



samlexamerica®

**INVERTERS -
GENERAL
INFORMATION**

Excerpt from Inverter
Charger Series Manual

BY:
VIJAY SHARMA
ENGINEER

INVERTERS - GENERAL INFORMATION



INFO

Please read White Paper "Characteristics of Sine Wave AC Power" for understanding electrical parameters discussed in this section.

1.0 WHY AN INVERTER IS NEEDED?

The utility grid supplies you with alternating current (AC) electricity. AC is the standard form of electricity for anything that "plugs in" to the utility power. Direct current (DC) electricity flows in a single direction. Batteries provide DC electricity. AC alternates its direction many times per second. AC is used for grid service because it is more practical for long distance transmission.

An inverter converts DC battery power to AC power, and also changes the voltage. In other words, it is a power adapter. It allows a battery-based system to run conventional AC appliances directly or through conventional home wiring. There are ways to use DC directly, but for a modern lifestyle, you will need an inverter for the vast majority, if not all of your loads (in electrical terms, "loads" are devices that use electrical energy).

Incidentally, there is another type of inverter called "Grid-Interactive". It is used to feed solar energy (or other renewable energy like wind or hydro driven generators) into a grid-connected home and to feed excess energy back into the utility grid.



WARNING! This inverter is NOT "Grid Interactive".

2.0 INVERTER SHOULD MEET THE APPLICATION

To choose an inverter, you should first define your needs. Where is the inverter to be used? Inverters are available for use in buildings (including homes), for recreational vehicles, boats, and portable applications. Will it be connected to the utility grid in some way? Electrical conventions and safety standards differ for various applications, so don't improvise.

3.0 SELECTION OF BATTERY SYSTEM VOLTAGE

All conductors used in electrical devices resist the flow of electric current by varying degrees depending upon their electrical property called "Resistance". Flow of current through a resistance produces voltage drop and heat. The heat energy is wasted and contributes to the loss of efficiency. For a specified value of resistance, the heat loss is proportional to the square of the current e.g. 2 times increase of current produces 4 times heat dissipation. Hence, it is desirable to use conductors with the minimum possible resistance and also to reduce the value of current to reduce the loss of power due to heat dissipation. By increasing their size (area of cross-section) to practically permissible limits, the resistance of the conductors can be reduced.

Electrical power (e.g. DC power) is a product of the Voltage and the Current i.e. $\text{Power} = \text{Voltage} \times \text{Current}$. This equation shows that a particular value of power can be obtained by either increasing the current and reducing the voltage or by increasing the voltage and reducing the current. From the consideration of power loss due to the heating effect of current as explained above, it is desirable to consider higher Voltage and lower Current option.

In view of the above, a higher battery system voltage improves efficiency due to consumption of lower current resulting in lesser power dissipation inside the inverter and in the DC side wiring. Also, lower current at higher voltage will require smaller size of wiring which makes the system wiring cheaper and easier.

The DC input voltage of the inverter must conform to that of the DC electrical system / the battery bank. 12 Volts is recommended for small, simple systems. 24 and 48 Volts are the common standards for higher capacities.

4.0 ELECTRICAL STANDARDS

The inverter's AC output must conform to the conventional power in the region in order to run locally available appliances. The standard for residential / light commercial AC utility service in North America is Single Phase 120 VAC and Split 120 / 240 VAC at a frequency of 60 Hertz (cycles per second). In Europe, South America, and most other places, it is 230 volts at 50 Hertz.

INVERTERS - GENERAL INFORMATION

The rated output power (in Watts) of the inverters is normally specified for resistive type of loads that have unity (1) Power Factor. In a reactive type of load, the phase angle θ of the sine wave-form of the current drawn by the load may lead or lag the sine wave-form of the AC voltage source. In this case, the power factor of reactive loads is lower than unity (1) – generally between 0.8 and 0.6. A reactive load reduces the effective power that can be delivered by an AC power source.

5.0 SPECIFYING THE POWER RATING OF AN INVERTER

The Power Factor of an AC power source (like an inverter) that is supplying an AC load is controlled by the AC load and NOT by the AC power source. For example, a resistive load will have a Power Factor of 1, a motor load will have a Power Factor of 0.8, a non Power Factor Corrected Switched Mode Power Supply may have a Power Factor of 0.5 to 0.6 etc. Hence, the power rating of an AC power source should normally be specified as Apparent Power in Volt Amperes (VA) as this rating is not influenced by Power Factor as against specifying it in Active Power in Watts which is dependent on Power Factor.

