3.3 General Project Concept

The institutional concept being used is to utilize an external service agency which retains ownership of the systems and provides all maintenance for a fixed monthly fee. Through this approach, the finance of the systems can be arranged over a term consistent with the life of the primary components, the solar panels, and lower income customers and customers with a seasonal income will have a lower cost of entry for obtaining electrification and will not have to worry about meeting sudden, large maintenance costs at the time of controller or battery failure.

The concept is not system rental or lease since under those schemes, the fee pays only for the use of the system and the customer is responsible for most aspects of system maintenance. The concept proposed is instead that of an electrical utility which provides electrical service for a fee and maintains all generation and distribution equipment with no technical interaction by the user.

Although a utility type structure could not be created for a pilot project of only 100 houses and 12 community facilities, the Study Team has attempted to design a pilot project which as closely as possible creates the service conditions provided by such a utility as far as the user is concerned. This is expected to enable the team to determine the user satisfaction with the concept and to estimate the real cost of operating a rural solar utility in Zimbabwe and thereby to provide information needed to determine the preferred institutional approach to be proposed under the master plan.

3.3.1 Household Site Selection

The project is located in two clusters of approximately 50 households each. Both are in Kadoma District with one centered in the north around the Geja clinic (near Sanyati) and the other in the south around the Turf clinic. The socio-economic characteristics of the two areas are different. The Geja area residents are largely engaged in commercial farming of cotton and have a relatively high cash income. Further, that area has been settled for a long time and the social structure is traditional in nature with both Government and traditional social governing structures in place. The residents of the Turf area have been resettled from other areas within the past 15 years and have no traditional governing structure making the Government the sole governing structure in that area. The Turf area residents have a lower average cash income per household than those in Geja since their economy is largely based on small family farming of maize. By choosing these two socially and economically different areas for the pilot project, the acceptance and use patterns of the PV systems by households having a wide range of socio-economic conditions can be examined in the study.

To allocate the 100 systems, a RDC representative visited the two areas and through public meetings and household visits explained the program and asked households which were interested to sign up for systems. Then a call was be made to those interested households to pay a connection fee of Z$750 and sign a contract accepting the terms of use. By June, the 50 systems allocated for the Geja area had been allocated and fees paid. Through a clerical error, 51 systems were actually allowed to be paid for and installed. In the Geja area, many of the larger GEF systems had already been installed and in nearby Sanyati the two active solar installer/distributor companies had widely publicized PV electrification at local meetings and fairs. The rapid acceptance of the systems in the Geja area appears to be due to a combination of the relative wealth of the area, the low cost of entry for the JICA systems when compared with the GEF systems and a general familiarity with PV systems for home electrification.

In the Turf area, acceptance was much slower than in Geja. This was partly due to the lower average income in the area which made the decision to commit to payment for the systems more difficult but a major reason for slow acceptance appeared to be a general lack of prior contact with PV systems and their capabilities. There are no companies in the Turf area which is promoting PV system purchase and few GEF systems have been installed in that area. Further, some households in the area had purchased low quality amorphous panels and had not had good experiences with PV electrification making other households in the area skeptical about solar systems. By the end of June, only 36 households had paid the fees for installation. In July, the team decided to extend the geographic boundary of the project to include the nearby village area of

Monyoni. A public meeting led by BUN was held in Monyoni and through this means, the remaining systems were allocated.

Therefore, for the pilot project, 51 homes were installed in the Geja area, 38 in the Turf area and 11 in Monyoni with one more system installed in Turf in December for a total of 101 household installations.

3.3.2 Fee Structure and Institutional Arrangement for Households

The institutional approach for this Study is not to sell systems to the household users, but rather to sell the electrical service delivered by the systems. The ownership of the systems is to remain with an external service agency that will be able to finance the systems over a term which is comparable with the life of the major component, the solar panel. Further, the Study intends that the external service agency will provide full maintenance service for the electricity supply system as part of the service fee. This approach is proposed because the target group of users are middle to low income rural households which are expected to have problems raising the money for outright purchase or purchase through short term (3-year) financing as well as having problems with unexpected maintenance costs, particularly battery or controller replacements.

The systems are designed for minimum user interaction. The users are not expected to have a technical capability nor are they expected to have any interest in maintaining the systems. The systems are intended to be regularly maintained by trained personnel who are employees of the service organization owning the systems.

The selection and installation of components to replace those in the system which have failed will be by the service company, not the user. The components will be paid for through a small periodic payment by the user (as part of the service fee) rather than by a major lump sum payment by the user. This insures that the replacement items will be replaced promptly and will be of equal or better quality than those originally installed as well as eliminating the large, unexpected payment which would have to be met by the user when a controller or battery fails if ownership remained with the user.

Lower user abuse of the system is expected through frequent interaction with each user household by trained service personnel and through the deliberate difficulty of access by the users to the battery or controller connections provided by keeping the battery in a locked box and having the controller mounted on the battery box under a metal cover. Users will receive frequent advice from the local technician about the most effective way to balance the use of their system under various conditions of weather, appliance type and household needs.

For the study to provide the most useful information for forecasting the acceptance of such an approach to PV based rural electrification in Zimbabwe, from the user's point of view the project has to provide the same service conditions at the same cost as would be the case with full scale PV based rural electrification.

Because the Study will only cover 100 households, the system cost will be higher than would be the case with large scale purchases of components and "production line" installation methods. The service organization will also have higher per household operating costs than would be the case with a much larger installed customer base. Further, the project needs to be monitored more closely than would be required for general electrification purposes which adds significant cost.

Therefore, the actual cost of the systems, the cost of system installation and the cost of provision of support services will be substantially greater per user than should be the case for large scale implementation of PV based rural electrification of the same type. Therefore the fee structure is based not the actual pilot project installation and operating cost but on what is expected for a full scale implementation of this form of rural electrification.

For these small 25Wp systems, where designs are specifically oriented around such systems, an installed system cost of Z$3,800 is considered achievable for large scale PV based rural electrification where installation personnel are local residents and materials are warehoused within a 50-km range of the site. A connection fee of Z$750 is imposed to help insure that persons signing up for the service are serious and do have the means and intention of paying the periodic fees. This is about half the connection fee charged by ZESA for rural electrical service. This connection fee will reduce the amount of cost which must be financed to Z$3,050.

For a utility type institutional structure, 20 year financing is reasonable and 15% money available. The monthly finance cost of Z$3,050 at an annual rate of 15% is Z$40.16 per month. Replacing the Z$600 battery (after a useful life of 2.5 years) can be met by a monthly payment into an interest bearing account of Z$18 assuming a real 6% interest rate as corrected for inflation. To replace the Z$500 controller (after a useful life of 5 years) can be met by a monthly payment into an interest bearing account of Z$8 assuming a real 6% interest rate as corrected for inflation. The cost of a maintenance visit to the site by a local technician on a bimonthly basis should be about Z$10 per month. The total of these estimated costs is Z$76.16. Therefore, the proposed monthly fee to be charged the user is Z$75.

It is recognized that this represents a substantial amount when considered in the light of the income of many rural households. However, there are strong indications that for a majority of households this amount is not excessive and is about half the cost per month for just the three year credit purchase of a comparable system at a price which does not include battery replacement and maintenance after the initial warranty period is over. The determining factor as far as customer acceptance is concerned is expected to be the level of priority in rural households for the services which can be provided by these small systems. This priority will be a function of the household's perception of solar PV as a reliable and suitable electricity source and the cost of alternatives to PV for lighting and entertainment systems as well as household income and the amount of fixed expenses of the household.

3.3.3 Project Operation

(1) Operation Outline

JICA directly purchased all components for the systems and likewise contracted with installers for the placement of the systems on the homes of users paying the connection fee of Z$750. JICA, through the Study Team, contracted with Biomass Utilization Network (BUN), a local NGO, to act as the service provider to the Study project. The service contract is for a term of five years with the first year costs subsidized by the project and the last four years self funding through fee collections.

After one to two years of experience in collecting fees and maintaining the systems, the real cost of operation and maintenance will be determined by BUN and the surplus in the collection account made available for system expansion or the installation of new systems. A significant surplus is anticipated since JICA will fully capitalize the systems and the capital finance charge to be levied against users will be available to cover the cost of operation and maintenance in addition to the fee component specifically for operation and maintenance.

(2) Household Responsibilities

Prior to installation, households were required to sign a service contract which includes agreement by the household to:

1. Not in any way modify the installation without written permission from the maintenance agency and all modifications will have to be carried out by an authorized technician;
2. Allow the service technician access for maintenance;
3. Be responsible for the security of the system. If a system or its components are stolen or vandalized, the household will be held responsible;
4. Maintain at their own expense appliances and wiring from the controller load terminals to the appliances;
5. Prevent panels from being shaded by trimming trees as necessary;
6. Use the system in accordance with instructions from the maintenance agency
7. Report to the supervisor at the maintenance agency of any problems with the service being provided; and,
8. Pay fees as agreed and allow removal of the system if fees are not paid.

(3) BUN Contractual Requirements

During the installation phase, BUN acted as overall supervisor on behalf of the Study Team and disbursed JICA purchased materials to installation companies from the materials stock held in a warehouse at the Kadoma RDC. For operation of the project, when systems are operational and user fees have been properly paid as per the user contract, the user contract binds BUN to do the following tasks at no additional cost to the user. Its specific duties would be to:

1. Visit the site approximately monthly for maintenance checks and an interview with the user concerning the service obtained;
2. Replace the controller, panel or battery if it becomes faulty;
3. Maintain wiring, panel mountings and other components of the solar installation excluding appliances and wiring from the controller to the appliances which are the responsibility of the user;
4. Advise the user on the proper manner of operation of the system where improper use is observed;
5. Overhaul and re-commission the system at the time of any battery replacement; and,
6. Make available and install additional solar system components and appliances for upgrading the installation as requested by the user for an additional installation charge and increased service fee following an initial two year trial period.

At the end of the five year contract term, BUN, the Department of Energy and users will in combination determine the allocation of systems one of three ways: (1) with no change to the system of ownership and maintenance; (2) transfer of ownership to users with no further responsibility by BUN for maintenance; or (3) transfer of ownership to users with a service contract to BUN for maintenance.

Operational Responsibilities of BUN

During the first year of operation, the JICA team required assistance from BUN in system monitoring and in surveys of both technical and social nature. Therefore the costs to BUN of operating the project were significantly higher than that incurred through normal operation. Therefore JICA provided additional financial input above that provided by fee collections for the first year. The amount provided was dependent on the added services required by the JICA team to fulfill their study requirements.

The maintenance arrangement includes one trained technician at each cluster of homes and one more experienced senior technical person with advanced training based at BUN in Harare. All technicians are full time employees of BUN.

The field technician is not directly paid by the users for his services but is paid a salary by BUN. The field technician is provided a tool kit, technical training, record keeping materials and administrative training. A bicycle is provided for transport within each service area. The tool kit and bicycle is provided by BUN at no cost to the technician but should tools be lost the tools would be replaced by BUN and the full cost deducted from technician salary payments. If tools are broken, a percentage of the replacement cost will be borne by the technician through salary deductions. The bicycle will be maintained by the technician and should it be damaged or lost, the replacement cost will be deducted from the technician's salary after adjustment for age of the bicycle.

For the first year of the pilot project, the field technician visited each site at least monthly and made maintenance checks by a checklist. He also interviewed the users for the determination of problems and to give advice for using the system as needed. The checks are witnessed by the user and signed for by the user. A log of each visit has to be maintained in duplicate, one at the site and one in the technician's possession.

The senior technician is expected to visit each site at least once per year to check on the performance of the field technician. These checks are to be spread out over the year (about 9 randomly selected households visited per month) so a relatively continuous checking will take place.

The senior technician is responsible for removing any system from a house where payment has been in arrears longer than allowed by the payment agreement.

Where a battery replacement is required, the senior technician is responsible to see that complete system checks are carried out and that the system, after battery replacement, meets new system specifications.

BUN will maintain a waiting list of households desiring installations and should a system be removed due to non-payment, it will be transferred to a household on the waiting list after payment of appropriate fees and signing of a new service contract.

(4) Funds Administration by BUN

BUN, with the assistance of the RDC organization, will collect and account for all fees from households and deposit them in an interest bearing account. At the end of approximately two years of operation, the actual cost of maintenance will be estimated from prior experience (including an amount set a side for battery and controller replacement) and the surplus put into a capital expansion account.

That account will allow for the expansion of the household systems if requested by the users or for the addition of new customers from the waiting list. Expansion would result in an additional connection fee and an increased service fee in accordance with the size increase in the system. All funds generated by the scheme would be applied to either maintenance (including administration costs for the maintenance organization) or system expansions.

3.4 Training

3.4.1 Training Requirements

A widespread problem with donor-backed PV rural electrification projects has been a lack of access to technical training after the initial donor-funded training program has completed. In the case of this particular study, approximately 15 installing personnel and a minimum of three full time technicians, two living in the field and one supervisory technician in Harare, will be involved with the installation, operation and maintenance of the project both during its JICA monitored phase (approximately one year of operation) and during the continued operation of the project for at least four more years by BUN.

The provision of competent, locally based training for solar PV technical personnel over the long term is an important part of the development of PV as a viable means for rural electrification in Zimbabwe that has not been addressed to date. Such training as has been available thus far has been tied to specific projects and not available after the project administration departs. For solar PV technician training to be available for the long term, it needs to be integrated into the regular vocational-technical training system of Zimbabwe.

3.4.2 Establishment of a Technician Training Centre

The Study Team considers it most appropriate that training be carried out through assisting an existing technical training institution in Zimbabwe to include the training of PV technicians in its curriculum. Therefore the Kwekwe Technical College was selected by the team as the best initial choice for integrating PV technical training into regular trades training. The central location of the school and its nearness to the JICA project were the main factors in that selection. The College was visited by team members on March 19, 1997, and discussions were held with the Principal and appropriate staff regarding the possibility of that school acting as a pilot institution to integrate solar technology into the existing training electrical trade straining program and to establish the capability to offer short courses for PV installation and maintenance personnel. The proposal was met with enthusiasm by the Principal and staff and an agreement was reached to proceed.

The Ministry of Education was approached by Kwekwe Technical College with a proposal that the Kwekwe school be allowed to act as a pilot school for solar technical training due to its proximity to the Kadoma JICA study area and its central location in Zimbabwe. Approval was granted and the JICA team agreed to provide approximately Z$200,000 worth of equipment to support the training program and for a JICA team member to train instructors in preparation for the College to independently provide the technician courses.

To achieve the dual goal of establishing a long term capability at Kwekwe Technical College for PV technician training and to accomplish the actual training of the technicians for the JICA project, a two week training program was established by the team. The first week was intensive training primarily for the Kwekwe Technical College instructors and the BUN Senior Technician and the second week was a training course for field technicians which served to act as a supervised practice teaching session for the Kwekwe instructors and as training for the four technician trainees selected by BUN for maintenance of household systems.

In addition to the seven electrical trades instructors from Kwekwe Technical College and the senior technician from BUN, the Chief Technician from the Mechanical Engineering Department of the University of Zimbabwe and the solar technician from Battery World attended the instructors course. In the field technician course, besides the four BUN field technicians, 8 technicians from solar installation companies, three technicians from the GEF project a BUN technician and a University of Zimbabwe technician attended.

The following table lists the training participants, their affiliation and work location.

The instructor's course was taught by a JICA team member with prior experience in PV instructor and technician training. The first week of the course was approximately 60% lecture and 40% laboratory work with the emphasis on how to teach PV principles to field technician trainees and on aspects of PV technology which are different from conventional electrical trades training. As part of the training, the instructors designed and tested their own experiments for PV training and created lesson plans for course instruction. In the second week, the instructors taught a full scale PV field technician course emphasizing proper installation methods, system troubleshooting and system maintenance. The course was taught under the supervision of a JICA team member. In that second week, each instructor took responsibility for a component of the course and taught that component in English.

The JICA team was impressed with the enthusiasm and dedication of the Kwekwe Technical College as evidenced by the consistent attendance of all instructors at the course even though the school was in session and regular courses in the electrical trades section had to be held in abeyance during at least the first week of the JICA course. Since the majority of the students at the technician training course were already experienced in the installation and use of PV systems, the interaction between student and instructor was lively and useful both to the instructors and the students. The end of course evaluation indicated that the students felt that the course was satisfactory and the students specifically complimented the Kwekwe instructors for their efforts and good performance in the class.

A final examination was given the students. It was intended to test the understanding of the students regarding basic principles of PV system installation and maintenance. The results of the examination indicate that in general the goals of the course were met and most trainees left the course with a sufficient level of knowledge to adequately install and maintain household PV systems.

Following completion of the course, the Kwekwe Technical College administration stated that they wished to integrate solar training into their regular electrical trades curriculum and were prepared to offer short courses as demanded by the solar community. Since the initial course, the College has provided one short course on its own and more are planned.

3.4.3 User Education

User education is an important component of the Study, particularly in view of the small size of the systems and their limited capability to provide services desired by the rural recipients. In such a case, the manner in which the systems are used will have a great effect on their capability to provide service. Therefore, it seems particularly important to develop a strong user education component in the project.

User education is to be delivered in three stages. The first stage was provided at the time of installation by the installing company technicians. Users were given general information about the way the system works and how to best use it. The second phase followed from one to three months later during the inspection visits by JICA team members and the BUN Senior Technician. At that visit, users were again informed about the PV system, its limitations and the proper means of operation. By this time, users had used the systems for at least one month and had a better basis for understanding the information provided about proper system use.

The third phase will be carried out about mid way in the project. Since it will be too expensive to take Harare based trainers to every household specifically for user education and, based on the experience of other projects, the effectiveness of mass training at a community center does not seem to be good, it is intended that the local field technicians deliver the training using a video produced by the project. The video was prepared by BUN using a dramatic format developed by the Girl's High School Drama Club which uses students to illustrate right and wrong ways to use a solar system through an entertaining and easily understandable ten minute video drama. A portable 8 mm VCR and small color TV would be powered by the household solar system and the user training video shown to each household individually. Then the field technician can add further explanation and answer questions about use of the system which were not clear to the household.

The monthly visits of the field technician to the households will also have a strong user training component. At each visit the technician will interview the users and if there have been power outages or other problems relating to the manner which the system is being used, the technician will explain the cause of the problem and how the user can adjust the pattern of use of the system to reduce or eliminate the problem.

4

PV SYSTEM EVALUATION

4.1 Study Aspects

Because the project is primarily intended to provide information to the study team regarding technical and institutional aspects of PV rural electrification for input into the Master Plan, several components of the household component of the project were varied in order to determine their effects. Two technical components were varied, the type of battery and the presence of a visible battery charge indicator. Additionally, some installations were fitted with data loggers to measure the actual energy flows in the systems. Two clinics were fitted with data loggers and two households were as well.

To determine the relative merit of an oversize automotive battery and a modified automotive battery intended for deep discharge service, half the installations received a 65Ah automotive battery and half received a 40Ah deep cycle modified automotive battery. The low voltage disconnects were set so that both batteries effectively would provide the same number of Ah to the appliances between full charge and LVD cutoff. Thus the automotive battery is discharged a significantly lower percentage than the deep cycle battery. The cost of the two batteries was comparable but delivery of the automotive battery was off the shelf while delivery of the deep cycle batteries was several months making the automotive battery preferable for replacements if its life proves comparable. Thus far, users have not reported any service difference between the two types of battery.

To determine whether or not users actually consider LED charge indicators in making use of the PV system, half the households were provided with controllers having LED charge level indicators and half were provided with no charge level indicators. Monthly checks by the field technician provides information about the average level of charge of batteries and a comparison between the two groups indicates whether or not the presence of the LED indicators is actually worth the added cost and power consumption. Since the controllers were changed from the locally made controllers to the improved

JICA controller about four months after initial installation, long term data could not be gathered but at the time of removal of the locally made controllers, there had been no indication that there was any difference in level of charge of batteries installed in homes with LED charge indicators and in those without indicators. The improved JICA controllers are all housed under cover at the battery and no indicators are visible in any installations.

4.1.1 Component Delivery and Quality Control

Since installations necessarily depend on availability of components, the component delivery schedule was critical to the smooth operation of the installation process.

The GEF project agreed to provide the PV panels from its stock which was valuable to the project since PV panel manufacturers were quoting several month delays in delivery.

Two major vendors received supply contracts for the remaining components. Sollatek was contracted to supply high efficiency 12VDC lights and associated light bulbs. Sollatek also was contracted to supply voltage reducers for operating 9V radios from the 12V system. Battery World received the contract to provide controllers, Battery Boxes, 65Ah automotive batteries for households, 40Ah deep cycle household batteries and 100Ah deep cycle batteries for clinic and school installations. Delivery for all components except deep discharge batteries was scheduled for 30 June.

Because Battery World could not provide the deep cycle batteries in time to meet installation schedules, they agreed to provide comparable automotive batteries temporarily until the deep cycle batteries could be delivered on 31 July.

With the exception of spare light bulbs which were delivered several weeks late, Sollatek met their contractual delivery obligations. Battery World delivered the automotive batteries and battery boxes on time, however they were unable to deliver the controllers as scheduled and several partial deliveries were received between two and four weeks late with the final delivery early in August. Deep discharge batteries for households which had been promised for 31 July were actually delivered late in October and deep discharge batteries for clinics also promised for 31 July were partially delivered on 9 November and the remainder had not been delivered by 1 December despite many promises by Battery World management for deliveries on earlier dates.

The sporadic and very late delivery of controllers and batteries seriously disrupted the installation process. It also significantly increased costs due to the need for installers to make extra visits to sites and to the need to keep security personnel additional months at the distribution warehouse in Kadoma. In order to meet commitments to users for the installations, it was necessary to install many early systems without controllers or deep cycle batteries. The need to make partial installations first without controllers or deep cycle batteries, then adding the controller and later exchanging the automotive battery for a deep cycle battery lowered the quality of the installations and lowered the level of user satisfaction.

In the Turf area, the slower acceptance of the systems by households also delayed completion of the installations and again increased installation cost due to the added trips to the site made necessary by the delays in placing the last 14 systems with households.

Because of these problems, household installations were not completed until November and clinic and school installations were not fully completed until March of 1998 due to the very late delivery of the remaining 100Ah deep cycle batteries by Battery World.

The controllers from Battery World were each opened and checked for quality control. Inside controller boxes were found dead insects, loose nuts and almost all had plastic shavings from the drilling of mounting holes. The relays used in the controllers do not have covered contacts so foreign materials could easily get between the contacts and cause the controller to fail. Some printed circuit boards were found to be missing a support nut. Instead of using spacers to hold the boards above the box, a nut was placed above and below the board and it was common to find the board twisted as a result of the bottom nuts being at different levels. Also, instead of placing a proper spacer between the cover and the plastic box, a large nut was used. The electronics assembly seemed reasonably well done although transistors were mounted with excessively long leads which could be easily bent into a shorted condition. No conformal coating was applied. Printed circuit traces carrying power were adequate for the low currents in our 25Wp systems but could not carry the 20A that was claimed as possible by Battery World technicians without excessive heating and voltage drop.

Since several controllers did not work properly after installation, despite provision of "QC" documentation by Battery World, there are probably problems in the inspection process as well.

Because none of the locally made controllers were suitable for the low power systems (due to excessive power demand for the controllers themselves), the JICA team introduced a low power latching relay type design to local manufacturers and had three companies each assemble 7 of the controllers from kits of parts supplied by JICA. Three of the 21 failed to work properly. All the failed units were made by Battery World.

The deep discharge batteries delivered for the houses used two different top configurations, one with screw type individual cell caps (which was desired and what was shown to the team by Battery World as a sample) and one with two strips of three cap plugs which push into the cell holes which is considered less satisfactory. At least 6 of the batteries had the plus and minus terminal markings (as stamped into the tops of the terminal posts) reversed. When asked about that situation, Battery World said that it was not a problem, because the red and blue color code was correct.

Battery boxes provided by Battery World for the clinic and school installations were too small to hold the 100Ah deep cycle batteries even though they were also provided by Battery World.

No QC problems were noted with the radio voltage reducers delivered by Sollatek but their lights had a 1% inspection failure at the time of installation.

4.1.2 Evaluation of PV System Components

In carrying out the survey in Zimbabwe, locally produced products were used as much as possible as system components. To improve the technological level of local PV-related companies, these local components were purchased and their quality and characteristics were evaluated.

The electrical measurement equipment necessary to evaluate the PV system equipment should in principle be procured locally, but in order to conduct evaluation tests immediately after arriving on site, the Study Team procured some of the basic electrical equipment in Japan and brought them to Zimbabwe, where evaluation tests were conducted.

Most of the other measuring equipment had to be imported, and it often took several months after ordering for actual delivery to be made. Furthermore, in conducting the evaluation tests, even though specification and technical manuals for all of the tested equipment had been requested from the supplier companies, virtually none were received. As a result, evaluation tests had to be performed by referring to the specification sheets included with the parts.

(1) PV module

There are three types of PV modules marketed in Zimbabwe.

First is the imported single crystal modules for the GEF project. Since these are exempt from import tax, they have recently dominated the domestic market.

Second are imported amorphous silicon modules, but their impact in the local market seems small.

Finally, a Zimbabwe electronics company is assembling imported PV cells into modules. Their selling prices are slightly higher than panels imported for the GEF because they must pay import tax for PV cells.

