USAID | HAITI
FROM THE AMERICAN PEOPLE

PEPFAR / USAID / CDC MEDICAL PROGRAMS IN HAITI

REAL WORLD INSTALLATION CONSIDERATIONS

FOR INVERTER / CHARGER / BATTERY EQUIPMENT

APRIL 25, 2008

This publication was produced for review by the United States Agency for International Development's Office of Infrastructure and Engineering. It was prepared by Walt Ratterman of SunEnergy Power International.

PEPFAR / USAID / CDC MEDICAL PROGRAMS IN HAITI

REAL WORLD INSTALLATION CONSIDERATIONS

FOR INVERTER / CHARGER / BATTERY EQUIPMENT

CONTENTS

INTRODUCTION

The Haiti National Reference Laboratory and The United States President's Emergency Plan for AIDS Relief (PEPFAR) Program are in the process of expanding and improving the health facility laboratory infrastructure throughout Haiti. The success of this effort is highly dependent on the provision of stable and reliable electricity to these labs to support increasingly sensitive laboratory equipment being deployed throughout the country.

Haiti is plagued with unreliable electricity in both quantity and quality. Where the grid exists, it is often not energized. When it is energized, the quality of electricity in the lines is poor and cannot support lab equipment. Additionally, many health centers in the country are not even served by the electrical grid.

This situation has led many health system providers in the country to take action for providing clean and reliable power to their equipment. A key action that is seen widely throughout the country is the installation of inverter / chargers, and battery banks to provide utility back-up. These systems are installed with and without generators; as well as with and without solar panels. The inverter / charger / battery bank equipment forms the core of a variety of on-grid and off-grid power solutions.

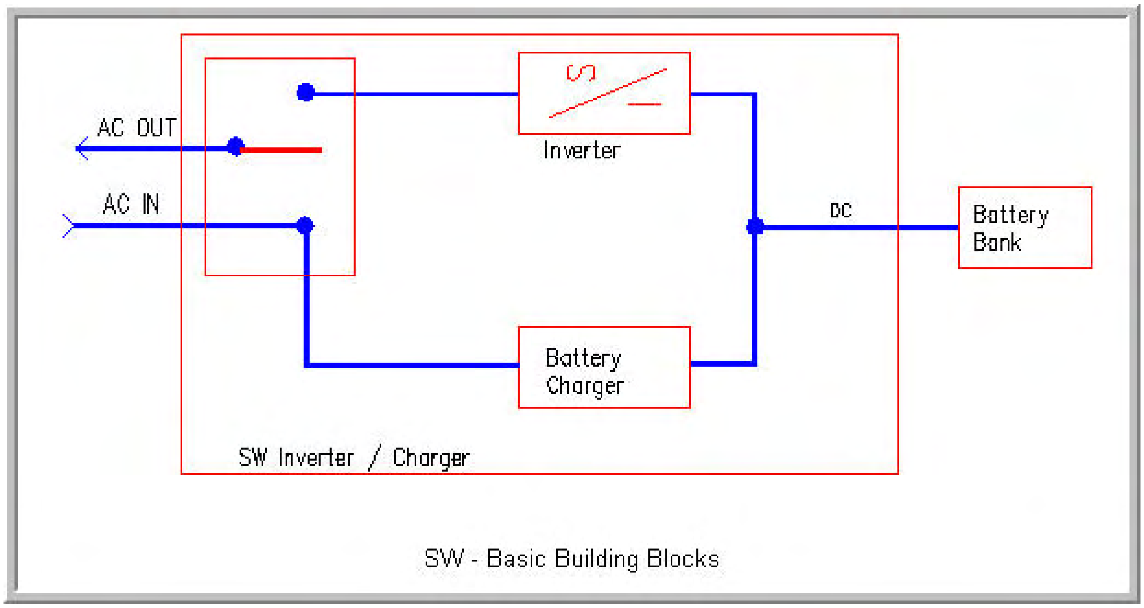
However, field visits to numerous hospitals and health centers throughout Haiti have revealed that one or more of these important installation practices have not been adhered to, leading to early battery failure, or in many cases – complete shutdown of the system. There is a need for a how-to-guide that addresses the most common problems observed in the field and discusses practical field applications necessary for proper installation of the inverter / charger and battery equipment.

This short manual from USAID on "Real World Installation Considerations for Inverter / Charger / Battery Equipment" is intended to serve that purpose. This manual is based on the Xantrex Model SW inverter, observed most frequently during field visits, and is applicable to models SW 4048 and SW 5548, which were most prevalent. This manual is prepared to be used as a supplement to the SW Owner's Manual and is not a substitute for it. With minor variations, this manual can be applied to Outback Power equipment and other manufacturers' equipment.

1.0 BASIC SYSTEM

The Xantrex model SW 4048 is not just an inverter, though it is frequently referred to as one. It can be better described as a power management center. Its equipment enclosure includes:

- DC to AC Inverter;
- AC to DC Battery Charger;
- Transfer Switch between using AC Incoming Power or Battery Power;
- Transfer Switch to choose between two different AC Sources;
- Relays to perform a variety of user selected functions; and
- Computer with LCD screen and user input for customizing most of the variables.



As shown above, the SW is basically an equipment enclosure housing all the above elements, with field connection points for incoming power (AC IN), load wiring (AC OUT), and battery connections (DC).

In the sections to follow, this manual will:

- Illustrate basic operating modes of the SW;
- Review best practices for making the connections from the equipment to a customized site;
- Provide an overview of the most significant programming functions required; and
- Provide inputs and suggestions for the continued operation and maintenance of this equipment.

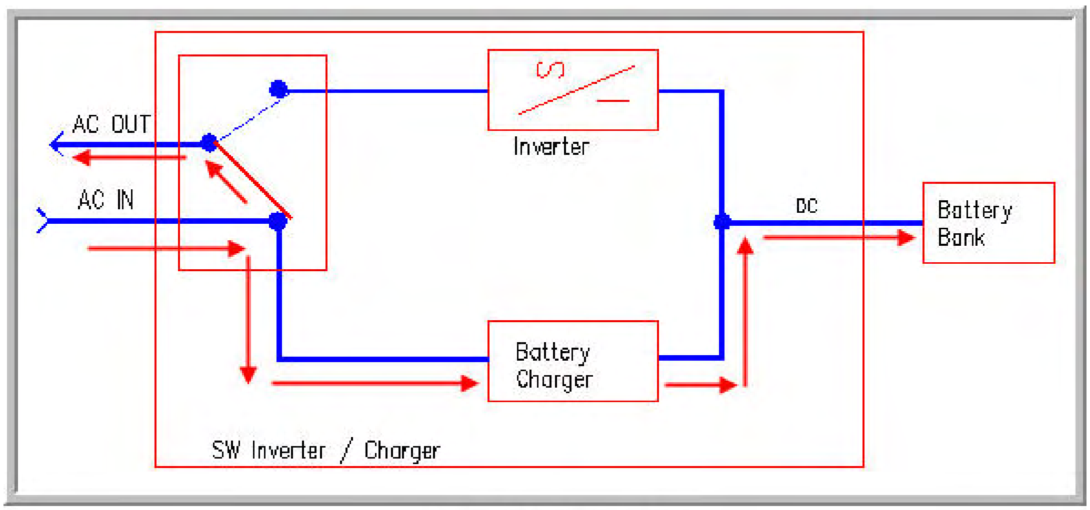
2.0 MODES OF OPERATION

The SW can be connected into an electrical scheme in many different ways. However, some common elements remain unchanged from installation to installation.

The over-riding purpose of the SW is to provide continuous power to the loads (AC OUT). If there is power (with the proper characteristics) at the AC IN terminals, then the equipment will utilize this power to:

- Feed the Loads (AC OUT); and
- Charge the Batteries – through the built-in Battery Charger.

The following diagram shows the operation and power flow when there is proper power supply at the AC IN terminals:



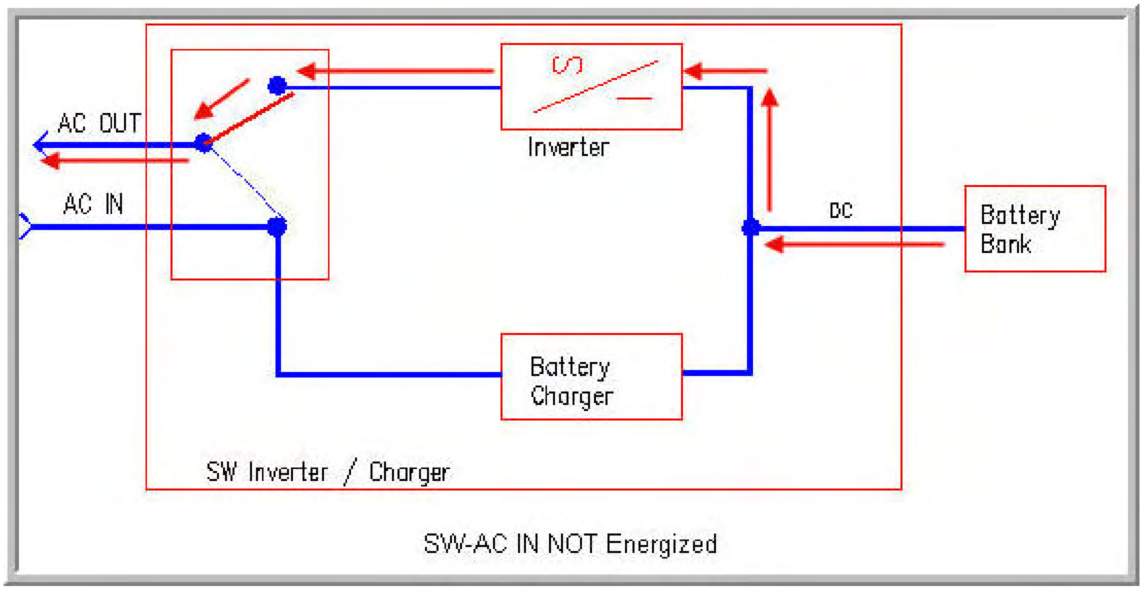
SW-AC IN Energized

The power flows in from AC IN, divides to energize the loads, and charges the battery bank through the battery charger. In this condition, the inverter is idle.

3.0 OPERATION – WHEN AC IN POWER IS LOST

When power is lost to AC IN, the on-board computer switches the transfer switch so that the AC OUT loads are fed from the battery through the DC to AC Inverter, and the inverter is turned on. This happens nearly instantaneously.

When this situation occurs, the entire load is being powered by the battery bank. Of course, this can not go on forever, and when the battery bank reaches a programmed low state of charge (depicted by low voltage) the system turns off. (Alarms can be installed to warn operators of impending cut-out, and this is covered later in this manual.)

