AJ's Technical Tips: Designing a Small Solar PV System Part IV; Selecting Wires for the System

A little while back Simon Nyukuri of Kitale wrote to ask me about sizing wires and cables for solar PV systems. I promised him that I would write about this topic, and I will do that now in this article. Simon asked:

"I would like to know if the cables / wires I add on solar systems could affect the performance? For example, I always use the 2.5mm2 T / E cable (editors note: T/E means two conductor wires with a third wire for earthing) but I find it impossible to terminate to smaller terminals on charge controller, lamps, converters etc. I fail to understand whether they were made for smaller cables only?"

First, the type and size of the wires and cables used can have a big effect on the performance of the system. I am glad to hear that Simon is using 2.5 mm2 wires, because this is often a good size for small solar PV systems (although there are many cases where the wires should be even larger). Many electricians use 1.0 mm2 and 1.5 mm2 wires in solar PV installations and these are almost always too small. Wires that are too small lead to high voltage losses. When you have high voltage losses this means that you are wasting electricity, and it can also lead to poor performance by some types of electric loads. For example, high voltage losses can contribute to blackening of the tube in fluorescent lamps. I will explain more about how to select the correct cables for a system a little later in the article, but in general I recommend that you always use wire that is at least 2.5 mm2 in size.

Second, Simon is correct that some charge controllers, lamps, and other electrical parts have terminals that only allow you to use smaller cables. The companies that make these should make the terminals big enough for the sizes of wires that you will need to connect to them, but sometimes these companies do not do a good job and this can be a problem. If the terminals are too small for a 2.5-mm2 wire then this is a bad design by the manufacturing company. My suggestion here is to decide how big your wires will be before you buy the charge controllers and other system parts. That way you can make sure that the terminals on the parts will be big enough for the wires that you want to use. However, I know that sometimes this is not possible because customers buy the parts before they talk with you, the technician. In these cases you can only do your best to make a good connection with parts and wires that you have.

In this article I will explain how to size the wires so that they are big enough for the system you are installing. Then I will talk about different types of wires and cables and how to pick the ones that are best for your system. Last, I will use this information to select wires for the system that we have been designing in the last few articles of Solarnet. I will also give some information about selecting a charge controller for the system.

You need to know three main things in order to calculate the size of the wires that you will need for the system. The first thing is the voltage of the system. Most small solar PV systems are based on a 12-volt battery, and so I will only talk about this type of system. You can get information about selecting wires for 24-volt systems from Mark Hankins' book titled *Solar Electric Systems for Africa*.

The second thing that you need to know is the **maximum** amount of current that will flow through the wire when it is being used. The third thing that you will need is the **length** of the wire. If you know all three of these things then you can calculate the size of the wire using the information given in Table 1. For example, let us say that we want to size a wire for a 12-volt system. The maximum current that will flow through the wire is 5 amps, and the length of the wire is 10 meters. Table 1 shows the current values across the top (in amps), the wire sizes down the left side (in mm2), and the wire lengths in the middle of the table (in metres). I can find the right wire size in this example by starting at the place where it says "5 amps" and then moving down the table until I find a wire length number that is at least 10 metres. The table does not show 10 metres in the "5 amps" column, but it does show 8 metres and 12 metres. To make sure that the wire is big enough, it is always best to pick the larger number (12 metres). I can then look from this number (12 metres) across to the left until I come to the wire sizes. This shows me that the correct wire size for this example is 4.0 mm2.

I will give you two more examples to do for practice now. In both practice examples the system voltage is 12 volts. You can find the answers for these practice examples at the end of this article.

Practice example #1: Find the correct wire size for a wire that must carry 3 amps for a distance of 8 metres.

Practice example #2: Find the correct wire size for a wire that must carry 6 amps for a distance of 12 metres.