Sometimes, the power rating of the inverter is designated as Active Power in Watts (W) at Power Factor = Unity (1). This rating will be equivalent to the Apparent Power Rating in VA (Because at Power Factor = unity (1), the Apparent Power = The Active Power).

If the power rating of the inverter has been designated as Active Power in Watts (W) and the Power Factor has not been indicated, it should be assumed as unity (1). Please note that in cases where the Power Factor is less than unity (1), the Apparent Power (VA) is higher than the Active Power (Watts) because the Apparent Power (VA) is the vectorial sum of the Active Power (Watts) and the Reactive Power (VAR). Instantaneously, the AC power source has to provide the total Apparent Power (VA) of the load and, therefore, should be sized based on the Apparent Power (VA) of the load and not on the Active Power (Watts) of the load.

If the power consumed by the load is designated as Active Power (Watts), it should be converted to the Apparent Power (VA) by dividing the Active Power (Watts) of the load by the Power Factor of the load. For example, a load rated at Active Power consumption of 600 W at Power Factor = 0.8 will require an Apparent Power of 750 W (Active Power of 600 W divided by Power Factor of 0.8 = Apparent Power of 750 Watts).

5.1 Power Rating – “Continuous” and “Surge”

How much load can an inverter handle? Its power output is normally rated in Watts. Read details under Section 2 titled “Characteristics of Sine Wave AC Power”. There are two levels of power rating - Continuous Rating and Surge Rating. Continuous means the amount of power the inverter can handle for an indefinite period of time. When an inverter is rated at a certain number of Watts, that number generally refers to its continuous rating. The “Surge Power Rating” indicates the power to handle instantaneous overload of a short duration to provide the higher power required to start certain type of devices and appliances. If the duration of the “Surge Power Rating” is not specified, it may be assumed to be < 1 sec.

5.2 Loads that require initial “Surge Power” to Start

Most loads have inrush currents that may be up to 3 to 10 times their steady-state currents. Therefore, the size of the inverter relative to its load is one of the most important considerations when sizing the power handling capacity of an inverter.

If an inverter cannot feed the surge power, it will get overloaded and may simply shut down instead of starting the device. If the inverter's surge capacity is marginal, its output voltage will dip during the surge. This can cause a dimming of the lights in the house, and will sometimes crash a computer. There is also a possibility of premature failure of the inverter and the load.



CAUTION!

Repeated overloading of under sized inverter when delivering high starting surge power may result in premature failure of the inverter and the load as follows:

- Drop in the output voltage of the inverter will force the load to draw even higher current to compensate for the voltage drop and this abnormally high current is likely to blow the input side fuses of the load and also damage the input section of the load.
- Higher current draw on the output side of the inverter will result in higher current draw from the battery. The DC input voltage fed from the battery will drop and the inverter will try to draw even higher current to compensate for the input side voltage drop. This cumulative effect of abnormally high DC input current is likely to blow the input side fuses of the inverter and at the same time damage the input section of the inverter.
- Any weakness in the battery and cabling to the inverter will further limit its ability to start high surge capacity loads. A battery bank that is undersized, in poor condition, or has corroded connections, can be a weak link in the power chain. The inverter cables and the battery interconnect cables must be sized properly. The spike of DC current through these cables is many hundreds of Amps at the instant of starting such loads.

INVERTERS - GENERAL INFORMATION

6.0 RESISTIVE LOADS – GENERAL INFORMATION

Resistive types of loads (like incandescent / halogen / quartz lamps, toaster, coffee maker, electric range, iron etc.) produce heat / emit light when electric current flows through them. Their power consumption (current drawn) is rated / specified at their operating (hot) condition. These loads are made up of resistive elements that have Positive Temperature Coefficient i.e. their resistance to the flow of current is lower when cold and rises with the rise of temperature. Hence, when resistive devices are initially powered on, the resistive element is cold, its resistance is lower and hence, it draws higher current. Within tens to hundreds of milliseconds, the element heats up, its resistance rises and the current consumption reduces to the lower value of the rated current.