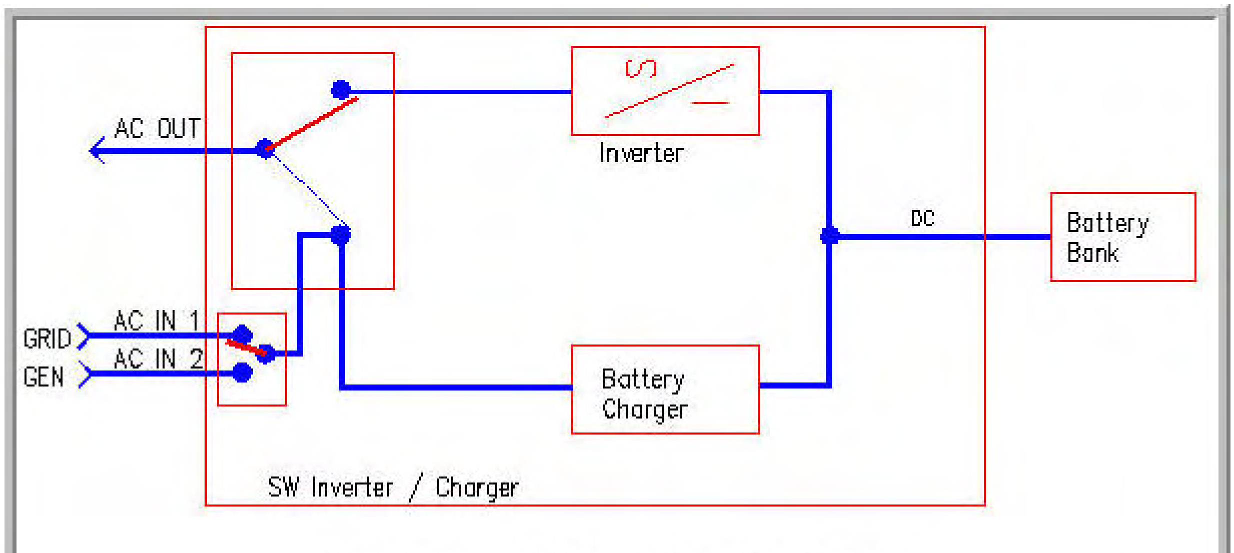


Here, power is lost at the AC IN terminals, so the transfer switch is switched and the inverter is turned on, allowing the loads to be fed from the batteries, through the inverter.

This is the basic operation, and everything else expands on this concept.

4.0 AC IN 1 AND AC IN 2

The SW model inverter/charger includes provisions for two AC Inputs. Field visits did not reveal any field application where both inputs were used. In many cases, both inputs will not be needed, but there are many applications where they would be useful. The basic system diagram changes only at the AC IN provisions:



SW-ADD Second AC IN and TRANSFER SWITCH

The above diagram shows that a second transfer switch is added (built in to the SW equipment) that selects between two possible inputs. AC IN 1 is meant to be for an incoming grid connection, whereas AC IN 2 is intended for power coming in from an on-site generator. Electrically, the two connections are different. Different maximum current flows can be programmed on each of the AC IN 1 and AC IN 2 terminals. This is explained below in the discussion on AC IN connections.

In the classic case of a system being connected to a grid with a stand-by generator, the normal power flow would be from the grid, powering the loads and charging the batteries.

When the grid power goes down and the generator comes on (started either manually or automatically) and voltage is present at the AC IN 2 terminals the transfer switch will switch to the generator input power and will then power the load and charge the batteries from the generator.

The AC IN 1 grid has priority, so if there was suitable voltage on both terminals, the SW would select the grid to power the loads and charge the batteries.

5.0 CONNECTIONS TO THE REAL WORLD

The SW equipment is strictly the core equipment necessary to monitor and switch power sources to feed the given load. In order to become part of the entire wiring system, it is essential to use proper wire sizes, and the proper fusing and disconnecting means to (a) protect the wiring, (b) protect the equipment, and (c) protect people. In many cases, when improper auxiliary equipment is used (or not used at all) not only is the result unsafe, but it also results in improper operation, and dead batteries and un-powered loads. These problems can be avoided by following some guidelines on connecting the SW equipment to the rest of the electrical system.

In the next section, the manual will discuss AC OUT connections, AC IN connections, and finally DC and battery connections.

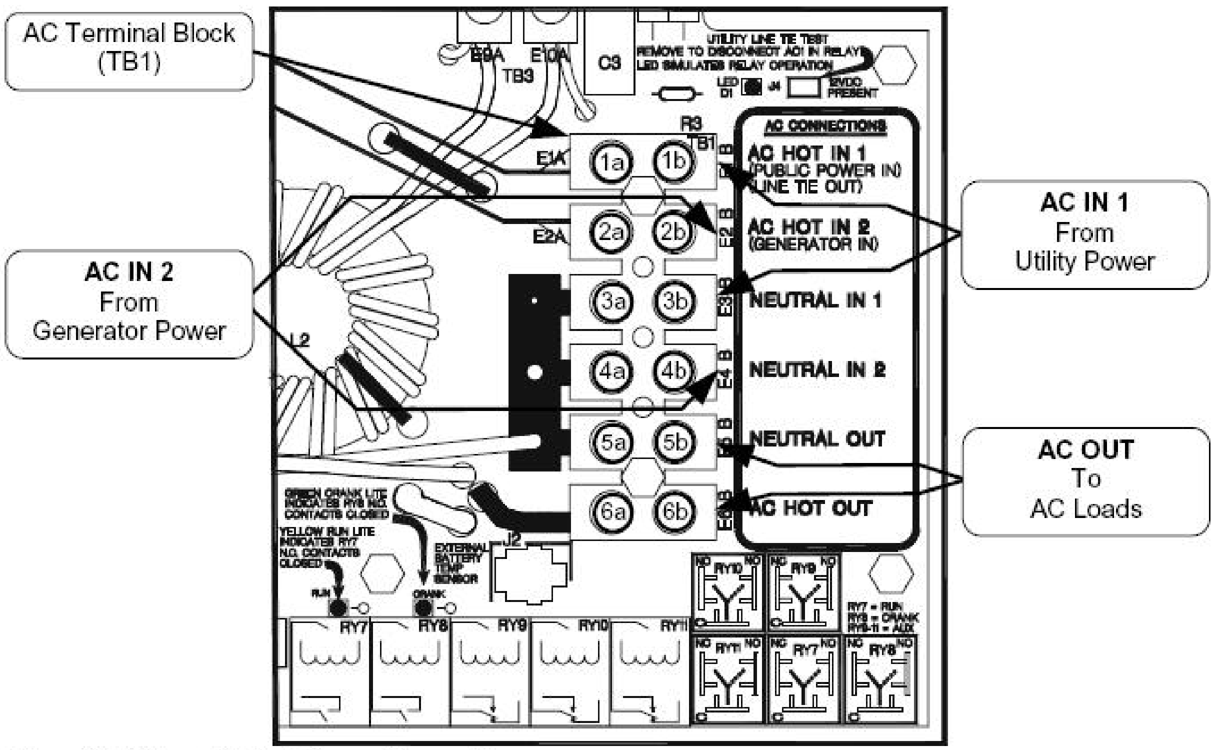


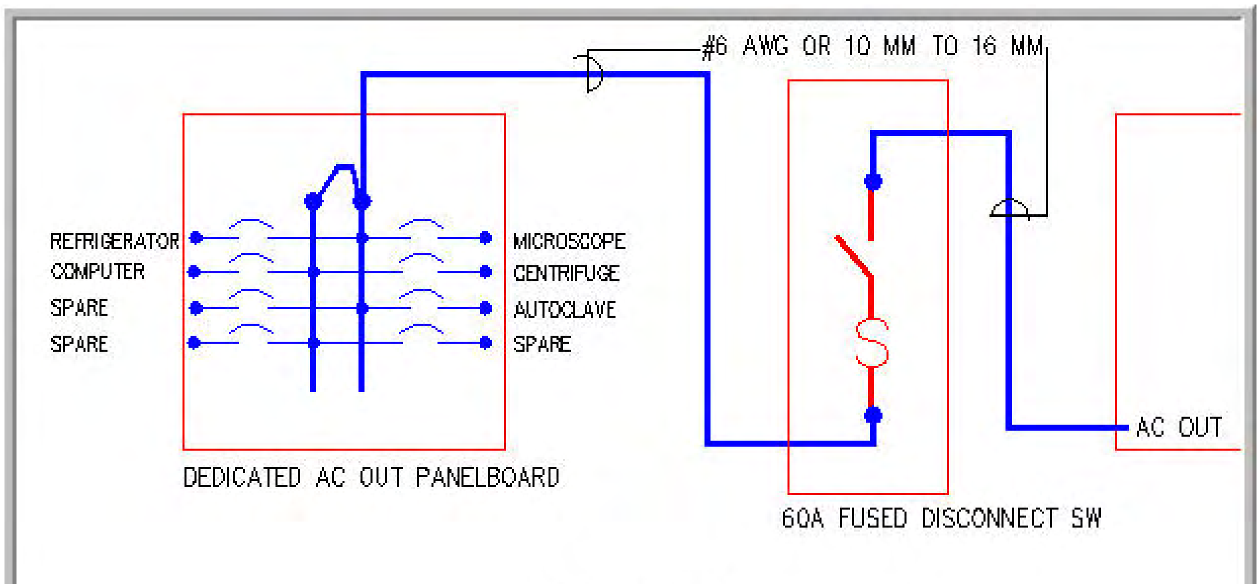
Figure 9, AC Input/Output Power Connection

From the SW Owner Manual

6.0 AC OUT CONNECTIONS

All of the AC terminal blocks inside the SW AC box (on the left hand side of the unit) will accept up to #6 AWG conductors (16mm2). It is advised that this #6, 10mm2, or 16mm2 wire be used.

The AC OUT terminals should be supplying only a pre-determined set of loads. These loads should have been the basis of the selection of the size of the battery bank and the size of the inverter. These loads should be fed from a separate, dedicated circuit breaker panelboard connected to the AC OUT terminals. The conductors carrying the load current from the SW to this panelboard should land first in either a fused disconnect switch, or a main circuit breaker on the panelboard.



AC OUT WIRING

The AC OUT wiring should be sized for the largest amperage output that the inverter is capable of producing. This is calculated as follows:

SW 4048 = 4000 watts. 4000watts / 120V = 33 amps.

SW 5548 = 5500 watts 5500watts / 120V = 46 amps.

It works best to standardize on #6 AWG or 10 mm2 or 16 mm2 conductors.