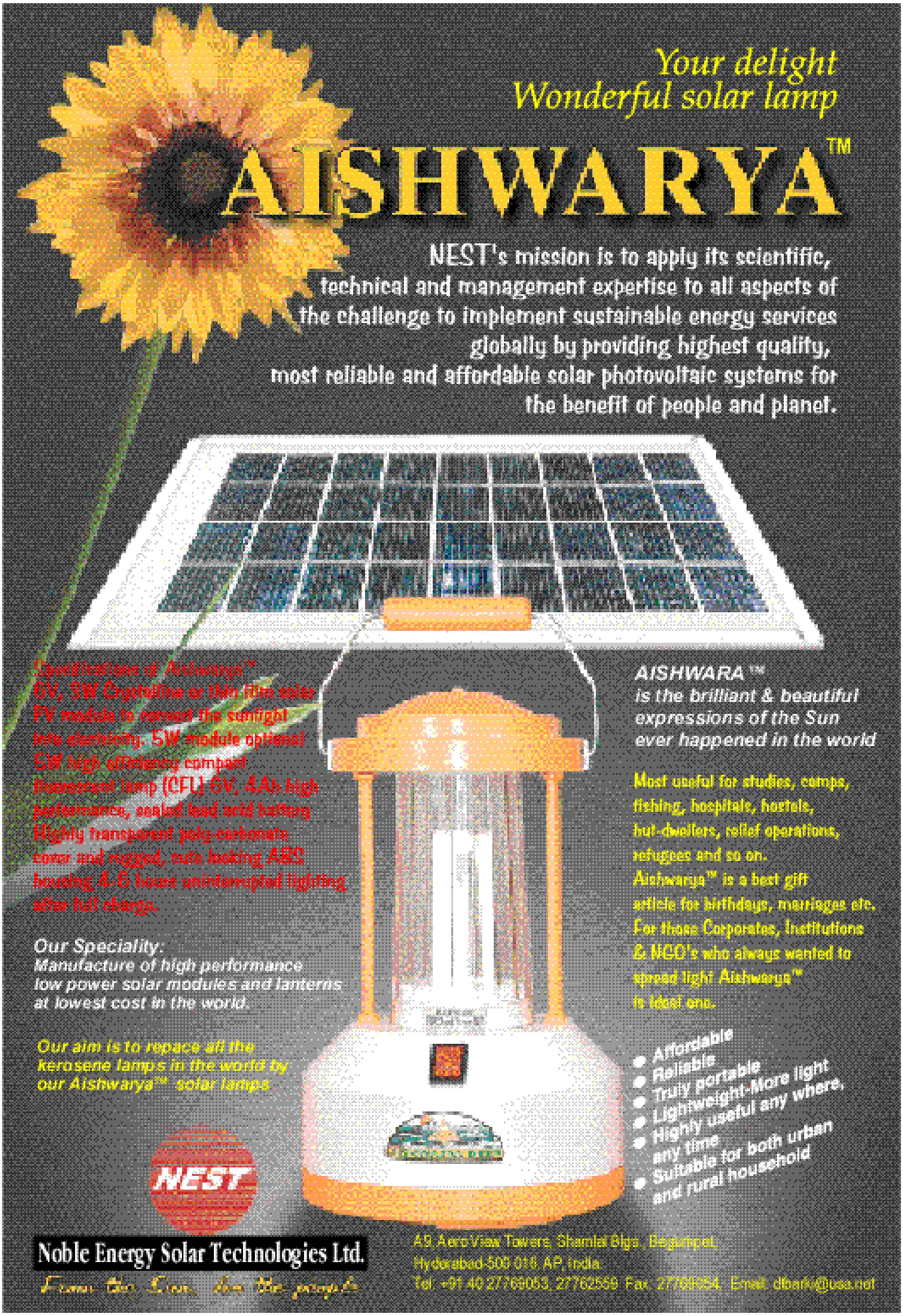
Table 1: Maximum wire length (in metres) for 12-volt systems
(0.6 volt maximum voltage drop, or 5%)