6.1 Resistive loads - Heaters

Heater type of resistive loads use Nichrome resistance wire in their heating element (e.g. toaster, coffee maker, electric range, iron etc.). The Temperature Coefficient of Resistance of Nichrome is lower i.e. 0.0004 per °C. Hence, the resistance of the heating elements in these types of loads does not increase appreciably from their cold state at room temperature to the hot state of operation. Consequently, these types of loads will NOT draw higher surge current at startup

Resistive loads – Tungsten filaments used in heating elements in Laser Printers and Laboratory Equipment and in incandescent lamps used in General Lighting Service (GLS)

The following lighting and heating devices use Tungsten filament:

- Incandescent lamps used for General Lighting Service (GLS)
- Quartz lamps used for flood lighting
- Quartz lamps used in Laser Printers as heating elements in the heated in the Fuser Unit for fusing the toner ink
- Quartz lamps used in some laboratory equipment for heating purposes

The Tungsten filament heats up to red-hot condition to emit light / produce heat. Tungsten has a Positive Temperature Coefficient of .0045 per°C which is 10 times higher than that of Nichrome (as indicated above, Nichrome resistance wire is used in heating elements for toasters, coffee makers, electric ranges, irons etc.). The resistance of the Tungsten filament rises steeply due to rise in temperature. The electrical resistance of the Tungsten filament at room temperature is initially quite low which results in a very heavy inrush current on initial powering on of the above devices. The inrush current rapidly heats the filament and the resistance increases 5 to 10 times the cold resistance to reduce the current to its over rated value. However, the actual initial inrush current is generally limited to some smaller value of around 3 to 5 times by circuit reactance and is a function of the position on the AC wave at which the voltage is applied. The time for the initial inrush current to decay to the rated current is determined almost entirely by the thermal mass of the filament, and ranges from about 50 milliseconds in 15W lamps to about 400 milliseconds in 1500W lamps. Thus, for accommodating the initial surge power of the above types of loads, the inverter has to be oversized as follows:

- For powering incandescent lamps and Quartz lamps for flood lighting, the Surge Power rating of the inverter should be at least 6 times the Watt rating of the lamps
- **For powering Laser Printers and laboratory equipment using Quartz lamps, the Surge Power rating of the inverter should be at least 8 times the Watt / VA rating of the Laser Printer / laboratory equipment.** Laser Printers and laboratory equipment use Switched Mode Power Supplies (SMPS) and motors that require additional surge power to start. Hence, for these devices, the inverter has to be oversized additionally. **Fig. 1 shows a screen shot of oscilloscope with a recording of 6600 VA inrush power for a Laser Printer rated at 860 VA**

7.0 INDUCTIVE LOADS

7.1 Ratings and starting characteristics of AC induction motors

The output power of AC induction motors is normally rated in HP (Horse Power e.g. 1 / 3 HP, ½ HP, ¾ HP etc.) and it is the power available at the output shaft of the motor at the rated RPM. Mathematically, 1 HP = 746 Watts. Considering an average motor efficiency of 0.6, the input power required for delivering 1 HP at the output shaft of the motor = 1243 Watts (746 Watts ÷ 0.6 = 1243 Watts). At a Power Factor of 0.8, 1243 Watts = 1553 VA (1243 W ÷ 0.8 = 1553 VA). If 1 HP motor is operated at 120 VAC, the rated full load current will be 1553 VA ÷ 120 V = 12.9 A

The current drawn by an induction motor is a function of the rotor speed. The applied voltage creates a rotating magnetic field that forces the rotor to rotate at nearly the same speed(Full rated speed is slightly less than the speed of the rotating magnetic field and depends on how much torque the motor must produce to turn the load).When the rotor is rotating at the rated speed, the input current is minimum. The full load current drawn by the motor at the rated power and the rated speed is termed "Full Load Amperes (FLA)."

When the rotor is stopped, the input current is a maximum. This is because the turning rotor produces a back EMF that reduces the input current. If the rotor is not turning, there is no back EMF, and the input current is the highest. This current is referred to as the "Locked Rotor Amperes (LRA)" because it is the same current that would be drawn if the rotor were locked in place so it can't turn. The locked rotor current (LRA) can normally reach up to 5 times the full load current (FLA). The high locked rotor current (LRA) normally lasts till the motor achieves 80% of the rated RPM. For example, if 1 HP motor with a rated full load current of 10.4 A is operated at 120 VAC, the locked rotor current will be around 52 A!