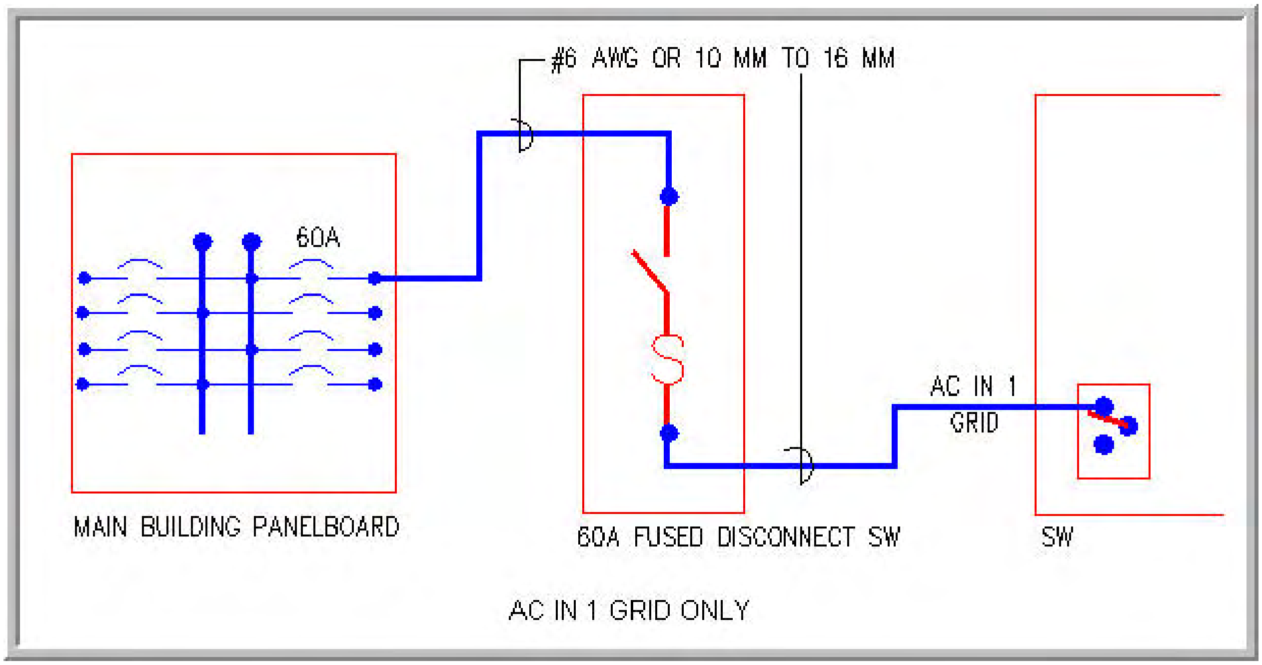
7.0 AC IN CONNECTIONS

There are several options for AC IN connections:

- AC IN from a grid supply only
- AC IN from a generator supply only
- AC IN from both a grid supply and a generator supply
- AC IN from a combined grid / generator supply.

The following section discusses each option.

7.1 AC IN 1 FROM A GRID SUPPLY ONLY

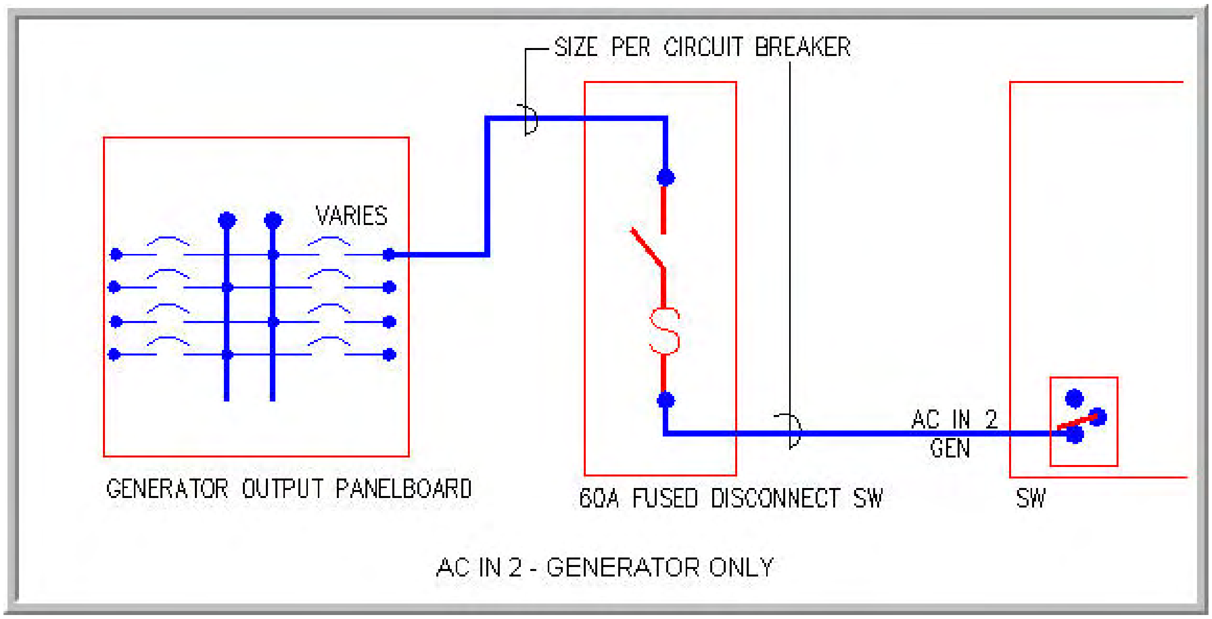


Here, the AC IN power is obtained from the main building panelboard, using a 60A circuit breaker and 60A wire.

Even though the output of the inverter is limited to either 33 or 46 amps, it is important that the 60 amp circuit breaker is used and conductors feed the AC IN terminals. This is because when the grid power is on, it is performing two functions: First it is feeding the loads, and secondly it is powering the battery charger. The battery charger could draw up to as much as 30 amps depending on how the settings are programmed.

If it is not possible to provide a 60 amp supply to the ACIN 1 terminals of the SW, then certain settings MUST be changed in the programming, and the design needs to be studied to be sure that the batteries will receive enough charging power. See the discussion under “Programming” for more information on this subject.

7.2 AC IN 2 FROM A GENERATOR SUPPLY ONLY



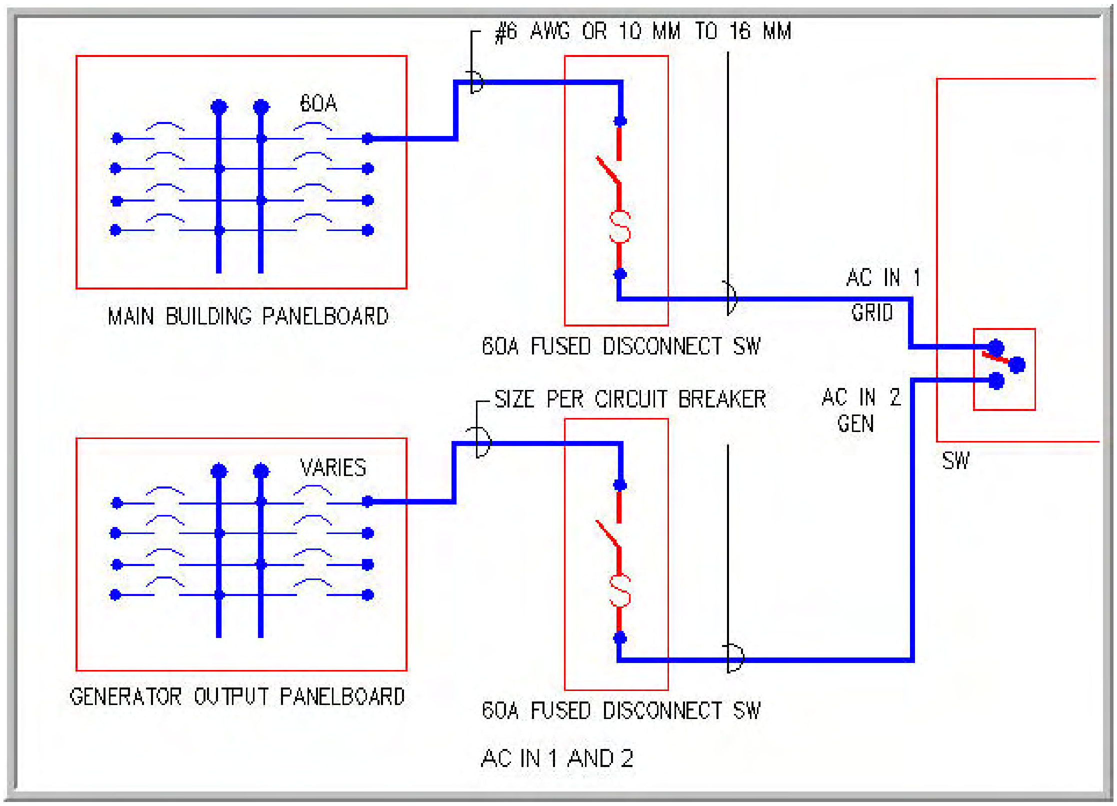
When power is supplied from a generator, it is safe to use the same 60A circuit breaker and wire as when supplying power from the grid. But this may not be necessary.

The amount of power that can be drawn from the generator needs to be calculated (based on the size of the generator and other loads the generator may have to supply). If, for example, a 6KW generator is dedicated to this inverter, then the maximum power that can be obtained from the 6KW generator (if it is single phase) is 6000w / 120V or 50Amps. In this case, a 40 amp breaker to feed the SW and a therefore, 40A wire will be sufficient.

If the generator is designed to support other loads as well, then how much of its power can be dedicated to the SW equipment needs to be determined and the breaker and conductors needs to be sized accordingly. The proper programming needs to be completed to match this value.

The equipment needs to be programmed so that it does not try to pull any more power than the circuit breaker feeding it (or any more power than the generator feeding it.). This would trip the breaker and/or overload the generator. See the section on “Programming” for more information.

7.3 AC IN FROM BOTH A GRID AND A GENERATOR SUPPLY – AC 1 AND AC 2

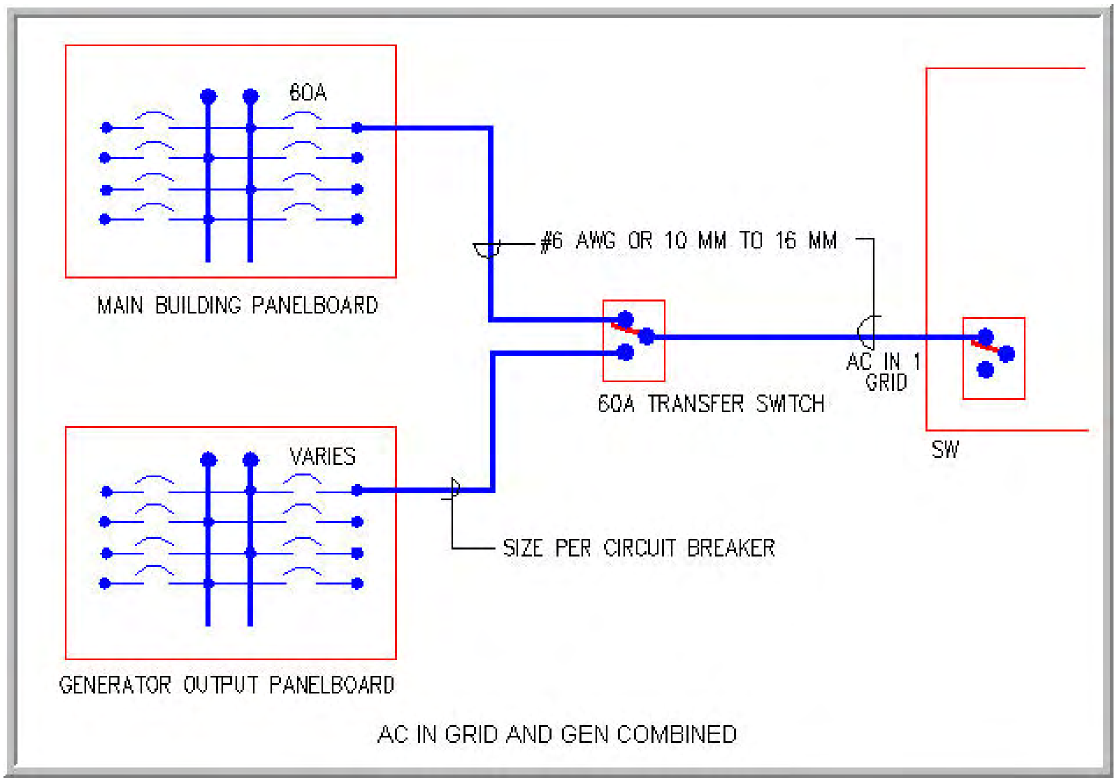


In all of the above cases, the fused disconnect switches should be located close to the SW equipment cabinet. Not only do they protect the wiring, but they are also there so that if someone needs to work on the terminals of the cabinet, they can be sure to disconnect all incoming power to the unit.