The study team evaluation program was targeted to get I-V characteristics of the GEF modules to be used in this project. They are Eurosolar MM25(25W) single crystal type for private houses use and Solarex MSX83(83W) poly crystal type for clinic and school use. Photograph 4-1 shows their appearance, characteristics and the sizes.

The international standard testing procedure for PV modules requires an expensive "solar simulator" which is not available in Zimbabwe. Therefore we used a simplified method using outdoor exposure to the sun.

The instruments used for the test were brought from Japan. They consisted of a data logger, LUX meter, voltmeters, ampere meters and other miscellaneous components.

The test results are given in the Figure 4-2 and 4-3, which shows the typical mono and poly crystalline module characteristics measured by the team.

From the tests, the tested products were found to be suitable for the project purpose and all units are considered suitable since they were made in mass production line by well known solar manufacturing companies which meet European and USA testing standards.

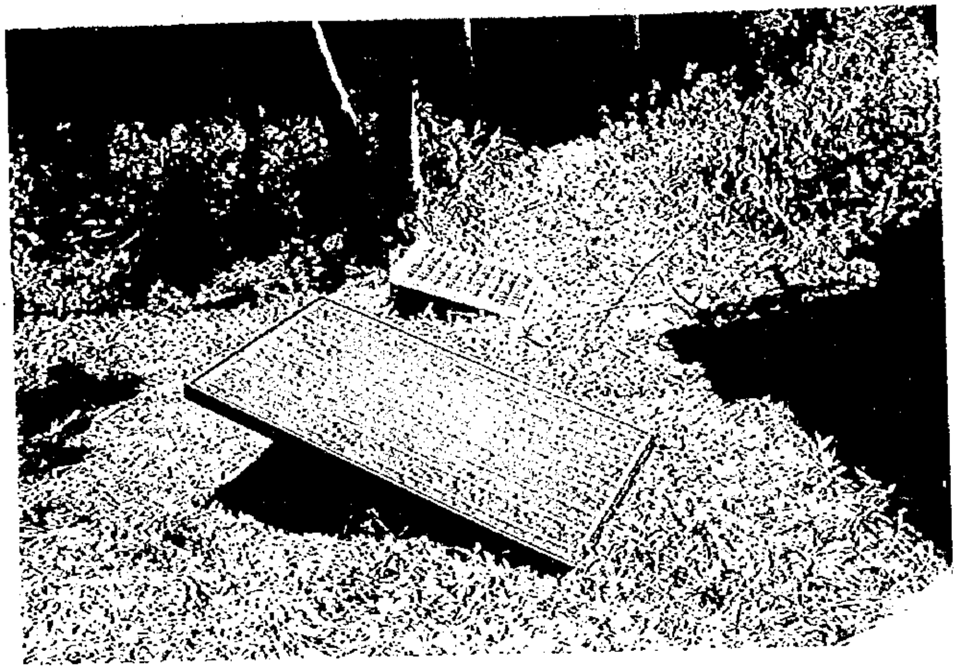


Photo 4-1 PV (photovoltaic) modules handled under the GEF Project
Upper: Small-sized 25-watt PV module manufactured by Eurosolar
Lower: Large-sized 83-watt PV module manufactured by Solarlex

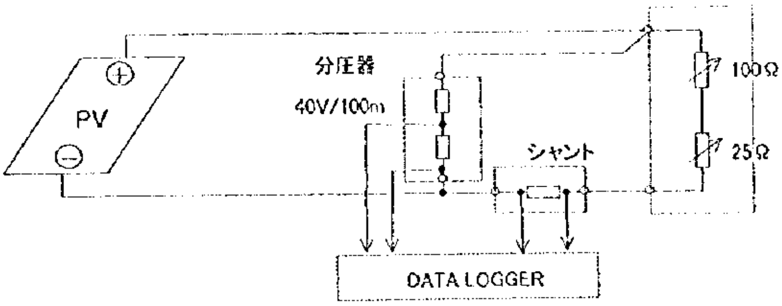


Fig.4-1 Measuring Circuit for PV Module

Type:	MM250-A	Voc:	21.4 V	Vmp:	16.9 V
Ser. No.:	D981025	Isc:	1.69 A	Ipm	1.53 A
Maker:	Eurosolare(Italy)	Pmax:	25.8 W	NOCT	43 deg

Vpm =	13.45 V	Irradiance:	1.017 kW/m2 (on module surface)
Ipm =	1.49 A	Mod. temp	60 °C
Pm =	19.99 W	Tilt angle	18 deg N

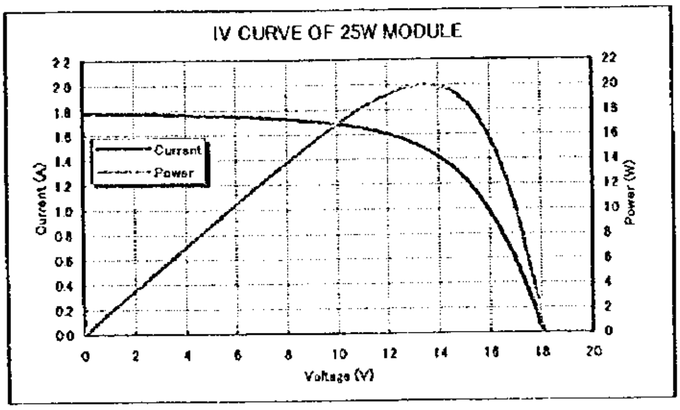


Fig. 4-2 IV Curve of Model MM 250-A

Type:	MSX83	Voc:	21.4 V	Vmp:	16.9 V
Ser. No.:	FW95K28691440	Isc:	5.35 A	Ipm	4.91 A
Maker:	SOLAREX(USA)	Pmax:	83 W	NOCT	49 deg

Vpm =	12.9 V	Irradiance:	1.017 kW/m2 (on module surface)
Ipm =	4.74 A	Mod. temp	61 °C
Pm =	61.2 W	Tilt angle =	18 deg N

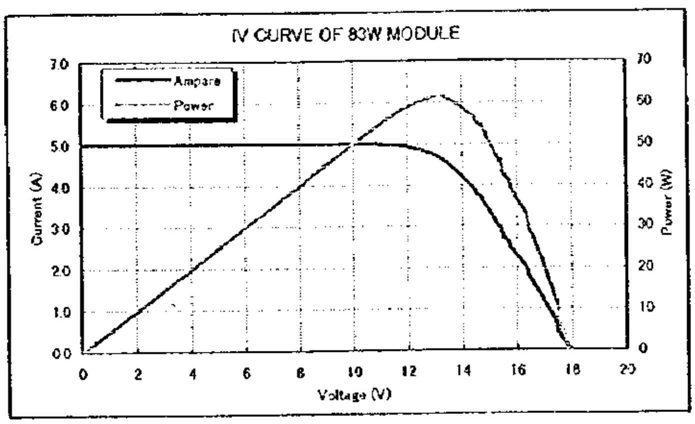


Fig. 4-3 IV Curve of Model MSX83 Photovoltaic Cell Module

Table 4-1 PV Modules Evaluated in Zimbabwe

Product number/Name	Manufacturer	Specifications		
MSX-83	Solarex	Polycrystal type Pmax Voc Isc Vpmax Ipmax	83 (W) 83.0 (W) 21.4 (V) 5.35 (A) 16.5 (V) 4.91 (A)	Photograph 4-1 (bottom module)
MM-250-A	Eurosolar	Monocrystal type Voc Isc Pmax Vm Im	25 (W) 21.4 (V) 1.69 (A) 25.8 (W) 16.9 (V) 1.53 (A)	Photograph 4-1 (top module)
Maxi BP	Solarcomm	Monocrystal type Npc Npv	40 (W) 2.4 (A) 17.1 (V)	Photograph 4-2
Midi BP	Solarcomm	Monocrystal type Npc Npv	20 (W) 1.17 (A) 17.1 (V)	Photograph 4-2

(2) Battery

In Zimbabwe, the local company Battery World manufactures and sells two basic kinds of batteries: (a) automobile batteries of various sizes and (b) deep discharging low-maintenance batteries for solar use. The Study Team tested the performance of the following:

12V/40Ah automobile battery, 1 unit (Photographs 4-3 and 4-4)

12V/40Ah deep discharging battery (for solar use), 1 unit

(Photographs 4-3 and 4-5)

To evaluate batteries, an automobile type 12V 3A incandescent lamp was connected as a continuous load to discharge the batteries under controlled conditions. To determine the proper LVD setting for the controller, a measure of the voltage versus the discharge time was recorded with the data logger until the voltage reached 11.5 volts. Fig. 4-4 and 4-5 shows the data obtained on this tests for both batteries.

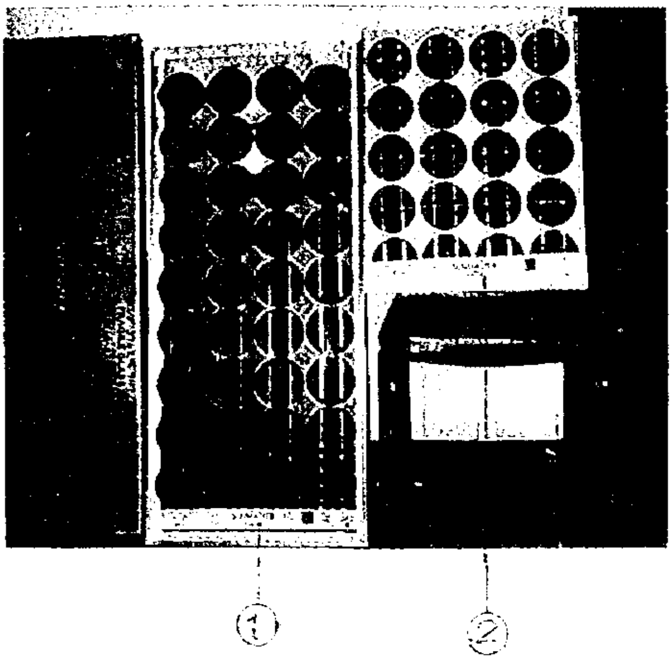


Photo 4-2 Solar cell modules manufactured in Zimbabwe

1: Monocrystal-cell-type module rated at 40 W and priced at Z$5,319

2: Monocrystal-cell-type module rated at 20 W and priced at Z$2,950

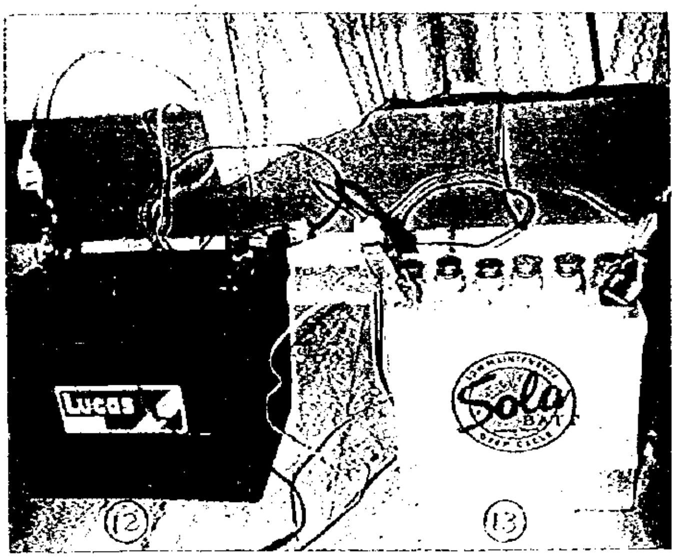


Photo 4-3 Storage batteries manufactured locally by Battery World

12. For automotive use: 12 V, 40 Ah, priced at Z$510

13. For deep-discharge use: 12 V, 40 Ah, priced at Z$520

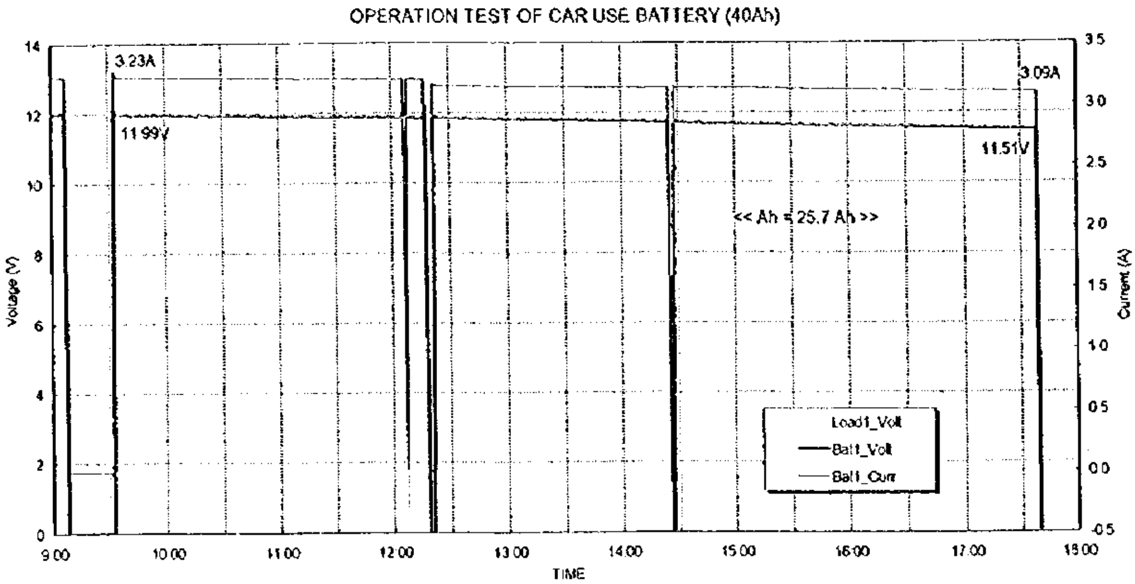


Fig. 4-4 Discharge characteristics of 40-Ah storage

Battery for automotive use battery (Locally manufactured battery)

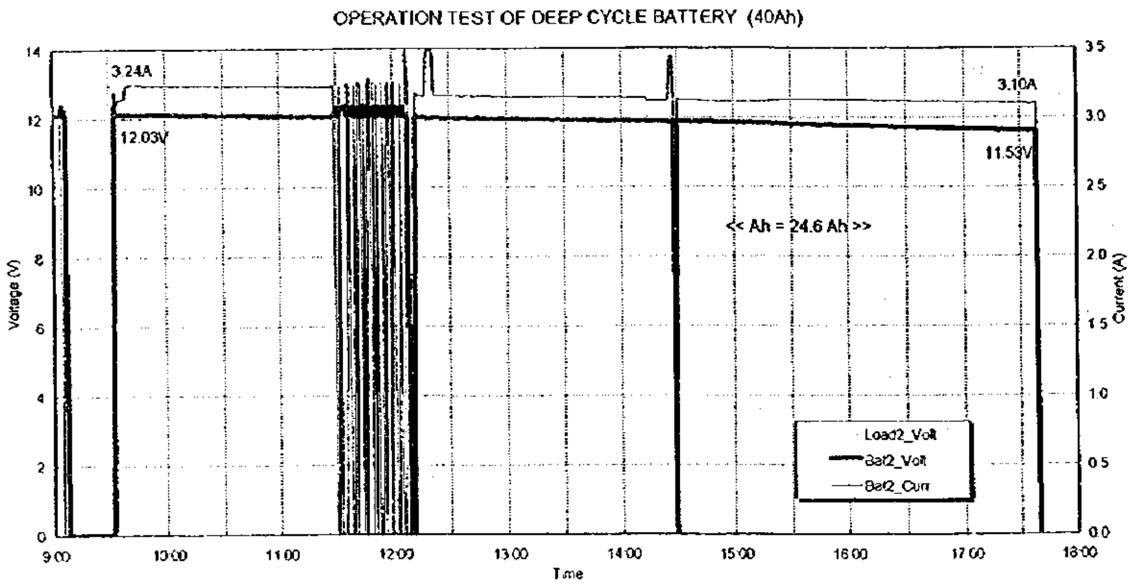
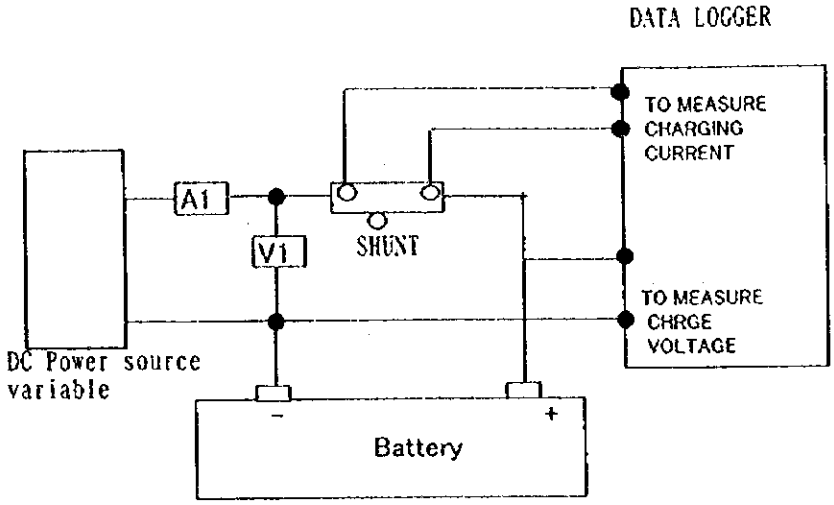


Fig. 4-5 Discharge characteristics of 40-Ah storage battery fof PV

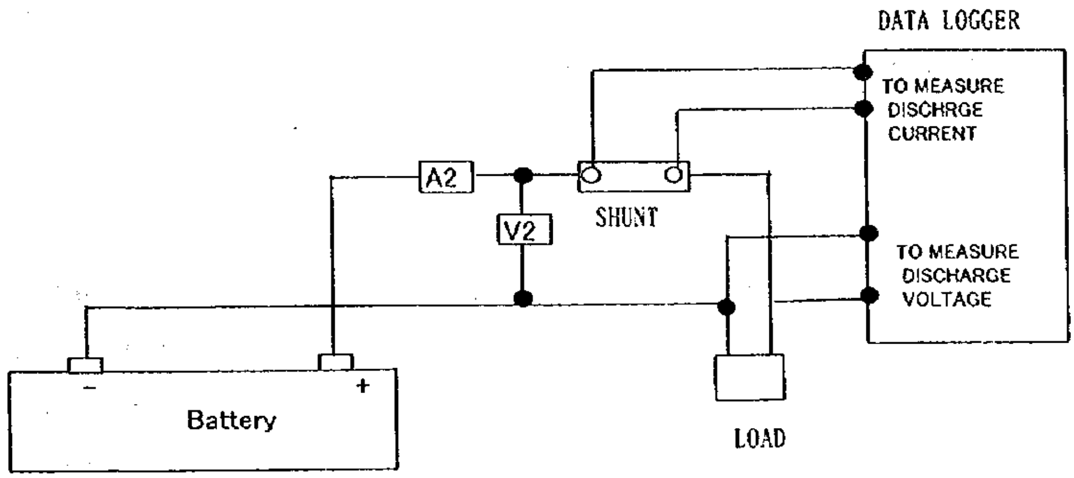
(Locally manufactured battery)

(Deep-cycle type battery)



A1 Amp. meter for charging current
V1 Voltmeter for charging voltage

Fig. 4-6 BATTERY CHARGE TEST CIRCUIT



A2 Amp. meter for discharge current
V2 Voltmeter for discharge voltage

Fig. 4-7 BATTERY DISCHARGE TEST CIRCUIT

A voltage of 11.5 V was confirmed as the proper LVD for the targeted batteries from the results of the test.

During the discharge period, which took 8 hours to fall to 11.5V no unusual voltage changes were recorded as the voltage fell consistently with time.

Referring to the data obtained, it was confirmed that the tested batteries were satisfactory to use when the LVD is set at 11.5V on the charge controller. The result was consistent with what would be expected for standard grade lead acid batteries.

To get sufficient data to accurately estimate the actual battery life, it could takes as much as 3 years to collect the data as well as using instruments intended for that particular purpose not available in Zimbabwe. However we are able to make a reasonable prediction of battery life from the data which has been obtained from the data loggers installed in clinics and houses.

(3) Charge Controllers

Several types of locally-produced charge controllers were available in Zimbabwe, and after studying charging and discharging methods, the Study Team determined that locally-produced charge controllers can be divided into the following two categories:

1) Semiconductor Type (Photograph 4-6)

This type of charge controller uses a non-contact control method that utilizes a semiconductor to control charging and discharging. In older charge controller models, automatic electric current contact and openings were performed by relay contact, and in many cases contact was poor and the relay coil consumed power. To rectify these problems, semiconductor type charge controllers have been adopted in many countries. Semiconductor type charge controllers have the advantage of lower power consumption than relay type controllers, but usually cost more (in Zimbabwe, Z$1,368). This is one problem that needs to be addressed in the future.

2) Magnetic Relay Contact Type (Photograph 4-7)

Usually, a magnetic relay is used to automatically turn the electric current on and off. Charge controllers for PV system battery charging and discharging have long used magnetic relay contact control methods. Such charge controllers cost less than non-contact types (in Zimbabwe, Z$700), but consume 10-20 times more power than the semiconductor type.

The Study Team chose to use the contact-type charge controllers (which are often used locally) for monitoring because of the low cost of the equipment, reliability, and simpler repair procedure in case of breakdown.

There are two local companies that manufacture and sell magnetic relay type charge controllers—Battery World and Sollatek. The Study Team decided to adopt the Battery World products since their basic design allows for lower power consumption during use (Photograph 4-8). Characteristics of each charge controller is as follows:

Characteristics data from Sollatek Charge Controller Evaluation

Model: SPCC 20-5

Specifications: DC12V 20A

Internal Power Consumption During LED Lamp Displays

LED Display	Lamp Voltage (H-L) (V)	Lamp Current (H-L) (mA)	Lamp Voltage (L-H) (V)	Lamp Current (L-H) (mA)
BATT FULL	16.73	213.0	16.40	195.5
BATT GOOD	12.90	186.2	13.25	180.0
BATT LOW	12.85	177.1	12.93	177.1
LOAD OFF	12.80	116.0	12.80	120.0

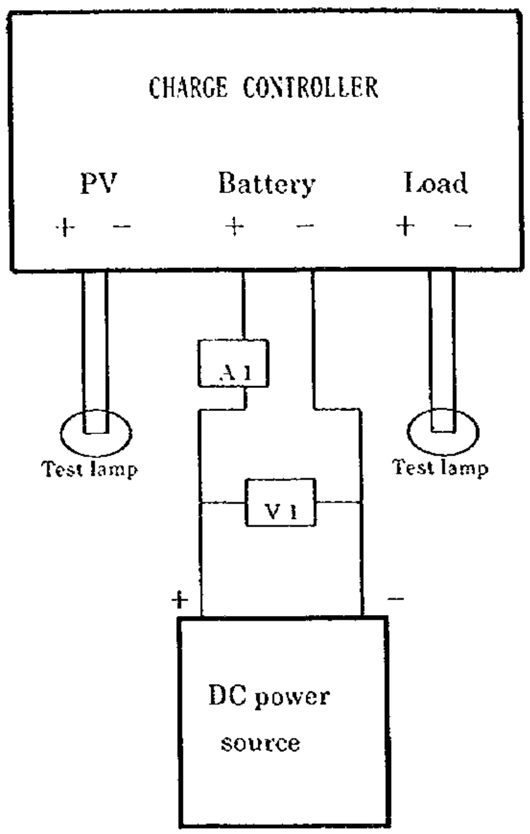
Note: H-L is the figure at the time the battery voltage is decreasing from a high value.

L-H is the figure at the time the battery voltage is increasing from a low value.

Power Consumption and Current on Supply Voltage

Battery Voltage (V)	Consumption Current (H-L) (mA)	Consumption Current (L-H) (mA)
17.0	176.0	174.2
16.0	161.6	225.2
15.0	147.3	208.2
14.0	132.0	192.4
13.0	175.6	122.3
12.0	108.9	108.9
11.0	96.6	95.6

CHARGE CONTROLLER



DC power source, variable DC 0 (v)~30(v)

V 1 : Voltmeter (Charge controller operation range)

HVD 14.5 (v)
HVR 13.0 (v)
LVD 11.5 (v)
LVR 12.5 (v)

A 1 : Amp.meter to measure the circuit current use.