7.2 AC induction motor driven loads with very high starting surge

AC induction motor driven loads that require starting against high back pressure / mechanical inertia like reciprocating pumps and compressors used in refrigeration, air-conditioning, Oxygen Concentrators etc. will initially require a very large additional starting surge current over and above

INVERTERS - GENERAL INFORMATION

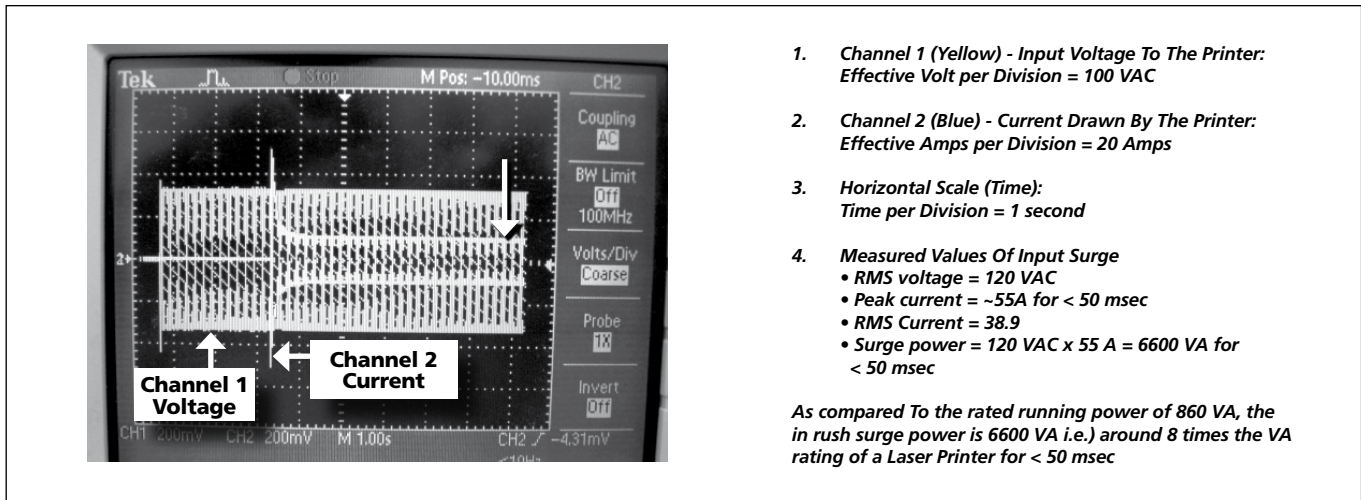


Fig 1: Very high inrush current on start up in a 860 VA Laser Printer

the Locked Rotor Current to start from rest. Once they have started moving and have attained their rated speed, their power requirement reduces to their normal rated running current. The starting RMS current surge in these devices may reach up to 5 times their normal RMS running current rating and the starting surge may last > 1 second. The reasons for higher starting surge current over and above the locked rotor current are as follows:

- The pumps and compressors use reciprocating pistons driven by a crankshaft. The crankshaft converts the rotary motion of the electric motor to "to and fro" linear motion of the pistons from the uppermost position (Top Dead Centre or TDC) to the bottom-most position (Bottom Dead Center or BDC). The piston reverses its direction of movement at the TDC and the BDC. If the position of the piston at rest (stopped condition of the pump / compressor) was just below the TDC or BDC, it will take much higher power to initially move the piston at the time of starting and consequently, will draw higher starting current.
- At the time of starting, the refrigeration and air-conditioning compressors may have to overcome residual elevated back-pressure in the condenser side if the compressor stops and starts within a very short time
- Pumps may have static pressure head that will be required to be overcome
- Well pumps that pump water into a pressurized water tank system will have to overcome the static water head as well as the pressure in the water tank
- Reciprocating pump compressors like air compressors with air storage tank and Oxygen Concentrators with oxygen storage tank will have to overcome the pressure in the storage tanks

8.0 CAPACITIVE LOADS

8.1 Switched Mode Power Supplies (SMPS)

Switched Mode Power Supplies (SMPS) are extensively used to convert the incoming AC power into various voltages like 3.3 V, 5 V, 12 V, 24 V etc. that are used to power various semi-conductor devices and circuits used in electronic equipment like battery chargers, computers, audio and video devices, radios etc.