When both grid power supply and generator power supply are available, the above is the preferred method for connecting to the system, particularly when the generator size requires a smaller circuit breaker and feeder that would be allowed by the grid input power.

However, in most cases with grid and generator available, the two sources are combined in a transfer switch, with one set of conductors going into the SW, as shown below.

7.4 AC IN FROM A COMBINED GRID AND GENERATOR POWER SUPPLY



This example is very similar to the previous example in that both the GRID and the GEN power is taken to the AC IN of the SW, but are combined before the internal transfer switch inside the SW.

The most common reason for doing this is in circumstances where the generator feeds the entire building through an existing transfer switch, and this transfer switch is in the generator building or in the main electrical room, some distance from the laboratory or equipment being served. To bring both the generator input power and the grid input power to the SW equipment would in effect double the quantity of wire required.

There are pros and cons to this approach

IF the generator is large enough to be feeding the entire building, and IF the full 60 amps of input current can be diverted to the SW equipment when the generator is running, then this situation really is no different than bringing both sets of conductors to the SW cabinet, and is fine. <u>But, it is important that if this is done, the existing main transfer switch is NOT automatic.</u> The SW needs to see a break in power between the two power sources or it can go into surge and disconnect in an error condition. Normally, automatic transfer switches are too fast and do not allow for this break in power. If the existing transfer is automatic, then it is best to run two sets of conductors to the SW equipment and install a manual transfer switch, or just run both sets of power into the SW.

IF the transfer switch is an existing transfer switch located in the generator shed or the main electrical room, some distance from the SW equipment room, then a disconnect switch should be installed on these conductors adjacent to the SW equipment so that the incoming power can be safely disconnected for maintenance purposes.

IF the power that will be available from the generator is less than 60 amps, than this is simply not a good arrangement. For example, if the maximum power that could be pulled from the generator was 30 amps, and an external transfer switch is used, then the AC IN setting would have to be programmed to always draw less 30 amps or less of power from the AC IN supply. This would greatly limit the ability of the SW equipment to charge the batteries.

7.5 SUMMARY OF AC IN AND AC OUT CONNECTIONS

There are several different configurations possible for the AC IN and AC OUT connections. Key factors to consider in planning the installation are:

- Sizing of the conductors for the greatest possible current that they may experience;
- Using dedicated, separate, AC OUT circuit breaker panelboards for the loads decided to be powered by the SW;
- Bringing separate AC IN 1 Grid conductors and AC IN 2 Gen conductors to the SW equipment panel; and
- Providing disconnecting means for the ACIN 1, AC IN 2, and AC OUT conductors to be able to isolate the SW equipment from any power wires.

Additionally, the SW Cabinet should be installed in a readily accessible location (not in a storeroom), where ventilation from left to right is unobstructed, to provide adequate cooling.

7.6 DC CONNECTIONS

As far as the SW is concerned, the DC Connections consists of simply connecting the cables coming from the battery bank to the positive and terminal post on the cabinet.

However, as in the AC Connections, when dealing with the rest of the real world beyond the cabinet there is a lot more to consider when properly connecting the DC side of the system.

Discussion topics here will include:

- Proper DC Cable connections to the SW Cabinet;
- Overcurrent / Disconnecting means in the DC Input cables;
- Connecting Strings of Batteries; and
- Paralleling the Strings of Batteries.

Proper DC Connections at SW Cabinet:

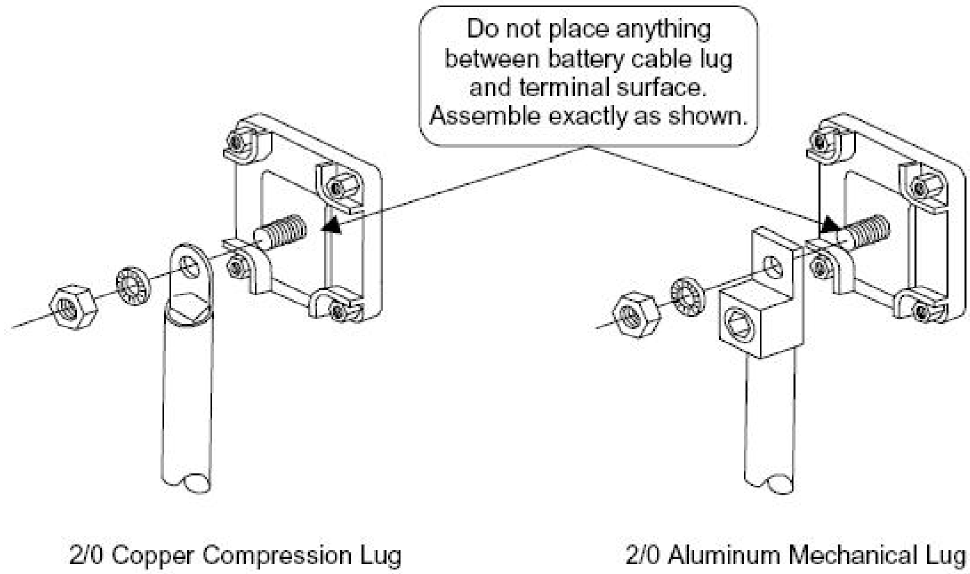


Figure 11, Battery to Inverter Cable Connection

From SW Manual

The DC Terminal posts on the SW Cabinet come equipped with one or more flat washers, a lock washer, and a nut. <u>None of these washers should be placed between the lug and the surface of the equipment cabinet.</u>

A common mistake is to place one or more washers between the equipment terminal plate and the DC cable lug. Often, these washers are stainless steel, which is not a good conductor. Also, the surface area of the termination is reduced when the washer is introduced. The effect has been severe enough to cause shut down of the equipment during large power surges. The reduced contact area impedes current flow and more heat is produced, which can put the equipment into its failure mode.

(If existing inverter installations are having trouble during large current demands, this is one easy thing to check!)

7.7 POLARITY

The DC terminals on the SW equipment are clearly labeled Positive and Negative, and color coded Red for Positive, and Black for Negative.

IT IS EXTREMELY IMPORTANT THAT POLARITY IS NOT REVERSED AT THESE TERMINALS. THIS IS ONE OF THE FEW CONDITIONS THAT IS NOT PROTECTED WITH INTERNAL PROTECTION ON THE SW EQUIPMENT. IF BATTERY POWER IS APPLIED AT THESE TERMINALS WITH REVERSE POLARITY, BESIDES PHYSICAL DAMAGE, MOST OF THE INTERNAL POWER TRANSISTORS WILL BE DESTROYED RESULTING IN NON-WARRANTY DAMAGE AND THE UNIT WILL HAVE TO RETURNED FOR EXPENSIVE REPAIRS.

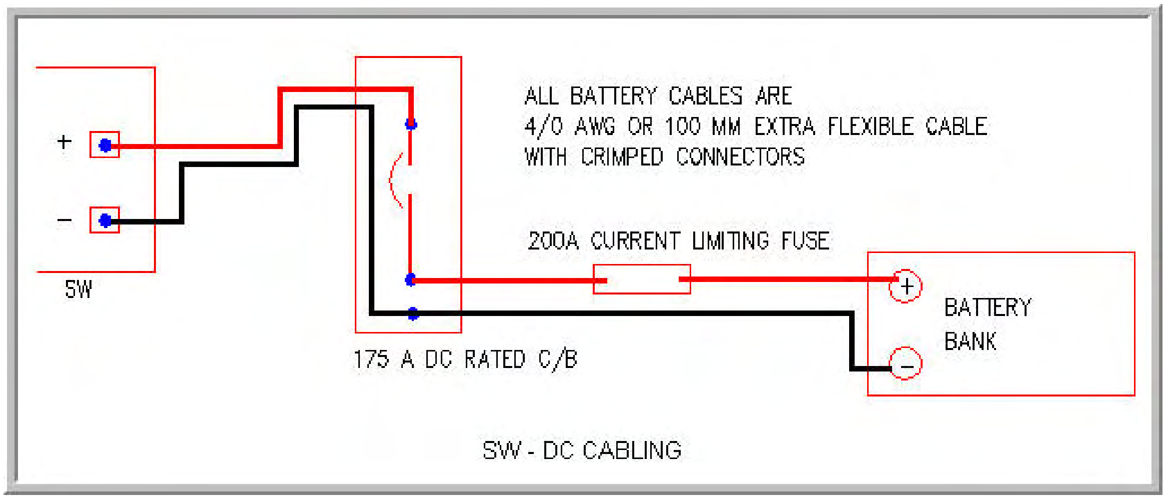
7.8 DC CABLING TO BATTERY BANK

There should always be overcurrent and short circuit protections, as well as a means of disconnecting the battery bank, in the DC cabling, before the cables reach the SW cabinet.

This can be achieved by means of a fused disconnect switch, or a DC rated circuit breaker or an in-line fuse. Generally, an in-line fuse is used for short circuit protection, and a DC circuit breaker is used for overcurrent protection and a disconnecting means.

If these items are omitted from the installation, the result can be a hazardous situation for personnel, as well as for the SW equipment. A typical installation is as follows:

7.9 DC CABLING



The above example would be for an SW5548 installation. If the inverter is an SW4048 (4000 watts) the DC rated circuit breaker could be reduced to 125 or 150 amps. The current limiting fuse could remain at 200A.

Although there are circumstances where 2/0 battery cables (or 70 mm2) would suffice, it is probably best to standardize on 4/0 battery cables for these installations. Consider the battery cable table from the SW Manual on the following page.

The two inverter models under consideration are the SW4048 and the SW548. The columns that call out the number of feet away actually mean the number of feet in the cable itself. It is difficult, if not impossible to get any significant cable run through a circuit breaker / disconnect switch and a fuse block and to the battery in 5 feet. It is hard enough to do it in 10 feet. For this reason, 4/0 cables in pre-fabricated, 10-foot lengths should be standardized.