Fig. 4-8 CHARGE CONTROLLER CHARACTERISTICS TESTING INSTRUMENT DIAGRAM

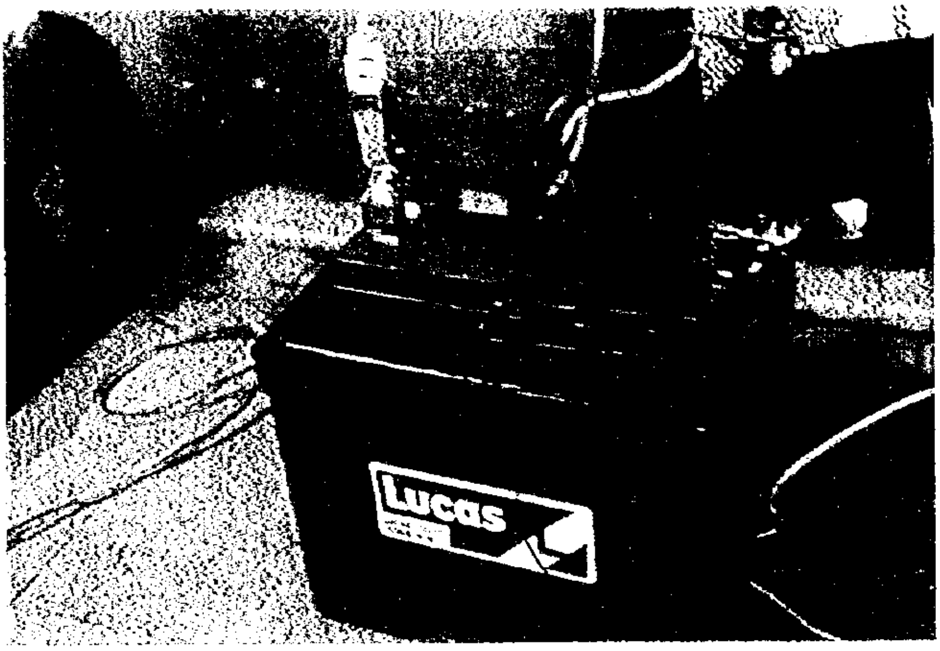


Photo 4-4 Storage Battery Rated at 12 V, 40 Ah Locally Manufactured By Battery World for automotive use

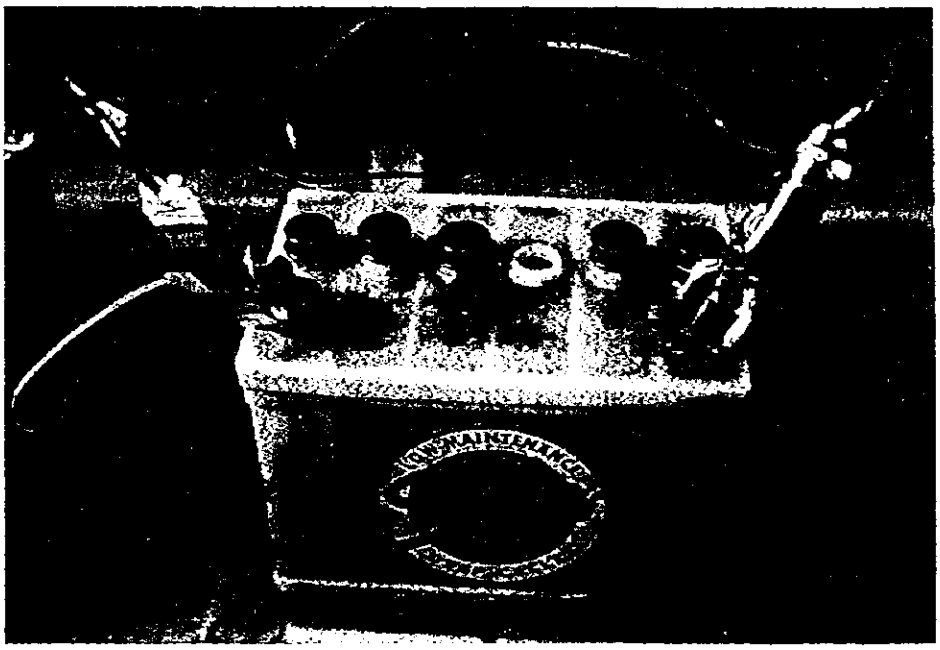


Photo 4-5 Storage Battery Rated at 12 V, 40 Ah Locally Manufactured By Battery World For Deep-Discharge Photo Voltaic Systems

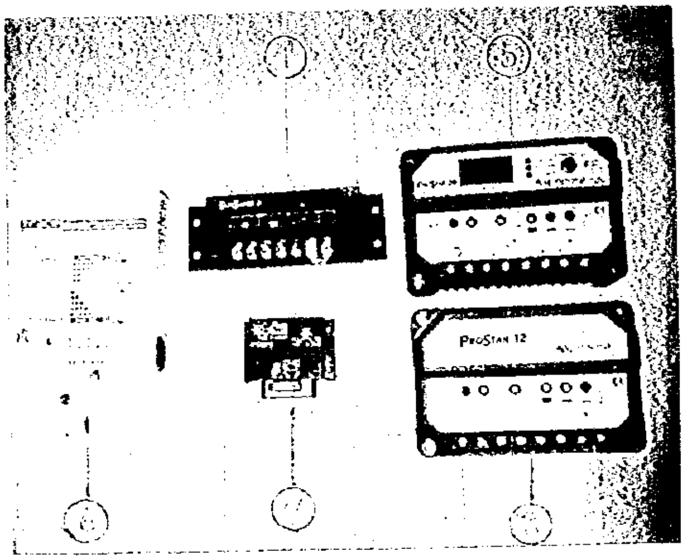


Photo 4-6 Charge Controllers,
Solid-State Type

4. Marketed by Solarex
5. " Z$2,399
6. " Z$1,100
7. " Z$ 660
8. " Z$1,400

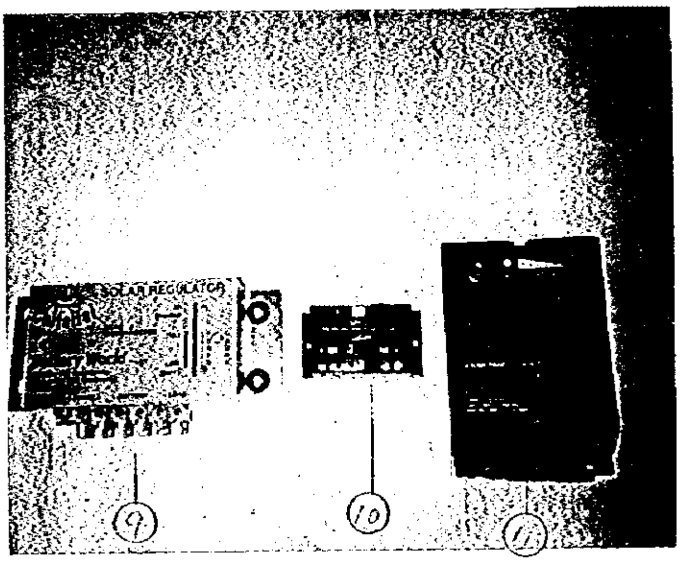


Photo 4-7 Charge Controllers,
Relay-Controlled Type

9. Manufactured by Battery World

Z$ 690
10. Manufactured by Sollatek
Z$ 357
Z$ 731
11. Manufactured by Sollatek

Improved/prototyped version of Battery World-made charge controller

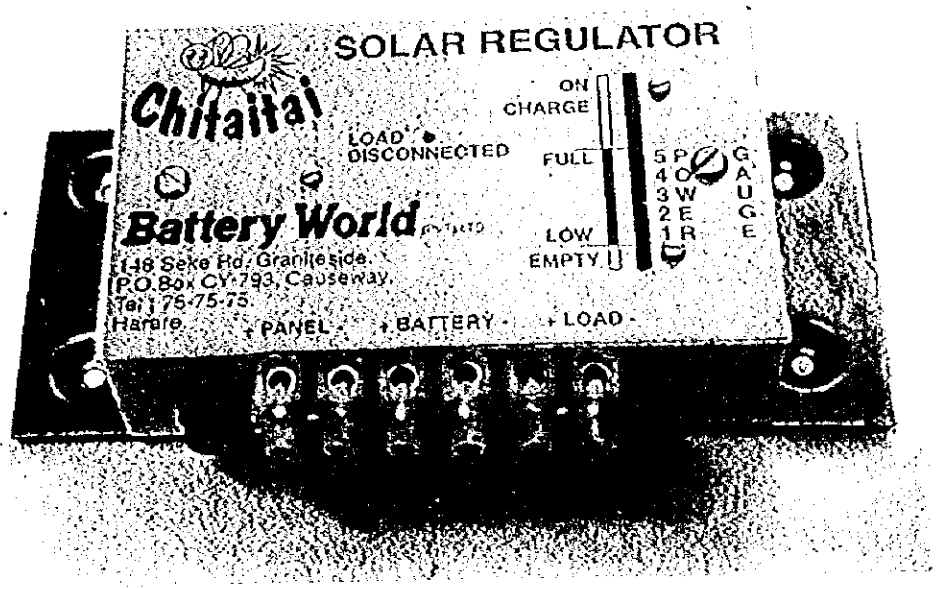


Photo 4-8 Designing and Prototyping of Improved PV-system Parts
Front View: Standard Unit before Modification

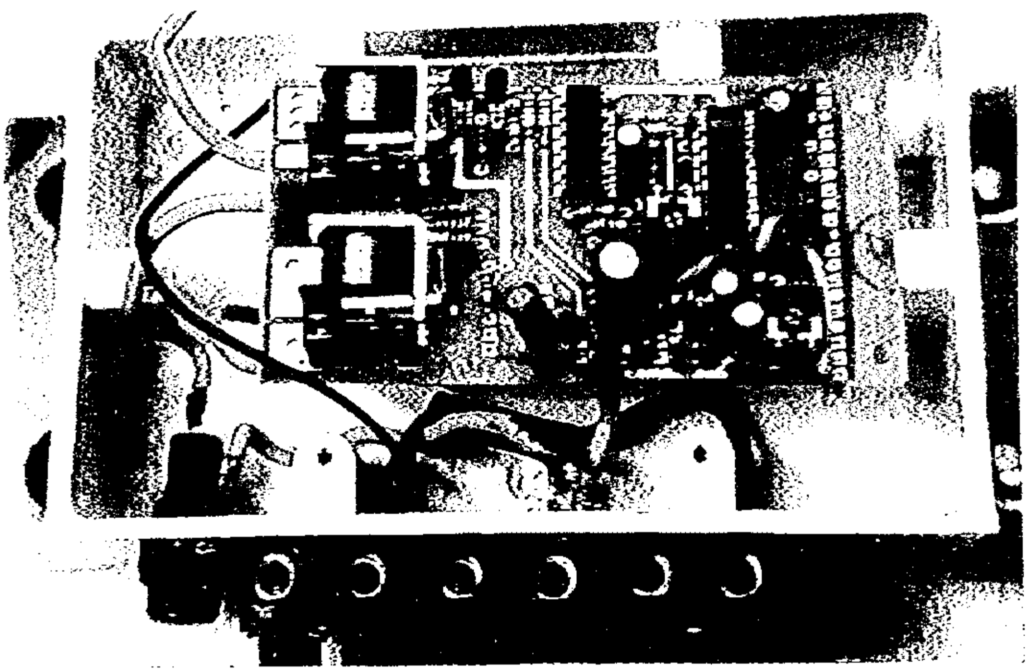


Photo 4-9 Printed Circuit Board (PCB) Housed in the Standard Unit
Designing and Prototyping of Improved PV-system Parts

Overcharge and over-discharge control operation characteristics

Overcharge voltage operating range

Voltage at which charging cuts off: 15.1V

Voltage at which charging resumes: 12.8V

Over-discharge prevention voltage operating range

Voltage at which load is disconnected: 11.85V

Voltage at which load is re-connected: 12.3V

Based on the consumption and current figures above (with the highest at 225.2mA), a small-capacity PV system (e.g. 25W) can not be expected to have high internal power consumption, but limited power for actual lighting. Such kind of unit is clearly not desirable.

Power consumption per day is as follows.

At maximum current: 0.2252A x 24h = 5.4Ah/day

At average current: 0.1756A x 24h = 4.2Ah/day

This power consumption is equivalent to operating two fluorescent lamps (PL7W) for four hours. For a small-scale system, it is advisable to select charge controllers that have low internal power consumption.

Characteristics data from Battery World Charge Controller Evaluation

Model: Solar Regulator

Specifications: DC12V 20A

Internal Power Consumption During LED Lamp Displays

LED Display	Lamp Voltage (L-H) (V)	Lamp Current (L-H) (mA)	Reference
Red	10.00	92.60	
Red	10.93	113.20	
Yellow	12.00	122.00	
Green	12.72	12.27	Load on
Green	13.01	11.42	
Green	14.00	11.41	
Yellow	14.20	145.60	Charging stopped
Yellow	15.00	150.10	

Note: L-H is the figure at the time the battery voltage is rising from a low value.

LED Display	Lamp Voltage (H-L) (V)	Lamp Current (H-L) (mA)	Reference
Yellow	15.00	150.10	
Green	14.00	125.20	
Green	12.77	12.60	Charging started
Green	12.00	11.32	
Green	11.00	11.31	
Red	10.90	109.30	Load off
Red	10.00	93.00	

Note: H-L is the figure at the time the battery voltage is decreasing from a high value.

Overcharge and over-discharge control operation characteristics

Overcharge voltage operating range

Voltage at which charging cuts off: 14.2V

Voltage at which charging resumes: 12.77V

Over-discharge prevention voltage operating range

Voltage at which load is disconnected: 10.9V

Voltage at which load is re-connected: 12.72V

The overcharge and over-discharge relay on the Battery World charge controller is the type that is on only when necessary, resulting in low internal power consumption. One problem with this particular charge controller, though, is that the relay coil is on when the protecting overcharging even voltage of battery becomes lower.

(4) Fluorescent Lighting Equipment (Photograph 4-10)

Fluorescent lighting equipment used with PV systems are manufactured and sold domestically. This equipment has a built-in inverter to produce the high frequency alternative current necessary to turn the lamp on. The products tested in Zimbabwe are as follows:

1) Sollatek – Fluorescent lamp direct current (12V)

   Lamp: 4-pin PL lamp 7 and 9W fluorescent tube

2) Solarex -- Fluorescent lamp direct current (12V)

   Lamp: 2-pin PL lamp 7 and 9W fluorescent tube

3) Solarcomm -- Fluorescent lamp direct current (12V)

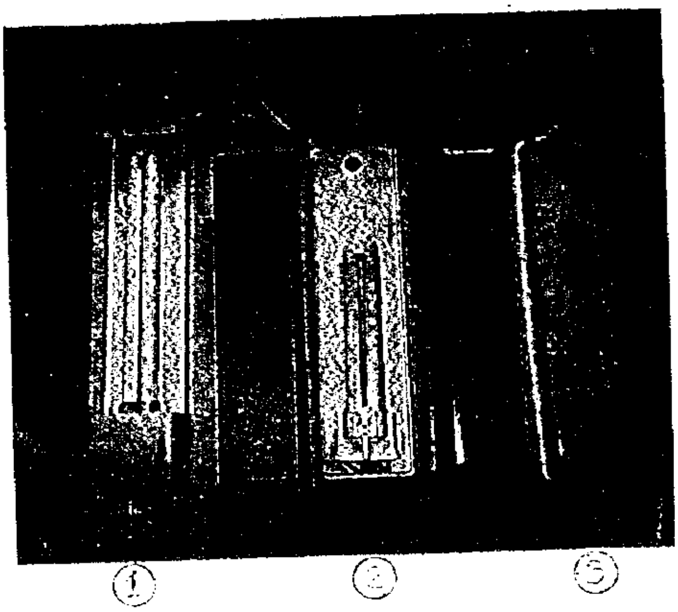


Photo 4-10 Fluorescent-lamp Lighting Fixtures for PV Systems
1. Solarex-made 2-pin PL rated at 11 W selling for Z$420
2. Sollacomm-made 4-pin PL rated at 7 W selling for Z$365
3. Sollatek-made 4-pin PL rated at 9 W selling for Z$330

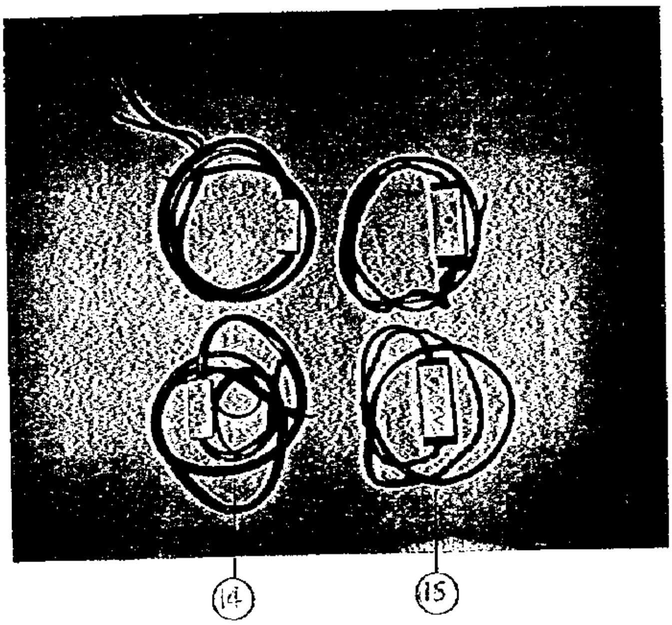


Photo 4-11 Voltage droppers
14. Sollatek-made droppers
15. Sollacomm-made droppers

Lamp: 4-pin PL lamp 7 and 9W fluorescent tube

Measurements were made using direct current constant power supply. Power consumption at a voltage of 12V was measured. In addition, by using an oscilloscope to examine the wave form at the alternating current side of the inverter, the Study Team checked for noise. The material of the print circuit board was also inspected (glass epoxy is the most desirable).

The test result shows that the products of Solarex consume a slightly higher current than the others tested.

All of three suppliers products provided sine wave current to the bulbs and appear to operate satisfactorily.

For the lamp fixture chosen for use in the JICA project was the Sollatek product because their product has a very stable sine wave for bulb operation and lower current consumption that the other tested units. An additional factor in their selection was their use of a high quality glass-epoxy resin printed circuit board where others use a phenolic type which is less strong and has lower resistance to electrical leakage.

Photographs 4-21 show examples of the sine wave shape delivered from the electronic ballast which is the most important factor in determining the life of the PL light bulbs.

Table 4-2 Results of Fluorescent Lamp Evaluation

Maker	Lamp Specifications	Direct Current Side			Alternating Current Side
		Voltage (V)	Current (A)	Power (W)	Frequency (kHz)
Sollatek	PL 7W 4 pin	12	0.58	6.96	45.24
	PL 9W 4 pin	12	0.63	7.56	45.20
Solarcomm	PL 7W 4 pin	12	0.52	7.44	35.08
	PL 9W 4 pin	12	0.73	8.76	35.08
Solarex	PL 7W 2 pin	12	0.91	10.93	18.41
	PL 9W 2 pin	12	1.19	14.28	18.41

(5) Direct Current Voltage Reducers (Photograph 4-11)

A direct current voltage reducer is necessary for operating a 9V direct current radio or cassette player from a 12V current, while a series regulator is used to drop the current, usually from 12V to 9V or 6V. As both products are sold in the local market, the Study Team purchased samples from two local companies for evaluation.

The basic method of evaluation was to connect a direct current constant power supply (12V) to the direct current voltage reducer, connect a 50W variable load to the output of the reducer (9V), and measure the voltage of both the input and the output currents of the reducer. Internal loss of the reducer was also checked.

1) Sollatek voltage reducer: 14 in Photograph 4-11 (without an LED voltage indicator)

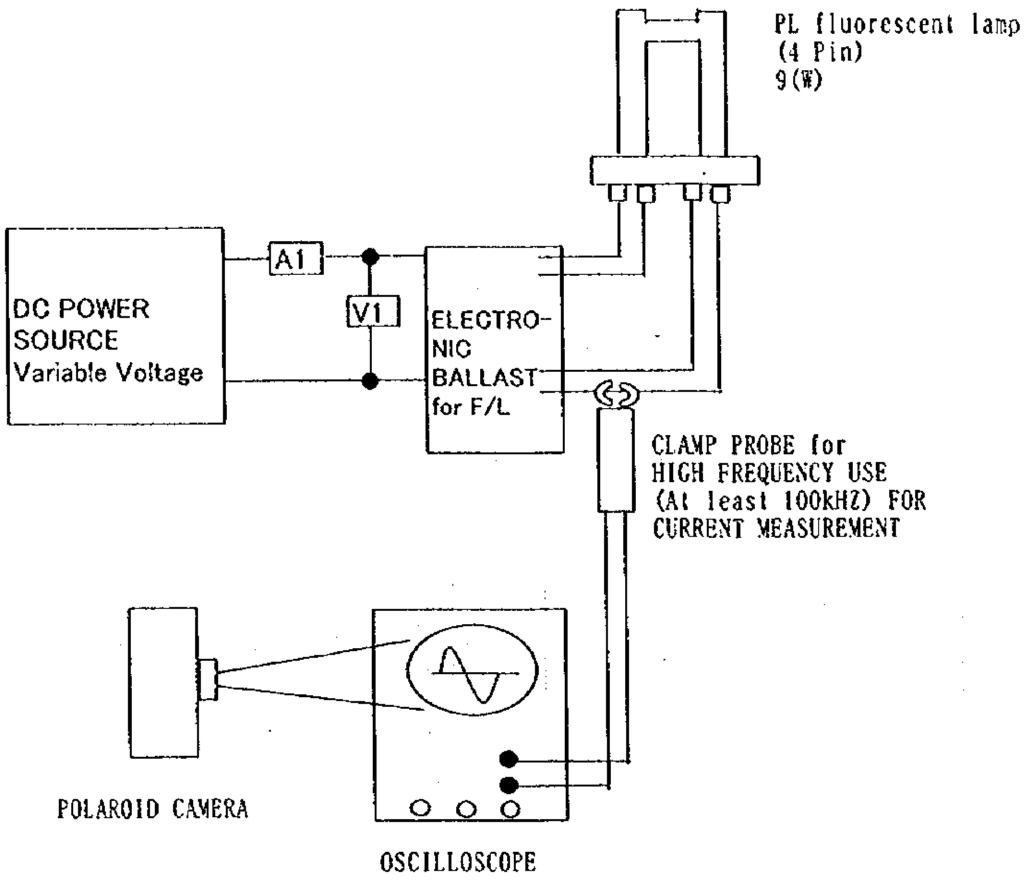
2) Solarcomm voltage reducer: 15 in Photograph 4-11 (with an LED voltage indicator)

It is recommended that the LED indicator included in the Solarcomm voltage reducer be eliminated as it is not necessary and consumes additional current without benefit.

The evaluation shows that there is not much deference between the two units tested as they use same internal semiconductor component. The only real difference is that there is a LED indicator in the Solarcomm which consumes power without real benefit to the user. For this reason the Sollatek product was selected for this project.

Table 4-3 Results of Direct Current Voltage Reducer Evaluation

	Model	Source		Dropped Voltage		Summary
		Voltage (V)	Current (mA)	Voltage (V)	Current (mA)	
Sollatek	M1014	12	4.8	8.96	0	No load
		12	163.4	8.02	159.1	Load
		12	303.7	7.15	300	Load
Solarcomm		12	16.5	8.90	0	No load
		12	217.0	8.02	200	Load
		12	319.5	7.21	300	Load



A1: AMP. METER
V1: VOLT. METER

Fig. 4-9 DIAGRAM FOR ELECTRONIC BALLAST CHARACTERISTICS EVALUATION TE.

Descriptions for the DC voltage reducer characteristics test circuit

The DC voltage dropper allows a 12V battery to operate 9V appliances like a radio or radio cassette, stepping down the 12V to 9V.

The voltage reducer consists of a semi-conductor device enclosed in a aluminum box. The circuit uses a "3 pin IC regulator" which has a capacity of 130 mA adequate to power typical radio or radio cassette operations.

The device is popular used for this purpose because of its stable output characteristic and low price.

Voltage Step down system

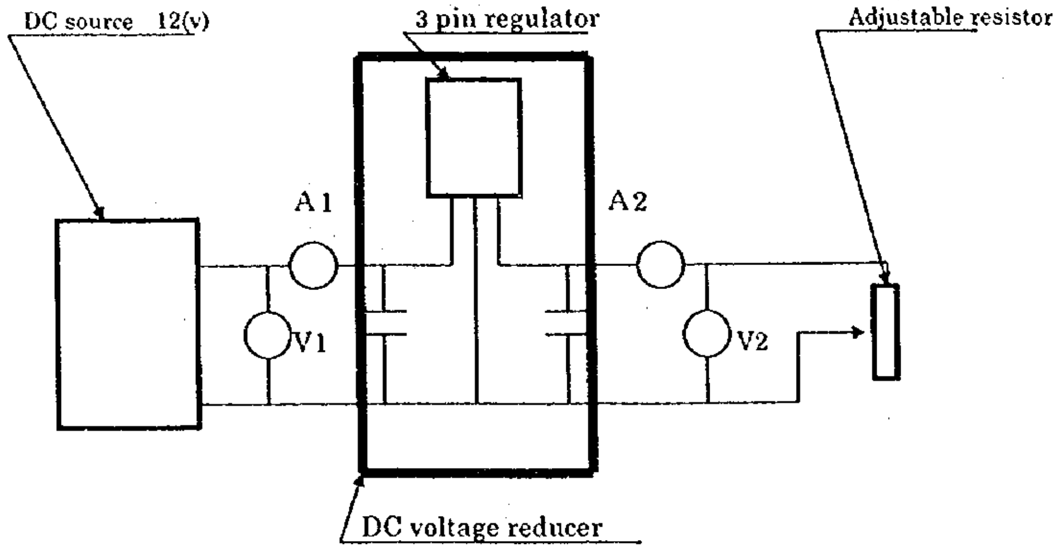


Fig. 4-10 Diagram of performance test system

SPECIFICATIONS OF THE MEASURING INSTRUMENTS

1. DC SOURCE: OUTPUT/Voltage 0(v) to 30(v)
   /Current 0(A) to 5(A)
2. A1: DC Amp. meter for supply side/500 (mA)
3. V1: DC Volt. meter for supply side/Max 30 (v)
4. DC Voltage reducer complete kit:
   3 pin IC Voltage reducer installed
   DC INPUT/Voltage DC12(v) to 20(v)
   /Current DC 2(A)
5. A2: DC Amp. Meter for the output/ DC 2(A) Max.
   V2: DC Volt. meter for the output/DC 9(v) Constant
6. Adjustable resistor to vary load current.

