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# The DC/AC Inverter

## Introduction, analysis and experiment to determine its efficiency

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The DC/AC inverter

## Introduction

An inverter changes DC voltage into AC voltage so that it can be used by common appliances. DC is usable for some small appliances; however, nearly all larger home systems should include an inverter.

An inverter takes the DC input and directs it into power switching transistors. By rapidly turning these transistors on and off, and feeding opposite sides of a transformer, it makes the transformer recognize it as AC. The transformer changes this 12, 24, or 48 volts "alternating DC" into 115 volts AC at the output.

## Nominal Power

The nominal power is the maximum power that can be supplied continuously by the inverter. It is the power at which the inerter should operate in order to have the maximum efficiency. The total power of the appliances connected should never exceed the nominal power. The nominal power of the Solarix 550 RI (at $30^o$ C) is 550 W. The continuous nominal power of the appliance will decrease as the temperature rises above 30°C.

## Type of Inverter

Depending on the quality and complexity of the inverter, it may put out a square wave, a "quasi-sine" (sometimes called modified sine) wave, or a true sine wave.

Square Wave

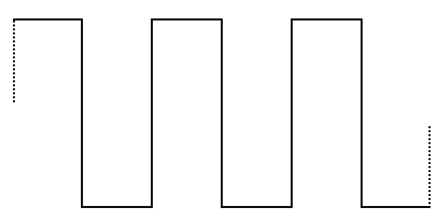


Fig. 1 – Square Wave

Application

Square wave inverters are largely obsolete, as the waveform shape is not well suited for running most modern appliances, and prices have come down considerably for the superior modified sine wave and true sine wave types.

Square wave inverters are usually only suitable for running some types of electrical tools and universal motors.

Modified Sine Wave (Quasi-sine wave)

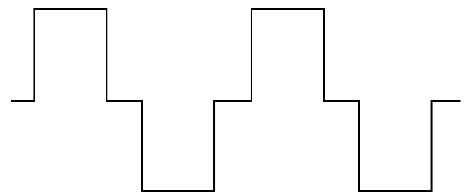


Fig. 2 – Modified Sine Wave

A modified sine wave inverter actually has a waveform more like a square wave, but with an extra step or so.

<u>Applications</u>

It is suitable for most standard appliances, but may not work well with some electronics.

- Motors, such as refrigerator motor, pumps, fans etc will use more power from the inverter due to lower efficiency. Most motors will use about 20% more power. This is because a fair percentage of a modified sine wave is higher frequencies - that is, not 60 Hz - so the motors cannot use it.
- Some fluorescent lights will not operate quite as bright, and some may buzz or make annoying humming noises.
- Appliances with electronic timers and/or digital clocks will often not operate correctly. Many appliances get their timing from the line power - basically, they take the 60 Hz (cycles per second) and divide it down to 1 per second or whatever is needed. Because the modified sine wave is noisier and rougher than a pure sine wave, clocks and timers may run faster or not work at all. They also have some parts of the wave that are not 60 Hz, which can make clocks run fast.
- Items such as bread makers and light dimmers may not work at all - in many cases appliances that use electronic temperature controls will not control. The most common is on such things as variable speed drills will only have two speeds - on and off.

<u>Sine Wave (True sine wave)</u>

Sine wave inverters use Pulse Width Modulation and average filtering to produce the true sine wave.

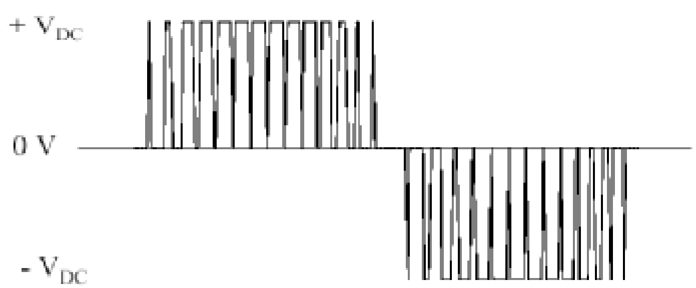



Fig.3 – Pulse Width Modulated Wave

A sine wave is what you get from your local utility company and (usually) from a generator. This is because it is generated by rotating AC machinery and sine waves are a natural product of rotating AC machinery. Sine wave inverters put out a wave that is better and cleaner. Sine wave inverters can run anything, but are also more expensive than other types.

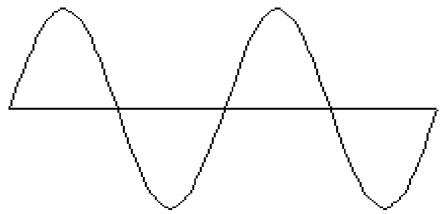


Fig. 4 – Sine Wave

Applications

- The major advantage of a sine wave inverter is that all of the equipment which is sold on the market is designed for a sine wave. This guarantees that the equipment will work to its full specifications.
- Some appliances, such as motors and microwave ovens will only produce full output with sine wave power.
- A few appliances, such as bread makers, light dimmers, and soe battery chargers require a sine wave to work at all.

The Solarix 550 RI is a powerful stand-alone inverter with genuine sinusoidal voltage output for a trouble-free operation even of sensitive appliances (hi-fi equipment, TV sets, computers).

