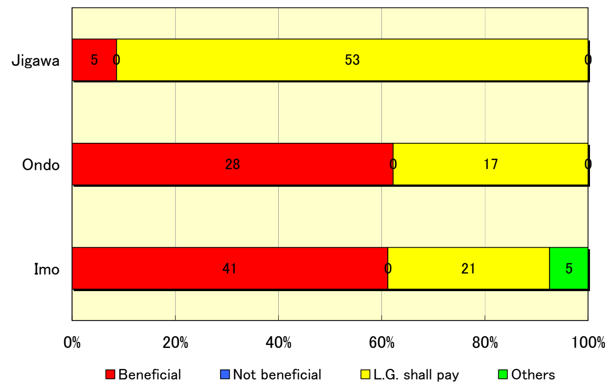

Fig. 3-4 Reason of the willingness to pay

"What is the reason of the above answer?"

4. SHS and BCS

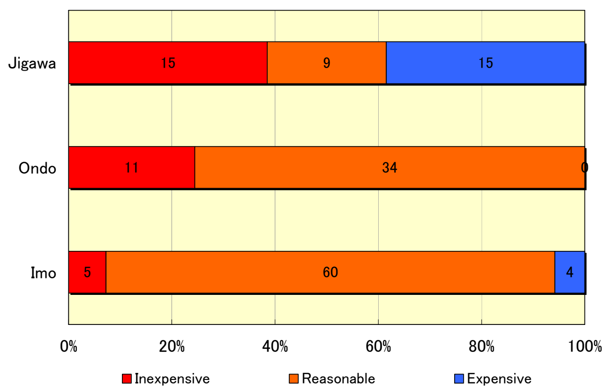

Fig. 4-1 Monthly tariff of SHS

"What do you think the monthly tariff of SHS?"

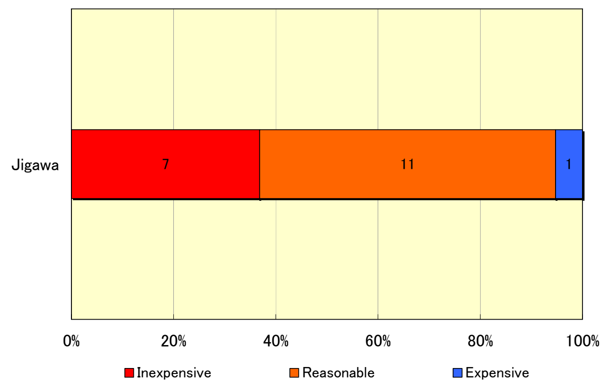

Fig. 4-2 Charging fee at BCS

"What do you think the charging fee at BCS"

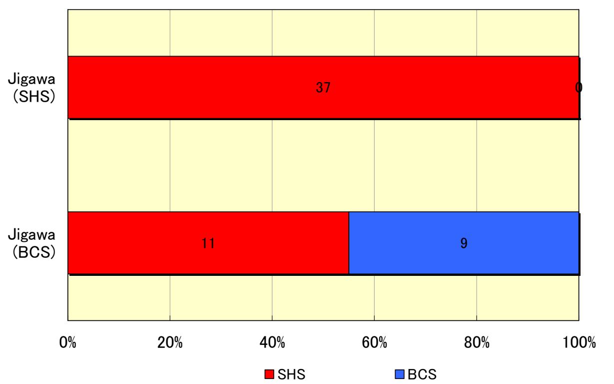

Fig. 4-3 Choice between SHS and BCS

"Considering the charging fee at BCS, which do you prefer, SHS or BCS?"

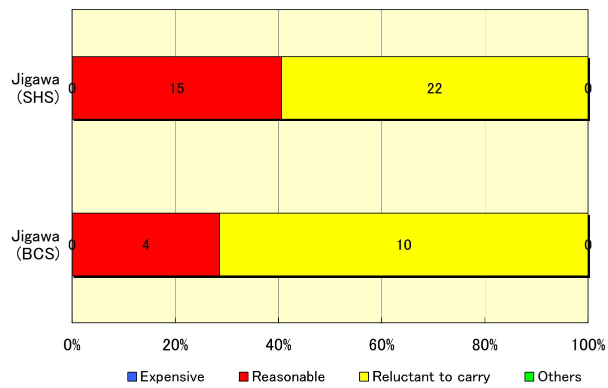

Fig. 4-4 Reason of the choice

"What is the reason of the above answer?"

