DESIGN OF PV SOLAR HOME SYSTEM FOR USE IN URBAN ZIMBABWE

J Gwamuri\textsuperscript{1}, S Mhlanga\textsuperscript{1}

Applied Physics and Radiography Department, Faculty of Applied Sciences, National University of Science and Technology, Bulawayo, Zimbabwe.

Email: jgwamuri@gmail.com/ jgwamuri@nust.ac.zw

Key words: Photovoltaic modules, insolation, charge controller, system sizing, continuous wattage, surge wattage.

Abstract
Zimbabwe is currently experiencing daily load shedding as the utility power company; the Zimbabwe Electricity Supply Authority (ZESA) is failing to cope with the ever increasing energy demand. Selbourne Brooks is one of the new up-market suburbs in the city of Bulawayo where residents have been waiting to be connected to the grid for more than five years. A feasibility study was conducted in the area to establish the status and potential of Solar Home System (SHS) as an alternative source of energy for urban dwellers in Zimbabwe. This paper explores the issues mainly related to system requirements and availability, policies, standards, awareness, participation and investments all of which are major ingredients of sustainable implementation of the solar project in Zimbabwe. Insights into how system sizing can help in implementing PV Systems in Africa in a sustainable way are also included in the analysis. An energy audit was carried out in both the high density residential areas and low density residential areas. It was established that in Zimbabwean urban areas, on average, households in the high density areas were allocated 1.7kVA while those in the Low density suburbs were allocated 13.5kVA. Energy consumption differed from household to household as it was mainly influenced by both the number and the type of appliances per individual household. A system capable of supplying energy of 13.5kVA was designed and component sizing was carried out. Major system components such as the photovoltaic modules, the charge controller, battery array and inverter are specified assuming insolation levels of eight average sun hours per day. An estimate of the total system costing is included together with the possible ways of lowering system costs without compromising on the total system performance.

INTRODUCTION
Zimbabwe is geographically located in the Savanna region and this implies that solar energy systems would be very efficient in this part of the world. Most areas in this country, both in urban and rural areas have not been connected on the utility grid due to a number of challenges including lack of funds for government to implement such projects. However, for even some of the urban dwellers who can afford the cost of installing the systems, awareness and inaccessibility of reliable and sustainable systems has been the major setback in the adoption of Solar Home Systems (SHS) as an alternative solution to their energy crisis. Available systems have very limited applications such as lighting, mobile handsets charging, powering radio and television sets. These systems are viewed as ideal for rural households and have been adopted widely in some rural areas of Zimbabwe. The ever intensifying energy crisis in Zimbabwe have seen the majority of urban dwellers turning to Green House Gases (GHGs) emitting generators to meet part of their essential energy demand. The designed systems were based on general energy demands of urban consumers.

\textsuperscript{1} Corresponding author
When designing a solar system, the essential issues to consider are the sunlight levels in the area i.e. (insolation) and the total power requirement. The optimum performance of a photovoltaic panel is obtained when it’s correctly aligned to the sun i.e. when the sun is directly overhead. This usually equates, as a fixed mounting, to an alignment of around latitude ±15 degrees[1]. There may only be around eight hours of full sun, due to reflection off the panel and the amount of atmosphere the light has to pass through. This will naturally be least when the sun is directly overhead which is often termed solar noon. When selecting the site for the PV array, a spot should be considered, that is un-shaded between the hours of 10 a.m. to 2 p.m. on the hemisphere’s shortest day since the seemingly inconsequential shading from a tree branch can cause a substantial reduction in generated power. To offset the effects of low insolation, additional panels or larger panels with a higher output or panels designed to track the sun’s passage across the sky may be installed, this helps in maximizing on correct orientation (although the depth of the atmosphere cannot be overcome). Concentrator panels, with a lens arrangement designed to better concentrate weak sunlight onto the cells are another alternative option. Unfortunately these options introduce one of the biggest constraints on a system’s size that is system costs. Solar panel output is measured in watts and is usually supplied at a nominal 12V although this may well be up to 17V effective output. Panels can be wired in series (+---) to increase voltage, parallel (++--) to increase amperage. A series/parallel wiring, where sets of panels already wired together in series are wired together in parallel may also serve to increase both voltage and amperage. The distance between the various components of the system should also be considered when choosing the nominal DC voltage. The greater the distance, the greater the voltage drop and a higher voltage will travel further than a low one around the same cabling. 24V or 48V nominal systems will avoid having to use more efficient cabling, especially if the batteries are a considerable distance from the solar panels.