The Solarix 550 RI stand-alone inverter supplies 230V / 50 Hz or 115V / 60Hz sinusoidal alternation voltage, capable of operating all common consumers requiring power up to 550 W:
- tools, such as drilling machines, piercing saws, orbital sanders
- household appliances
- entertainment electronics, such as TV sets, hi-fi equipment
- energy saving-, incandescent and fluorescent lamps
- refrigerators
- pumps and motors

**Distortion**

Inverters with a modified sine wave output have a harmonic distortion of around 40%. Due to the wave form and high harmonic distortion some motors will consume more power on a modified sine wave. The result is more noise, heat and energy losses. This is not usually a problem if this type of wave form is only being used for brief and infrequent backup power. However, for continuous year-around use, a motor running hotter will have a shortened expected life. You may even hear a distinct hum when running on modified sine wave power.

For a true sine wave inverter the total harmonic distortion is around 3%. This distortion is so small it is nearly identical to a pure sine wave.

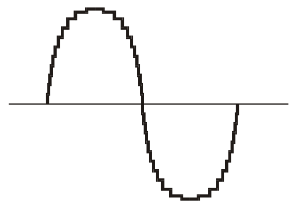


Fig. 5 – A stepped-sine wave – this diagram helps illustrate the shape of the distortion, although in reality the distortion of a true sine wave is much smaller.

The Solarix 550 RI is said to produce a true sine-wave signal almost without harmonics. Due to its genuine sinusoidal output, the stand-alone inverter ensures a trouble-free and efficient operation even of sensitive appliances. There will always be some degree of error, so we can assume that the sine-wave is not quite perfect, and therefore some distortion will be found in the output readings, but it is negligible.

**Surge Capacity**

This is the maximum wattage the inverter can output on a momentary basis. This means that the inverter will handle an *overload* of that many watts for a short period of time. This surge capacity will vary considerably between inverters, and different types of inverters. It may range from as little as 20% to as much s 300%. Generally, a 3 to 15 second surge rating is enough to cover 99% of all appliances - the motor in a pump may actually surge for only 1/2 second or so. To start critical loads the Solarix 550 RI stand-alone inverter is capable of temporarily producing the triple of its nominal power.

This is important as all appliances require more power to start than they use while running. Many appliances, such as refrigerators and water pumps, will require up to three times as much power to start as they require while running. The combined starting power required by all inverter powered appliances must be within the inverter's surge capacity rating.

**Characteristics of Performance of the FRONIUS DC/AC of the laboratory**

An experiment was carried out to study the performance of the inverter. For the experiment, the following equipment was used: ammeters, voltmeters, light bulbs as the power loads, and a battery as the power supply.