4.1.3 Improving the Component Parts of PV System

(1) Charge Controller

1) Overview

In accordance with the instructions to use locally manufactured equipment in the Study Installations, an evaluation was made during the first field study visit of the performance of charge controllers produced by two companies. Specifications for the charge controller were drawn up from this evaluation, and an order was placed with specifications appended (Table 4-4) for the 100 charge controllers to be used in the JICA project. Serial numbers were attached to all of the charge controllers. It was also requested that an actual operating voltage data for the charge and discharge protection settings be submitted. A long lead time of 3 months was required between placement of the order and delivery. During the second field study visit, these charge controllers were installed in household PV systems. Unfortunately, there were many problems with these charge controllers involving an unacceptably large number of faulty units, and improvements were clearly necessary.

Charge controllers basically determine the battery voltage level of PV systems and to perform this function, they require power at all times. For small capacity systems like the ones used in JICA's pilot installations, the Study Team deemed it most appropriate to use equipment that has minimal power consumption.

For the Battery World-manufactured charge controllers adopted for the project, some modifications had to be carried out to make them more energy-efficient. In particular, since they were not equipped with a separate battery-voltage sensing circuit, that is, voltage was sensed by the controllers using the main wiring rather than special wires for sensing battery voltage, a practice which in some cases can cause serious errors in voltage sensing. To allow separate sensing wires, the printed circuit boards had to be modified to have a exclusive battery sensing circuit because the sensing circuit is not attached now and the battery voltage sensing level is affected by load current, not just to enhance operating precision, but also to incorporate a function that allowed for easier monitoring.

Table 4-4 Set Voltage of Charge Controller

Name	LVD (v)	LRC (v)	HVD (v)	HVR (v)	Remarks	Quantity
	11.7	*12.2	14.2	12.6	Car Battery with LED	25
	10.8 - 11.0	*12.2	14.2	12.6	Deep Cycle Battery with LED	25
	11.7	*12.2	14.2	12.6	Car Battery without LED	25
	10.8 - 11.0	*12.2	14.2	12.6	Deep Cycle Battery without LED	25
For Reference: Set Voltage of Other Charge Controller						
GEF	11.5	12.5	14.5	13.5		
JICA	11.7	12.7	14.5	13.5		
Sollatec	11.4	12.3	14.5	12.6		
TRACE	11.5	13.0	14.0	13.5		
SAFT	11.3	13.1	14.3	12.2		
Morningstar (Prostar)	11.4	12.5	15.5	14.1	For Seal Battery	

* Check if can be Raised to 12.6 (v)
LVD Load Disconnect
LRV Load Reconnect
HVD Charge Disconnect
HVR Charge Reconnect

Actual modifications are described in more detail as follows (with the modified figure shown in Figure 4-11):

1) The number of indicator LEDs was reduced from 10 to 2 (red LED indicates over - discharge while yellow LED indicates state-of-charge).

2) The indicator LED lamps were separated from the main unit and installed in a separate box to allow mounting of the LED lamps in a highly visible location separate from the controller location which needs to be near the battery.

3) Modifications were made in the PCB (in places marked "x" on Figure 4-11)

These modifications were carried out primarily to reduce the LED count, thereby reducing the amount of power consumed by the charge controller.

After monitoring the performance of the modified charge controllers, the Study Team asked Battery World to manufacture the modified version.

Later, it was found out that aside from high internal power consumption, there were some other problems with the locally-manufactured charge controllers:

1) Order of charge controller's wire connection

There is a certain wire-connection sequence that must be followed at the time of installation — and unless wires are connected correctly in this sequence, the charge controller may not operate as intended. Figure 4-12 shows the correct wire-connecting sequence, which can be summarized as follows:

Step 1: Connect the wires from the photovoltaic (PV) module

Step 2: Connect the wires from the load

Step 3: Connect the battery voltage sensor

Step 4: Finally, connect the battery

In the actual installation process, the correct connection sequence was not always strictly followed by installers. Of the 100 charge controllers that were installed an unacceptably large number of units either failed to operate properly or were totally inoperative, probably because of this problem.

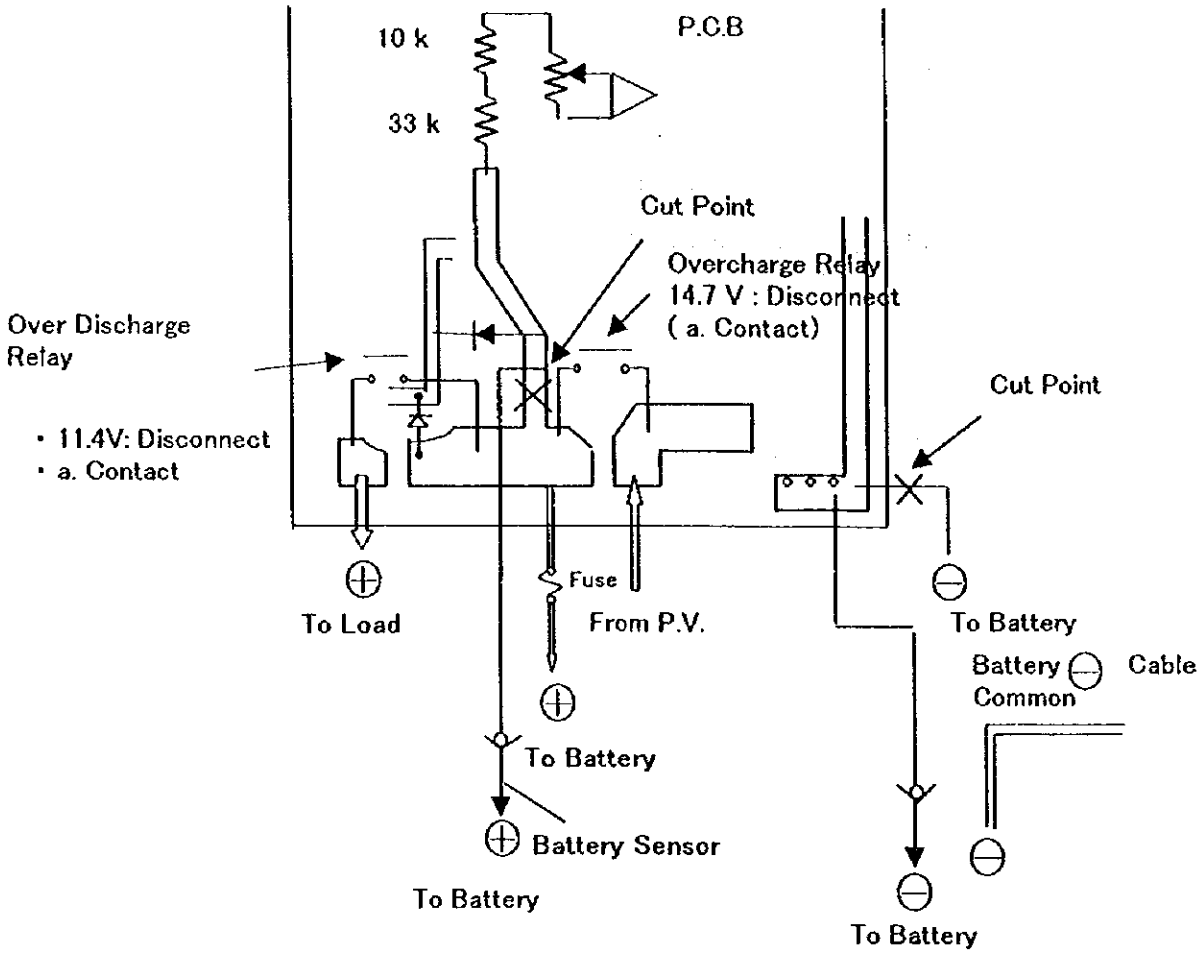


Figure 4-11 Modified Battery World Charge Controller

1. Connect wire to PV panel
2. Connect wire to load
3. Connect wire to battery voltage sensor
4. Connect wire ro battery

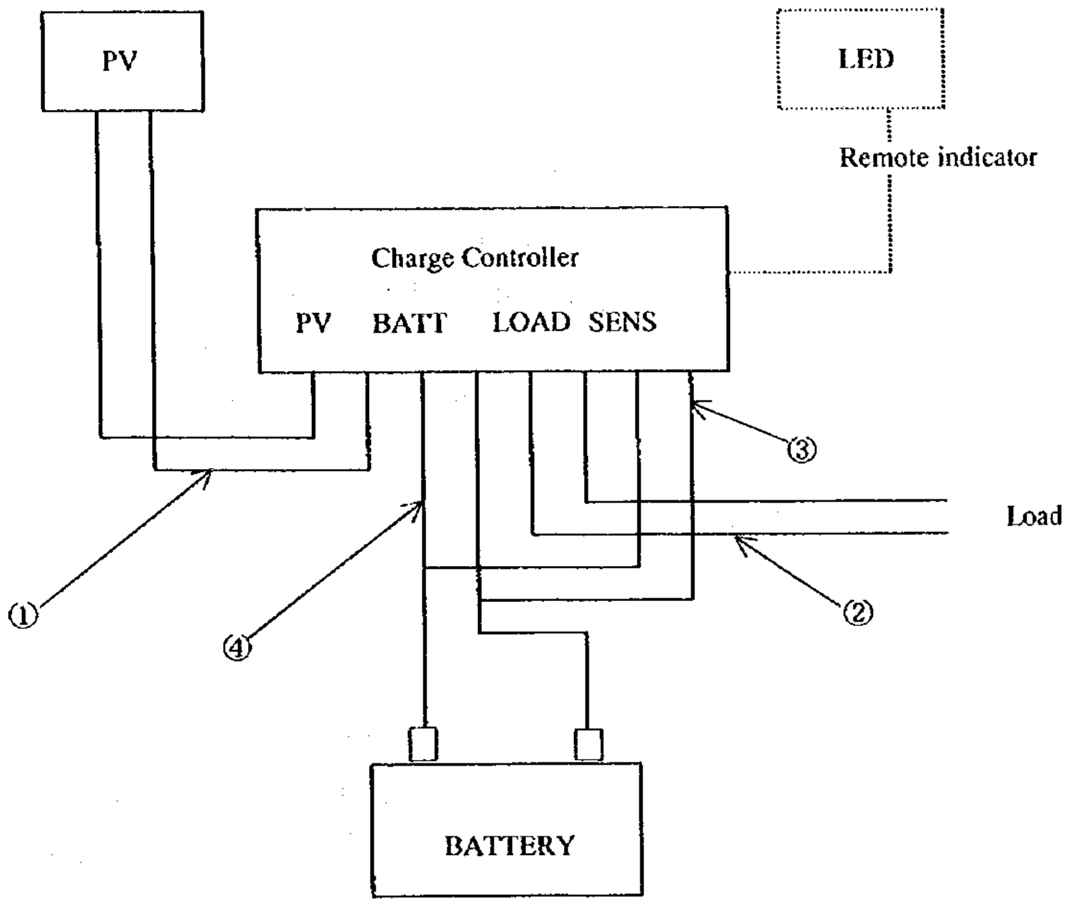


Fig. 4-12 Wire-connection sequence for charge controller

2) Minimum required battery voltage

The charge controller does not operate properly if the battery voltage is lower than 10 V. The battery voltage should, therefore, be higher than 11V to 12V when making wiring connections. Even though batteries may be delivered under fully-charged conditions, their voltage may drop to 10 V or lower due to self-discharge during storage before installation. In some cases, it was necessary for the Study Team to directly charge the batteries by bypassing the controller in order to recover the battery voltage and make the controller operative.

3) Manufacture of non-standard components

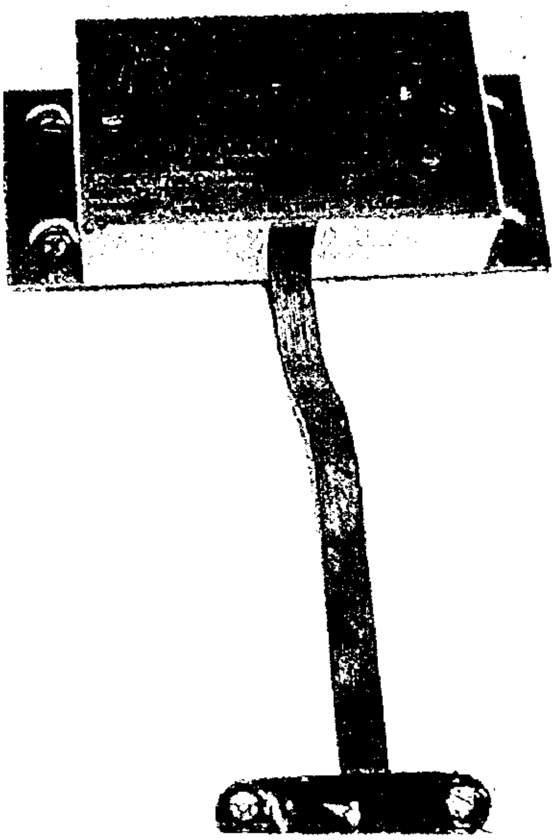
Local PV equipment manufacturers do not usually carry extra components in stock and make it a rule to place orders for components with their suppliers or parent companies in the minimum quantities possible (apparently due largely to lack of funds.

For this reason, when a modification involving components, the printed circuit board, the enclosure, an overlay panel, etc. is requested, the local manufacturer does not carry such articles in stock and cannot quickly honor the request unless the parts required to make the custom-designed modifications are easily available. If the manufacturer is forced to make such modifications, they have been found to make stop-gap modifications by making do with available but improper parts and to deliver poorly crafted products which do not meet specifications.

The Study Team ordered the following modified versions: a remote-LED-indication-type model from which battery-voltage status indicator LEDs were separated by wires approximately 2 meters (See Photos 4-12 to 4-14) and a model which was stripped of all its LED indicators (See Photos 4-15 and 4-16). Because the above models were made using only what was immediately, locally available (e.g. boxes and electrical components), there was no guarantee of stable operation over an extended period of time.

Photo 4-12 Improved Charge Controller

Remote LED indicator unit: This is a wall-mount-type unit incorporating the battery-voltage status LED indicator portion that has been separated from the cabinet of the charge controller via a cable measuring approx. 2 meters in length.



The LED indicator portion has been fashioned into a wal-mount unit for increased viewability. Since the manufacturer's off-the-shelf box is used, the size is of the box is relatively large.

Photo 4-13 Improved Charge Controller

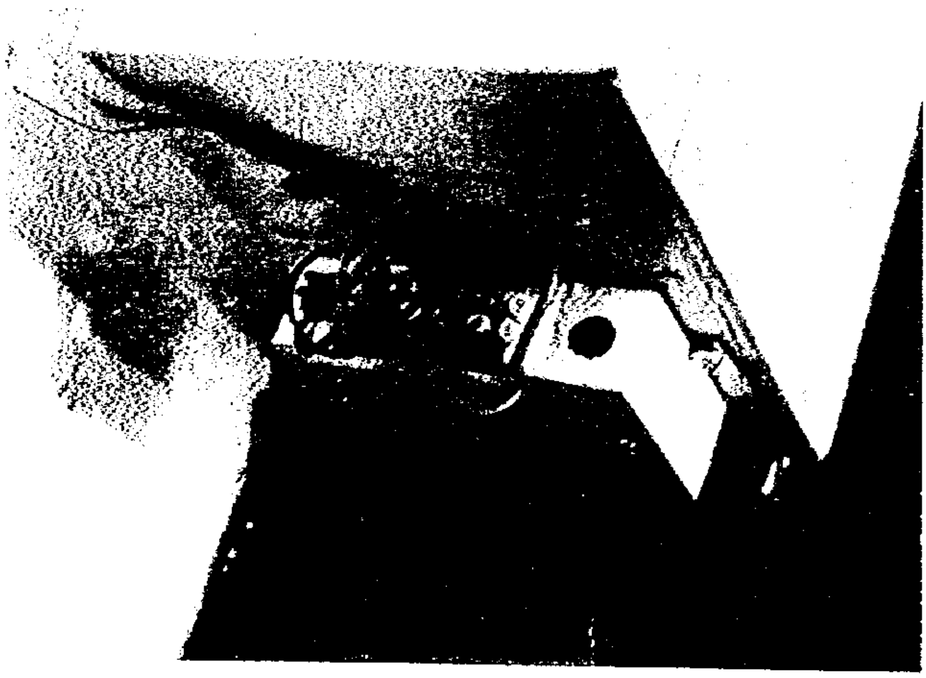


Photo 4-14 Charge Controller

(The LED indicator portion is not mounted)

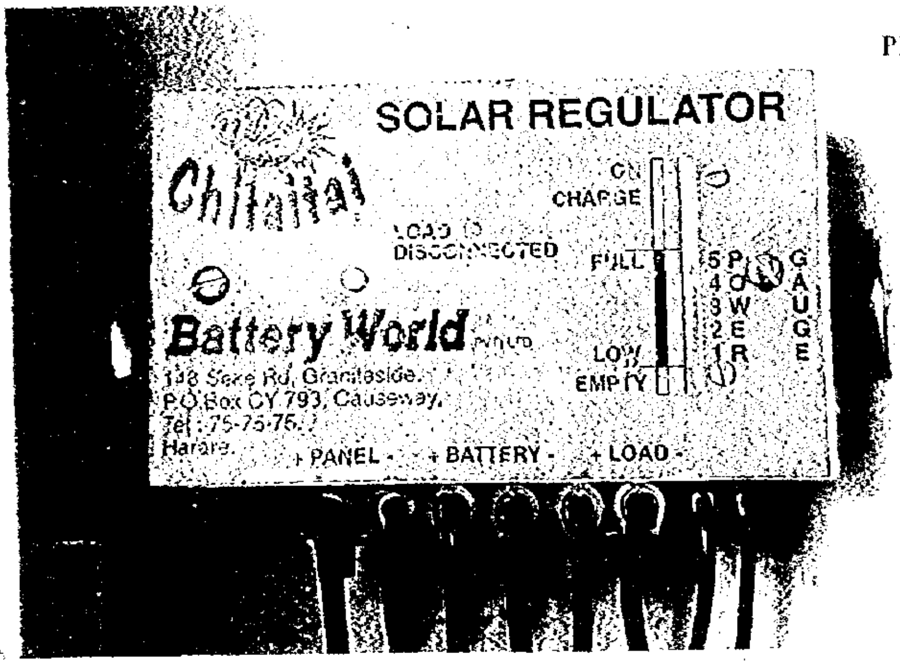


Photo 4-15 Battery World-made Charge Controller Model Devoid of LED Indicator Portion

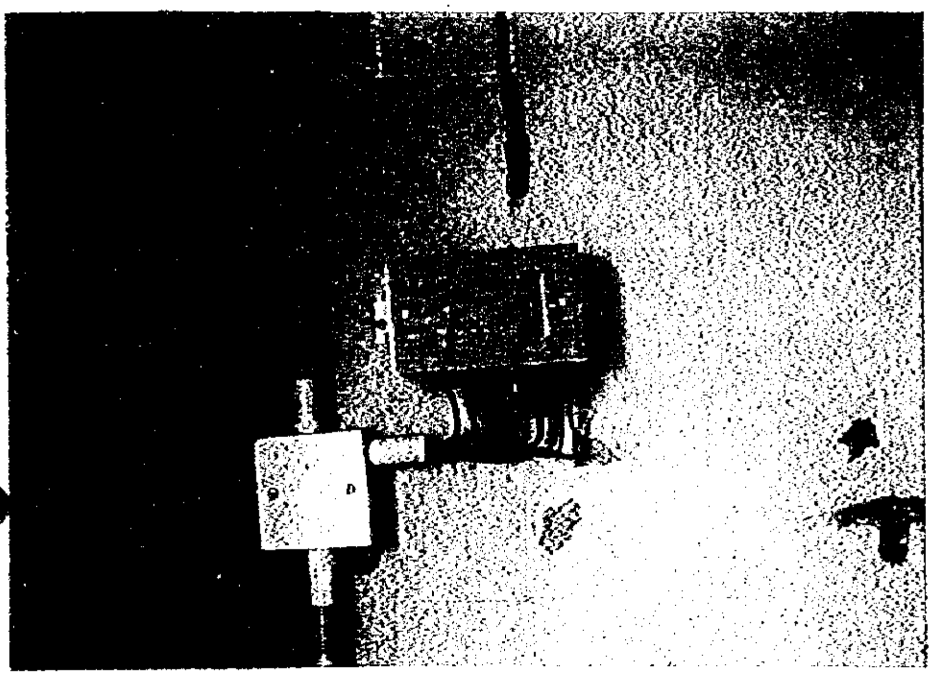


Photo 4-16 Charge Controller Proper Under Wall-Mounted Conditions

(Devoid of LED Indicator Portion)

4) Charge controller's internal consumption current

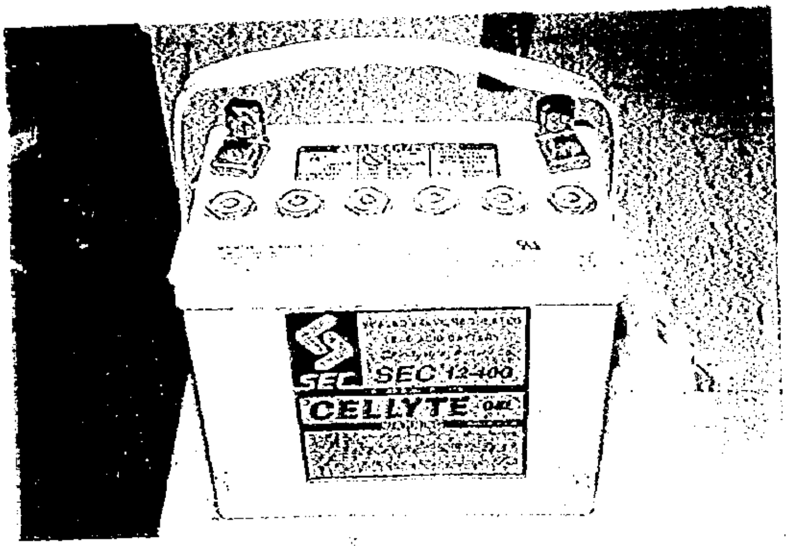
The locally-manufactured charge controllers require approximately 120mA to 180mA of current for their own consumption when relays are energized. On a 24-hour-a-day basis, this amounts to a daily consumption of 2.9 Ah to 4.3 Ah, while the average daily amount of current generated by a 25-watt photovoltaic system stands at approximately 1.5 A x 5 hrs or 7.5 Ah/day. What this means is that as high as 40% to 60% of the total power generated is consumed solely by the charge controller. Using a single 9-watt fluorescent lighting fixture, this current draw is equivalent to 3.6 to 5.4 hours of lighting time. As this represents a significant amount of current consumption, this problem requires an immediate solution.

(2) Battery

There are 2 local battery manufacturers in Zimbabwe and one of them is selling a battery advertised for solar use. The Study Team bought this battery for the systems to be installed. As it found several problems for this battery, the Team asked the manufacturer for its improvement. However, the manufacturer replied that it is impossible to do due to all parts are imported and other type of parts as requested by the team were not available for that battery.

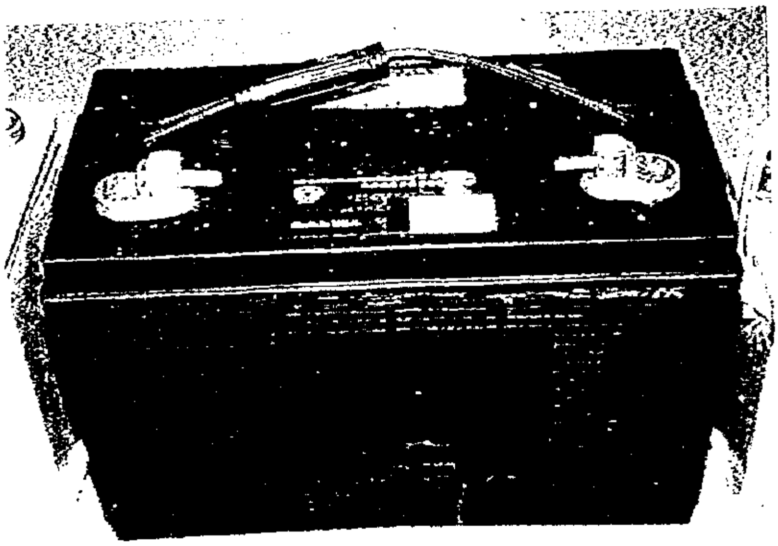
The observed major problems were its being easily contaminated by dust or insects due to a loose seal at the cover. The use of round terminals which did not allow the preferred screw type connection and being oppositely arranged for the polar characteristics of electrodes. This can result in burning out the appliances connected to this battery through the charge controller due to charging of reverse polarity of the electric voltage. The totally sealed type battery specifically designed for solar use would be preferred if it could be provided at an acceptable costs since it is totally leak free, does not require maintenance and uses flat terminals intended for screw type connections. It is, needless to say, necessary for the local manufacturers to improve their production technology including importing components to produce such types of solar battery as for future projects. (Refer to Photograph 4-17).