**System Description**

**Solar home system** is generally designed and sized to supply DC and/or AC electrical appliances. This consists of PV **solar module** connected to solar charge controller, inverter and a battery/ or battery bank. The generated DC power is stored into batteries through a charge controller and converted to AC power by the inverter for supplying AC loads. The renewable electricity is produced as Direct Current (DC). The DC electricity from the panels passes through a grid-interactive inverter, which converts the DC electricity into Alternating Current (AC). The AC electricity is then used by the appliances operating in the house. If more electricity is produced than the house needs then the excess will be fed into the main electricity grid. Conversely, when the renewable system isn't generating enough electricity to power the house, the house will draw power from the grid. Grid interactive systems eliminate the need for a battery backup for when the sun doesn't shine [2]. In effect, the grid serves as your battery. The major components are briefly described below.

**The PV modules**

Solar panels generate free power from the sun by converting sunlight to electricity with no moving parts, zero emissions, and no maintenance. The solar panel, the first component of an electric solar energy system, is a collection of individual silicon cells that generate electricity from sunlight. The photons produce an electrical current as they strike the surface of the thin silicon wafer. The most efficient and expensive solar panels are made with Mono-crystalline cells. These solar cells use very pure silicon and involve a complicated crystal growth process. Polycrystalline cells are a little less expensive and slightly less efficient than Monocrystalline cells because the cells are not grown in single crystals but in a large block of many crystals [3].
The Batteries
Batteries are rated by the amount of current they can supply over a period of hours i.e. in ampere hours (Ah). The design should ensure enough Ampere-hour capacity to take account of any bad weather periods. An additional one-fifth capacity is thought to be sufficient to cover this eventuality.

The Inverter
The inverter should be capable of coping with the power surges caused when starting certain appliances, especially those incorporating high-power. The minimum surge rating will be roughly twice that of the continual wattage the system is calculated at.

Methodology
The study involved field visits to the sites (Selbourne Brooke residential area (low density) and Emganwini residential area (high density)). Three households were selected randomly for the energy audit. The most common household appliances were listed together with their power ratings. Interviews were conducted to establish the number of hours the different appliances were most likely to be kept on. A desk study was also carried out to obtain technical information from the utility company (ZESA) related to the generation and distribution of electricity to consumers in different residential zones in the city of Bulawayo. Using data from both the technical visits and the desk study, a generalized list of household appliances was drawn. The list was then used to come up with a general charge utilization table which was then used for system sizing.

System Sizing
The first step to sizing a solar electric system is to determine the average daily energy consumption. The average daily energy consumption should be as accurate as possible, and ways to conserve power should be considered as well because the total energy consumption will determine the size of the system.

The PV Solar Array Sizing
Two important factors in solar array sizing are the sunlight levels (i.e. insolation values) of the area and the daily power consumption of your electrical loads. Taking the peak insolation of 8 hours for Zimbabwe, and assuming also that the battery efficiency is 80% and Panel Efficiency is also 80% then the Panel Catalogue Power was determined using the following relationship;

\[
\text{Panel Catalogue Power} = \frac{\text{Average Daily Energy Utilization} \times \text{Peak hours} \times \text{Battery discharge efficiency}}{\text{Panel Loss factor} \times \text{Panel Rating} \times \text{Panel loss factor}}
\]

Therefore numbers of 235 W (or/ higher) Mono/Polycrystalline panels that will be required were evaluated.

Charge Controller Sizing
The controller size was determined as follows;

\[
\text{Current Rating} = \frac{\text{Panel Catalogue Power} \times \text{Panel Efficiency}}{24 \text{ hrs}}
\]
Inverter Sizing
Inverters are rated in continuous wattage and surge watts. To properly determine inverter size, the power requirements of the appliances that will run at the same time are summed up and 25% - 30% of the sum is added for safety reasons.

\[ \text{Inverter Size} = \text{load size} \times \text{Safety factor} \left( \frac{1.3}{1.25} \right) \]

Battery Sizing
The size of the battery bank required will depend on the storage capacity required, the maximum discharge rate, the maximum charge rate, and the minimum temperature at which the batteries will be used.

\[ \text{Battery Load} = \frac{\text{Average Daily Energy Utilization}}{\text{Battery Voltage}} \]

The battery should supply the required load plus the distribution losses. It should also supply the load for 3 days of autonomy in the absence of the sun. Therefore, the required battery Ampere-hour was also evaluated.

\[ \text{Battery Ampere-hour} = \frac{\text{No. of Days of autonomy} \times \text{Battery Load}}{\text{Depth of Discharge} \times \text{Distribution losses}} \]

Therefore the batteries ampere-hour required and total voltage they must supply to the inverter including the total power rating was determined.

RESULTS AND DISCUSSION
Charge Utilization Table
The following charge utilization table was used to keep track of each appliance to be powered by the system and the amount of time it will be in use.