Wire Size (mm2)	**Maximum Current in Wire**								
	1 Amp	**2 Amps**	**3 Amps**	**4 Amps**	**5 Amps**	**6 Amps**	**8 Amps**	**10 amps**	**14 amps**
1.5	22	11	7	6	4	4	3	2	2
2.5	38	19	13	9	8	6	5	4	3
4.0	60	30	20	15	12	10	8	6	4
6.0	88	44	29	22	18	15	11	9	6
10.0	150	75	50	38	30	25	19	15	11

Source: Mark Hankins, 1995, *Solar Electric Systems for Africa*

The size of the wire is important, but there are also other important parts of selecting the correct wire or cable. There are a number of different types of wires and cables. I list a few of the more common types in Table 2. Twin flat cables are commonly used in circuits that do not require earthing, while twin with earth (T/E) cables include a third wire for making the earthing connection. In general it is not necessary to earth small DC solar PV systems (that is, 12 volt DC systems that are smaller than 50 Watts) unless the system is in an area that gets a lot of lightning storms. However, sometimes you may want to use cable with an earthing connection so that the owner will not have to change the wires if he or she is able to connect to the AC mains in the future.

For cables that will be outdoors it is best to install the wire in conduit (this is a plastic pipe that is designed for holding electrical wire) or to use a type of cable that has sunlight resistant PVC insulation on the outside. The sunlight resistant insulation will protect the wires from damage by the sun (sunlight resistant insulation is sometimes also called "UV resistant" insulation). Normal PVC wire insulation will begin to crack after a few years if it is left out in the sun, and this can lead to dangerous short circuits or other problems. Finally, for cables that will be buried underground or that will be installed in places where they might get damaged or cut it is best to use armoured cable.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Highly transparent poly-carbonate cover and rugged, cute looking ABS housing 4-6 hours uninterrupted lighting after full charge.
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Most useful for studies, camps, fishing, hospitals, hostels, hut-dwellers, relief operations, refugees and so on.
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Table 2: Some Common Wire Types for Electrical Installations

Wire / Cable Common Name	Description	Common Use
Twin flat	2 wires with PVC insulation (red is positive, black is negative)	Indoor wiring
Twin with earth (T/E)	3 wires with PVC insulation (2 conductor wires plus a third wire for earthing)	Indoor wiring
Twin with sunlight resistant PVC insulation	This type has sunlight resistant PVC insulation on the outside. It is available with 2 or 3 wires.	Outdoor wiring (protected or attached to building)
Armoured Cable	This type has a tough metal shield & insulation on the outside. It is available with 2 or 3 wires.	Outdoor wiring (buried cable)

There are, of course, other choices that you can make about which wires and cables to use. For example, insulated copper wires can be either "single stranded" (i.e. a single thick wire covered by insulation) or "multi-stranded" (many small wires held together with insulation on the outside). It is often easier to work with the stranded wire because it is more flexible, but it is also more expensive. You should choose which type you want to use, but I prefer "multi-stranded" if I can get it.

Now that we have talked about wire sizing and the different types of wires, I will now select wires for the solar PV system that we have been designing for the last few issues of Solarnet. You will remember that we selected the solar panel and the battery for this system based on the electric loads that it will power. We chose to use two 12-Watt solar panels and a 50 amp-hour solar battery. These were used to provide power to a television (13 watts), a fluorescent lamp (7 watts), and a radio (2 watts). For small systems like this one I usually recommend 2.5-mm2 wire for all of the circuits. That is, **2.5-mm2 wire is the smallest size that you should use**, even if the information in Table 1 tells you that a smaller wire might be ok. One important reason for this is to allow the owner to make the system bigger by adding another solar panel or more electrical loads without changing the wiring. It is important to remember that using the 2.5 mm2 wire instead of smaller wires does not add very much to the cost of the system. For example, if you are using twin flat wire, the difference between 2.5 mm2 and 1.5-mm2 wire is only about 80 Shillings for every 10 metres of wire. This small extra cost is usually worth it in most cases because of the higher cost of re-wiring the system later if the owner wants to make the system bigger.

In the system that we have been designing, there are three main circuits. The first is the connection between the solar panels and the charge controller, and the second is the connection between the charge controller and the battery. The third circuit is actually a combination of three different circuits. These are the connections between the charge controller and the electrical loads (that is, the TV, the light, and the radio). See Figure 1 for a diagram of the wiring for the system.