Table 2, Minimum Recommended Battery Cable Size vs. Cable Length

INVERTER MODEL	TYPICAL DC AMPS[1]	NEC AMPS[2]	1 TO 3 FEET ONE WAY	3 TO 5 FT ONE WAY	5 TO 10 FT ONE WAY
SW2512	267 Amps	334 Amps	#4/0 AWG/107 mm^2	#4/0 AWG/107 mm^2	Not Recommended
SW2612E	278 Amps	348 Amps	#4/0 AWG/107 mm^2	#4/0 AWG/107 mm^2	Not Recommended
SW3024E or J	160 Amps	201 Amps	#4/0 AWG/107 mm^2	#4/0 AWG/107 mm^2	#4/0 AWG/107 mm^2
SW4024 or W, K	214 Amps	267 Amps	#4/0 AWG/107 mm^2	#4/0 AWG/107 mm^2	#4/0 AWG/107 mm^2
SW3048E or J	80 Amps	100 Amps	#2/0 AWG/67.4 mm^2	#2/0 AWG/67.4 mm^2	#4/0 AWG/107 mm^2
SW4048 or K	107 Amps	134 Amps	#2/0 AWG/67.4 mm^2	#2/0 AWG/67.4 mm^2	#4/0 AWG/107 mm^2
SW4548E or A	120 Amps	150 Amps	#2/0 AWG/67.4 mm^2	#2/0 AWG/67.4 mm^2	#4/0 AWG/107 mm^2
SW5548	147 Amps	184 Amps	#4/0 AWG/107 mm^2	#4/0 AWG/107 mm^2	#4/0 AWG/107 mm^2

[1] *TYPICAL DC AMPS is based on Low Battery Voltage with an efficiency of 85%.*

[2] *NEC AMPS is based on Low Battery Voltage, an efficiency of 85%, and a 125% NEC de-rating.*

WARNING! Battery cables that are too small will melt and burn the first time the inverter is operated at high power levels.

In the above sketch (SW-DC Cabling) DC Cables are shown running together for a specific reason. As battery cables are separated by a distance, they have much more inductance than if they are close together. This induction creates an induced current which opposes the applied current. This leads directly to loss of inverter performance and greatly reduced efficiency. With cables separated by 48”, the inductance can be 3 times greater than the inductance recognized if the cables are together.

The result can be as dramatic as the inverter failing to allow certain loads to start, because it can not get the required current to flow in the batteries. This has been seen in cases where installers have done a very neat job in the installation but have grouped all positive cables on one side of a wall, and the negative cables on the other side.

Wherever possible, the positive and negative wires should be kept together. Cable ties are a good method to do this. If passing through metal cabinets with knockouts, paired positive and negative cables should be put through the same knockout. (Putting the positive cables through one knockout and the negative cables through the other should be avoided.)

7.10 BATTERY CONNECTIONS – SERIES AND PARALLEL

The most common battery in use in Haitian health facilities is the Trojan, T-105. This is a 6V 225 Ah battery.

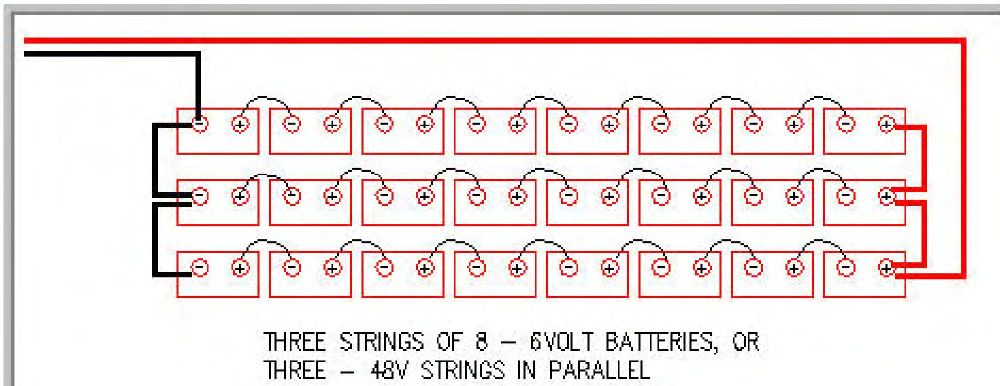
The inverters being used are mostly 48V machines and 48VDC battery banks have to be built to work with them. Connecting batteries in series adds voltages, so one “battery” for the SW 4048 or SW 5548 consists of 8 – 6V Trojan T-105’s wired in SERIES (plus to minus).

Depending on the size of the loads, and the hours of energy required from the batteries, only 1-48V battery or 2 or 3-48V batteries may be needed

When using more than one battery, they have to be connected in PARALLEL (plus to plus, minus to minus).

The following diagrams show two methods of connecting multiple 48V batteries in parallel.

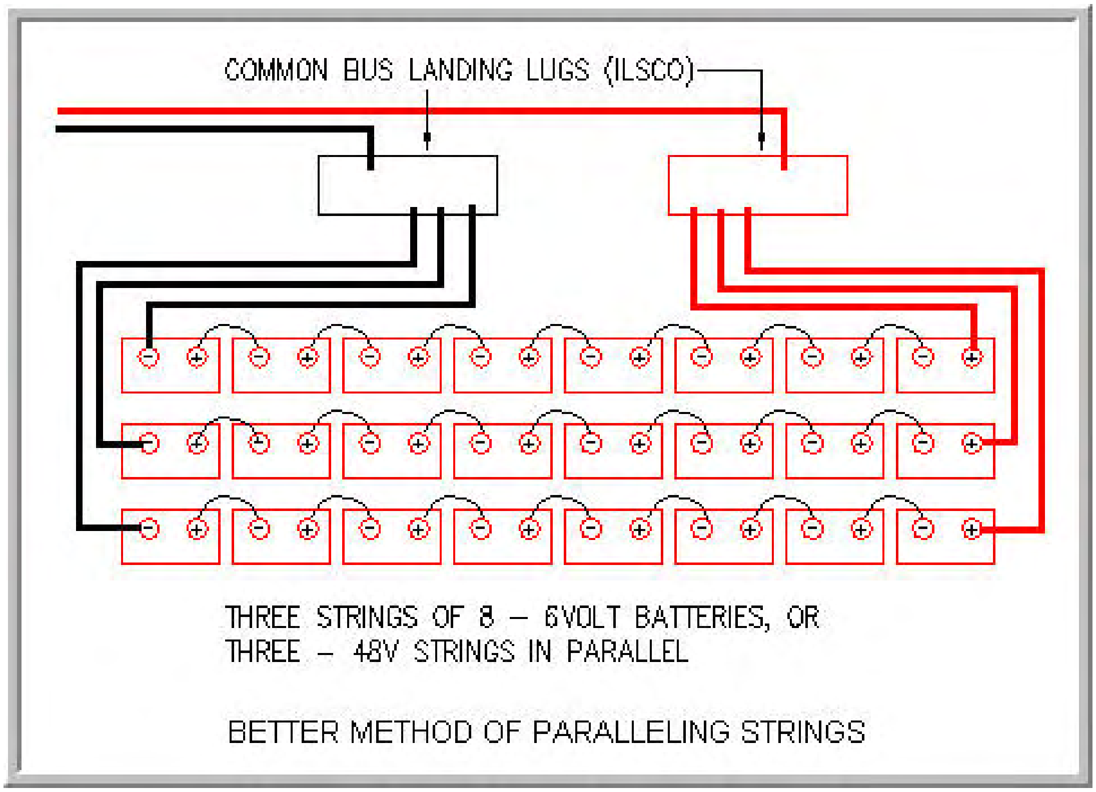
OK:



OK METHOD OF PARALLELING STRINGS

This is the method seen most often, with the paralleling conductors connecting the positive ends and negative ends of each 48V battery.

Better:



In this second method, there is a more direct path for the charging current to reach each string of batteries. It is important in this method to keep all of the paralleling cables the same length. This way, the resistance in each circuit, from the SW equipment to the battery is equal for each string of batteries and the charging currents will more likely be equal than if installed in the first method.

When different strings of batteries are charged at different rates (which can happen with differences in overall lengths of charging conductor) then, over time, one group of batteries will not be charged as fully as the other strings, and will tend to “pull down” the voltages on the other strings as well.

8.0 PROGRAMMING

The last section of the manual dealt with the practical aspects of installing the inverter / charger unit into a real world electrical situation. This section focuses on the programming.

The menus can seem confusing at first, but it is a good idea to take the menu map in the back of the SW manual, and complete it for those parameters that need to be changed. In most cases, the default values will be appropriate.

The menu map is divided into two sections:

User Section	menus 1 through 8	anyone can access
Setup Section	menus 9 through 20	press red and green button together

A discussion follows on the Setup Menu items that generally need attention or changing.

8.1 MENU 9: INVERTER SETUP

Inverter Setup 9	Set Grid Usage	FLT SELL SLT LBX	FLT
	Set Low Battery cut out VDC	32.0 - 70.0	44.0
	Set LBCO delay minutes	00 - 255	15
	Set Low battery cut in VDC	20.0 - 71.0	52.0
	Set High battery cut out VDC	20.0 - 66.0	64.0
	Set search watts	00 - 240	48
	Set search spacing	20 - 255	59

In the Inverter Setup Menu, it is recommended that the Low Battery Cut out VDC setting be changed to 46.0 instead of the default value of 44.0 VDC. This gives added protection to the batteries. (The auxiliary relays can also be used to set up a pre-alarm condition when the batteries drop to 47.0 volts. This will be discussed in the Operation and Maintenance section.)

Some of the other settings in Inverter Setup bear discussion, and may need to be changed as well.

8.1.1 Low Battery Cut-In

This is the battery voltage point were the inverter turns itself back on, once turning off due to a Low Battery cut out. If there is weak charging, or large battery banks, it is advisable to adjust this value down to 51.0 VDC, so that the system turns back on without having to get nearly to float voltage.

8.1.2 Search settings (Watts and Spacing)

When the loads are going to be off for a given time, say laboratory loads that will not be used during the night, the Search capability allows the inverter to turn itself off and “go to sleep” saving energy. Every so many cycles, it “searches” to see if there are any loads requiring power (equal to the search setting in watts), and if it sees such a load, the inverter turns itself back on to power the load.

If there is a refrigerator on the circuit, the search function might as well be disabled. And, if there are very small loads that might want to be allowed to come on – (such as a 7W night light) then the watt setting will have to be changed. (If a 7W load wants to come on at night, and the search setting is set to 48Watts, the inverter will not come on until it sees a demand for 48 watts, so the 7W light will not come on.)

Quite often, the search function is disabled and can serve as an energy saver.