These power supplies use large capacitors in their input section for filtration. When the power supply is first turned on, there is a very large inrush current drawn by the power supply as the input capacitors are charged (The capacitors act almost like a short circuit at the instant the power is turned on).The inrush current at turn on is several to tens of times larger than the rated RMS input current and lasts for a few milliseconds.

An example of the input voltage versus input current waveforms is given in Fig. 2, page 5. It will be seen that the initial input current pulse just after turn on is > 15 times larger than the steady state RMS current. The inrush dissipates in around 2 or 3 cycles i.e. in around 32 to 48 milliseconds for 60 Hz sine wave.

Further, due to the presence of high value of input filter capacitors, the current drawn by an SMPS (With no Power Factor correction) is not sinusoidal but non-linear as shown in Fig 3, page 5. The steady state input current of SMPS is a train of non-linear pulses instead of a sinusoidal wave. These pulses are two to four milliseconds duration each when on 60 Hz power, with a very high Crest Factor corresponding to peak values around three times the RMS value of the input current.

Many SMPS units incorporate "Inrush Current Limiting". The most common method is the NTC (Negative Temperature Coefficient) resistor. The NTC resistor has a high resistance when cold and a low resistance when hot. The NTC resistor is placed in series with the input to the power

INVERTERS - GENERAL INFORMATION

supply. The cold resistance limits the input current as the input capacitors charge up. The input current heats up the NTC and the resistance drops during normal operation. However, if the power supply is quickly turned off and back on, the NTC resistor will be hot so its low resistance state will not prevent an inrush current event.

The inverter should, therefore, be sized adequately to withstand the high inrush current and the high Crest Factor of the current drawn by the SMPS. Inverters are normally designed to withstand surge current of around 2 times their rated continuous current for < 1 sec. Hence, it is recommended that for purposes of sizing the inverter, the continuous rated power of the inverter should be > 3 times the continuous rated power of the SMPS. For example, an SMPS rated at 100 Watts should be powered from an inverter > 300 Watts.

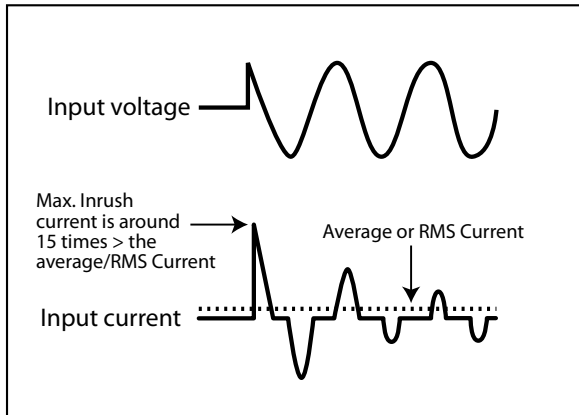


Fig 2: Inrush current in an SMPS

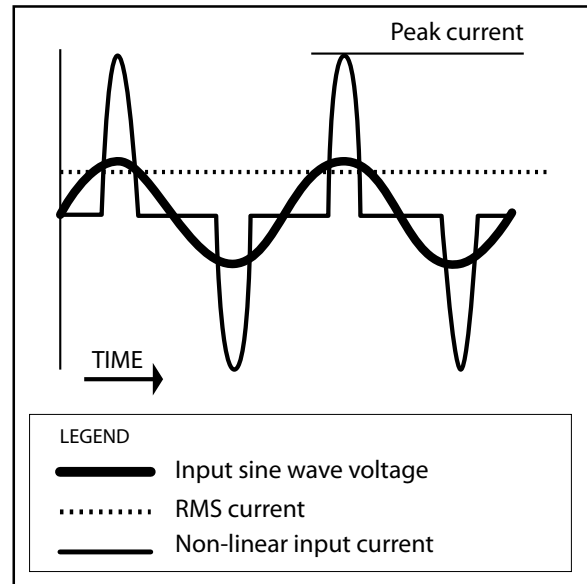


Fig 3: High Crest Factor of current drawn by SMPS

8.2 Photographic Flash / Strobe Lights

A strobe / flash unit basically consists of the following:

- A sealed glass tube lamp filled with Xenon gas that produces a high intensity burst of light when the gas is ionized due to very high voltage electrical energy fed across the ends of the tube.
- A bank of capacitors that store low voltage electrical energy that is rated in "Watt Sec". "Watt Sec" rating is an energy rating and it is obtained by multiplying the power in Watts by the time in Sec. Please note that the energy rating in "Watt Sec" is NOT the same as the power rating in "Watt".