For each of these circuits we will need to know the current flowing in the wire and the length of the wire in order to pick the correct wire size. You should do the same thing when you select the wires for the systems that you design. That is, you should choose the correct wires and cables for *each* of the circuits in the system by sizing the wires correctly and by also picking the correct type of cable. Often you will need to use different sizes and types of wire for the different circuits in the system.

I can see from Table 1 that for circuits that are smaller than 3 amps we can use 2.5 mm2 cable for distances that are up to 13 metres (look in the table to make sure that you understand why this is true - if you look at the wire length number in the table that matches the listing for 3 amps and 2.5 mm2 wire you will find that the maximum distance for this combination is 13 metres). This means that for the small system that we have been designing it is probably ok to use 2.5-mm2 cable for the whole system. Let us check this to be sure.

We know that the system has two 12-watt solar panels, and from the manufacturer's specifications I know that each one of these can produce 0.75 amps when the sun is shining brightly. This means that together the two panels can produce 1.5 amps. Let us say in this case that the distance from the solar panels to the charge controller is about 10 meters. This tells us that 2.5 mm2 wire is ok, because 1.5 amps is less than 3 amps and 10 meters is less than 13 meters.

Next, we need to know the current that is used by each of the electrical loads so that we can know how much current will flow in those wires. We have said that for this system the television draws 13 watts, the lamp draws 7 watts, and the radio draws 2 watts (see AJ's Technical Tips, Solarnet volume 3, number 3). From this we can calculate the current for each appliance by dividing the power (in watts) by 12 volts. For the television this gives 1.1 amps (13 watts ÷ 12 volts = 1.1 amps), for the lamp this gives 0.6 amps (7 watts ÷ 12 volts = 0.6 amps), and for the radio this gives 0.2 amps (2 watts ÷ 12 volts = 0.2 amps). None of these currents is larger than 3 amps, so unless the distances from the charge controller to each of these electric loads are very large 2.5-mm2 wire will be ok.

Finally, we can look at the wire between the battery and the charge controller. For this example let us say that this wire is 2 meters long. The wire will carry the current that comes from the solar panel and it will also carry the total current that goes to the electrical loads. We should size the wire based on the larger of these two currents. The current from the solar panels is 1.5 amps, while the current that is required by all of the loads combined together is 1.9 amps (1.1 amps for the TV + 0.6 amps for the lamp + 0.2 amps for the radio = 1.9 amps). The total current for the electrical loads is the larger number so we should use this one (1.9 amps) for sizing the wire. Again, the current in this wire is less than 3 amps and the distance is short (2 meters), so 2.5-mm2 wire is ok.

Now that we are sure that 2.5-mm2 wire is ok for all of the wires in the system we need to decide which type of wire to use. This is a small 12-volt DC system that is smaller than 50 watts, so it is not necessary to use earthing (however, sometimes it is still good to include earthing in case the owner is able to connect to the AC mains later). The wire from the solar panel to the charge controller is outside on the roof, so we may want to use twin flat with sunlight resistant PVC insulation.