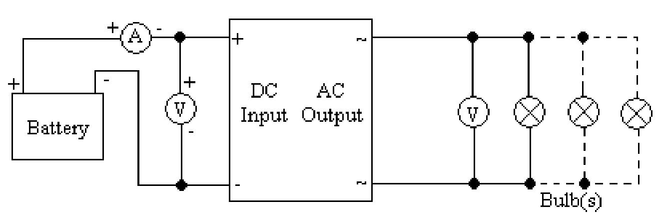



Fig. 6 – The set-up of the experiment to check the efficiency of the inverter

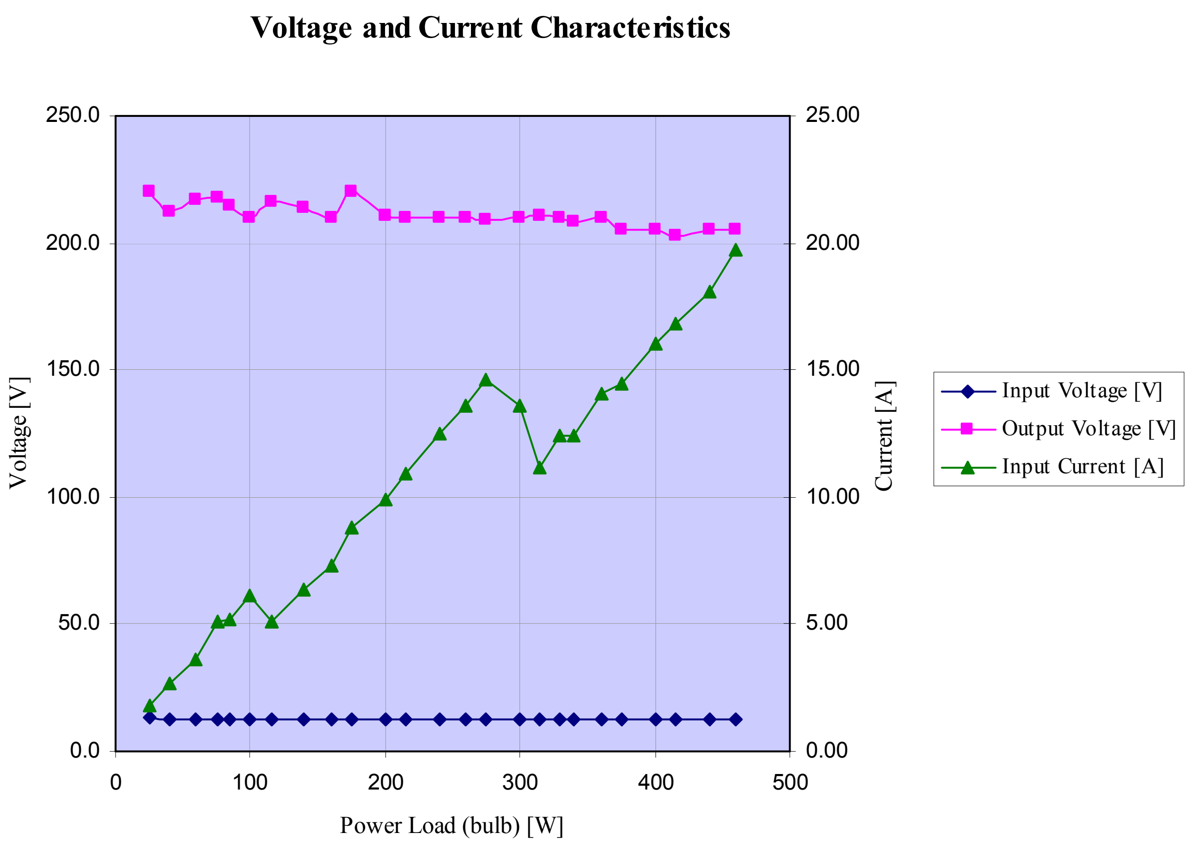



Fig. 7 – Voltage/Current characteristics of the AC/DC inverter according to experimental results

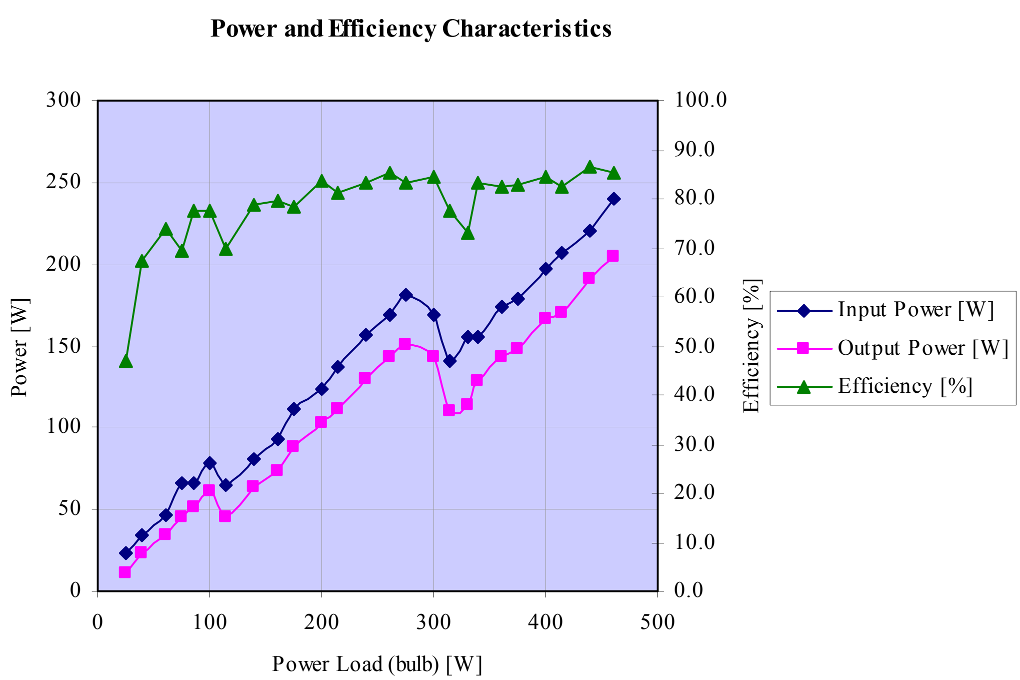
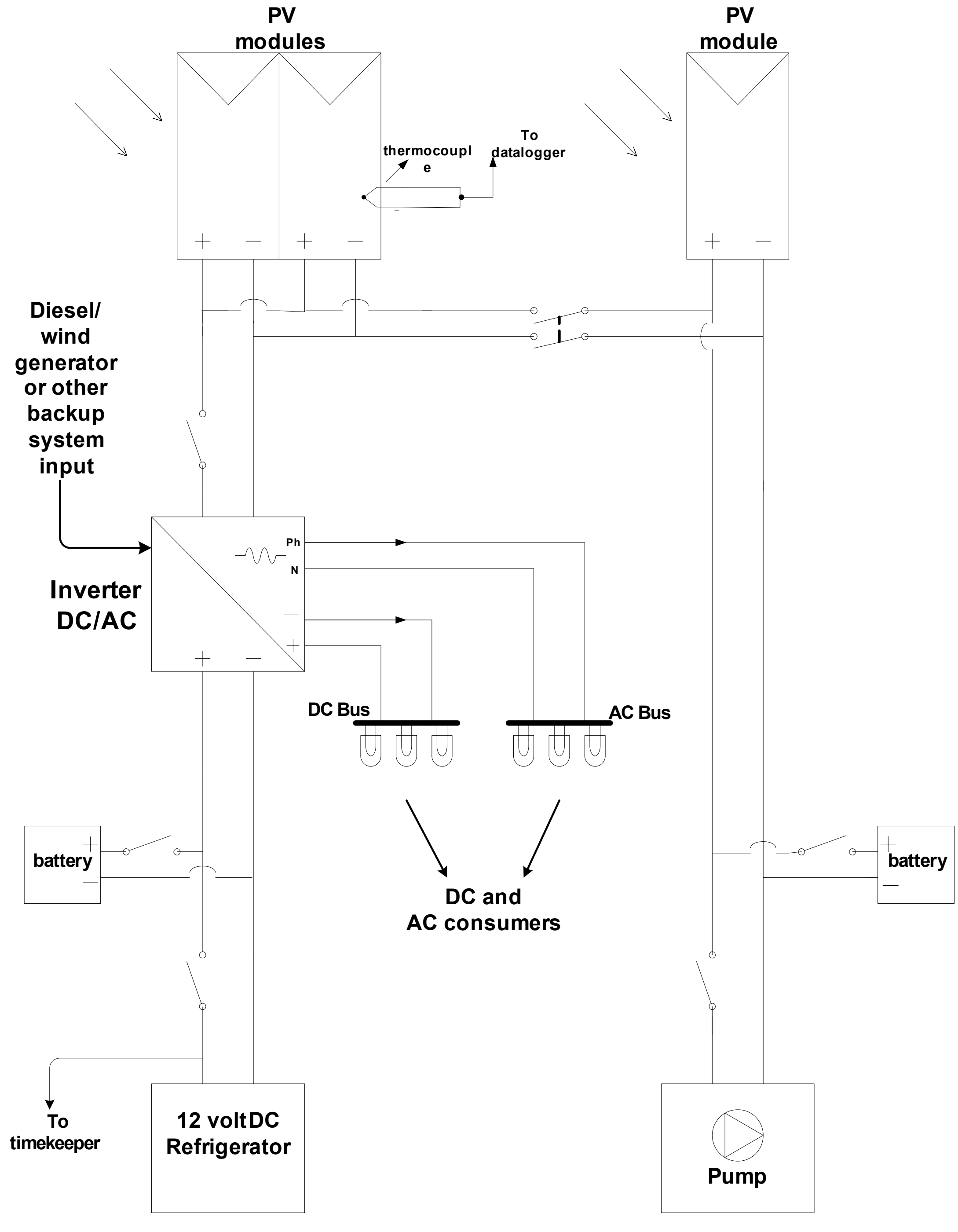