8.2 MENU 10: BATTERY CHARGING

Battery Charging 10	Set Bulk volts DC	40.0 - 64.0	57.6
	Set Absorption time h:m	00:00 - 23:50	02:00
	Set Float volts DC	40.0 - 64.0	53.6
	Set Equalize volts DC	40.0 - 64.0	57.6
	Set Equalize time h:m	00:00 - 23:50	02:00
	Set Max Charge amps AC	01 - 35	30
	Set Temp Comp	LeadAcid Nicad	LeadAcid

The Bulk volts, Float volts, and Equalize volts all need to be set in accordance with the battery manufacturer's recommendations. For example, manufacturer's data from the Trojan website for some of their batteries would show:

	System Voltage				
Voltage Settings	6V	12V	24V	36V	48V
Daily Charge	7.4	14.8	29.6	44.4	59.2
Float	6.6	13.2	26.4	39.6	52.8
Equalize	7.8	15.5	31	46.5	62

SAMPLE VOLTAGE SETTINGS FROM A TROJAN DATA SHEET

Terminology is not always the same. In this case, "Daily Charge" would correspond to Bulk Charge rate.

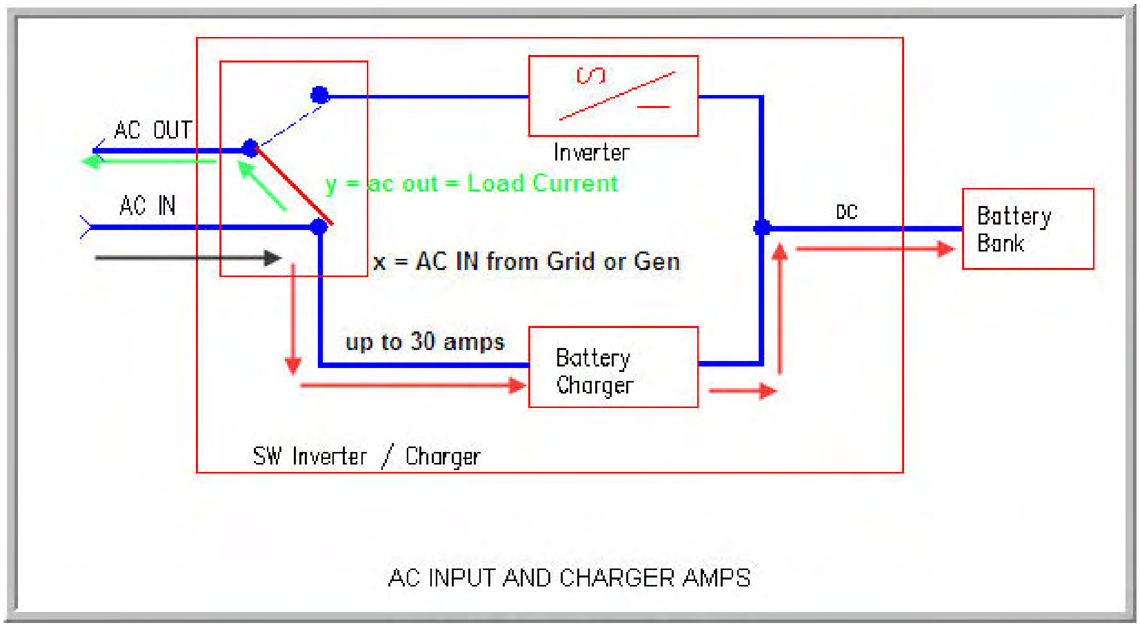
The "Maximum Charge Amps" sets the maximum amount of AC input current that the battery charger will use to charge the battery. This setting works together with the AMPS AC setting of the particular AC INPUT (menu 11). These parameters will be discussed together under menu 11 settings in the following section.

8.3 MENU 11: AC INPUTS

AC Inputs	11	Set Grid (AC1) amps AC	00 - 63	60
		Set Gen (AC2) amps AC	00 - 63	30
		Set Input lower limit VAC	80 - 111	108
		Set Input upper limit VAC	128 - 149	132

The settings for AC1 Grid Input Amps, AC2 Gen Input Amps, the Maximum charging amps from Menu 10 all work together.

Consider the following sketch:



In this sketch, it is assumed that the MAX CHARGE Amps is set in Menu 10 to 30 amps.

The Load Current, y, plus the current going to the battery charger are not generally permitted to exceed the AC IN current, x.

So, if the AC IN is from the grid, and if the GRID AC1 amps is set to 60 amps, then the battery charger can draw its full 30 amps leaving 30 amps for the load current.

Under this condition, if the load current rises to 40 amps, then the current going to the battery charger would automatically limited to 20 amps (for a total, not to exceed 60 amps.) Then, if the load current rose to 60 amps, there would be nothing left for the battery charger. If this situation persisted, the batteries would not get charged.

Since the normal loading of an SW4048 would be 33 amps, and the normal loading of an SW 5548 would be 46 amps, this limiting condition will likely not be seen on the grid connection.

If the AC IN is from the Generator and the GEN AC2 amps is set to 30 amps, then it is seen that any load on the AC OUT terminals of the system will detract from the current that can go to the battery charger.

In these settings, the most important ones to get correct are the GRID AC1 Amps and the Generator AC2 Amps, since the battery charger amps is automatically reduced as the load increases.

In general, the GRID AC1 amps and the Generator AC2 amps settings should be the same as the circuit breaker feeding AC1 IN and AC2 IN respectively. So, with a grid input, and a 50 amp breaker feeding the SW equipment, the GRID AMPS AC1 should be set to 50 amps. If the setting is left at 60 amps, and the combination of the load and the battery charging exceeds 50 amps, the SW will not know to back off, and the breaker will trip, disconnecting the battery charging, and powering the loads from the battery. If this were to happen at night, when the AC INPUT is supposed to charge the batteries, the result could be discharged batteries by the morning.

Similarly, the GEN AC 2 Amps setting must match the output that is expected out of the generator. Sometimes this takes some experimentation. Many generators are labeled as 10KW generator but can only be reliably loaded up to about 5 or 6 kw.

The difficulty in all of this comes in when the combined AC1 Grid and AC2 Gen feeds into one transfer switch before the feeders reach the SW equipment. At this point the lowest current setting will have to be picked – one that will not cause the system to trip out on overload.

So, if normally the system is running on the grid on a full 60 amp circuit, but a 30 amp circuit (or less) is powering the system when the emergency generator is on, then settings have to be programmed to match the generator capacity, or there is a risk of the entire system shutting down when the generator is powering the system.

This relates back to an earlier suggestion in the manual that if possible, when there are a grid feeder and a generator feeder, both feeds be brought to the SW equipment to take advantage of this ability to program the incoming capacities differently.

The last item under Menu 11 is the setting for the lower limit of Voltage AC that the system will accept (to power the loads and charge the batteries.) This needs to be set with some thought. If this window is kept tight, this will assure that low voltage electricity does not reach the loads. This might be appropriate if there are problems with low voltage only during short, intermittent parts of the day. However, if there are constant low voltage problems and the window is set tightly, then this will also prohibit the equipment from connecting to the grid to charge the batteries.

It is generally good to set this at the lowest voltage level that is acceptable to the equipment being powered.

8.4 MENU 12: GENERATOR AUTO START SETUP

The manual does not recommend using automatic generator start functions, so this menu heading will be skipped. However, the manual includes a discussion on how some of these functions can be used to operate an alarm that will precede the system shut-down, and tell an operator when the system feels the battery voltage is getting unacceptably low.

8.5 MENU 18: GRID USAGE TIMER

Generally, the grid usage timer is not used. Grid electricity is used whenever it is available.

A situation where the grid usage timer might be used would be in an area where the day-time grid power supply is not clean enough to power the laboratory loads. If the grid power is connected to the SW, the grid power is fed through the SW, without conditioning, to the loads. In this case the grid power feed to the inverter equipment should be turned off during the lab hours of the day, allowing the lab equipment to be fed from the clean power manufactured by the inverter.

Then, when the laboratory work is finished, the grid power could be reconnected to the SW equipment during the night, to charge the batteries.

This could be done as described above, operating manual disconnect switches at the beginning and end of the shift, or by setting the Grid Usage Timer, to only use the grid power between say 6 p.m. and 6 a.m.

8.6 SUMMARY – PROGRAMMING

This discussion covers only a few of the programming parameters that can be changed and viewed. But these are most likely the only parameters that will have to be changed from the default values. Users should become familiar with all of the menus – both user and setup menus – available in the complete SW Owner’s Manual.

These non-custom parameters all need to be set with the overall design in mind, along with knowledge of the available power supplies. It is these setting that allow the equipment to work together with the real world power situation on site, to provide the right power to the loads, and to keep the batteries charged.

The engineer responsible for the design of the system would make the initial setting determinations. These settings should be recorded in the site manual so the operators know what the settings should be, or if they have to be re-established.

IF THE DC POWER TO THE SW EQUIPMENT IS LOST, DUE TO EITHER TURNING OFF THE CIRCUIT BREAKER, OR REMOVING ONE OF THE BATTERY CABLES, ALL NON-DEFAULT PROGRAMMING IS LOST, AND THE SETTINGS REVERT BACK TO FACTORY DEFAULTS UPON RECONNECTION TO DC POWER. THEREFORE, ONCE THE SETTINGS ARE DETERMINED THEY SHOULD BE PRINTED, LAMINATED, AND POSTED AT THE INVERTER AND KEPT IN THE SITE OPERATIONS MANUAL.

9.0 OPERATION AND MAINTENANCE

The SW Owner's Manual has several good sections that cover many facets of Operations and Maintenance, including a comprehensive Troubleshooting Guide.

The purpose of this manual report is to supplement the information in the Owner's Manual, by focusing on the more common problems faced by operators based upon direct observation at many facilities in Haiti.

9.1 OPERATION

Once the system is PROPERLY installed, the maintenance of the system, while critically important, is not difficult.

To be PROPERLY installed, the following criteria need to be met:

- SW equipment is solidly mounted on a wall with working space in front of it and to the sides.
- There is proper ventilation space to the left and to the right of the SW equipment.
- The area in front of the SW equipment is reserved as work space and not storage space. Operators should be able to walk up to the inverter equipment and work on it without climbing over equipment (or batteries).
- The AC IN 1 and AC IN 2 feeds go through disconnect switches prior to entering the SW.
- The AC OUT feed goes first to a disconnect switch and then to a dedicated circuit breaker panel to feed the loads.
- All AC In and OUT wiring is properly sized, and protected with circuit breakers.
- The batteries are properly installed on a rack with adequate spacing to allow for inspection and filling of electrolyte, and for cleaning.
- All series connecting cables are tight and clean and of the right size conductor.
- The paralleling cables go to a common landing block.
- The home run battery cables go to a fuse and then to a DC rated circuit breaker before landing on the SW Equipment.
- The load wiring is run professionally, from the dedicated circuit breaker panel to the individual loads, with any outlets clearly marked with their specific purpose.

The operator will need to know from the designer what the daily routine functions need to be. These functions will vary from site to site, depending on the quality (or the existence) of the incoming grid power.