Photo 4-17 Maintenance-free Batteries



40(Ah)

60(Ah)



110(Ah)

4.2 PV Installation

4.2.1 Installation of Household Systems

Household systems were installed in the Geja area by Munyati Solar Distributors, a company based in Sanyati which is less than 10 km from the project area. Household systems in Turf and Manyoni were installed by Enercare Electrical Consultants, a Harare company with an agent in Kwekwe. Both companies were contracted to install 50 systems each with completion by 31 July. Due to the late delivery of components by Battery World, household systems could not be completed until late October at the earliest creating numerous problems for the installation companies including added cost due to extra trips to sites and delayed payment since under the contract final payment was tied to completion of all installations.

Installer quality control was poor. Some installations were very well done, others from the same company were inadequate with twisted wire connections, damage to the house walls, crooked wiring runs and battery connections that consisted of wire wrapped around the posts. Although specifications for the installations were provided, they were often ignored. Tilt angles for the panels were particularly a problem in all three companies with some exceeding 45 degrees instead of the nominal 17 as specified. Upon investigation it was learned that the installers had no idea what 17 degrees actually meant and had just had the panel mounts made like the ones they had used before for the GEF project whose inspectors were accepting very steep angles for panel mountings. Although pole mounts were specifically required for all houses, the Sanyati installer used wall mounted panel supports as in the GEF project. When asked why, the installer stated that the poles were too expensive and the wall mounts better anyway.

Several sites were visited by the JICA study team during the installation process. Workers had few tools and those that they had were often incorrect for the job being done. Screws were seen to be installed using knives instead of screwdrivers and pliers used instead of wrenches for tightening nuts on panel mounts. Drills were dull and of the wrong size so holes were made then reamed to the more or less correct size by wriggling the bit in the hole. When the correct tools were provided, the workers did not know how to use them properly. It was also common to find that one or more components had been left behind at their warehouse so many delays resulted.

Panel location was in several cases such that as the seasons shifted severe shading would occur due to the change in the sun's path from north to south over the year. Installers did not seem to understand this problem even after careful explanation.

All sites were inspected after installation by a JICA study team member and the senior technician from BUN. Nearly half were rejected due to problems ranging from incomplete installations to failure to patch plaster where holes in the walls were made. The installer has had to make corrections in order to receive final payment on the contract. The Turf/Manyoni installation company used technicians based in Harare and was very slow in returning to the sites to make corrections since they were also heavily involved in installing GEF systems. In many cases, BUN technicians ended up having to make the necessary corrections in order to have the systems completed and acceptable within a reasonable time.

User instruction by installers was not satisfactory. One installation company told users that if the battery was fully charged, as indicated by the top green light being on at the controller, that they should turn on the lights all night to keep the battery from being damaged. This, of course, ran the battery down and activated the LVD shutting the system down for several days while the battery recovered. In actual fact, the charge controller prevents battery damage due to overcharge and damage due to overcharge is impossible with the 25Wp panel in any case so long as the electrolyte level is monitored and water added when necessary.

The clinic and school installations were by JOTPAV Solar Systems, a Kadoma company representing a Harare installation company. The installations were generally better than those provided to households but again quality control was poor. As in household systems, panel tilt angles of over 45 degrees were initially installed. Proper connectors for batteries were not used initially and wire was just wrapped around battery posts until the proper connectors were obtained.

The installer told clinic users not to use the system unless absolutely necessary which resulted in most of the energy from the 83Wp panels going to waste. The data loggers at two of the clinics showed that as a result of this instruction the actual energy use at the clinics was less than at the households and systems were being poorly utilized.

4.2.2 Improving the Installation

(1) Installation Materials and Equipment

1) Frames for PV panel mounting: Present Status

The frames are made of L-section steel angle which are welded together by welding shops in nearby towns or in Harare. The finished product varied substantially in dimensions and quality. In many cases, it is doubtful that the workers have followed the design drawings. For this reason, there is almost no control over basic and essential frame features such as strength, tilt angle in the north-south direction, and horizontal mounting in the east-west direction.

Some of the companies used a triangular jig to set the tilt angle and make sure it was approximately 22.5 degrees, which is within the ideal tilt angle range for Zimbabwe. The frames from these companies were well made and posed no problems in that respect. However, even these companies did not use any jig to ensure horizontal support in the east-west direction and an angle to the support pole of 90 degrees. At present, some further improvement is desirable.

2) Improvement Measures:

In order to ensure that the basic frame requirements are met, we emphasize the importance of controlling the tilt angle. To do this, a triangular jig for angle setting should always be used. We recommend using an angle of about 20 degrees as this matches the average latitude of the entire country. A right-angle jig should be used to ensure consistent horizontal support in the east-west direction. This jig should be used during the welding process to make sure the support pillar is at 90 degrees to the frame.

(2) PV Module Installation

The following three methods are used in Zimbabwe to support the modules, depending on the type of building in which the system is to be installed:

a) A straight support pillar is bolted to a side wall of the building

b) An L-shaped support pillar is bolted to a side wall of the building

c) A support pole is set in the ground near to the house

Method (b) is only useable in the case of buildings with comparatively strong walls, such as clinics. For houses which are not of such sturdy construction, method (a) or (c) is appropriate. Photos 4-18 and 4-19 show examples of supports on which PV modules are installed.

Regardless of the installation method used, it is important to make sure that the support pillar is vertical. One way to do this is to drill a hole for inserting a single bolt in the support pillar before drilling all of the mounting holes and to temporarily mount the PV module on it. After aligning the module a tilt meter is used to position the module properly and this then determines the position of the second bolt hole. Next, the module's east-west axis is turned approximately 90 degrees, and a spacer is used along with the tilt meter, as above. Using this method ensures that the support pole is vertical. After this, the module is turned so that its surface faces north and is then secured in place. Finally, a tilt meter should be used to check that the tilt angle of the module is between 15 and 20 degrees. Spacers can be used for adjustment.

When making the bolt holes, the drill must be perpendicular to the surface of the wall. It is not acceptable to make holes in walls by driving them through with a hammer since this method may seriously damage the wall.

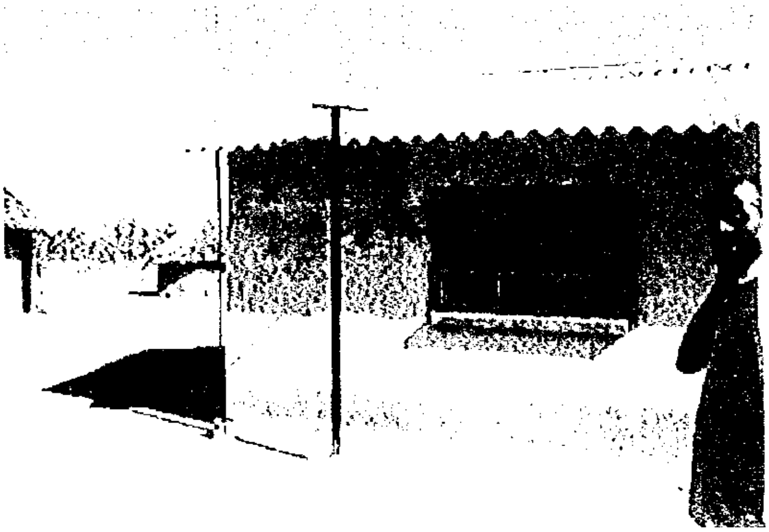


Photo 4-18 PV Array Mast (C)

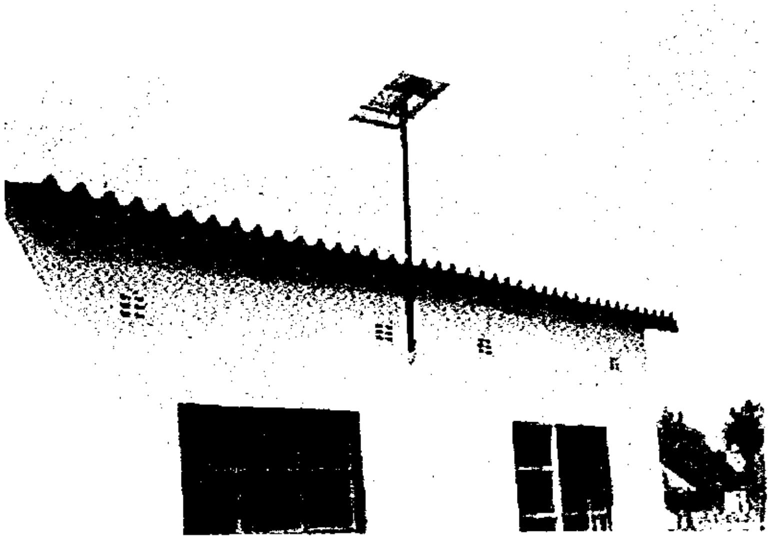
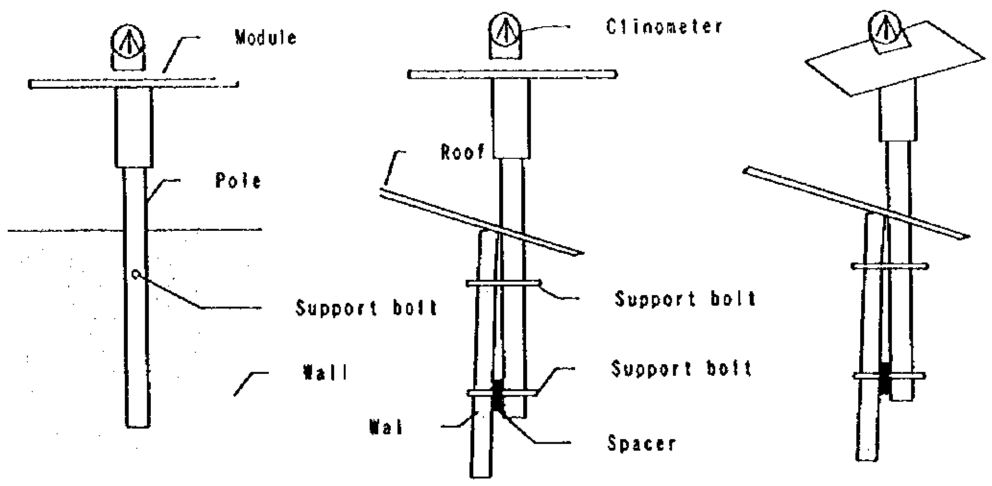


Photo 4-19 PV Array Mast (A)



a. Adjustment from front

b. Adjustment from side

c. Adjustment of panel orientation

Fig.4-13 Procedure of PV array setting

(3) Orientation of the PV Module

The installers use a small compass to check the orientation of the modules, but it is difficult to orient a module on a roof accurately with this method. As a result, there is a great deal of variation in the orientation accuracy. The Study Team devised a supplementary tool to make it easier to make accurate orientation settings. This tool is suitable for local manufactured. Once the marker line has been aligned with north as indicated by the compass, simply aligning the edge of the module with it specifies the correct orientation.

An example is shown in the following figure. For individual installers, it is worthwhile studying/devising various other methods.

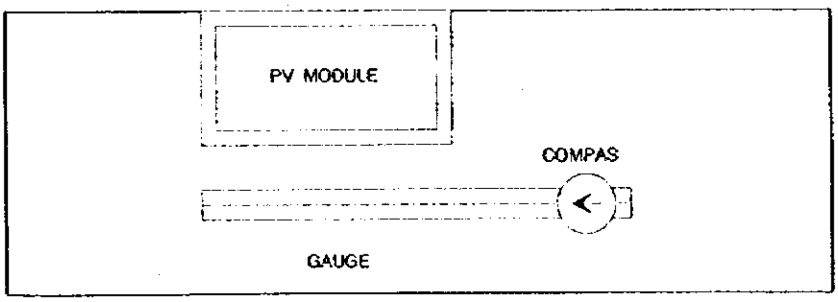


Figure 4-14 Example of PV cell array orientation gauge

(4) Wiring Installation

The GEF project has properly sized the wire sizes to be used by local contractors in the solar PV systems. However, an examination of the wiring installations reveals some need for improvement. A basic problem is that there are almost no identification markings on the wires. If there were markings on the wires, installation could proceed faster and with fewer mistakes.

(5) Precautionary measures when making battery connections

When it is necessary to change PV panel connections with the storage battery connected, either the battery terminals should be disconnected or the battery or charge controller's fuse should be removed before disconnecting the PV module's wires. The reason is because in small PV system, blocking diode normally mounted on charge controller is cut for more efficiency, so shortening of wires causes accident.

If this is not done damage can result to the system should the PV panel wires accidentally be shorted together. During this project, we have observed some cases where an installer made connection changes on a PV module with the battery connected and accidentally shorted the removed wires. Since the installation was not complete and no fuse had been installed at the battery, the controller was damaged by the high current through the HVD relay. Since "hot-wiring" work done while the battery is connected can cause serious short circuit problems (leading to fire) it should be avoided at all costs.

(6) Battery Connections

There are two main types of battery configurations: open cell and maintenance free or sealed types. Two widely used types of open cell batteries employed in PV systems are automobile starting batteries and deep cycle batteries. Automotive batteries usually have round terminals for clamp type connectors while deep cycle batteries have square ones for bolted connections. Clamp type connections are not good for use with solar systems. Therefore we recommend the square terminal configuration over the round one.

A large amount of grease is presently being applied to prevent corrosion after connections have been made to the terminals. Such large amounts are not necessary and it is not good practice to apply more than a thin film of grease to terminals. It is also necessary to teach installers not to allow electrolyte to come in contact with the terminals and to keep everything clean.

(7) Mounting the Charge Controller

Under GEF standards, the mounting position the charge controller is quite high to prevent it from being meddled with by children. The disadvantages of having to use long wires between the battery and the controller are overcome by using large-gauge wire.

For small capacity systems such as the JICA systems, it is important to reduce the power consumption by the system itself and to reduce the cost in order to reach the low-income families. The JICA improved controller was made smaller in size and eliminated the special terminals for the battery voltage sensors. When this was done, it became difficult to find space on the controller for terminals big enough to accommodate the large-gauge wires used by GEF standards.

To keep the wires short and losses small, it is necessary either to mount the charge controller on the battery box, or to mount it on a wall very near the battery. The biggest problem with this method, which is ideal from an electrical standpoint, is the possibility that the system will be meddled with by children.

To eliminate this concern, several approaches are possible. One is the GEF-prescribed installation method in which the charge controller is installed 1.5 meters above the floor and thick wires about the twice the required size are used to make connections to the battery, or the JICA Study Team's method wherein the charge controller is placed in a locked container on the battery box. Although both these methods have disadvantages in terms of the system's usability, they satisfactorily address the goal of preventing/minimizing tampering.

4.3 Improved Prototypes

Initially, the charge controller and fluorescent lamp electronic ballast components of the locally manufactured PV systems were programmed for improvement by the Study Team. However, since it proved very difficult to obtain the parts required by the Team in Zimbabwe within the allowable time and it was deemed best to produce improved prototypes in Japan and take those parts to the Zimbabwean manufacturers for technology transfer.

4.3.1 Charge Controller

Of the various parts making up a PV system, the charge controller plays a very important role in terms of the system's operating characteristics. The Study Team, unable to find any charge controller which satisfied its requirements, decided to use the one manufactured by Battery World as it had the lowest internal power requirement (when compared other locally-available products). Some improvements were still necessary, however, since they still consumed a relatively large amount of power. Since the designing of circuits to reduce power consumption, component layout, and a contact-protection circuit to prolong the life span of relay contacts was found to be too formidable a task to be carried out locally, as was the task of procuring parts for the improved design in Zimbabwe, most modifications had to be done in Japan.

(1) Design and specifications

The design philosophy behind JICA's improved charge controller was to provide equipment suited for use by end-users who have limited knowledge of PV. Charge-controller specifications and details of improvements made based on this design principle are as follows:

1) Charge controller's wire connection sequence

When JICA's improved charge controller is installed, outside circuit can be connected at your optional order.

2) Minimum required battery voltage value

Circuit operation was designed to go into standby mode with the panel connected to the battery and load disconnected to prevent the battery voltage drop to abnormally low levels.

3) Charge controller's internal power consumption was minimized

All charge controllers made in Zimbabwe were observed to draw unacceptably large currents for their internal consumption. The reason is that the coils of relays used for charge/discharge control in the Zimbabwe controllers consumed large currents (ranging from 120 to 180 mA).

In the case of JICA's improved model, the relays used have very low power consumption in the range of 20 mA, and power consumption is much less than that of the locally made controllers.

This type of charge controller is well-suited for the small-scale PV systems (20-25 watts) utilized by JICA.

(2) Evaluation of the improved charge controller

During the fourth field study, the improved charge controller prototyped in Japan was installed in the JICA PV systems, and their performance was recorded on a data logger. It was observed that the system's operating hour count increased due to the lower internal power consumption, and that the battery's maximum voltage were higher than levels normally reached by the conventional, locally-manufactured systems. A more detailed explanation is given under Section 4.6 of this chapter.

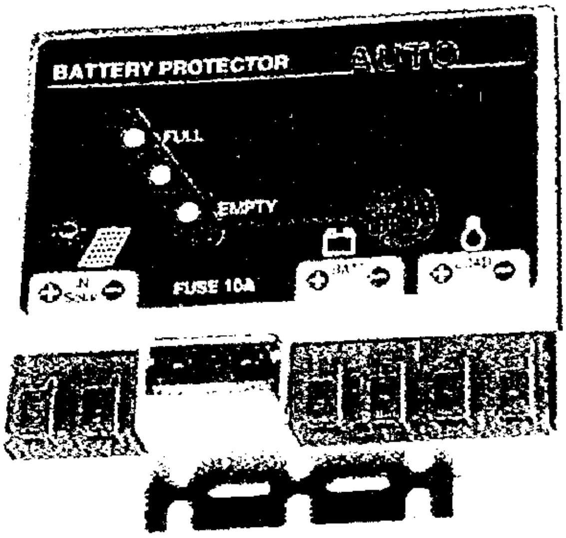


Photo 4-20 Improved charge controller

4.3.2 Ballast for Fluorescent Lamps

As with the charge controller, the fluorescent lamp ballast is an important component of a PV system. Improvements in efficiency and quality prolong the life of the fluorescent tube saving PV users the trouble and expense of frequently changing fluorescent tubes and improving customer satisfaction with the PV systems. JICA's fluorescent-lamp ballast was designed with the following main considerations;

- Because of the small scale of the PV system, significant energy savings and high luminous intensity should be achieved;
- Circuits should not be damaged even if a power source with reverse polarity is inadvertently connected;
- Circuit components should be easy to procure, and the fluorescent-tube circuit should be easy to assemble;
- Circuitry should be stable and have long life.
- Safety measures should be incorporated in the design.

Details of the individual specifications are as follows:

1) Energy savings and high-luminous intensity

The Study Team selected a high-luminous intensity fluorescent tube available in the world market and designed a circuit with discharge characteristics specifically tailored to that tube (i.e. able to oscillate at a discharge frequency of 25 kHz) so that the highest possible luminous intensity could be obtained.

2) Measure to protect against reverse-polarity connection of power source

The circuit was designed specifically to prevent the semiconductor circuitry from being damaged even when a power source is connected with reverse polarity.

3) Procurement of circuit components and assembly

The Study Team adopted system parts that are marketed in most countries worldwide and made assembly simpler in order to lower production costs.

4) Stable circuit conducive to increased life of fluorescent tube

For the high-frequency oscillator circuit, the Study Team used radio-frequency-grade components that can withstand high voltage for more stable operation. We also provided a gap in the core of the oscillator transformer in order to fashion the oscillator's frequency waveform (which determines the life span of the fluorescent tube) into a sinusoidal wave shape (considered ideal for the fluorescent tube).

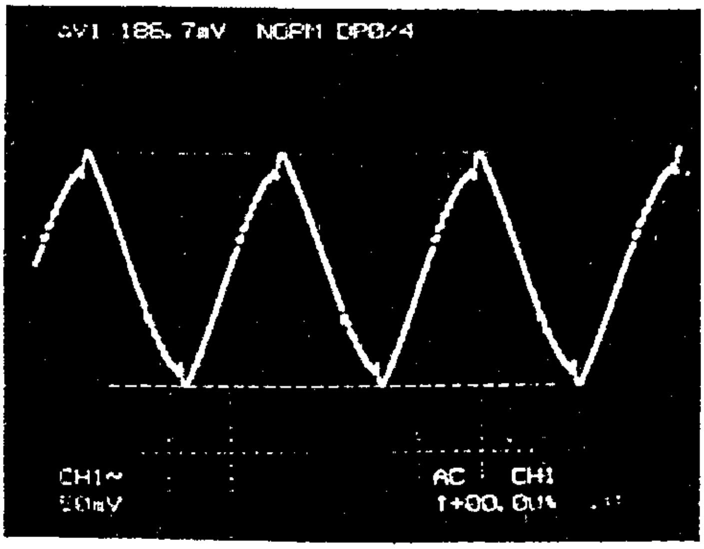
5) Safety measures

As a safety measure, an appropriate fuse was installed in the input portion of the ballast circuit.

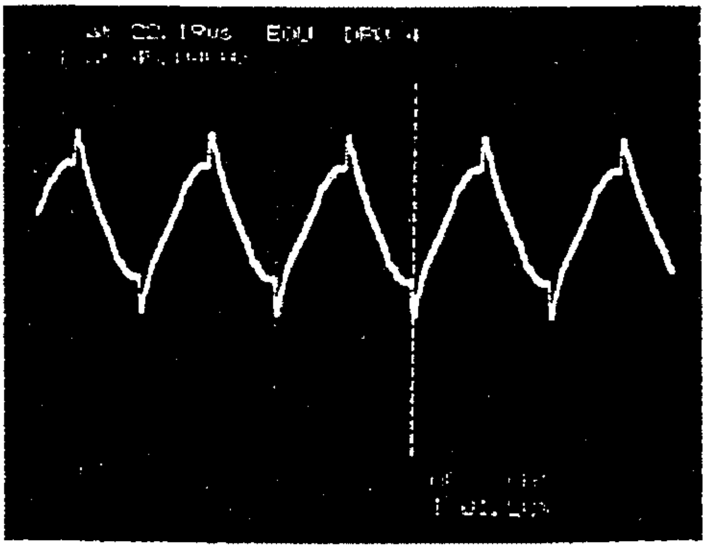
(2) Evaluation of improved ballast

By incorporating the above-mentioned improvements, members of the Team prototyped the improved ballast in Japan and made evaluations. By using radio-frequency-grade parts for the high-frequency oscillator circuit, it became possible for the unit to generate an ideal AC-sine waveform at no additional cost. It was also observed during the performance tests that the crests of the sinusoidal wave became rounded off which should prolong the life of the fluorescent tube.

In Photo 4-21, the upper image shows the ideal waveform while the lower one shows the wave shape recorded before modifications were made. The original sine wave had sharp-pointed crests, indicating that a high voltage is applied to the fluorescent tube for a short time in each cycle. This causes shortening of its life. Since the improvement of this particular component would greatly improve the system's overall performance, the Study Team sought to transfer this technology to our counterpart at workshops and at its assembly facilities.



Ideal wave curve
(after improvement)



Bad shaped wave curve
before improvement

Photo 4-21 JICA Improved Fluorescent Inverter AC Output Wave Curve

4.3.3 Evaluation of Improved Charge Controller and Inverter Assembly

For the sake of technology transfer, the Study Team designed the circuitry of the improved charge controller and fluorescent-lamp ballast, determined the parts to be used, prepared physical designs and supplied all required parts but relegated the work of assembling the parts to local manufacturers. Following are the results of evaluations which the JICA study team has performed on the charge controllers and fluorescent-lamp ballasts that were assembled by the individual local manufacturers.

(1) Charge controllers

The Team asked three local companies to assemble the JICA-designed improved charge controller by providing them documentation called "Technical Literature for Assembly of JICA Improved-type Charge Controller and Fluorescent-Lamp Inverter" (Reference material 4-2) along with all the required parts. We instructed them to return finished and adjusted charge controllers for testing. The completed assemblies delivered to the team were then subjected to evaluation tests, the results of which are as follows:

1) Company A

This company delivered the requested items in semi-finished conditions, meaning that parts were simply soldered to the printed circuit board, and no voltage adjustments had been made. Since the units were not to specifications, we instructed our counterpart how to make operating voltage set point adjustments, and asked them to bring all seven items to the specification needed. The study team was able to visit the company's subcontracting factory and inspect the factory's finished-product adjustment area. We found out that the facility was not equipped with the proper DC power sources and meters necessary to adjust the controller, and was therefore only capable of assembling printed circuit boards.

2) Company B

All seven charge controllers which we asked the company to assemble were delivered to us in a fully finished state. Since this factory operates based on an assembly-line, division-of-work method of manufacture in its production processes, it manufactures good products that compare favorably in quality with those manufactured in industrialized countries. Its final set-point adjustment facilities are well equipped with measurement equipment where well-trained workers make voltage set point adjustments to specification. This factory appears to be a good candidate for local manufacture of the improved controllers in the future.