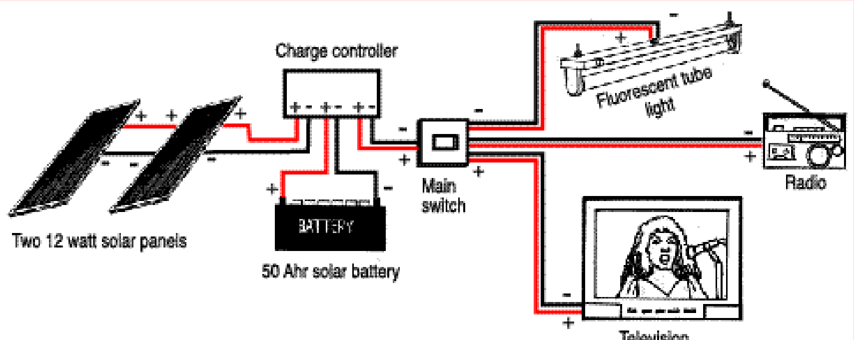

Figure 1: Wiring Diagram for a Small Solar PV System

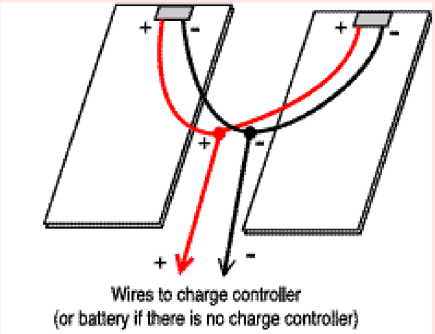

Figure 2: Wiring Two Solar Panels in Parallel

This may not be necessary if the wire is not in the sun (for example, if the wire goes from behind the solar panel, through the roof, and into the house without having any part of it being in the sun), but if any part of the wire will be in the sun then I recommend using wire with sunlight resistant insulation if you can get it. The other wires (from the charge controller to the battery and from the charge controller to the electrical loads) are indoors, so normal twin flat wire is ok.

Finally, this system has two solar panels, which should be wired in parallel. To connect the solar panels in parallel you should connect the positive wire from the first panel to the positive wire of the second. Then connect the negative wire from the first to the negative wire of the second. See Figure 2. Many solar panels come with lead wires that are about 1 meter long that can be used to connect the panels together. If the panel does not have these wires then you can use 2.5-mm2 wire to make these connections. Again, I recommend twin flat wire with sunlight resistant PVC insulation for these wires that connect the solar panels together if any part of the wire will be in the sun during the day.

There are a few additional things that I would like to mention before finishing this article. First, I have not yet talked about sizing the charge controller for the system. I will give more information about charge controllers in my next article, but for now I will say a few things. First, the charge controller that you select should have a current rating that is a bit larger than the maximum current from the solar panels to the battery and from the battery to the electric loads. In this case the current from the solar panels is 1.5 amps and the total current to the loads when they are all on is 1.9 amps. From this, I would recommend a charge controller that has a current rating of at least 3 amps. However, very few charge controllers are available in sizes smaller than 5 amps, so for these small systems you can usually use the smallest size that is available. In addition, I think that it is always best to get a charge controller that includes a low voltage disconnect (LVD).

Second, you should always make sure that all of the circuits are fused. You should always include a fuse between the solar panel and the battery and also between the battery and each of the electric loads. If you use a charge controller in the system, then you may not need to add additional fuses, because many charge controllers have a fuse between the charge controller and the battery. This fuse protects the circuit from the battery to solar panel and it also protects the circuit from the battery to any load that is connected through the charge controller (if a load is connected directly to the battery then it should have its own fuse). If the system does not have a charge controller then you should be sure to include the correct fuses. Also, if you include a main switch in the system then this protects the circuit between the battery and the electric loads. The important thing is to make sure that the wiring includes enough fuses to protect the circuits from the solar panel to the battery and from the battery to each of the electric loads. The size of the fuses should be large enough to hold the maximum current that you expect in each circuit, but small enough so that it protects the electrical part in the system that has the lowest current rating (in amps). For example, in this system the current from the solar panel to the battery is 1.5 amps, so the fuse for this circuit should be at least 2 or 3 amps. We calculated that the circuit from the battery to the electric loads carries up to 1.9 amps, so the fuse for this circuit should be at least 3 amps. This tells us the smallest size that these fuses can be. We also do not want the fuses to be too big or they will not protect the equipment in the system. For example, often the charge controller is the system part with the smallest current rating. If we choose a 5-amp charge controller then the charge controller should have a 5-amp fuse. Even if you do not have a charge controller in the system, the 5-amp fuse is often a good size for protecting circuits for small systems like this one.