Fig. 8 – Power and Efficiency characteristics of the AC/DC inverter according to experimental results (Where $\mathbf{P_{IN} = I_{IN} V_{IN}}$, $\mathbf{P_{OUT} = I_{OUT} V_{OUT}}$ and $\mathbf{\eta_{INV} = P_{OUT} / P_{IN}}$. )

**How the DC/AC inverter is linked to the circuitry**



**Efficiency**

The efficiency of an inverter is related to how well it converts the DC voltage into AC. This usually ranges from 85% to 95%.

The overall efficiency of the system depends on the efficiency of the SUNLIGHT-into-DC and the DC-into-AC conversion efficiencies.

**The efficiency of the inverter varies with the load level** – the two are related by the function $\boldsymbol{\eta} = \mathbf{a+be^{-cx}}$, where $\mathbf{x} = \mathbf{P_L}$. This relation is varied for each inverter, but a conventional model has a load/efficiency curve similar to the one shown below. Therefore, a key consideration in the design and operation of inverters is how to achieve high efficiency with varying power output.

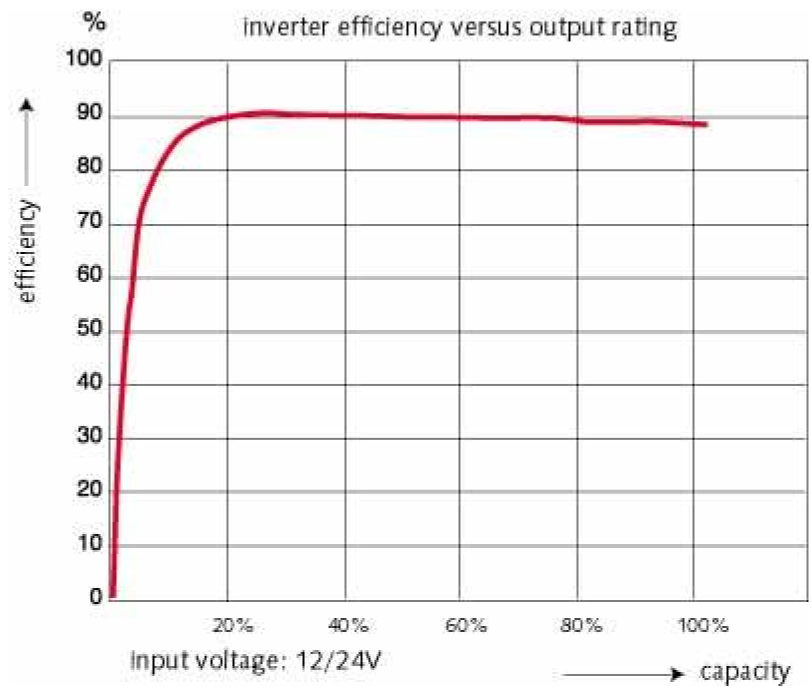



Fig. 9 – A model of the conventional load/efficiency characteristics of an AC/DC inverter (see http://www.mastervolt.com/inverter/index.asp)

It is necessary to maintain the inverter at or near full load in order to operate in the high-efficiency region. However, this is not possible. Some installations would never reach their rated power due to deficient tilt, orientation or irradiation in the region. There are some suggested simple design options that can improve conversion performance.