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Power Rating (W)</th>
<th>Number of usage hrs per Week (h)</th>
<th>Watt-hours per Week (Wh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD/ DVD player</td>
<td>35</td>
<td>35</td>
<td>1225</td>
</tr>
<tr>
<td>Fan</td>
<td>40</td>
<td>28</td>
<td>1120</td>
</tr>
<tr>
<td>Kettle</td>
<td>1000</td>
<td>7</td>
<td>7000</td>
</tr>
<tr>
<td>Desktop Computer / Laptop</td>
<td>170</td>
<td>12</td>
<td>2040</td>
</tr>
<tr>
<td>Hair Drier</td>
<td>1000</td>
<td>3</td>
<td>3000</td>
</tr>
<tr>
<td>Iron</td>
<td>1000</td>
<td>7</td>
<td>7000</td>
</tr>
<tr>
<td>Microwave</td>
<td>1000</td>
<td>7</td>
<td>7000</td>
</tr>
<tr>
<td>Refrigerator</td>
<td>150</td>
<td>70</td>
<td>10500</td>
</tr>
<tr>
<td>Toaster</td>
<td>900</td>
<td>3</td>
<td>2700</td>
</tr>
<tr>
<td>Colour T.V.</td>
<td>150</td>
<td>35</td>
<td>5250</td>
</tr>
<tr>
<td>20 HB LEDs</td>
<td>11</td>
<td>56</td>
<td>12320*²</td>
</tr>
<tr>
<td>Stove</td>
<td>2000</td>
<td>16</td>
<td>32000</td>
</tr>
<tr>
<td>Satellite dish Decoder</td>
<td>30</td>
<td>35</td>
<td>1050</td>
</tr>
<tr>
<td>TOTAL WATTAGE PER WEEK</td>
<td></td>
<td></td>
<td>72885</td>
</tr>
<tr>
<td>AVERAGE WATTAGE PER DAY</td>
<td></td>
<td></td>
<td>10412</td>
</tr>
</tbody>
</table>

Table 2: Summary of Specific System Components

² DC Value for HB-LED not used in calculations
The batteries required should be 200AH, and should be wired in such a way that they supply 24 Volts to the inverter with a rating of 2035 AH. Therefore 16 200AH, 12 Volts connected in a series/parallel connection are required.

**Table 3: System Cost Evaluation**

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>UNIT COST US$</th>
<th>QUANTITY</th>
<th>TOTAL US$</th>
</tr>
</thead>
<tbody>
<tr>
<td>235W Mono/polycrystalline PV Modules</td>
<td>553</td>
<td>9</td>
<td>4977</td>
</tr>
<tr>
<td>Heavy Duty Solar Mountings(Row of 9 Panels)</td>
<td>621</td>
<td>1</td>
<td>621</td>
</tr>
<tr>
<td>12V 200Ah Batteries</td>
<td>524</td>
<td>16</td>
<td>8384</td>
</tr>
<tr>
<td>13.5 kW Inverter</td>
<td>7932</td>
<td>1</td>
<td>7932</td>
</tr>
<tr>
<td>60 Amp Charge Controller</td>
<td>563</td>
<td>1</td>
<td>563</td>
</tr>
<tr>
<td>TOTAL COST</td>
<td></td>
<td></td>
<td>22477</td>
</tr>
</tbody>
</table>

**Conclusion and Recommendations**

This study has presented the components required for the design of a stand-alone photovoltaic system that will power all electric appliances at a medium-energy-consumption residence in Selbourne Brooks in Bulawayo. The factors that affect the design and sizing of every piece of equipment used in the system have also been presented. Over and under-sizing have also been avoided to ensure adequate, reliable, and economic system design.

A cost estimate for the whole system is also provided. The same procedures could be employed and adapted to applications with larger energy consumptions and could also be employed for other geographical locations, however, the appropriate design parameters of these locations should be employed. The capital cost of such systems is relatively high and the payback periods are more than 10 years, however, the benefits and the environmental impact should not be underestimated.

The recommendation would be that, the governmental role has to be present and influential in encouraging people to turn to such alternative energy systems. This role should encourage and support renewable energy research and should provide technical assistance to potential users. Another way would be through facilitating the import of the equipment used to construct such systems, especially the import of low dc-voltage appliances, that are still absent from the local market. New energy policies should be endorsed that allow tax exemption and rebates or at least minimal taxes on equipment used in photovoltaic systems. In addition, policies that allow utility-interactive systems are needed to enable the purchase of surplus solar energy from users. The national utility company should adopt the smart grid technology and publish feed-in tariffs which will encourage the adoption of the solar home
systems. Furthermore the private sector must be encouraged to invest in this market in return for exemption and other benefits.

REFERENCES.

Appendix
Continuous wattage is the total watts the inverter can support indefinitely.
Surge wattage is how much power the inverter can support for a very brief period, usually momentary.