3) Company C

Unlike the above two companies which were operating in cooperation with foreign companies, this company is a 100-percent Zimbabwean-operated company on which the GEF project was also pinning expectations. Within four days of our assembly request, this company delivered finished products, considerably ahead of the other two companies. The results of performance evaluations were also good. Although this is a small company, the company is considered to be a good candidate factory when to commission production in the future since transferring PV-related manufacturing technologies and providing the materials and equipment required for manufacture to such a company can help lead to the proliferation of PV lighting systems in Zimbabwe.

(2) Fluorescent-lamp ballast

Just as was the case with the charge controller, the task of assembly of the JICA-designed improved fluorescent-lamp ballast was given to the above three companies. By virtue of the small parts count and the easy-to-assemble printed circuit board (PCB), all companies submitted goods that were satisfactory and were comparable in terms of finished condition.

4.4 Project Operation following Installation

4.4.1 Household Systems

Although the majority of installations were made by August, 1997, some systems were delayed in installation and all systems were completed by the end of September, 1997. Prior to that time, each household cluster area was being serviced by two technician trainees under BUN. Following the technician training course held at Kwekwe Technical College, BUN placed under full time contracts two of the technician trainees, one for the Sanyati area cluster and one for the Turf/Manyoni cluster of households. Although monitoring checks had been made irregularly both by BUN technicians and the JICA Study Team prior to that time, with the hiring of the technicians, regular monthly visits to each system for preventive maintenance and monitoring were begun by the newly hired technicians. Each month, a report of the monitoring findings was forwarded to BUN in Harare for analysis and forwarding to the JICA Study Team.

Each field technician has been provided a tool kit, technical training, record keeping materials and administrative training. A bicycle was provided for transport within the service area. To reach the more distant houses, particularly a problem in the Turf/Manyoni area, the technician carries the bicycle on the local bus between areas then makes his local maintenance rounds with the bicycle. The tool kit and bicycle were provided by BUN at no cost to the technician but should tools be lost they would be replaced by BUN and the full cost deducted from technician salary payments. If tools are broken, a percentage of the replacement cost will have to be borne by the technician through salary deductions. The bicycle is maintained by the technician and may be used for personal as well as business purposes.

At the time of the visit, the technician cleans all components except the panel which is not cleaned unless clearly dirty (due to problems of access and possible damage), checks battery electrolyte level, measures cell electrolyte density with a hydrometer and measures battery voltage. If the battery charge level is unusually low, the system is checked for loose connections, controller malfunction and abuse. The user is interviewed about the system, particularly about problems with power outage or unusual occurrences since the last maintenance visit. Additional information included in the report to BUN covers the weather conditions for the previous two days (to help ascertain if low battery charge levels are due to cloudy conditions), the temperature of the battery electrolyte and the general condition of the system as observed by the technician.

Where repairs are needed, the technician will attempt to effect a repair on the spot. In the case of charge controller failure, the battery will be connected directly to the panel until a replacement controller can be brought to the site. Some spare controllers, light bulbs and light fixtures are held in stock by the technician and those will be used to effect replacements where necessary. Items replaced are returned to BUN in Harare for repair and to determine the reason for their failure.

Batteries and panels are not kept in stock by the technicians. Panels very rarely fail. Should a panel be broken or stolen a replacement must come from the Harare stock. When a battery fails, one must be sent from Harare to Kadoma, Sanyati or Kwekwe for pick up by the technician who then takes it to the site for replacement. The failed battery will be kept by the technician until the next visit of the BUN Senior Technician when it will be returned to the manufacturer for recycling and credit if still under warranty.

During the start of monitoring by the technicians, an average of three to four household systems were not operating properly at the time of each visit. For most cases, repairs were made on the spot by the technicians. The system problems were usually related to a controller malfunction or battery, in the case of the Manyoni Civil Servant households, failure was due to serious abuse of the systems leading to unacceptably low battery charge levels and power loss to the system.

As part of the monitoring process, users were interviewed regarding their use of the system and their satisfaction. In almost all cases, the level of satisfaction was high with the only common problem being a desire for increased capacity to allow longer periods for watching TV and more lights connected to the system. One customer in Manyoni asked that the system be removed because the capacity was too small.

Another indicator of customer satisfaction is the collection of fees. In other projects when customer satisfaction has been low, fee collection has also been poor. In the case of this project, the collection rate has been virtually 100%. Approximately 90% of the users prefer paying annually at the time of harvest so fee collections on a monthly basis is not a problem and at harvest time, annual fees were collected as expected. The remaining 10% of the users are largely salaried employees of the Government (teachers, civil servants or health workers) and payment has generally been prompt.

Also showing general customer satisfaction is the fact that there is a formal waiting list for the JICA systems which is kept by the Sub-District Officer in Sanyati. As of June, 1998, 60 households had signed up in that cluster area. In Turf/Manyoni there is no formal waiting list but nine households have asked the BUN technician for systems when they become available.

4.4.2 Clinic Systems

In addition to the 100 household project, five clinics in Kadoma District (Nyamatani, Geja, Jondale-Bumbe, Turf, Nyabango) and five clinics in Gokwe South District (Msita, Tongwe, Chitave, Gawa and Chemahororo) were electrified using solar energy. The capital cost was paid by JICA but maintenance is expected to be paid by government, the community or the RDC according to the sponsor of the clinic. The system was designed for low maintenance by using oversized panels and deep discharge batteries. Therefore, maintenance is expected to be simple and minimal so basic maintenance should be easily handled by clinic staff.

On behalf of the JICA Study Team monitoring effort, the BUN Senior Technician made spot checks of the clinic systems during the first half of 1998 and in May 1998, he made a complete tour of all clinic and school installations to determine how well the systems were being maintained by institutional staff and to gain information about the manner in which the systems were being used.

The visit confirmed that the systems all were working satisfactorily with minor problems such as defects in some lights and switches. However from about 1 year later, the problem of local-made battery has brought. The battery is degrading so fast.

The visit also made clear that the hour of use of the systems tended to be shorter than expected but in all cases, the staff stressed the value to them and the community of having the improved lighting and the adequate capacity that lighting can be relied on for enough hours in the case of a serious health problem or injury that requires immediate treatment at night.

The quality of maintenance carried out by clinic staff has been found to be very variable. Most clinics have provided excellent maintenance while in a few there has been some abuse the systems such as leaving lights on all night when not required, using the systems for non-health related private and social activities, charging batteries for private use and ignoring basic maintenance chores such as refill of electrolyte when levels are low. As an example of improper use of the systems, an early morning visit to the Tongwe clinic by the BUN Senior Technician in May, 1998, found private batteries connected to the panels for charging and a TV operating in the treatment room. There does not seem to be a pattern for correlating the quality of maintenance to clinic ownership, it appears to be mainly a function of the quality of clinic management.

Following the completion of the JICA Study Team's activities in Zimbabwe, BUN intends to provide maintenance visits to clinics at approximately 4 month intervals unless a specific and serious problem arises with a clinic system requiring an immediate visit. With the basic maintenance expected to be carried out by clinic staff and the low maintenance required with the clinic system design, this maintenance visit frequency should be adequate. However, visits cannot be made by BUN without cost recovery and arrangements for the clinics to pay for the labor and transport cost of the technician.

4.4.3 School Systems

Two secondary school lighting systems were installed with one in each of the area selected for household systems. The St. Charles Secondary school near Geja clinic is a RDC sponsored school selected for system installation by the JICA Study Team. The Benhura Secondary School in the southern area of Kadoma District is a privately sponsored secondary school also selected by the JICA Study Team for system installation. The capital cost for both school installations was paid by JICA with maintenance expected to be paid by the RDC, the community or the private organization sponsoring the school. Monthly maintenance is handled by the field technicians serving the nearby household clusters.

The observed use of the systems included severe abuse and failed operation of most systems at St. Charles School to very good at Benhura School where systems were working well and being used as expected. In the case of St. Charles Secondary School the severe abuse included charging teacher's personal batteries from the systems, altering the wiring, discharging the batteries to damaging levels and failing to add water when electrolyte level was below minimums.

4.5 Analysis of Data from Data Loggers

The original data loggers were installed at the Tongwe Clinic, the Turf Clinic, and the house of Mr. Cuthbert Murandu in the Turf region. An additional data logger was installed in November 1997 at a house in the Sanyati region. The data loggers installed at the Turf Clinic and the Tongwe Clinic were equipped with pyranometers to measure the amount of solar irradiation. Photo 4-22 shows one of the data loggers installed. Photo 4-23 shows a PV array with a pyranometer mounted on it.

The data loggers are used where a main power supply is not available for the data logger, a personal computer, or a signal converter, therefore, all the internal data signals are at extremely low power levels and they are provided from conventional dry batteries. A shunt resistor is used for current detection for the low-impedance circuits, so it is unavoidable that the main circuit current interferes somewhat with the other signal levels. It is necessary to keep this relationship in mind when evaluating the data.

The data obtained from the first nine months (August 1997 through April 1998) and the analyzed data are listed in Tables 4-6 through 4-11. The special characteristics of these results are described below.

1) Solar Irradiation Data

The actual tilted solar irradiation data for the ten months following the installation of the PV systems, the global irradiation data obtained locally, and the calculated tilted solar irradiation based on them are listed below.

Table 4-5 Actual Measurements of Tilted Solar Irradiation and Estimated Solar Irradiation (Example of Turf Clinic)

Month of measurement	Actual tilted solar irradiation		Estimated tilted solar irradiation kWh/m²/day	Global irradiation kWh/m²/day
Clinic Name	Turf	Tongwe		
August	6.74	5.85	6.51	5.69
September	5.95	5.60	6.77	6.39
October	6.26	6.25	6.53	6.65
November	5.78	5.85	6.05	6.50
December	6.32	6.96	5.41	5.91
January	5.45	5.62	5.71	6.20
February	6.75	6.52	5.55	5.78
March	6.48	6.10	5.79	5.71
April	6.71		5.99	5.74
May	7.01		5.95	5.05
Average	6.11	6.04	5.99	5.75

Though the actual measured values of the tilted solar irradiation were slightly below the tilted solar irradiation estimated based on the local global irradiation data, there were no large discrepancies between the two sets of figures.

The local long-term statistical data shows that values around 6 kWh/m^2/day and consistent with the measured values have been observed. The measured solar irradiation data confirms that the use of estimated solar irradiation based on Zimbabwe global solar irradiation as corrected for a tilted surface seems to be appropriate.

As expected, the data from the rainy months of December and January show the lowest tilted surface solar irradiation. They are significant to the design of future systems. They prove that the estimated tilted solar irradiation of 5.4 kWh/m^2 used for designing the system was appropriate.

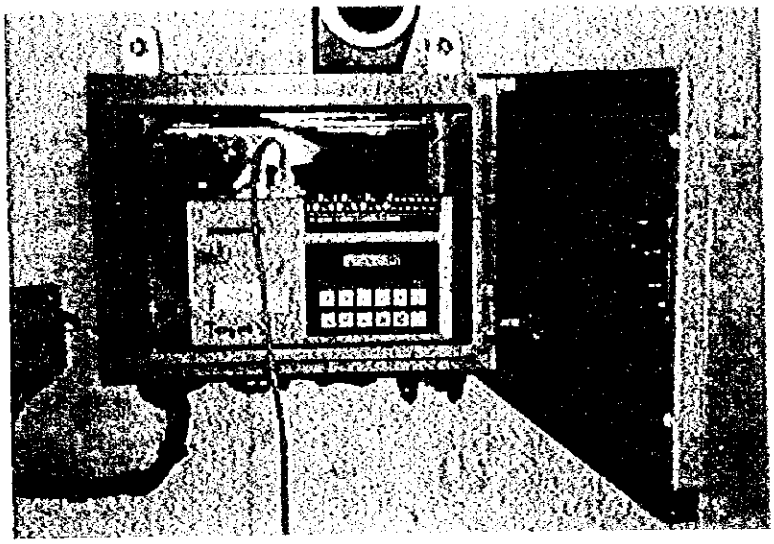


Photo 4-22 Installed Data Logger

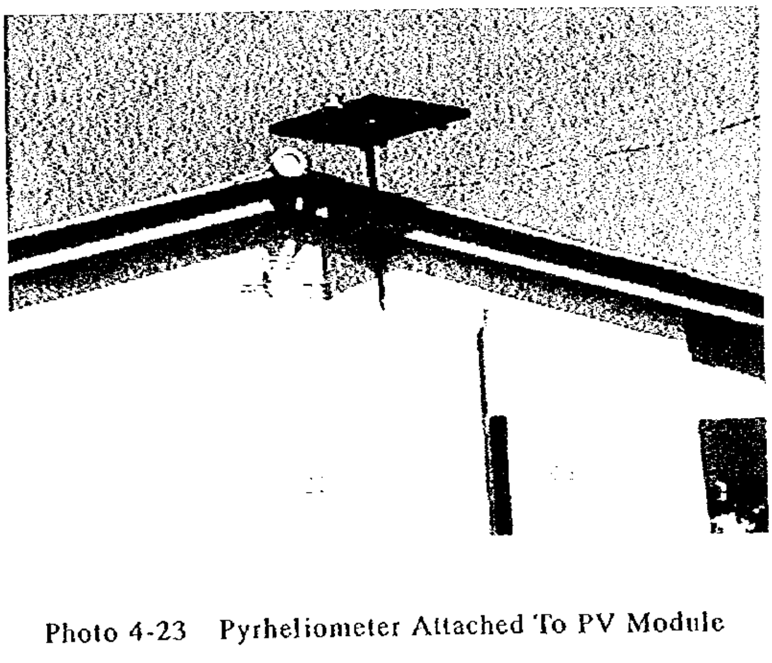


Photo 4-23 Pyrheliometer Attached To PV Module

Table 4-6 MONTHLY OPERATION DATA OF PV SYSTEM IN TURF CLINIC #1
PV module : 83 W

Month	PV current (Ah)	Charge current (Ah)	Discharge current (Ah)	Discharge/ Charge	Load current (Ah)	Maximum battery voltage (V)	Minimum battery voltage (V)	Inclined irradiation (kW/m2)	Load on Time (h)
Aug-97	5.32	5.19	-1.07	0.19	0.80	14.20	12.48	6.74	0.62
Sep-97	6.73	6.97	-1.49	0.31	1.19	14.06	12.48	5.95	0.79
Oct-97	8.45	8.37	-0.66	0.11	0.37	14.09	12.48	6.26	0.31
Nov-97	13.23	13.18	-0.87	0.10	0.37	14.21	12.62	5.78	0.34
Dec-97	11.58	11.42	-2.04	0.19	1.61	14.47	12.83	6.32	2.24
Jan-98	12.65	12.17	-3.60	0.29	3.55	14.44	12.68	4.99	3.94
Feb-98	7.37	7.31	-1.27	0.16	0.70	14.48	12.78	6.75	0.82
Mar-98	12.31	11.68	-5.85	0.46	5.95	14.46	12.66	6.48	8.93
Apr-98	17.36	15.93	-8.79	0.56	9.81	14.45	12.53	6.71	14.86
May-98	17.16	15.82	-8.91	0.57	9.86	14.46	12.47	7.01	15.15
Jun-98									
Jul-98	19.29	18.29	-12.05	0.67	12.80	14.48	12.33	5.77	13.63
Aug-98	20.28	18.90	-10.75	0.58	11.86	14.41	11.69	6.05	12.30
Sep-98	23.30	22.52	-10.61	0.48	11.12	14.44	12.24	6.26	10.95
Oct-98	25.51	24.20	-11.82	0.51	12.87	14.36	12.45	6.36	12.95
Nov-98	23.36	22.13	-11.45	0.52	12.42	14.41	12.47	6.67	12.39
Dec-98									
Average	14.93	14.27	-6.08	0.38	6.35	14.36	12.48	6.27	7.35

Table 4-7 MONTHLY OPERATION DATA OF PV SYSTEM IN TONGWE CLINIC #1
PV module : 83 W

Month	PV current (Ah)	Charge current (Ah)	Discharge current (Ah)	Discharge/ Charge	Load current (Ah)	Maximum battery voltage (V)	Minimum battery voltage (V)	Inclined irradiation (kW/m2)	Load on Time (h)
Aug-97	12.53	12.47	-2.72	0.30	2.36	14.16	12.27	5.85	2.58
Sep-97	10.51	10.39	-3.01	0.41	2.70	14.08	12.28	5.60	3.03
Oct-97	11.66	11.61	-3.94	0.41	3.56	14.15	12.24	6.25	3.16
Nov-97	11.71	11.68	-4.00	0.40	3.60	14.01	12.17	5.85	2.61
Dec-97	13.32	13.07	-6.10	0.50	5.91	14.12	11.83	6.96	4.57
Jan-98	12.23	12.14	-3.19	0.29	2.86	14.04	11.61	5.27	2.80
Feb-98	11.46	11.22	-4.47	0.44	4.25	14.08	12.18	6.52	4.30
Mar-98	10.86	10.66	-5.52	0.56	5.25	14.06	12.01	6.10	4.87
Apr-98									
May-98									
Jun-98									
Jul-98	6.94	6.92	-4.76	0.65	4.33	14.15	11.96	4.90	2.88
Aug-98	8.87	8.53	-5.92	0.65	5.82	14.17	11.94	5.26	3.68
Sep-98	13.22	11.67	-7.20	0.61	8.32	14.10	11.83	5.67	12.46
Oct-98	13.23	11.26	-4.37	0.40	5.93	14.13	11.55	6.15	13.13
Nov-98	25.69	25.62	-0.22	0.01	0.08	14.24	9.83	6.10	0.10
Dec-98	18.22	16.37	-0.26	0.02	1.91	14.67	9.71	5.07	2.60
Average	12.89	12.40	-3.98	0.40	4.06	14.15	11.67	5.83	4.48

Table 4-8 MONTHLY OPERATION DATA OF PV SYSTEM IN TURF CLINIC #2

PV module : 83 W

Month	PV current (Ah)	Charge current (Ah)	Discharge current (Ah)	Discharge/ Charge	Load current (Ah)	Maximum battery voltage (V)	Minimum battery voltage (V)	Inclined irradiation (kW/m2)	Load on Time (h)
Aug-97									
Sep-97									
Oct-97	11.94	11.80	-2.56		2.45	13.91	12.44	6.26	2.47
Nov-97	13.42	13.33	-1.67		1.45	13.95	12.00	5.78	1.79
Dec-97	7.51	7.45	-1.16	0.17	0.86	14.15	12.39	6.32	1.27
Jan-98	6.80	6.75	-1.46	0.18	1.14	14.16	11.96	4.99	1.53
Feb-98	7.68	7.65	-1.07	0.17	0.72	14.14	12.40	6.75	0.83
Mar-98	6.96	6.89	-1.39	0.22	1.08	14.15	12.28	6.48	1.47
Apr-98	11.83	11.83	-0.40	0.03	0.05	14.16	12.45	6.71	0.08
May-98								7.01	
Jun-98									
Jul-98	4.48	4.41	-0.70	0.15	0.44	14.19	10.63	5.77	0.46
Aug-98	7.77	7.77	-0.39	0.10	0.04	14.17	12.11	6.05	0.04
Sep-98	7.78	7.78	-0.59	0.13	0.23	14.18	11.97	6.26	0.15
Oct-98	7.54	7.49	-0.72	0.15	0.40	14.11	12.02	6.36	0.43
Nov-98	9.85	9.75	-1.14	0.22	0.91	14.08	12.10	6.67	0.96
Dec-98	5.03	4.85	-0.78	0.21	0.64	14.14	12.21		0.68
Average	8.35	8.29	-1.08	0.16	0.80	14.12	12.07	6.20	0.94

Table 4-9 MONTHLY OPERATION DATA OF PV SYSTEM IN TONGWE CLINIC #2

PV module : 83 W

Month	PV current (Ah)	Charge current (Ah)	Discharge current (Ah)	Discharge/ Charge	Load current (Ah)	Maximum battery voltage (V)	Minimum battery voltage (V)	Inclined irradiation (kW/m2)	Load on Time (h)
Aug-97	9.67	9.66	-2.64	0.28	2.36	13.76	12.37	5.85	2.34
Sep-97	7.63	7.62	-3.65	0.40	3.36	13.67	12.36	5.60	3.86
Oct-97	7.73	7.69	-3.49	8.57	3.21	13.92	12.34	6.25	4.00
Nov-97	13.51	12.73	-8.04	0.74	8.48	13.91	12.06	5.85	8.14
Dec-97	11.90	11.72	-6.78	0.65	6.63	14.16	12.11	6.96	6.83
Jan-98	19.50	17.77	-12.11	0.72	13.58	13.98	10.97	5.27	12.44
Feb-98	19.24	18.01	-14.44		15.45	13.98	12.12	6.52	13.17
Mar-98	15.03	14.83	-12.29	0.86	12.27	14.10	12.03	6.10	9.68
Apr-98	17.44	16.94	-14.26	0.87	14.48	14.08	11.93		12.13
May-98	17.67	17.28	-14.02	0.77	14.15	14.17	11.91		10.51
Jun-98									
Jul-98	4.83	4.83	-1.36	0.31	0.96	14.27	12.22	4.90	0.89
Aug-98	9.22	9.08	-4.75	0.49	4.54	14.25	12.14	5.26	3.69
Sep-98	6.91	6.89	-3.18	0.45	2.81	14.21	12.19	5.67	2.34
Oct-98	9.04	8.92	-5.58	0.73	5.33	14.17	12.16	6.15	3.54
Nov-98	9.83	9.49	-6.40	0.74	6.39	14.07	12.08	6.10	4.31
Dec-98	9.72	9.66	-7.99	0.81	7.75	14.18	12.01	5.07	4.84
Average	11.80	11.44	-7.56	1.16	7.61	14.05	12.06	6.09	6.42

Table 4-10 MONTHLY OPERATION DATA OF PV SYSTEM IN TURF HOUSEHOLD
PV module : 25 W

Month	PV current (Ah)	Charge current (Ah)	Discharge current (Ah)	Σib-/Σib+	Load current (Ah)	Maximum battery voltage(V)	Minmum battery voltage(V)	Inclined irradiation (kWh/m2/d)	Load-on time (h)
Aug-97	6.06	5.96	-1.68	0.15	2.43	12.49	11.53	6.74	2.50
Sep-97	7.67	7.39	-2.49	0.41	2.54	13.42	12.20	5.95	3.10
Oct-97	8.99	8.72	-2.59	0.32	2.61	14.53	12.51	6.26	3.19
Nov-97	8.39	7.95	-2.48	0.33	2.68	14.43	12.60	5.78	3.16
Dec-97	9.80	8.82	-3.54	0.46	4.31	14.39	12.58	6.32	5.29
Jan-98	7.58	7.15	-2.24	0.31	2.43	14.60	12.65		3.05
Feb-98	9.29	9.03	-1.19	0.14	1.20	14.71	12.62		2.18
Mar-98	8.85	8.45	-2.49	0.32	2.67	14.52	12.52		3.44
Apr-98	8.28	7.68	-3.06	0.44	3.46	14.32	12.51		4.46
May-98	7.24	6.22	-4.50	0.84	5.34	14.06	12.51		6.38
Jun-98									
Jul-98									
Aug-98									
Sep-98									
Oct-98									
Nov-98									
Dec-98									
Average	8.08	7.67	-2.50	0.33	2.83	13.98	12.35	6.21	3.38

Table 4-11 OPERATION DATA OF PV SYSTEM IN SANYATI HOUSEHOLD
PV module : 25 W

Month	PV current (Ah)	Charge current (Ah)	Discharge current (Ah)	Σib-/Σib+	Load current (Ah)	Maximum battery voltage(V)	Minmum battery voltage(V)	Inclined irradiation (kWh/m2/d)	Load-on time (h)
Aug-97									
Sep-97									
Oct-97									
Nov-97	7.02	6.15	-4.19	0.81	4.70	12.57	10.93		4.77
Dec-97	8.42	6.79	-5.99	0.97	7.31	13.20	11.97		7.22
Jan-98	6.16	5.25	-5.16	1.05	5.76	13.22	11.97		5.06
Feb-98	7.69	7.33	-4.93	0.69	4.92	14.37	12.15		4.98
Mar-98	7.94	7.53	-5.10	0.69	5.12	14.32	12.17		5.20
Apr-98	8.56	8.04	-4.81	0.61	4.98	14.39	12.19		4.61
May-98									
Jun-98									
Jul-98	5.36	4.66	-3.64	0.91	3.88	14.16	10.99		4.73
Aug-98	7.43	6.32	-5.25	0.87	5.89	13.78	11.94		5.74
Sep-98	7.81	7.08	-5.42	0.79	5.67	13.75	11.90		5.34
Oct-98	9.27	8.68	-3.95	0.49	4.10	13.94	11.39		3.97
Nov-98	8.66	8.43	-1.26	0.15	1.19	13.99	10.51		1.25
Dec-98	4.76	4.63	-2.43	0.55	2.18	14.17	10.16		2.37
Average	7.42	6.74	-4.35	0.71	4.64	13.82	11.52		4.60

Discussion of the Discrepancies found in the observed Data:

The solar irradiation data obtained shows a discrepancy of about 7% between the two pyrometers that were installed. Causes could be possible to consider as:

One is that there may be a difference in the actual solar irradiation in two locations. Another is that the difference is due to differences in the tilt angle or mounting position. Yet another is that the discrepancy is caused by the data logger measuring the solar irradiation and the voltage and current levels of the PV systems.

If the discrepancy was caused by signal interference, it might be possible to eliminate it by using separate loggers to record the signals from these pyranometers.