**Most of the installed grid connected PV systems use a single inverter with a nominal input power at least equal to the installed PV peak power.** Below are two design options in order to increase DC - AC conversion efficiency:

1. **Multiple inverters** of the same rating to cover the full range of power levels with better inverter saturation.

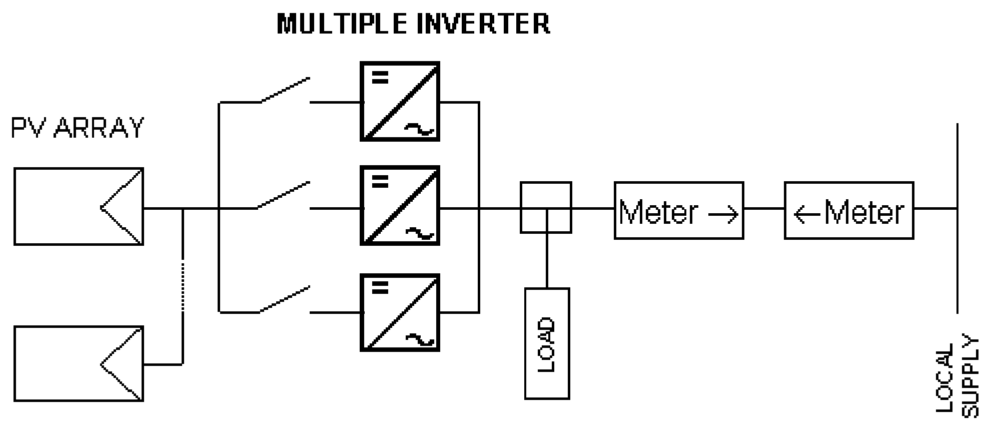



Fig. 10 - Grid Connected PV System with Multiple Inverter.
(see http://www.mastervolt.com/inverter/index.asp)

2. **Sizing** of the inverter with respect to the installed PV peak power, losing some energy in peak generation and increasing efficiency in low power levels.

Modern electronic inverters are very efficient over a wide range of outputs, but some power is required simply to keep the inverter running (the standing losses) and they are less efficient when running small loads.

Consequently, sizing the inverter for its required purpose is extremely important.

- If it is undersized, then there will not be enough power - demanding more than their limit will shut them off.
- If it is oversized, it will be much less efficient (due to the standing losses) and more costly to buy and run.

In inverter sizing the most important factor is peak power consumption: the peak power demand should not exceed the rated peak output of the inverter.

This is difficult when it is possible for many devices to consume power at the same time, and is further complicated by any electric motors in the system.

Some types of electric motors require three times as much power to start them as is required to run them. If two or more motors are started at the same time the surge power demand is much higher than the average demand. Consequently, the inverter should be sized to be able to at least start the largest motor in the system and measures taken to ensure that all motors do not start at the same time.

Proper energy management can reduce peak demand, and so the inverter can be sized closer to the average power demand, thereby increasing the system's efficiency and reducing hardware costs.

A load seeking circuit is normally included to ensure that battery power is conserved for useful purposes by automatically switching the inverter on and off as loads are applied or discontinued.

The inverter selected for this experiment is the Solarix 550 RI. It is an efficient sine wave inverter integrated with a solar charge controller. This one has been chosen as it is the appropriate solution for a 230V (actually 220V +/- 10%) stand-alone systems.

| Efficiency ($\eta_{\%}$) = Average Power Output ($P_{OUT}$) / Average Power Input ($P_{IN}$) x 100 |
|---|