For example: energy rating of 320 Watt Sec can mean 320 Watts of power for 1 Sec or 3200 Watts of power for 1 / 10 Sec or 32,000 W of power for 1 / 100 sec, etc.

- When the strobe / flash unit is triggered, this stored low voltage electrical energy in the capacitors is converted to a very short (around 1 / 1000 of a Sec) pulse of very high voltage energy and this high voltage energy is used to trigger the Xenon lamp
- The light output of the strobe / flash is measured in "Candle power Sec". The conversion of the electrical energy in "Watt Sec" to the light energy in "Candle power Sec" depends upon the efficiency of conversion of the particular strobe / flash unit.

An oscilloscope screen shot of re-charging current of a 250 Watt Sec strobe / flash unit when powered from 120 VAC utility power is shown in Fig.4).

It is seen that during re-charging, the current (power) drawn by the capacitors in the strobe / flash unit is in the form of very short duration pulses of around 1msec duration occurring 120 times per second (one pulse every 1/2 cycle of the 60 Hz sine wave).

The peak value of the current pulses is higher in the first 50 milliseconds and then reduces.

The peak current at startup is around 7 A and,

The power at this time is $120\text{ V} \times 7\text{ A} = 840\text{ W}$

Which is around 3.4 times the 250 Watt Sec rating of the Strobe Unit.

Hence, for sizing the inverter for powering these lights, the Surge Power Rating of the inverter should be more than 4 times the Watt Sec rating of the strobe / flash unit. For example, a 300 Watt Sec strobe / flash unit should be powered by an inverter that has a Surge Power rating of more than 1200 Watts

INVERTERS - GENERAL INFORMATION

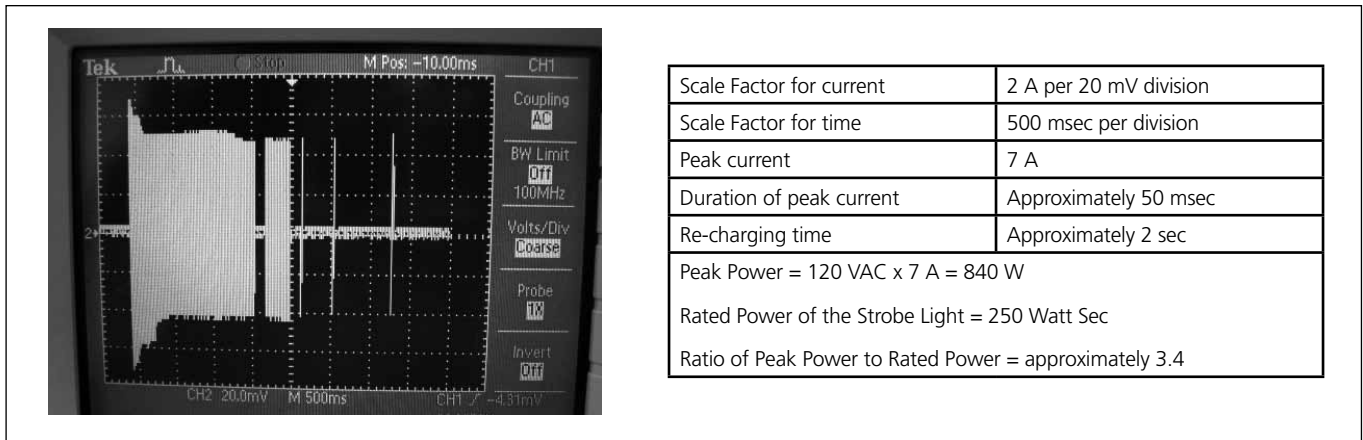


Fig 4: Screen shot showing recharging of 250 Watt Sec Strobe Unit

9.0 POWER RATING OF MICROWAVES

The power rating of the microwave generally refers to the cooking power. The electrical power consumed by the microwave will be approximately 2 times the cooking power. The power rating of the inverter should, therefore, be more than 2 times the cooking power of the microwave. For example, a microwave rated at a cooking power of 800 Watts should be powered from an inverter rated >1600 Watts.