Two examples of situations that would entail different operations are:

Grid power quality is sufficient to run the lab equipment, but has infrequent dips and/or complete brown-outs:

In this case the system would operate more like a UPS and would remain connected to the grid whenever the grid is available. The AC IN settings would establish a voltage window that is suitable for the equipment being powered. When the grid voltage drops, or turns off, the system will disconnect from the grid and power the loads by the batteries. In this case, most of the time the batteries are full, and are being maintained at a float charge by the system during the day.

Grid power quality during the day is NOT good enough to run the lab, but is good enough to charge the batteries in the evening and through the night.

In this case, it may be better to have the batteries and inverter powering the lab during the day-time working hours, without trying to depend on any input from the grid. This will give high quality electrical energy to the lab equipment.

This can be set up by either (a) manually turning off the AC IN disconnect switches in the morning and turning them on in the evening, or (b) setting up the Grid Usage Timer as described above in Menu 18, so that the grid will only be used between 6 p.m. and 6 a.m.

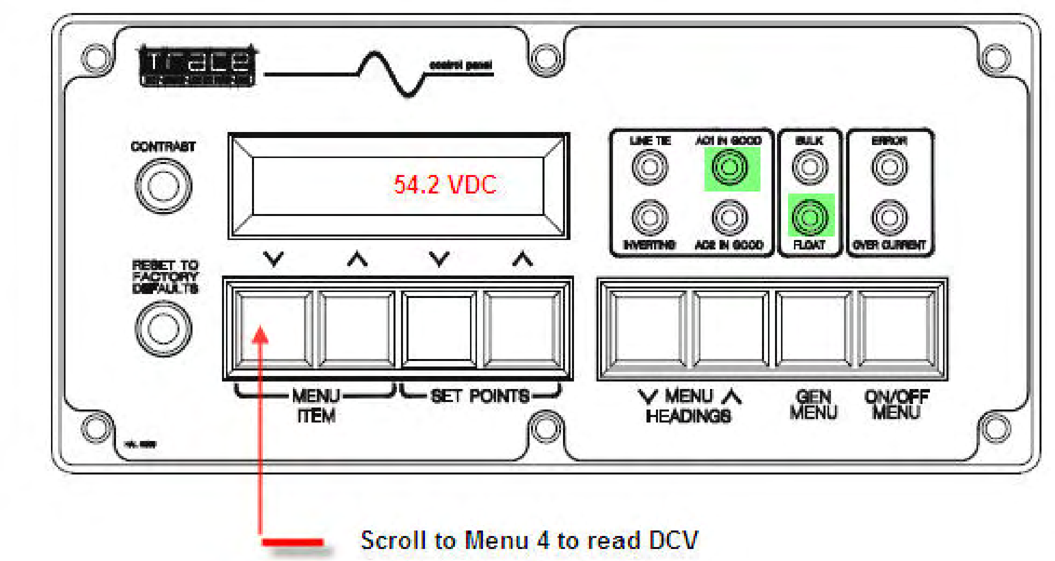
This type of operation requires a battery bank that will power the loads for the full day, and this decision needs to be made by the designer, determining the size of the battery bank.

Other than the above possible daily operations, the daily responsibilities of the operator will be primarily to check all parts of the system, including the LED indicators, to be sure that everything appears to be working normally, and to maintain the daily log.

9.2 DAILY LOG

It is suggested that every day, at the beginning of the shift, and at the end of the shift, the operator records the DC Voltage of the batteries, along with the state of the inverter equipment as read by the LED lights. This information should be kept in a binder and transmitted to the engineering group on a periodic basis.

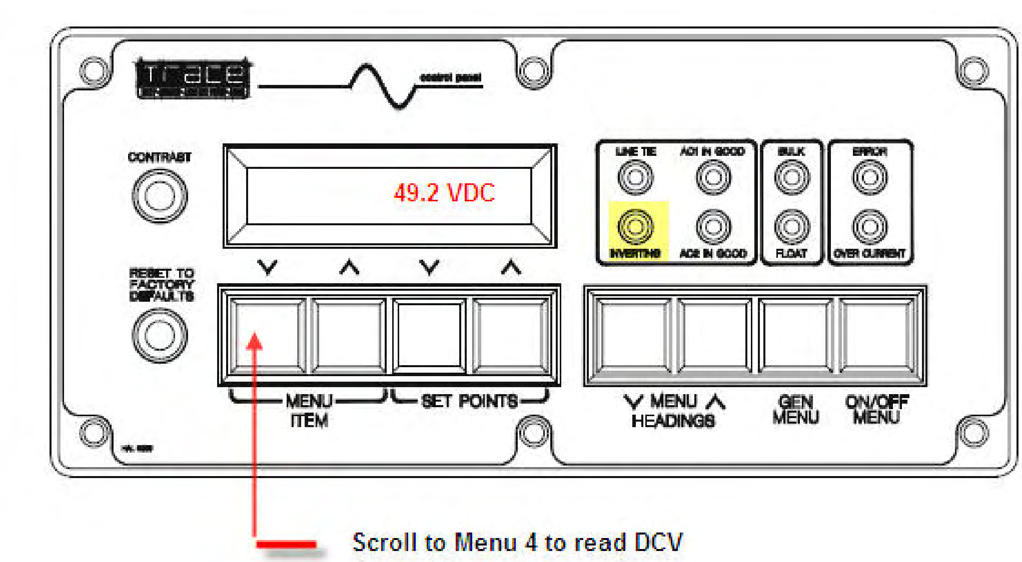
This diagram below depicts a picture of the control panel on the SW.



In this case, the AC1 IN light is green, meaning the inverter is connected to the grid.

The Float indicator is green, meaning that the system is float charging the batteries, which means it has already completed the bulk charge cycle. The voltage is a reasonable level for a system that is float charging the batteries. The record in the log would show the voltage and that AC1 IN is connected and the system is in Float charge.

Consider this reading:



In the above control panel configuration, it is seen that neither AC1 nor AC2 is supplying power to the inverter. This means either (a) there is no grid power or generator power, (b) there is power but it is turned off – possibly intentionally, possibly not, or (c) there is grid power but the grid usage timer has told the system not to use it.

Since there is no power coming in, the system is neither float nor bulk charging and the loads are being powered by the batteries. The voltage will be lower than the fully charged battery voltage since there is no charging going on, and 49.2 VDC is a reasonable and healthy voltage to see at this point.

It is preferable to make these log entries just before starting the day's work in the lab, and just after ending the day's work. This will give a good idea as to how the system is operating in general.

9.3 BATTERY MAINTENANCE

Keeping the batteries working is the key to keeping the system working.

Suggestions for maintaining battery life are as follows:

- Do not discharge them more than 50%.
- Maintain the liquid level on the batteries.
- Keep the batteries clean.
- Perform an equalizing charge when necessary.

9.4 DEPTH OF DISCHARGE

To keep from discharging a battery too much, it is critical to (a) ensure that only the designed loads are connected to the system, and (b) the system is being charged regularly as designed.

9.4.1 Load Management

The battery system should be designed so that the batteries are never discharged more than 50%.. The job of the operator is to assure that only the equipment on the design sheet is plugged into the system, and this equipment is only used for the number of hours that the designer indicates. Therefore it is important that this list of loads and hours/day be posted on the site, in prominent view of the operator and lab technicians. A system designed to supply 4,000 watt hours a day simply will not have a chance if it is being asked to supply 8,000 watt hours a day.

9.4.2 Proper Charging

The designer would have determined what the charging cycle is. Normally, the batteries will either be in constant float (with a decent grid system) or used during the day and expected to be charged back up at night. Either way, the operator needs to be sure that the charging is taking place. If the loads are correct, but the charging is not happening, again, the batteries will not last long at all.

9.5 MAINTAIN THE LIQUID LEVEL ON THE BATTERIES

In most cases, Haitian facilities use the Trojan T-105 battery. This is a lead-acid, liquid filled battery. When it charges, water evaporates from the cells. When the water level gets down to the level of the top of the plates in the battery, air is able to reach the plates and this is detrimental. The batteries are constructed so there is a reservoir above the plates, but this must be checked frequently, and the cells topped off.

ONLY USE DISTILLED WATER. DO NOT USE REGULAR WATER, AND DO NOT ADD ACID.

Many people add acid solution that can be found in automotive stores. This is to be avoided. When the batteries are charging, and liquid is escaping, it is only the water that is escaping – not the acid. So, if acid is added, the specific gravity is changed (and therefore the entire chemical reaction) of the battery. It is recommended that only distilled water be added.

The liquid level on the batteries should be checked AT LEAST once/week. They may not need filling every week, but it is important to check them every week.

The operator should record in the log (a) when the batteries were checked for electrolyte level, and (b) whether or not distilled water was added, and if so how many liters.

9.6 KEEP THE BATTERIES CLEAN

The batteries should be cleaned at least once every week. They should be cleaned more often if they are excessively dirty at the weekly cleanings.

With dust and moisture on the batteries, current paths can set up between the terminals causing tracking, corrosion, and quicker discharge. Clean batteries last longer.

9.7 EQUALIZATION

Equalization is a process where the batteries are given an extra high voltage charge for a couple of hours. This is generally done once/month. During normal use, chemicals build up on the plates, and this high charge "boils" the batteries, knocking the chemicals down to the bottom of the battery.

Because of this "boiling" effect, more liquid will be lost during the equalization. The batteries should be assured to have sufficient electrolyte before the equalization charge, and then they will need to be topped off following the equalization cycle.

The equalization charge is started under menu item 2 on the control panel. Please refer to the Owner's Manual for additional information on the equalization process.

For additional information on Battery Maintenance, please refer to the Trojan brochure – "Deep Cycle Battery Maintenance", provided with this manual.

10.0 COMMON PROBLEMS

During field visit around Haiti, some common problems were noted that were causing the systems not to operate properly, if at all. It will be helpful to review these, to ensure that these problems are not repeated.

Just about all of the problems in these systems end up resulting in dead batteries, but they can be from a variety of causes.

10.1 POWER QUALITY PROBLEMS AND VOLTAGE WINDOW

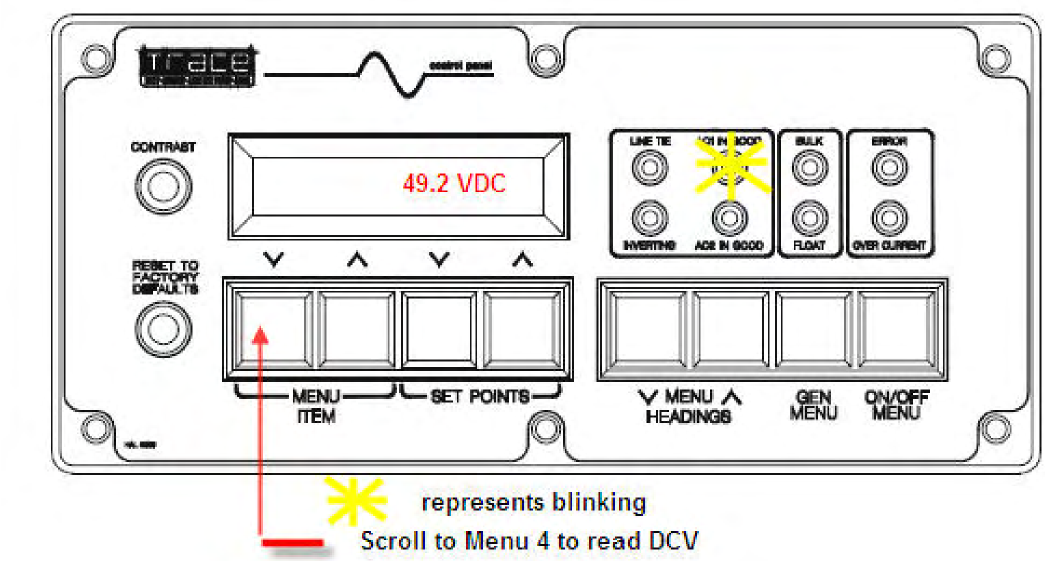
In many areas of Haiti, there were problems with low voltages. The SW equipment default “voltage window” is from a low of 108VAC to a high of 132 VAC. So, when the voltage dips below 108, the system disconnects.