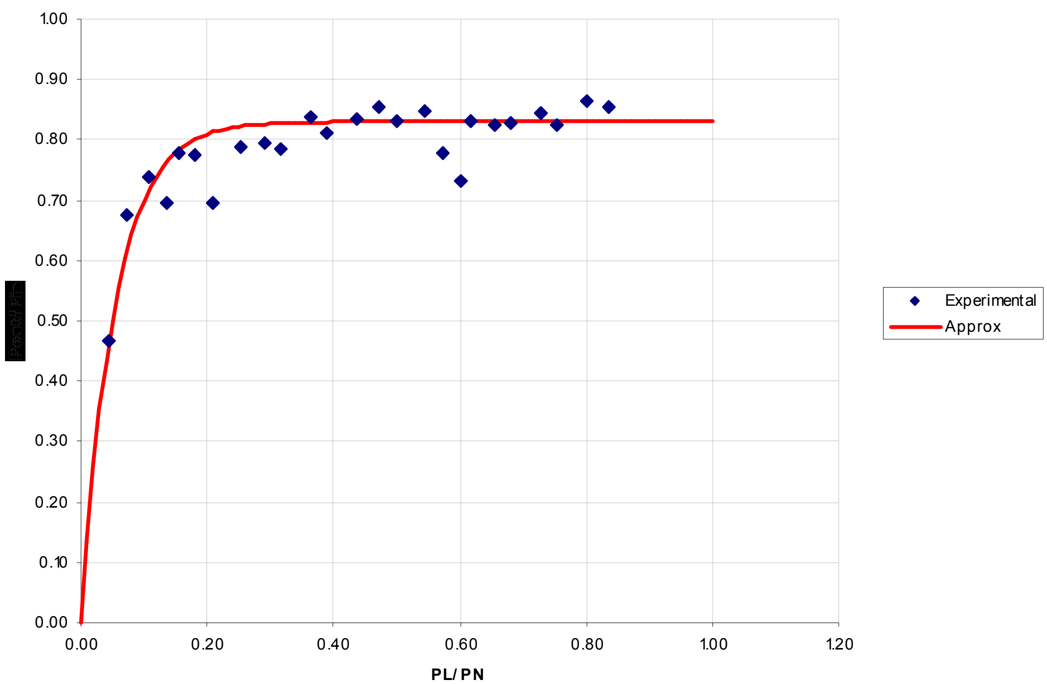



Fig. 11 – The efficiency curve (showing the load/efficiency characteristics) of the AC/DC inverter – both the efficiency found experimentally, and an approximation of the efficiency curve based on both experimental data and theory.

The theoretical efficiency curve (line of best fit) has been found by applying the function: $\mathbf{y = a + be^{-cx}}$, where y is the approximated efficiency of the inverter and $\mathbf{x = P_L/P_N}$.

By fitting this line to both the experiment and theory, the following approximation has been made: $\eta_{inv} = 0.83 + 0.83^{-18.5}$.

To ensure the usage of the Solarix is at maximum efficiency, the capacity of the battery used should be at least 200 Ah (we have around 600 Ah); otherwise problems may occur when starting motors, pumps or refrigerators.

**Modes of operation of this FRONIUS type**

Three different operating modes are available for the Solarix which ensures a trouble-free and reliable power supply to every type of appliances on one hand and a careful utilisation and economic administration of the battery power on the other hand.

Stand-By Mode (Load Recognition)

Stand-by mode is mainly used in such cases where consumers are switched on only temporarily and no current is required in the meantime. In this mode the Solarix periodically emits a test pulse to the output. As soon as a consumer with a power consumption above 5-25 W (depending on the type of consumer) is connected to the output the Solarix changes to continuous operation. Once the consumer is disconnected the Solarix changes back to stand-by mode. In stand-by mode the power consumption is reduced to less than 60 mA.

Continuous Mode

230 V AC are continuously present at the AC output. Power is reliably supplied to all consumers connected.

Sleep Mode

If no AC voltage is required for an extended period of time the Solarix should be switched to sleep mode. In sleep mode the power consumption is reduced to about 20 mA for the Solarix 550 RI. No voltage is present at the AC output which ensures careful utilization of the battery power.

**How to choose the type/Power of a DC/AC**

Inverters come in size ratings all the way from 50 watts up to 50,000 watts, although units larger than 11,000 watts are very seldom used in household or other PV systems. The first thing you have to know about your inverter is what will be the maximum surge, and for how long.

The inverter's output capacity must be matched to the size of the electrical loads it will run. The total power of the appliances connected should never exceed the nominal power.

Each appliance has a nameplate that lists its amperage or wattage rating. Calculate the wattage ratings of all of the appliances you plan to operate and then select an inverter with a rating equal to or greater than your total wattage rating. (Appliances with electric induction motors require approximately 2-3 times their nameplate wattage when starting).

**Various Configurations of an inverter with an extra back up system**

In photovoltaic applications, inverters can be connected in either a grid-connection or a stand-alone system.

A stand-alone installation is a PV installation for providing an autonomous power supply in situations where there is no connection to the public electricity network. In stand-alone installations, the electricity is stored in batteries. A special charge controller regulates the energy from the solar modules so as to ensure optimum charging of the batteries. In simple installations, the power is drawn directly from the battery by DC consumers, while on installations with normal AC consumers the battery voltage is converted by an inverter.

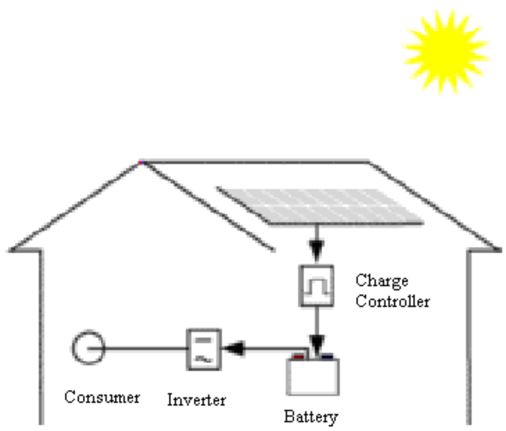



Fig. 12 - Scheme of a stand-alone installation

Grid-connected installations are connected to the utility transmission grid and work like a small power plant. In grid-connected installations, DC - generated in the modules - is converted into AC by a special inverter. The entire installation is controlled and monitored by the inverter, and feeding the grid is fully automated.