There is almost no difference between the two measured solar irradiation data at Turf and Tongwe in their average, and therefore it is considered that difference of the data to be occasionally found may be caused by actual difference of solar irradiation at each measuring point.

2) Overview of the PV System's Operation

a) Overall aspects of Operation

When the systems were first installed, some of the households were not able to charge their batteries because the charge controllers did not operate properly.

As an emergency measure, the charge controller was bypassed, an acceptable action because the level of current from the small 25Wp panel is not great enough to cause rapid electrolyte loss. Since then, the demand for power was covered without difficulty thanks to the excellent solar irradiation conditions.

It would appear that there were few problems and that the systems operated satisfactorily. Based on the information recorded by the data loggers installed, the PV systems seem to have worked out well, however, the data does show some differences between actual system operation and the expectations we had at the design stage.

b) Charge Controller Operation Characteristics

Examples of the design specifications and the operating characteristics of the locally procured charge controllers that were installed are provided below.

The data on operating characteristics was taken from Figure 4-15 and Figure 4-16, which were compiled by analyzing the collected data.

Table 4-12 Specifications and Operating Characteristics of Locally Produced Charge Controllers

Setting item / Operating level	HVD (High Voltage Disconnection)	HVR (High Voltage Reconnection)	LVD (Low Voltage Disconnection)	LVR (Low Voltage Reconnection)
Spec	14.5 V	13.5 V	11.5 V	12.5 V
Locally produced units	14 V - 14.2 V	12.5 V - 12.7 V	11.6 V	12.7 V

Not only are the voltage settings observed significantly different from the specification values, there is also unacceptable variation in the operating voltages of the individual units. The voltage setting designed to prevent overcharging (HVD) operated at around 14 to 14.2 V in the case of Tongwe Clinic, which is listed above. This is between 0.3 and 0.5 V below the specification. The reconnection voltage (HVR) of the overcharge prevention circuit operated at around 12.5 to 12.7 V. This is about 1 V lower than the 13.5 V of the specifications. Furthermore, the operating level of the same controller was not stable. The operation of the storage battery over-discharge prevention voltage setting (LVD) was recorded only once in the case of the house in the Turf region. Though this cannot be said to be typical, the system installed at the house in the Turf region disconnected the load at a level of approximately 11.6 V. This level is acceptable. The reconnection voltage setting (LVR) operated at about 12.7 V. This is somewhat higher than the 12.5 V of the specifications but not unreasonable.

In conclusion, the operation level of the overcharging control portion of the controllers was too low, making it difficult for the storage batteries to recover to full charge. The operating voltage level was also somewhat unstable and shifted over time.

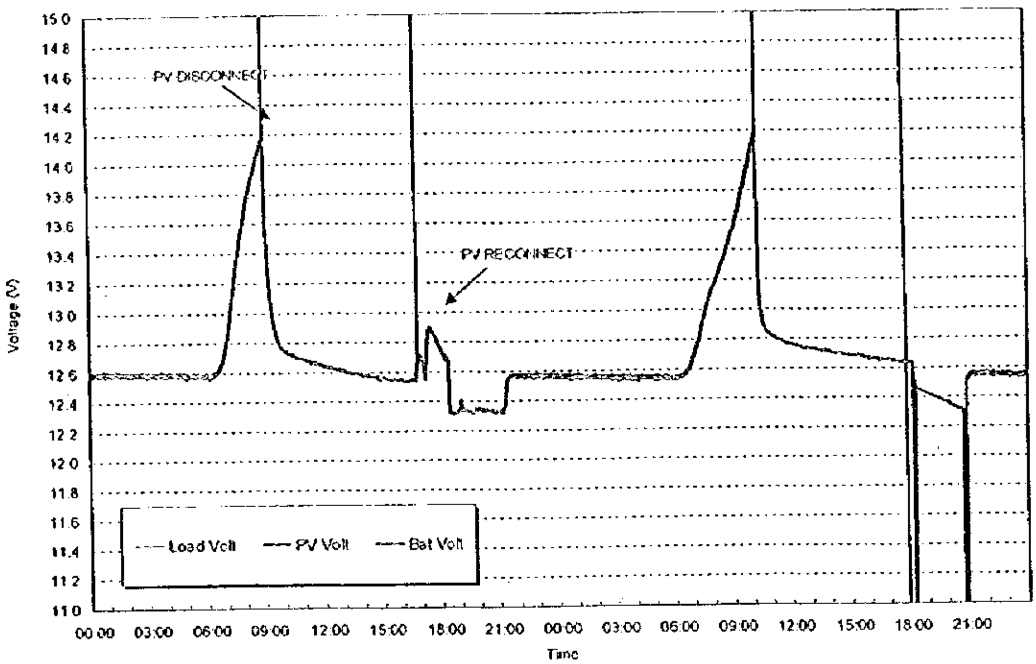


Fig. 4-15 An Example of Performance Characteristic of Charge Controller for the Tongwe Clinic System (8/17, 8/18)

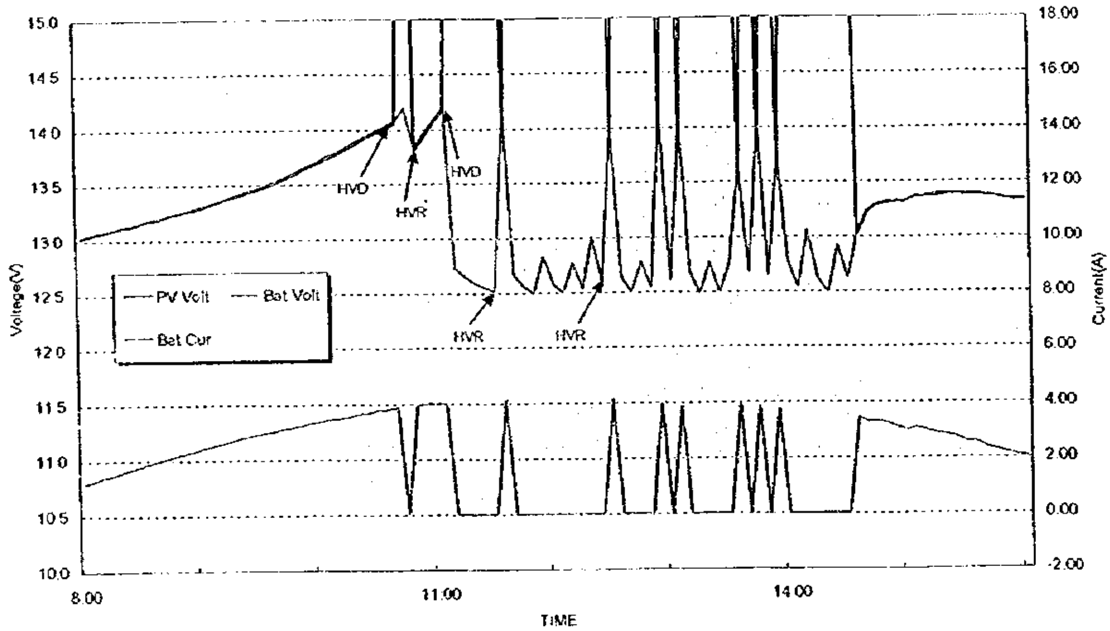


Fig. 4-16 An Example of Performance Characteristic of Charge Controller for the Tongwe Clinic System (8/23)

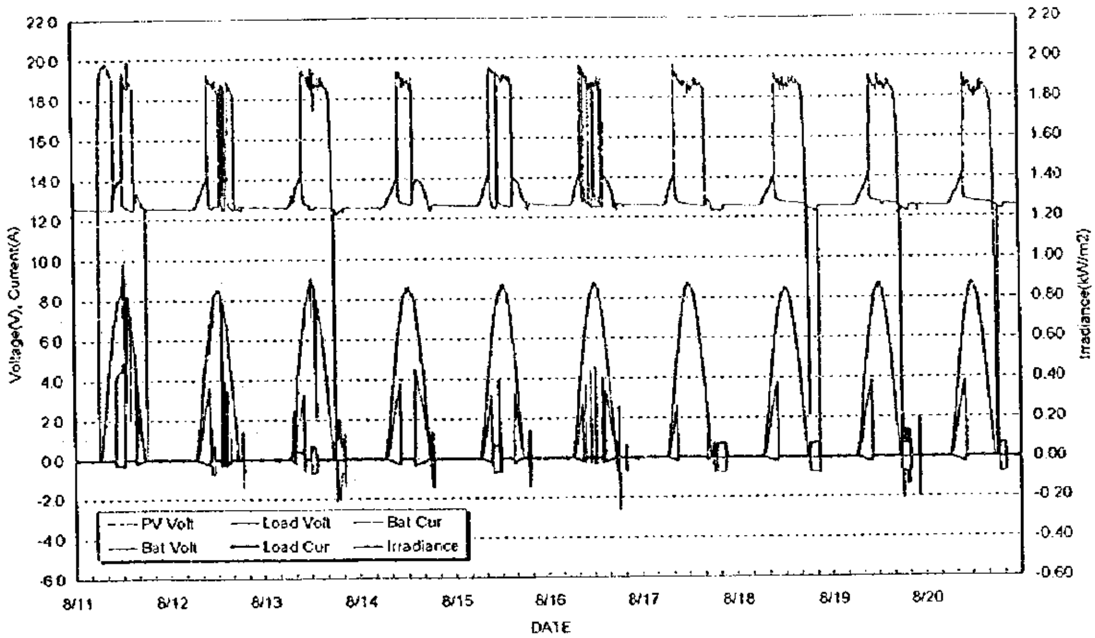


Fig. 4-17 An Example of Operational Characteristic of PV System for the Tongwe Clinic System (8/11-8/20)

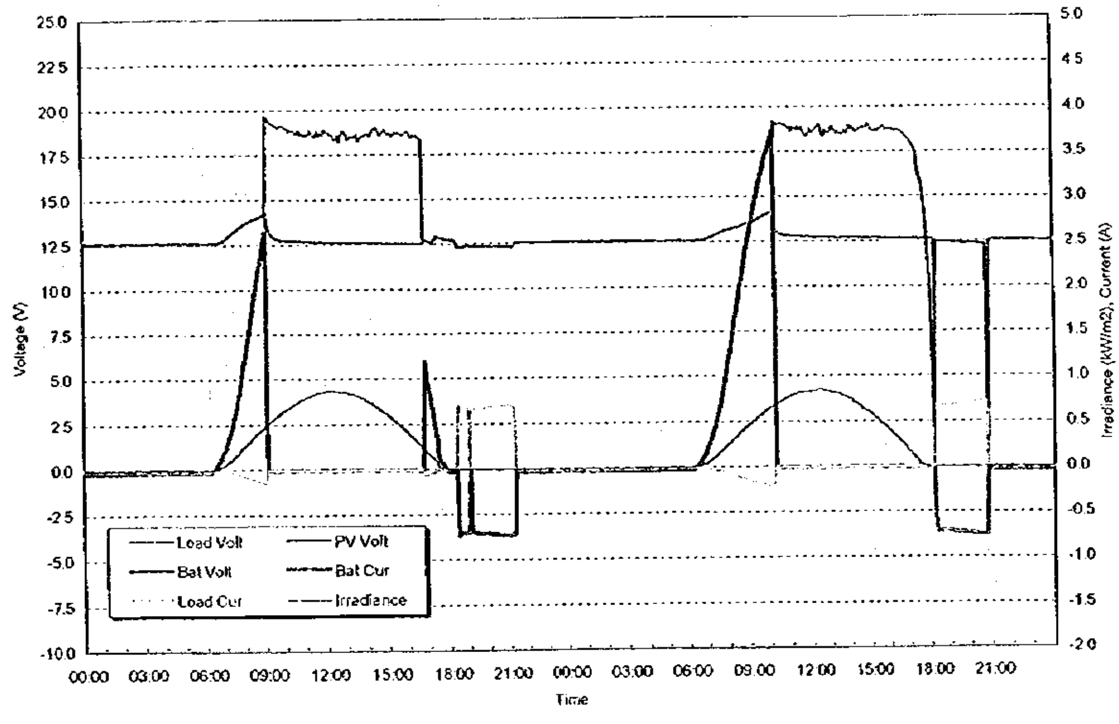


Fig. 4-18 An Example of Operational Characteristic of PV System for the Tongwe Clinic System (8/17-8/18, Enlarged One)

c) The operational characteristic of an improved JICA charge controller

Specification of an ideal charge controller and an example of the operational characteristics of locally procured equipment initially installed are shown as following. The operational characteristic was directly obtained from actually measured data through analysis of the collected data. At Turf Clinic, the low voltage disconnection (LVD) voltage level and the low voltage reconnection (LVR) voltage level was not recorded since the system was managed quite well and no shut-down of load was experienced.

Table 4-13 Specification and Operating Characteristics of JICA improved type Charge Controller

Setting item / Operating level	HVD (High Voltage Disconnection)	HVR (High Voltage Reconnection)	LVD (Low Voltage Disconnection)	LVR (Low Voltage Reconnection)
Spec	14.5 V	13.5 V	11.5 V	12.5 V
of JICA improved C/C	14.3 V - 14.0 V	13.52V – 13.58V	V	V

In the following data set, the HVD is recorded at a low level when compared to the specification. The actual level is not necessarily different from the specification level since there may exist some time lag between the HVD actuation time and the data recording time because the data sampling time was set to be at 5 minute intervals. Therefore the measured battery voltage will average a slightly lower level than occurred at the actual HVD cutoff point. Fig. 4-20 shows the control characteristics of the improved JICA charge controller for Turf Clinic system. In comparison to this, Fig. 4-19 shows the control characteristics of the locally made charge controller previously used in the same clinic system. Those tables also clearly show the that the improved JICA controller switches the PV power on and off during daytime thereby allowing maximum charge, but the locally made charge controller disconnected the PV power at about the same condition as the JICA controller but never reconnects the panel the rest of the day unless a load is turned on and the battery significantly discharged.

As indicated by the Fig. 4-20, the improved JICA charge controller shows very precise working voltage stability and provides an appropriate charge control.

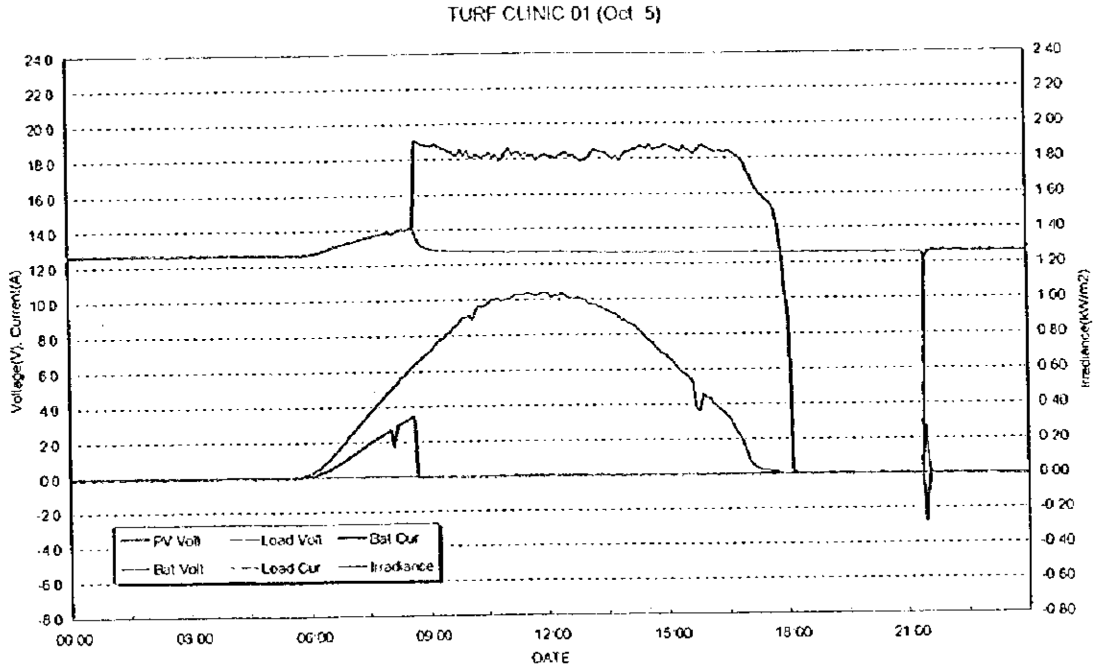


Fig. 4-19 Battery Charge Control by a locally made charge controller (an example for the turf clinic system on October 5)

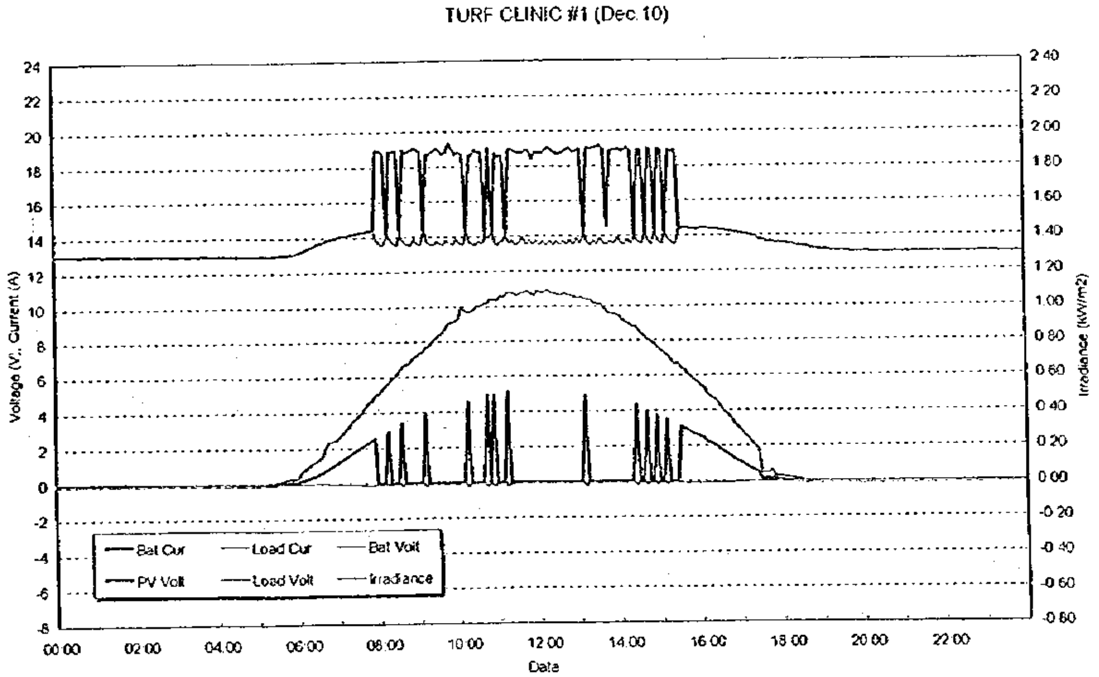


Fig. 4-20 Battery Charge Control by an improved JICA charge controller (An example for the turf clinic system on December 10)

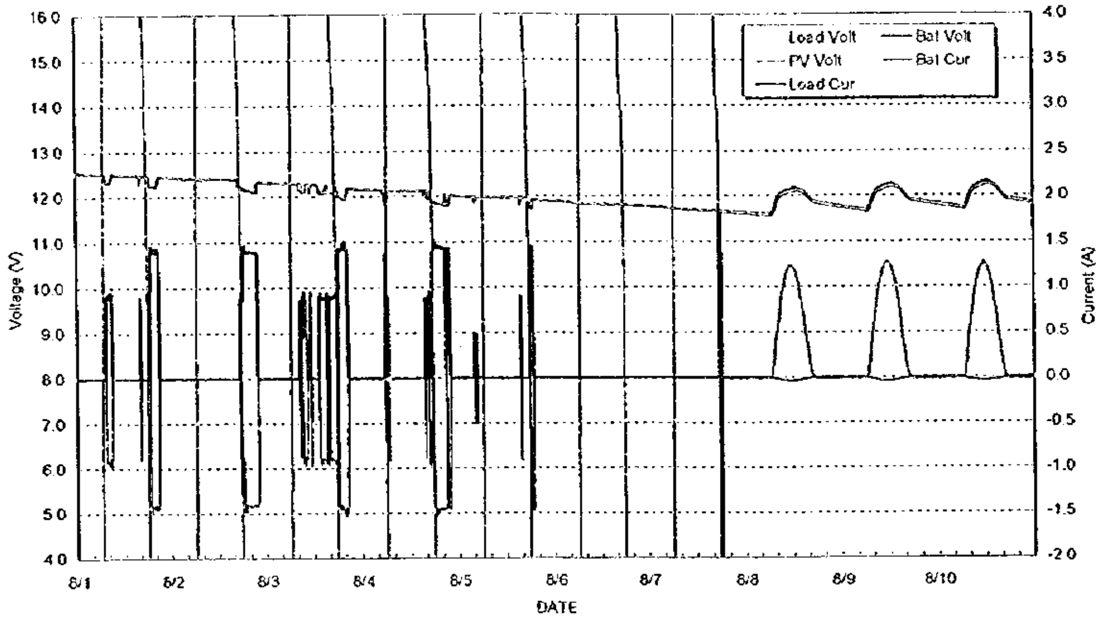


Fig. 4-21 An Example of Operational Characteristic of the Turf Household PV System (8/1-8/10)

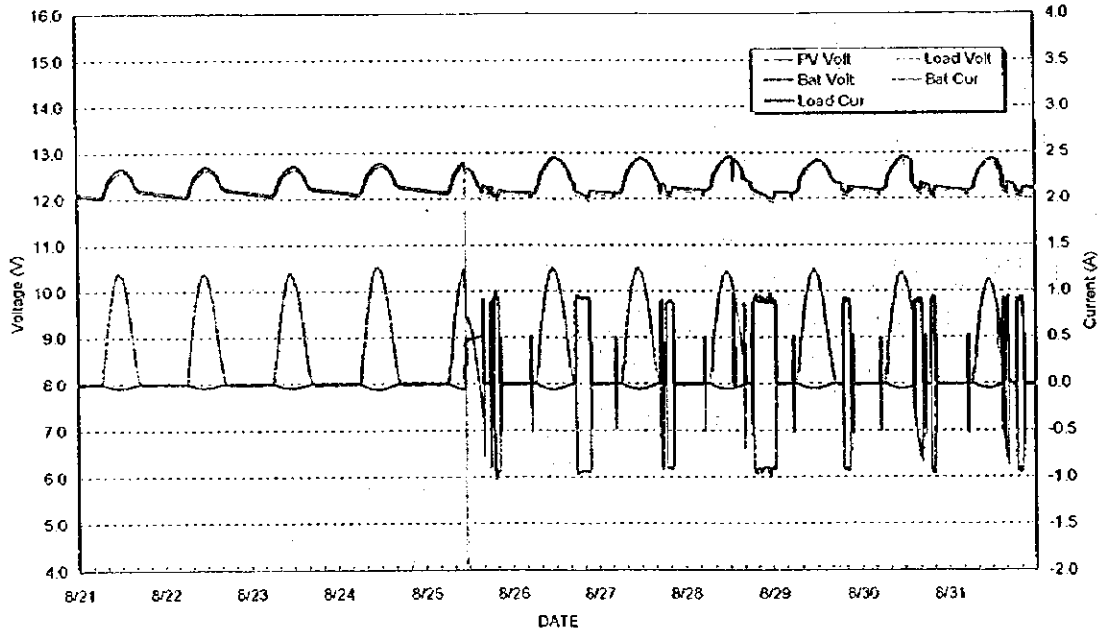


Fig. 4-22 An Example of Operational Characteristic of the Turf Household PV System (8/21-8/31)

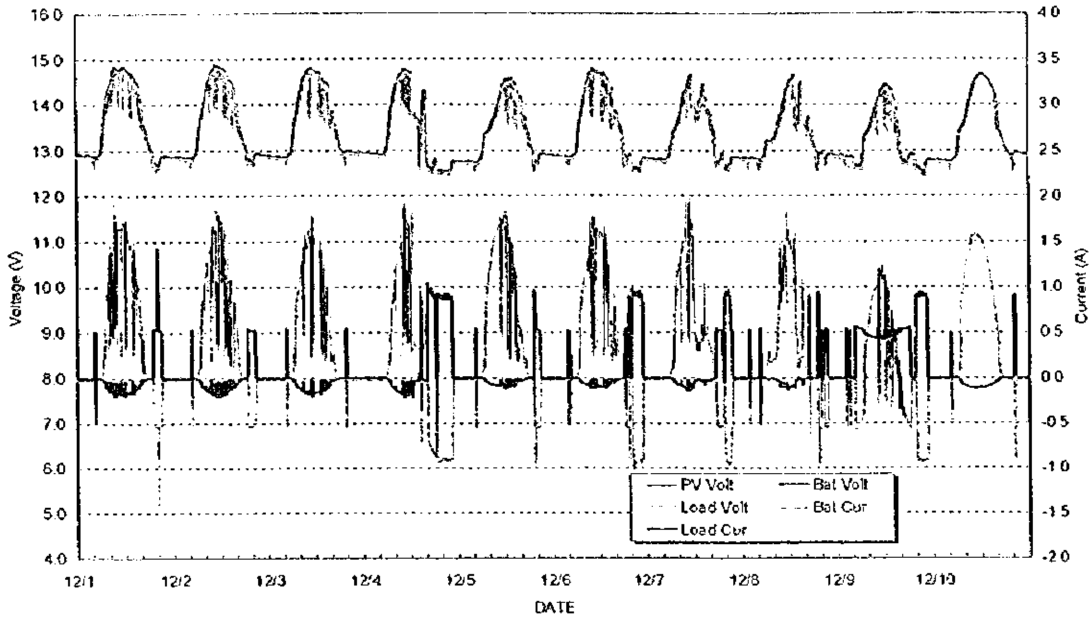


Fig. 4-23 An Example of Operational Characteristic of the Turf Household PV System (12/01-12/10)