If the system disconnects, then the loads are being powered by the batteries, and no charging takes place. If the grid power is below 108V almost all of the time, then the batteries never get charged.

An operator can see this from observing the LED lights on the control panel. If the system is designed to be connected to the grid all day (as opposed to disconnected during the day and connected during the night), then the normal state during the day would be similar to the first control panel picture above. The yellow AC IN (1 or 2) light would be on, and the system would be in either bulk or float charge.

If the operator expects the system to be on but it is not, the control panel observed is similar to the second picture. This shows no AC IN, and all power to the loads coming from the batteries.

If, however, the operator observes the following:



The blinking light on AC1 IN means that the system sees voltage present at AC 1 IN (from the grid), and is trying to synchronize with this voltage. If either the voltage or the frequency is out of range, the system can not connect.

Frequently, a cycle is observed, where the blinking light occurs for a while, and then goes solid, indicating that the system saw acceptable voltage and frequency and connects to the grid. Then, shortly after, the system disconnects from AC 1 IN and goes back into the invert mode. Then, a blinking light is observed again, indicating that the SW is trying to connect to the grid.

This indicates one of two things:

- It could be that the grid is fluctuating in and out of the acceptable voltage window.
- It could be that the very act of connecting to the grid CAUSES the voltage to drop.

In the first case, where the grid voltage is just lower than the window, the grid voltage needs to be monitored to assess the situation. If it is constantly at 100 to 105 Volts, or even 90 volts, and if the equipment is working satisfactorily at this voltage, the voltage window can be adjusted (as discussed under programming above – Menu item 11) to accept the grid voltage.

However, the second case is frequently witnessed– where the act of the SW connecting to the grid power CAUSED the low voltage. There are reasons for this.

The main reason for this is that the system is fed with wire that is too small, or too long or both. When voltage is measured at the end of a very long piece of wire with NO LOAD on it, an acceptable level of voltage drop can be measured. However, as soon as a load is put on to the wire, the voltage drop changes dramatically.

If for example, there is a long run of 2.5 mm2 cable feeding the AC IN terminals (this is not advised but was observed during field visits), then, under no load, the voltage reading may be acceptable – say 110V. However, as soon as the inverter locks onto the AC IN from the grid, it turns off the inverter and immediately attempts to (a) power the loads, and (b) power the battery charger. At the default programmed values for AC IN (60 amps) and charger current (30A), the load on the 2.5mm2 conductors could be as high as 60 amps. As soon as this load is placed on a long, small conductor the voltage will drop well below the 108V window and the system will disconnect.

When the load is disconnected, the system will now read an acceptable voltage, and try to connect again, simply continuing the cycle, never charging the batteries, and tending to burn up the cable feeding the system.

In this case, the solution is NOT to change the voltage window, but to change the conductors feeding the system.

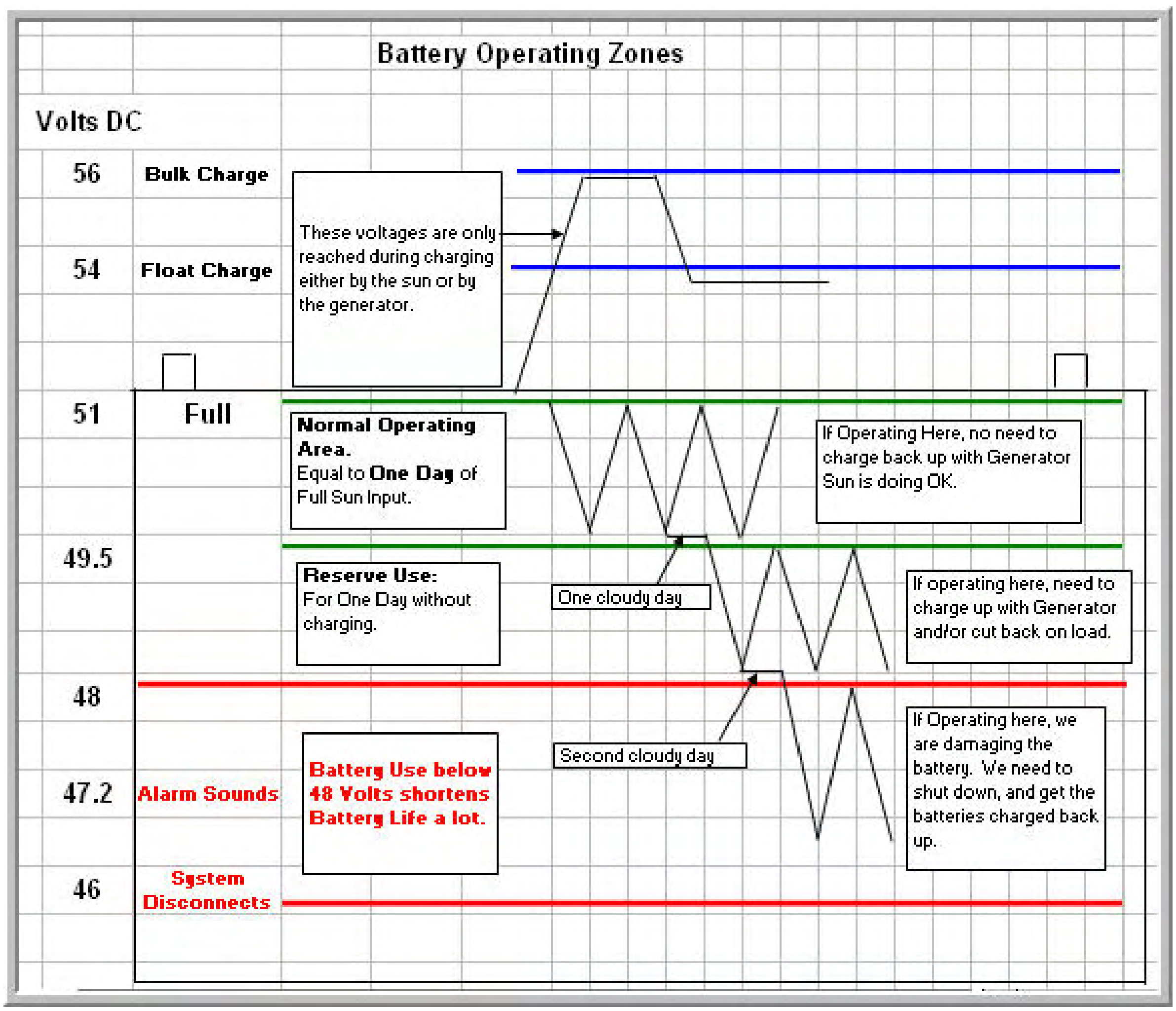
10.2 LOAD MANAGEMENT AND BATTERY MANAGEMENT

The operator's function is to ensure that the batteries stay healthy, and charged, and that the loads do not exceed the design loads.

In the section on programming, the manual states that the Low Battery Cut-Out voltage for the batteries should be raised from the factory default of 44 VDC to 46VDC. This will give the batteries a higher level of protection.

However, too often the systems are managed to where the batteries simply discharge to this low level, and then when the system comes back on after charging, the batteries are drained again to this low level and the system disconnects, and the cycle continues. This is detrimental for the batteries and can lead to battery failure. Even 46V is too low a voltage to be reaching on a daily or even weekly basis, and should be considered a cause for alarm that something is wrong with either the charging of the batteries or the load management.

Battery chart



The above graph assumes that the batteries are designed with an extra day of autonomy, meaning that if the grid (or other charging source such as PV) fails for an extra day, the system will continue to operate. The normal operating area is where we want to keep the battery, in this case above 48VDC, and if possible, above 49.5 VDC.

On a regular basis, full charging of the battery is needed. If the battery continues to operate in the zone between 48 and 49.5 VDC, it will never be charged fully and the life will be shorter.

If the voltage reaches 46VDC, (the newly programmed Low Battery Cut Out value), the system can be seriously damaged – particularly if this happens regularly.

Therefore, it is recommended that an alarm be added to the system to notify the operator when the system has reached a dangerous, but not disconnection, point. This point should be set around 47 or 47.2 volts DC.

In a typical alarm scenario, the relays provided on the SW equipment are used to trigger the alarm. The relays can be programmed when to turn the alarm on and when to turn it off. (These relays are often used for actually starting a backup generator.)

The way this works is that when the batteries reach this pre-determined value of, say 47.2 VDC, a loud horn and a light are energized indicating that the batteries need to be charged. The relay is programmed so that it does not disengage until the battery voltage is up to a level determined to be safe – usually around 51 or 52 volts.

The horn is energized through a timer, so the operator can disconnect the power to the horn, for up to 6 hours, while the system is being charged, but the light stays on. After 6 hours, if the batteries are not charged up, the horn sounds again, and can again be silenced.

This system is highly recommended, and gives a pre-warning to the operator and medical personnel alike that there is a problem that needs to be dealt with.

If the alarm is triggered, and there is no charging source (no grid, no generator), then the only answer is to NOT USE the loads until there is a charging source.

(By setting the alarm at 47 volts, there remains some emergency power available before LBCO in case there is a medical emergency during this time that the loads are turned off that requires a light or lab instrument.)

11.0 CONCLUSION

This manual is prepared to be used ALONG WITH the SW Owner's Manual, and is not a substitute for it. This manual is meant to address the most common problems observed in the field application, installation, and maintenance of these systems.

The following issues need to be addressed to ensure proper system operation:

- Design to match the application;
- Proper equipment and materials provided;
- Quality installation;
- Use of proper connection equipment – such as conductors, disconnect switches, circuit breakers, and information placards;
- Continuous – daily observation and record keeping;
- Regular battery maintenance; and
- Reporting of any abnormalities to designated technician at the Haiti National Lab.

Adherence to these practices will help assure that quality electrical support can be provided for health practitioners.

As a final note, this manual is centered on proper installation of the inverter / charger / equipment to provide continuous power to the laboratory equipment. There are times when this goal cannot be accomplished even with the best equipment installation practices and additional power quality enhancing equipment is required.