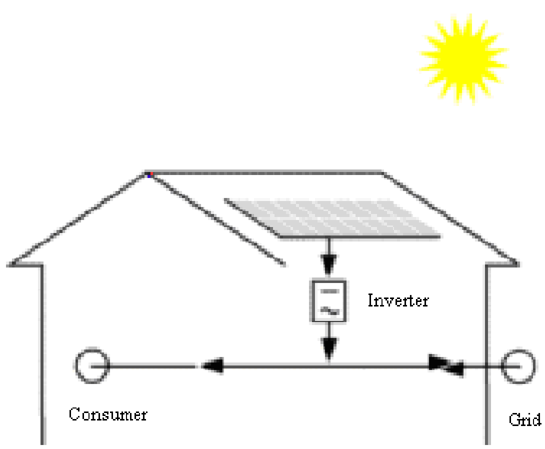



Fig. 13 - Scheme of a grid-connected installation

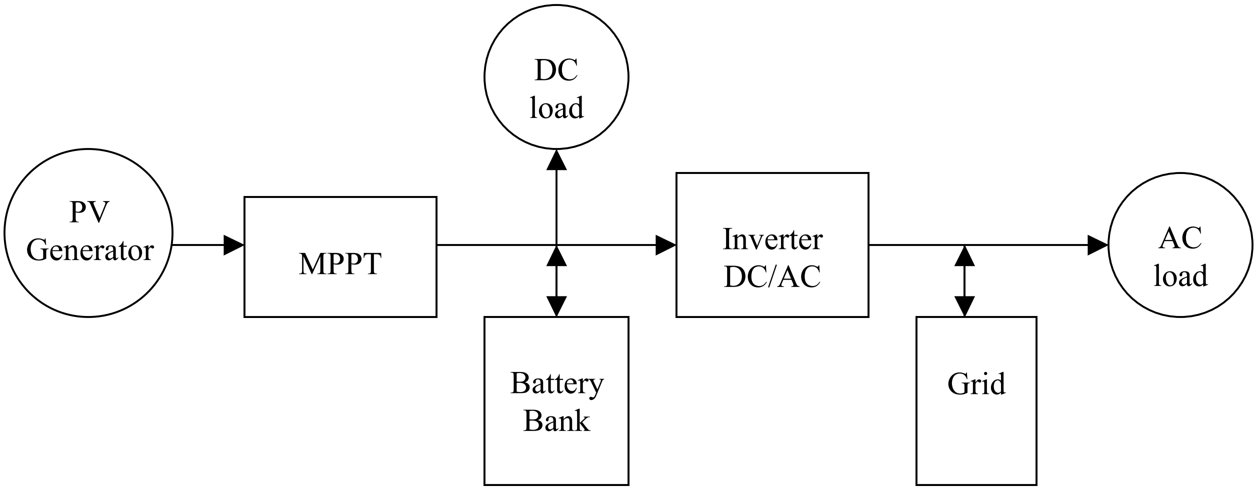



Fig. 14 - A PV-generator linked to a MPPT to meet both the DC and AC loads via a DC/AC inverter. (see Technology of PV-Systems and Applications – Prof. Dr. S. Kaplanis)

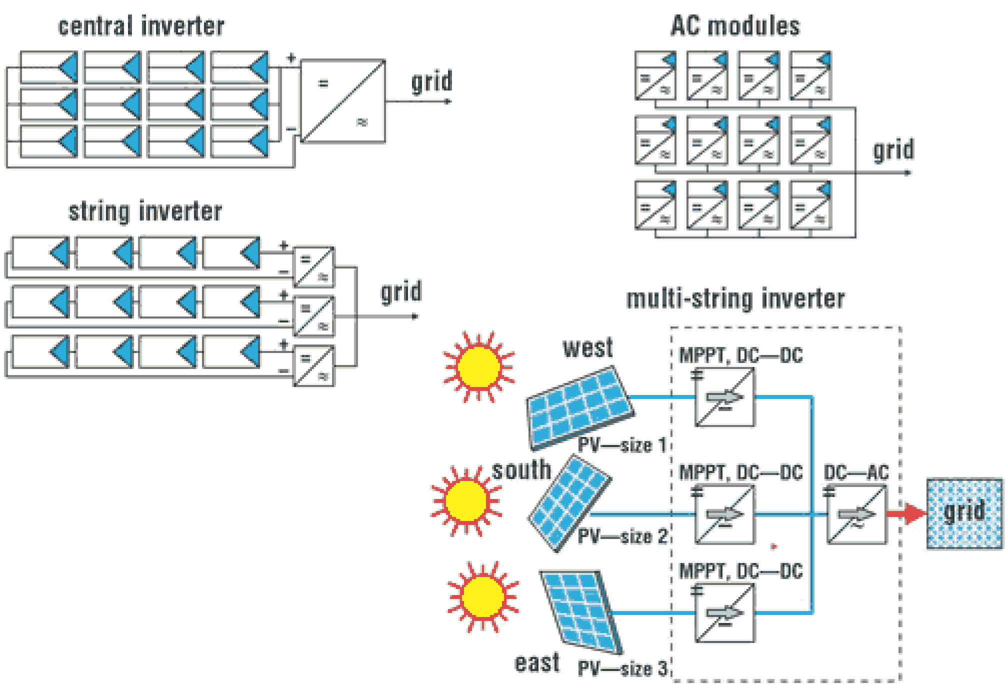



Fig. 15 – Basic design concepts for PV installations - central, string, multi-string or AC module inverters (see http://www.jxj.com/magsandj/rew/2004_02/inverter.html)