Table 4-1 Tariff of charges（Naira）

State	Monthly tariff of SHS	Charging fee at BCS
Jigawa	400	30
Ondo	250	—
Imo	350	—

5. Village Committee

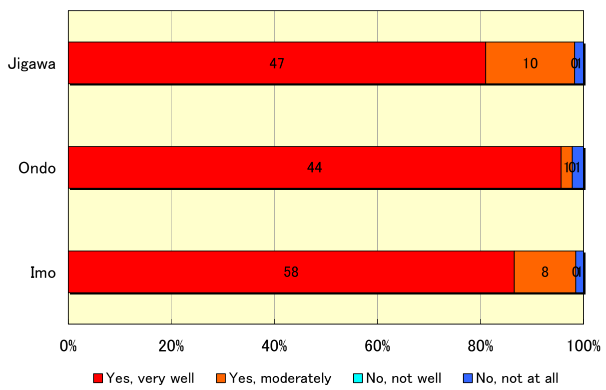

Fig. 5-1 Evaluation of the committee

"Does the committee manage the Pilot Project?"

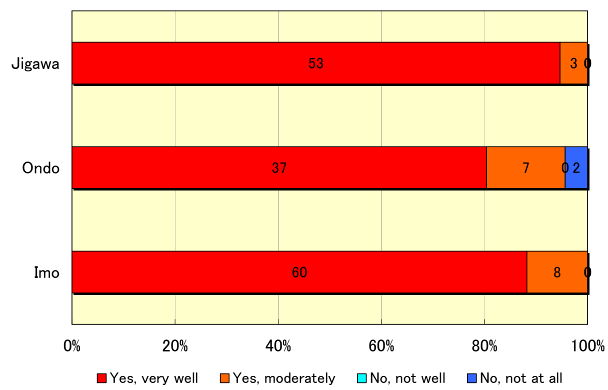

Fig. 5-2 Evaluation of the maintenance staff

"Does the maintenance staff maintain the PV system properly?"

6. Local Government and State Government

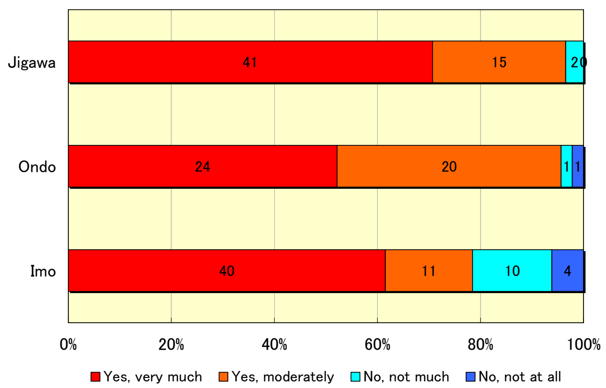

Fig. 6-1 Evaluation of the L.G./S.G.

"Do you think the L.G./S.G. contribute to the Pilot Project enough?"

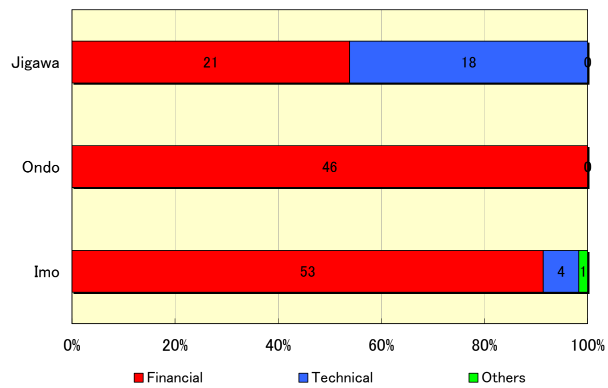

Fig. 6-2 Expectation from the L.G./S.G.

"What do you expect the L.G./S.G. to do?"

Note)

1) All numbers in the figures show the number of answers which are categorized by the alternatives.
2) In Fig. 1-3, most of the respondents in Imo state answered that their yearly income are below N50,000. However, the result of socio-economic survey shows that their average income are approximately N200,000. Therefore, the respondents do not figure out their income correctly.
3) In Fig. 2-6, not all respondents who answered that they stared business sell products to the others. As a result of the interviews, some respondents started house industry for their private use.
4) In Fig. 2-7, 8, and 10, the answers are weighted based on the priorities since the questionnaires are multiple choices.