10. POWERING A WATER SUPPLY PUMP

A water well or pressure pump often places the greatest demand on the inverter. It warrants special consideration. Most pumps draw a very high surge of current during start up. The inverter must have sufficient surge capacity to handle it while running any other loads that may be on. It is important to size an inverter sufficiently, especially to handle the starting surge (If the exact starting rating is not available, the starting surge can be taken as 3 times the normal running rating of the pump). Oversize it still further if you want it to start the pump without causing lights to dim or blink. In North America, most pumps (especially submersibles) run on 240 VAC, while smaller appliances and lights use 120 VAC.

To obtain 240 VAC from a 120 VAC inverter, use a 120 VAC to 240 VAC transformer. If you do not already have a pump installed, you can get a 120 Volt pump if you don't need more than 1 / 2 HP.

11. SIZING CHART FOR TYPICAL LOADS THAT REQUIRE HIGH STARTING SURGE

The manufacturers' specification for power rating of the appliances and devices indicates only the running power required. The surge power required by some specific types of devices as explained above has to be determined by actual testing or by checking with the manufacturer. This may not be possible in all cases and hence, can be guessed at best based on some thumb rules

The Surge Power Rating of inverters is normally specified as 2 times their Continuous Power Rating. In a majority of the cases, the time period for sustaining the Surge Power is not specified and should be assumed to be less than 100 milliseconds. As the duration of the Surge Power Rating is very short and is normally not specified, this rating should not be considered for sizing purposes. Only the Continuous Power Rating should be considered for sizing of the inverter

Table 1, page 6 lists some common loads that require high surge power on start up. A "Sizing Factor" has been recommended against each which is a multiplication factor to be applied to the rated running Watt rating of the load to arrive at the Continuous Power Rating of the inverter (Multiply the running Watts of the device / appliance by the Sizing Factor to arrive at the size of the inverter).

12. IDLE POWER / SELF CONSUMPTION / POWER SAVE

Idle power / self-consumption is the consumption of the inverter when it is on, but no loads are running. It is "wasted" power, so if you expect the inverter to be on for many hours during which there is very little load (as in most residential situations), you want this to be as low as possible. Some inverters have a Power Save option where the inverter outputs momentary full power of a few cycles every 3 to 5 sec (generally 1 cycle of around 16 ms {for 60 Hz} output).

13. PHANTOM AND IDLING LOADS

Most of the modern gadgets draw some power whenever they are plugged in. Some of them use power to do nothing at all. An example is a TV with a remote control. Its electric eye system is on day and night, watching for your signal to turn the screen on. Every appliance with an external wall-plug transformer uses power even when the appliance is turned off. These little loads are called "phantom loads" because their power draw

INVERTERS - GENERAL INFORMATION

is unexpected, unseen, and easily forgotten. A similar concern is “idling loads.” These are devices that must be on all the time in order to function when needed. These include smoke detectors, alarm systems, motion detector lights, fax machines, and answering machines. Central heating systems have a transformer in their thermostat circuit that stays on all the time. Cordless (rechargeable) appliances draw power even after their batteries reach a full charge. If in doubt, feel the device. If it’s warm, that indicates wasted energy.

TABLE 1 SIZING FACTOR FOR A/C DEVICES	
Type of Device or Appliance	Sizing Factor*
Air conditioner	5
Refrigerator / Freezer (Compressor based)	5
Air Compressor	4
Sump Pump / Well Pump / Submersible Pump	3
Dishwasher	3
Clothes Washer	3
Microwave (In cases where the rated output power is the cooking power)	2
Furnace Fan	3
Industrial Motor	3
Portable Kerosene / Diesel Fuel Heater	3
Circular Saw	3
Bench Grinder	3
Incandescent / Halogen / Quartz Lamps	3
Laser Printer / Other Devices using Quartz Lamps for heating	4
Switched Mode Power Supplies	3
Photographic Strobe / Flash Lights	4 @
* (Multiply the Running Power Rating {Watts} of the appliance by this Factor to arrive at the Continuous Power Rating of the inverter for powering this appliance)	
@ In the case of photographic strobe / flash unit, the surge power of the inverter should be more than 4 times the Watt Sec rating of the unit	

For more information, visit: www.samlexamerica.com