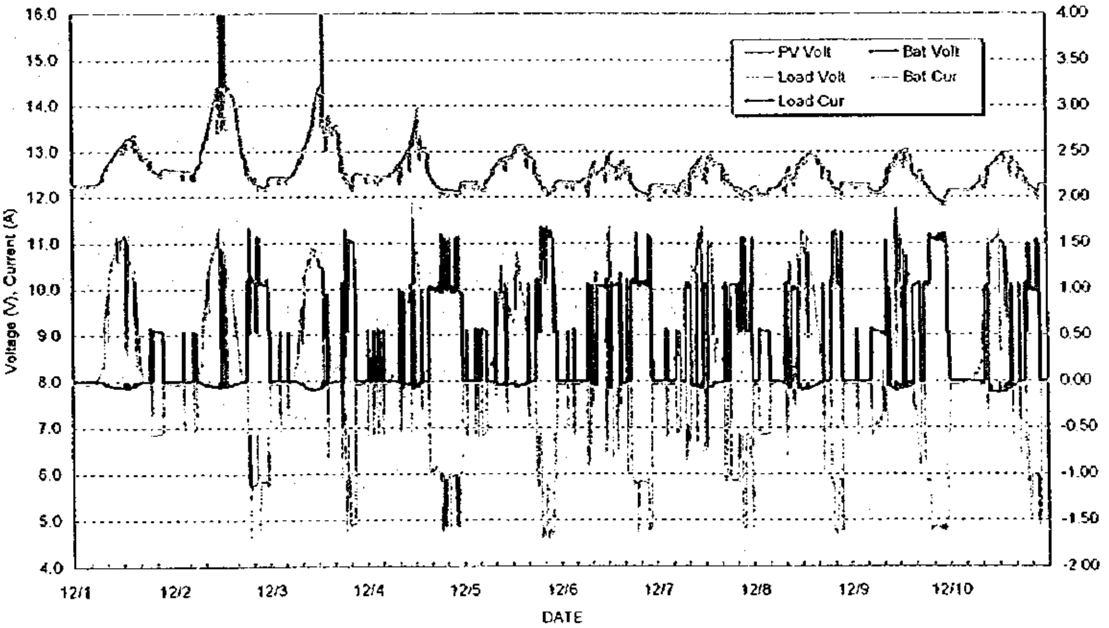


Fig. 4-24 An Example of Operational Characteristic of the Sanyati Household PV System (12/01-12/10)

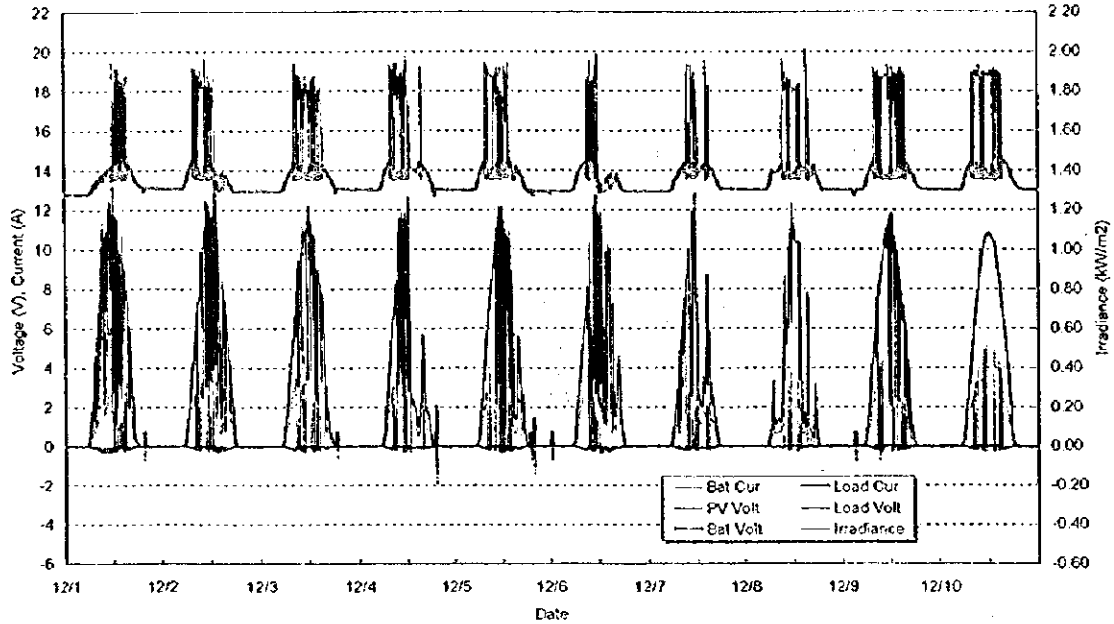


Fig. 4-25 An Example of Operational Characteristic of the Turf Clinic PV System (12/01-12/10)

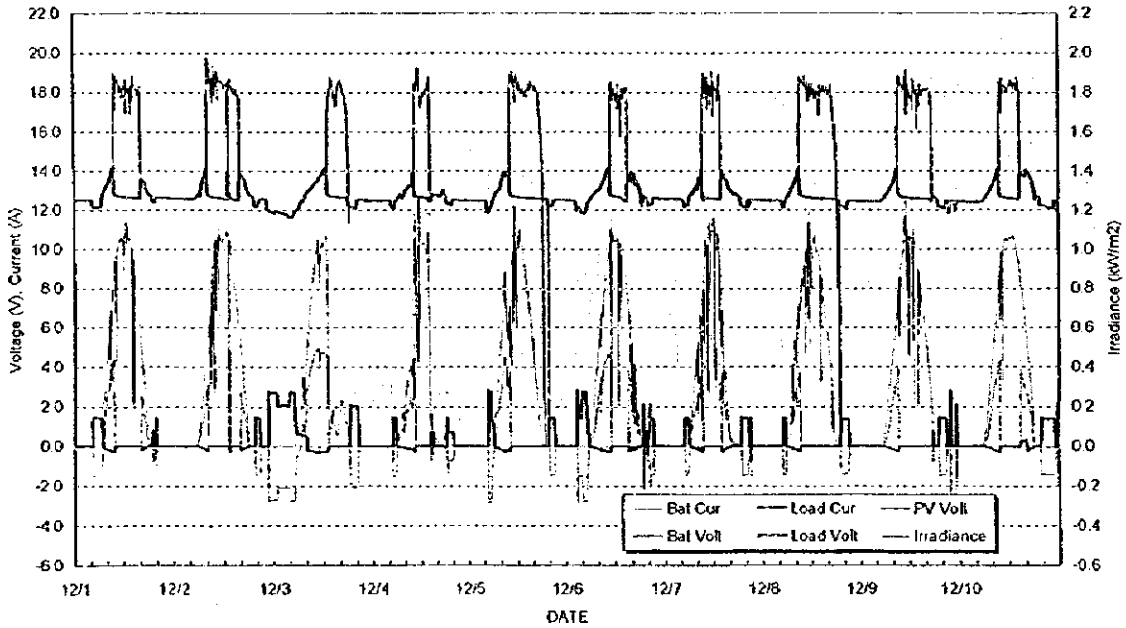


Fig. 4-26 An Example of Operational Characteristic of the Tongwe Clinic PV System (12/01-12/10)

3) Operation Data for PV Systems Installed in Clinics and Schools

With regard to the PV systems installed in the clinics and schools, Table 4-14 shows the results compiled from the operation data collected continuously at Turf and Tongwe clinics using data loggers. The values used in the "PV System Design" section were the basis of the design values used so that each system used one 83 W PV module and the design assumed 5.41 kWh/m^2/day (the figure for December, when the tilted solar irradiation is lowest) as the amount of energy that would enter the PV module. Table 4-14 is for each of the clinics in January 1998.

Load consumption for this month in the Turf Clinic system was several times larger than other more ordinary months and was apparently due to the use of lights by the PV installation team who were allowed to temporarily reside at the clinic while installing the rest of the Turf household systems. Compared to this, load consumption in the Tongwe Clinic system was somewhat lower than the average month.

An improved JICA type charge controller was installed at the Turf Clinic system and a locally made one was installed in the Tongwe Clinic system so there exists a difference in the type of the charge controllers used in the Turf and Tongwe systems as well as a different load consumption pattern between the two

In spite of the measured solar irradiation being almost the same as design value, the measured battery charging current was measured as less than 50% of the expected value, as shown in the table below. The reason for this apparent discrepancy is that the battery stays very close to its full charge condition since the load consumption is very small (less than 30 % of the design value), and thus the PV panel is disconnected much earlier in the day than expected thereby reducing the amount of energy sent to the battery. This condition means that this system is not being fully utilized by clinic personnel and does not indicate a design method problem.

For the Turf Clinic system, which is controlled by the improved JICA charge controller, the measured battery maximum and minimum voltages were as designed. On the other hand, both the maximum and minimum voltages are lower than the design value in the Tongwe Clinic system, which is controlled by the locally made charge controller. This is the result of the HVD of the charge controller being more than 0.4V lower than specified value of 14.5V and also that the battery can not be charged fully in spite of the unexpectedly low load consumption because the reconnection voltage is too low to reconnect the battery to the panel the rest of the day.

Based on the data, it is concluded that using the locally made charge controller for PV systems installed in public facilities does not allow utilization of the potential capacity of the system because the battery cannot be charged to the intended level. Given the current low usage of the PV system, there exists no particular problem since the load is small compared to the design value, but it is expected that battery life will be shortened due to the insufficient battery charge level causing an increased sulphation rate and should the load increase in the future, the system may have inadequate energy available.

This problem can be resolved by installing improved JICA charge controllers at Tongwe clinic and the two schools as was done at Turf earlier. The locally made charge controller for the Turf Clinic system was replaced by the improved JICA unit in November, 1997, as a test. The data indicates that the improved controller provides a much more desirable battery charging/discharging characteristic.

Table 4-14 Operating Characteristics of Clinic PV Systems

Item	Planned value	Actual value	
		Turf Clinic	Tongwe Clinic
Tilted solar irradiation (kWh/m²)	5.41	5.45	5.62
Storage battery charging current Ah)	29.5	13.46	11.66
Planned supply-capable current (Ah)	15.3	–	–
Load current (Ah)	14.53	3.95	2.51
Load use duration (h)	4.0	4.32	2.57
Storage battery maximum voltage (V)	(14.5)	14.45	14.07
Storage battery minimum voltage (V)	(11.5)	12.68	11.98

Details on the planned load shown once again below.

Planned load: 14.53 Ah

(Breakdown):	Type	Spec	Lighting hour (h)	Current consumption capacity (Ah)
	Fluores. lamp	FL 11W #1	4 h	3.68
	Fluores. lamp	FL 11W #2	4 h	3.68
	Fluores. lamp	FL 9W #1	4 h	3.00
	Fluores. lamp	FL 9W #2	1 h	0.75

Fluores. lamp	FL 7W #1	1 h	0.59
Fluores. lamp	FL 7W #2	1 h	0.59
Radio	9V / 5W	4 h	2.24
Total			14.53

Based on the monthly operation data information (Table 4-6, 4-7), the following comments can be made about system operation.

a) Total Charging Current to the Storage Battery

The total charge to the storage battery was lower than the design value at both Turf and Tongwe Clinics. At Turf Clinic, it was only 45.6% of the design value and at Tongwe Clinic was 39.5%. Because the load at the clinics was much lower than the design expectation, storage batteries were frequently operating in the nearly fully charged state. Therefore, during the day, the charge controller disconnected the PV module from the storage battery much earlier than expected and remained disconnected for longer periods of time than the design value. While this does not pose any problems with regard to system operation, it is not appropriate in terms of making effective economic use of the system.

For the future if the system load increases, it is anticipated that the different characteristics of the controllers installed in Tongwe and Turf clinics may result in the Tongwe clinic batteries not receiving full design charge while those in service at Turf clinic should receive the design level of charge. This would be caused by the local controller installed at Tongwe not reconnecting the battery to the panel once it detects full charge voltage. This will result in lower effective capacity for the system and most likely, shortened battery life. In case of the Turf Clinic system which is controlled by an improved JICA charge controller, daily connection time of the PV panel to the battery is prolonged because the controller reconnects the PV panel to the battery many times a day and thereby increases charging amount accordingly as the load increases

b) Load current

Load consumption levels of both clinic systems are small. The daily average load current at the medical treatment buildings is just 1.3 Ah/day in case of the Turf Clinic system and 3.81 Ah/day in case of the Tongwe Clinic system, as indicated by the Tables

4-6 and 4-7 which shows the daily average for first 6 months to January 1998 from installing system. Those values correspond to 9% and 23% of the expected value of 15.3 Ah/day, at each site.

Lighting time is also very short. The time when at least one electric light is lit is around 1.4 hours per day for the Turf Clinic system and around 3.1 hours per day for the Tongwe Clinic installation. This situation is similar to the assumed use where time of lighting each room was expected to be around 4 hours a day, but load consumption was less than 1/4 of expected. From the data, it seems like that not only is the lighting time very short, but also rarely are rooms being lit simultaneously. Additionally, the load consumption after January and in February and later on which half a year has past, is quite different in that the load consumption during the later period is much larger than that observed during the initial period. It is not clearly understood whether the load consumption increases due to changes in use patterns of the clinic staff as they better learn how to use the systems, because of changes in the number of patients being served during the rainy season or a combination of both reasons.

After 10 months since the system installed, the load consumption of Turf clinic were 10.8 Ah/day in May 1998 and 12.6 Ah/day in December 1998, those of Tongwe clinic were 4.5 Ah/day and 5.7 Ah/day respectively.

At Turf clinic, the load consumption has been increasing from May, 1998. The reason is they use the light all night for the security since a thief had broken into the clinic in April.

At Tongwe clinic, the load consumption increased compare to the beginning, however the increase is not so large as Turf clinic.

It is predictable that an increase in consumption may occur as the staff get used to using the lights, but it remains unlikely that many lights will be used at the same time due to the manner in which the clinic is used at night.

Turf clinic has been increasing the current consumption from May 1998 for the clear reason that they have lighting their outdoor security-light against theft which once they experienced.

As Table 4-8 and Table 4-9 show, there are clear differences on the consumption between the bedroom building and diagnostic building for both of the clinic. In case of Turf clinic average consumption was 0.8 Ah/day and Tongwe was 7.6Ah/day accordingly, which counted 5% and 50% of the planned capacities. Turf clinic use the bed rooms only for the patients and its consumption is low, while Tongwe clinic have stated from January 1998 to use the bedrooms for their guests accommodations as well as patients use, and made the consumption extremely high. During this period power consumption of Tongwe clinic was 14Ah and it was counted more than maximum light of over 91%. As above example show it is clear that there are no set power consumption patterns for clinic bed rooms.

Regarding management of the clinic systems, electricity usage management, battery maintenance and general operation of the systems at Turf Clinic system has been handled well but maintenance at the Tongwe Clinic system is not good. Batteries are not checked regularly and electrolyte levels have been observed well below minimums and general cleanliness of the systems was not good. Interestingly, even with such poor management of the PV system, the load consumption was small and stayed at a level comparable that of ordinary household use. This has important implications for the sizing of future systems for clinics.

Processing the clinic data sets on a daily basis, there were no days when the full design load was present and it was unusual to find total lighting time greater than 12 hours.

Fig. 4-27 and Fig. 4-28 show (both of the clinic's load demand for the diagnose building), Fig. 4-29 and Fig. 4-30 show load demand of the bedroom building.

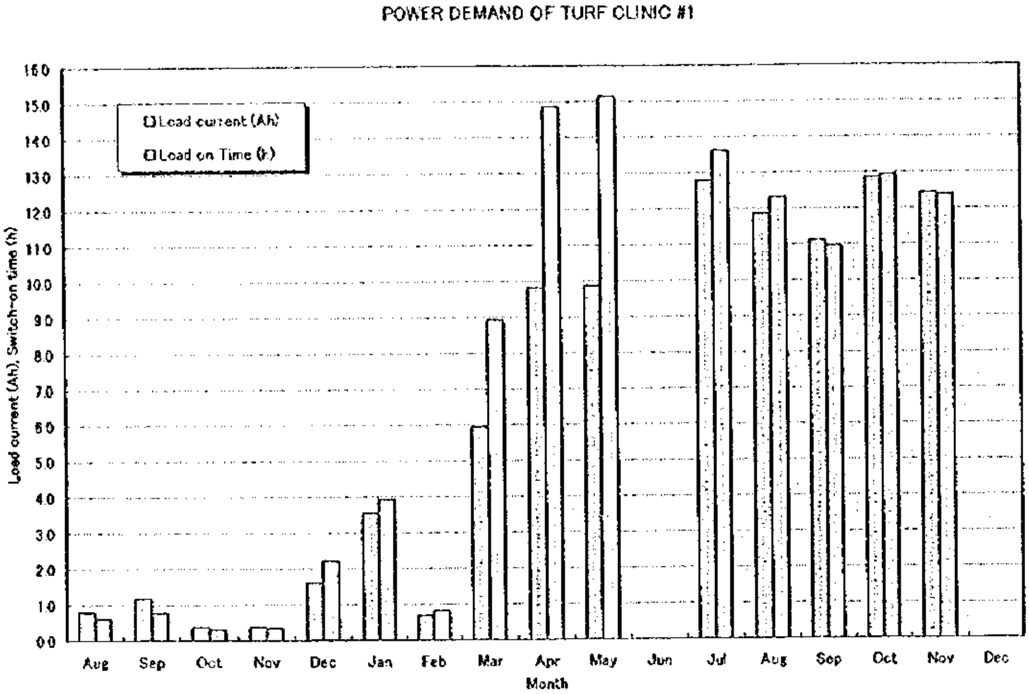


Figure4-27 Power Demand of the Turf ClinicSystem

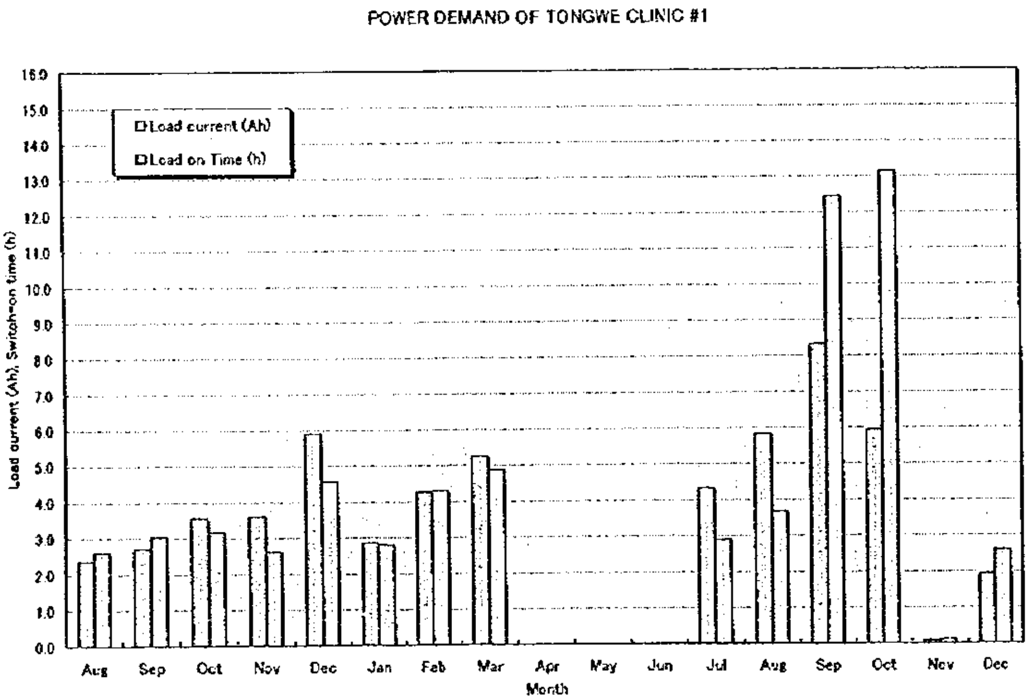


Figure4-28 Power Demand of the Tongwe ClinicSystem

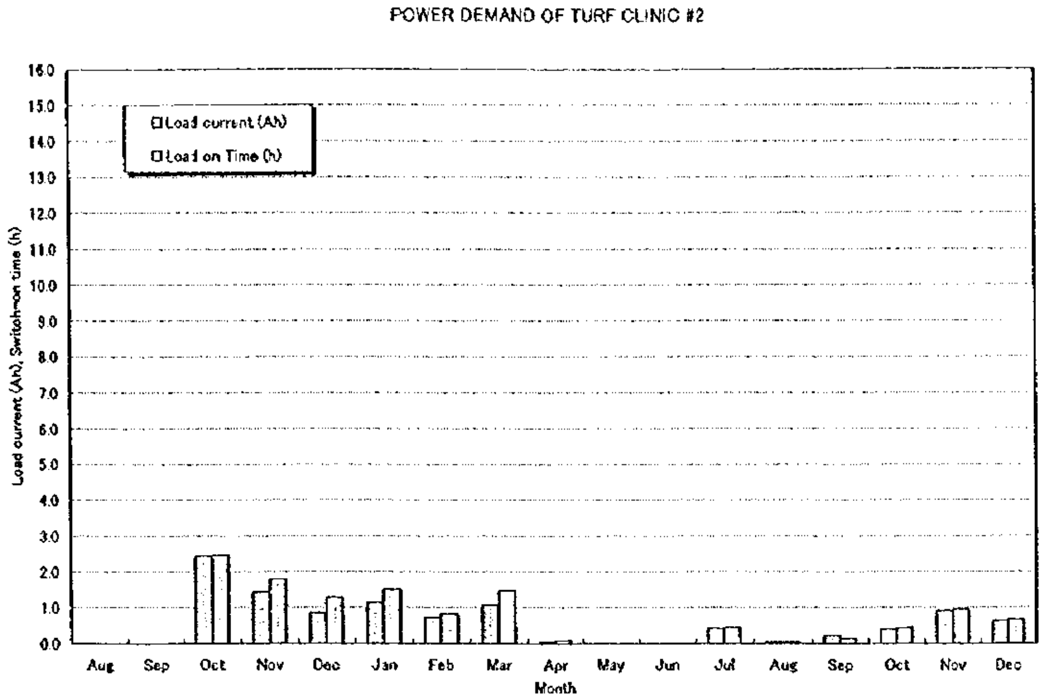


Figure4-29 Power Demand of the Turf Clinic (Ward)

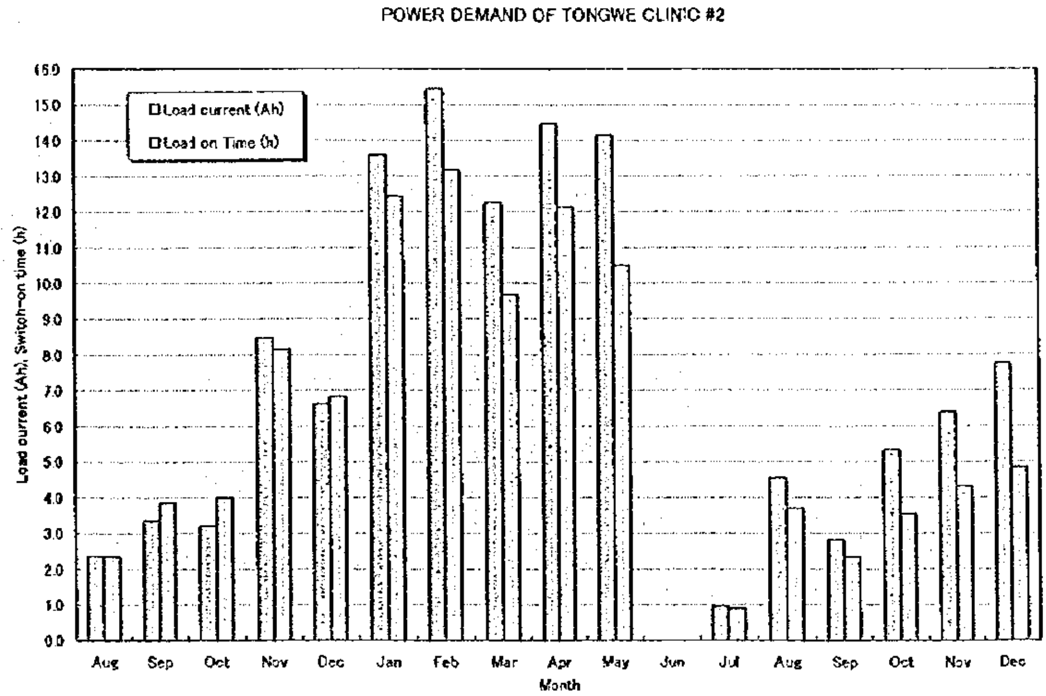


Figure4-30 Power Demand of the Tongwe Clinic(Ward)