Finally, diodes are sometimes used to prevent the energy in the battery from getting wasted at night by flowing back through the solar panel. I have not included a diode in this system between the solar panel and the battery because I have used a charge controller. Many charge controllers protect against this problem by including a diode in their circuit or by disconnecting the panel from the battery at night so that a diode is not necessary. However, some charge controllers do not protect against this problem so you should check to be sure. If you are not using a charge controller or if the charge controller does not protect against current flowing backwards out of the battery to the solar panel at night then you may want to include a diode in the system. I will write a longer article about the use of diodes in a future article in Solarnet.

There are many more things that I could write about regarding the wiring of solar PV systems. For example, it is important to wire systems carefully so that the connections are good and so that the wires are neat. However, I save these topics for a future article. For now you should remember that it is very important to select wires carefully when you are doing a solar installation. For small systems with currents that are less than 3 amps I recommend the use of 2.5-mm2 wire for all of the circuits. However, if some of the wires are very long (that is, longer than 13 metres) or if you have a system with higher currents in the wires then you will need to use larger wire sizes.

When you calculate the size of the wire that you will use for each circuit, you need to know three things. These are the system voltage (often this is 12 volts), the current that will flow in the wire, and the length of the wire. If you know these things then you can use Table 1 to choose which size wire to use. Finally, in addition to picking the right wire size, you need to pick the correct wire type for the installation that you are going to do. For example, different wire types should be used for indoor and outdoor wiring. I have included information about some of the common wire types in Table 2.

I have talked a little bit about charge controllers in this article, but I will provide more information about them in the next article. Until then, *kwaherini*!

Answers to the wire sizing practice examples: Practice example #1 - the wire should be 2.5 mm2. Practice example #2 - the wire size should be 6.0 mm2.

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Energy Saving Tips to Solar End Users

Humans have enough resources that are under-utilized, over-utilized or not utilized at all. For the best results in any solar electric system, we would like to highlight on energy saving tips to solar end users. The following points are worth considering:

System Size: Just as you cannot use a motorcycle to ferry a one-ton load, your solar system should be properly matched. Whatever you draw from your battery(s) should be replenished by your module(s) the following day. Most solar users fail to be realistic when they buy solar systems. They invest less and expect more which will never happen in any corner of the earth!

Use only what you need: In natural circumstances you do not take your breakfast, lunch and supper all at ago. Do not leave appliances running when you do not need them e.g. leaving your radio on while you are away or leaving your bedroom lights on while you are in the living room.

Electrical/Electronic Appliances

The Power Ratings: This is worth considering before purchasing an appliance. For instance a (mains only) 14" Coloured TV has a power rating of 70watts while a similar size AC/DC Coloured TV is rated at 35 and 49 watts respectively. Apart from their low power consumption in comparison with the AC powered ones, it will save you from the hassles of looking for a DC – AC power inverter.

Lights: A10W DC fluorescent fitting will draw between 500-600mA, while an incandescent 10 watts solar bulb will draw a steady 800mA. In systems where inverters are used, a 75watts incandescent bulb will draw about 6 Amps. While a 14 watts energy saving bulb will draw 1.2 Amps and yet give you the same light intensity.

Power Inverters: Many solar system users do not understand the inverter and its applications. You will find clients with all sizes of solar systems (e.g. the starter kit) going for the power inverter. Before a client goes for a power inverter the following factors have to be put into consideration:

a) The type of appliances to be operated: In a system where all loads are DC operated, an inverter is needless and will only come in systems where there is an appliance,

b) Distance of cable runs: Only systems with longer cables runs should have the loads run via a power inverter to reduce the voltage drops encountered in DC systems,

c) Cost: Surprisingly the cheaper the inverter, the more expensive it is to your solar system. A MOSFET based 300watts power inverter will draw 620mA on standby i.e. so long as it is on without any load, which translates to 15AH in 24hours whilst their failure rate is also high. This has contributed to a lot of strain on solar systems. A transformer based 300watts power inverter draws 136mA on standby that translates to 3.3AH in 24 hours!!!!,

d) Inverter Waveform: When choosing an inverter it is necessary to know the type of waveform as we have pure and modified sine wave inverters and above all, not all inverters however big can run certain types of loads most precisely refrigerators,