**Appendix 1**: Technical Data for the Solarix 550 RI inverter

| | **Solarix 550 RI** |
|---|---|
| Output voltage | 220 V +/- 10% |
| Output current frequency | 50 Hz, optional 60 Hz |
| Nominal power | 550 W |
| Surge power (AC) | 300 % |
| Waveform | pure sine wave |
| AC Operation modes | on / load detection / off |
| Own consumption | 430 mA / 50 mA / 15 mA |
| Battery voltage nom. | 12 V |
| Battery current nom. | 46 A (Inverter)<br>+ 15 A (DC-load) |
| Module current nom. | 25 A |
| DC load current nom. | 15 A |
| Charge method | IU |
| Display | LED/ RI versions additional 16 char. LCD |
| DC connection | integrated terminal block $16mm^2$ |
| AC connection | rubber connector included |
| Inverse polarity protection | changeable automotive fuse |
| Dimension l x w x h (mm) | 320 x 244 x 120 |
| Installation | table / wall mounting |
| Weight | 5,5 kg |
| Degree of protection | IP 20 |
| Cooling | temperature controlled fan |
| Ambient temperature | -15 ÷ +45°C |
| Battery supervision | AtonIC SOC calculation |

**Appendix 2**: Table of Results from the efficiency experiment

| $P_L$ | $I_{IN}$ | $V_{IN}$ | $P_{IN}$ | $I_{OUT}$ | $V_{OUT}$ | $P_{OUT}$ | $P_{out}/P_{in}$ | ↑ ⇨↖⇨ | $P_{out}/P_n$ | PL/Pn |
|---|---|---|---|---|---|---|---|---|---|---|
| 460 | 19.70 | 12.2 | 240.3 | 1.00 | 205 | 205.0 | 0.85 | 85.3 | 0.37 | 0.84 |
| 440 | 18.10 | 12.2 | 220.8 | 0.93 | 205 | 190.7 | 0.86 | 86.3 | 0.35 | 0.80 |
| 415 | 16.80 | 12.3 | 206.6 | 0.84 | 203 | 170.5 | 0.83 | 82.5 | 0.31 | 0.75 |
| 400 | 16.00 | 12.3 | 196.8 | 0.81 | 205 | 166.1 | 0.84 | 84.4 | 0.30 | 0.73 |
| 375 | 14.50 | 12.3 | 178.4 | 0.72 | 205 | 147.6 | 0.83 | 82.8 | 0.27 | 0.68 |
| 360 | 14.10 | 12.3 | 173.4 | 0.68 | 210 | 142.8 | 0.82 | 82.3 | 0.26 | 0.65 |
| 340 | 12.40 | 12.5 | 155.0 | 0.62 | 208 | 129.0 | 0.83 | 83.2 | 0.23 | 0.62 |
| 330 | 12.40 | 12.5 | 155.0 | 0.54 | 210 | 113.4 | 0.73 | 73.2 | 0.21 | 0.60 |
| 315 | 11.20 | 12.6 | 141.1 | 0.52 | 211 | 109.7 | 0.78 | 77.7 | 0.20 | 0.57 |
| 300 | 13.60 | 12.4 | 168.6 | 0.68 | 210 | 142.8 | 0.85 | 84.7 | 0.26 | 0.55 |
| 275 | 14.60 | 12.4 | 181.0 | 0.72 | 209 | 150.5 | 0.83 | 83.1 | 0.27 | 0.50 |
| 260 | 13.60 | 12.4 | 168.6 | 0.69 | 210 | 143.9 | 0.85 | 85.3 | 0.26 | 0.47 |
| 240 | 12.50 | 12.5 | 156.3 | 0.62 | 210 | 130.2 | 0.83 | 83.3 | 0.24 | 0.44 |
| 215 | 10.90 | 12.6 | 137.3 | 0.53 | 210 | 111.3 | 0.81 | 81.0 | 0.20 | 0.39 |
| 200 | 9.88 | 12.5 | 123.5 | 0.49 | 211 | 103.4 | 0.84 | 83.7 | 0.19 | 0.36 |
| 175 | 8.82 | 12.7 | 112.0 | 0.40 | 220 | 88.0 | 0.79 | 78.6 | 0.16 | 0.32 |
| 160 | 7.28 | 12.7 | 92.5 | 0.35 | 210 | 73.5 | 0.79 | 79.5 | 0.13 | 0.29 |
| 140 | 6.36 | 12.8 | 81.4 | 0.30 | 214 | 64.2 | 0.79 | 78.9 | 0.12 | 0.25 |
| 115 | 5.13 | 12.7 | 65.2 | 0.21 | 216 | 45.4 | 0.70 | 69.6 | 0.08 | 0.21 |
| 100 | 6.15 | 12.8 | 78.7 | 0.29 | 210 | 60.9 | 0.77 | 77.4 | 0.11 | 0.18 |
| 85 | 5.19 | 12.8 | 66.4 | 0.24 | 215 | 51.6 | 0.78 | 77.7 | 0.09 | 0.15 |
| 75 | 5.14 | 12.8 | 65.8 | 0.21 | 218 | 45.8 | 0.70 | 69.6 | 0.08 | 0.14 |
| 60 | 3.65 | 12.9 | 47.1 | 0.16 | 217 | 34.7 | 0.74 | 73.7 | 0.06 | 0.11 |
| 40 | 2.68 | 12.9 | 34.6 | 0.11 | 212 | 23.3 | 0.67 | 67.5 | 0.04 | 0.07 |
| 25 | 1.81 | 13.0 | 23.5 | 0.05 | 220 | 11.0 | 0.47 | 46.7 | 0.02 | 0.05 |

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