150W Inverter- An Optimal design for use in Solar Home Systems

Dr Gawie J vd Merwe
Plan My Power (Pty) Ltd

Gawie@planmypower.co.za
www.planmypower.co.za

Abstract – **Single frequency Photovoltaic Inverters have been on the market since a need arose to produce AC from a DC source, probably long before the beginning of PV systems. With the growth in the PV industry, the need for better, more cost effective inverters is ever present. Producing an inverter of high quality at a low cost is a challenge. A high quality inverter at high cost can not compete in the low quality inverter's market. Solar Home systems are often offered inverters that do not look after the assets of the client, i.e. the lifetime of lights and various loads used on inverters. A investigation was done, looking at various 150W inverters (low as well as high cost), comparing and evaluating the results. A low cost inverter was then developed that caters for most loads at an affordable price.**

I. INTRODUCTION

The market for t he 150W inverters range, varies from low budget electrification to dedicated use for notebook computers and television viewing for social applications. In 3rd world countries the price of 1$/W is not affordable. The selling price varies from 0.3$/W up to 1.5$/W [1][2][3]. (Prices retrieved from market research Data). The quality of the available inverter units varies as much as the price does [4][5][6]. The report looks at various available inverters. An investigation on "load life time" due to inverter output waveform was undertaken. A thorough investigation was done on the state of current technologies. Some industry available Inverters were compared. Due to the cost and complexity to design a sinewave inverter, this option was not considered. The most critical and crucial loads is capacitive loads, such as magnetic ballast fluor escent lights, small 11W electronic ballast fluorescent lights, computers, notebooks, televisions; VCR's etc. This presentation discusses the design criteria of every functional block of such an 150W inverter. (**Due to shipping consideration 50Hz transformer inverter topology was not considered).**

A. Objective

The objective is to design and manufacture an high quality inverter at a "low quality" inverter price.

B. State of the Art

A wide range of small lightweight inverters was disseminated for cost [Table 2], MTBF, ability to drive any load within the specified power range [2][7][8][9]. **No 150W high frequency inverter could drive a 90W printing machine** Two inverters proved to be robust[2], but would not drive the load either (shut down on overload). The other two inverters were damaged. This single test is a good example of "state of the Art", 150W inverters simply do not deliver 150W under all load conditions.

C. Design Criteria

The resulting specifications for the 150W inverter are as follows.

a) Light weight and mobile.
b) Low noise – No distortion on TV or in vehicle etc.
c) MTBF - High (>5 years), while being capable of driving all loads up to 150W.
d) High Efficiency >90%- Inverters work from batteries, which are often limited in size and/or stored energy.
e) Optimal protection - a study needed to be done to determine what minimum but efficient protection circuitry is required - Protection often contributes to the circuit cost.
f) In this power range, most of the loads are capacitive of nature. (TV, 10W Fluorescent lights, Indecent lights, Notebook computers etc.) The inverter must be designed to compensate for this. If the load is inductive with a poor power factor, the unit must be capable of working without reducing the MTBF.
g) Manufacturing and maintenance cost must be as low as possible
h) Overload capability mu st be at least 3 times continuous rating. This is a world -wide standard. [2][3][4][5]
i) The Inverter's frequency must be stable and remain stable over the lifetime (>5 years).

II. INVERTER DESIGN

A. Input reverse polarity protection

In vehicle applications the cigarette lighter plug is part of the inverter. Damage caused by accidental reverse polarity is very slim. In other applications such as general leisure use for camping or solar installations the absence of reverse polarity protection can be a problem. Options for reverse polarity protection is investigated and compared inTable 1.

DESCRIPTION	RELAY AS INPUT	DIODE IN SERIE	FUSE IN SERIE+DIODE
Additional cost	With control +- $2	Complete work range +-$4	+-$0.4. Fuse is required
Power consumption	Up to 4W	Up to 6W	None
Life time problems	Contacts Burn	None	None
Overboard components	All	All	1 x 4A Diode ($0.4)
Advantage	Non-repairable protection	Non-repairable protection	Repairable protection

Table 1 Reverse Polarity Protection

Suggested solution
In Table 1 Reverse Polarity Protection method C, is the suggested option for following reasons:

a) Most of the applications would be for fixed or pre-wired set-ups.
b) If reverse polarity does occur, it will damage replaceable fuse, external warnings on the inverter could assist with this protection.
c) Cost saved with this method can assist to add quality in other parts of design
d) Reduced mechanical as well as heat dissipating components increases MTBF.

B. Input line filtering

In certain environments such as in mobile vehicles, certain vehicle manufacturers such as BMW, VW Audi etc. has an appliance input filter specification. These are the minimum suggested requirements for the input filtering to prevent the appliances from damage due to vehicle disturbances. Noise caused by the inverter, must also is limited, not to influence other appliance in use.

Suggested solution
An input filter stage with active components such as , L = 8 uH, C2 = 1uf, C3 = 0.1uf in Parallel with 2000Uf electrolytic, The respective input line filters have a cut -off at 1.36 kHz and output filters a cut-off at 61 kHz. Although not possible to design one cost effective unit, for all the applications, the above mentioned design caters very well.

C) Input over voltage protection

Input over voltage damage can occur due to one of the following reasons:

a) 12V inverter connected onto 24V batteries. In which case the maximum voltage could reach 29 V DC
b) In a PV installation the batteries were left of. The voltage applied to the inverter could go up to 22V DC

All 4 inverters tested [Table 2], over voltage shutdown was offered, but when a 24V DC was left on the Inverters, the input DC capacitors all blew.

DESCRIPTION	INVERTER A	INVERTER B	INVERTER C	INVERTER D
Rating	150 W	150 W	150 W	100W
Input voltage	12V DC	12V DC	12V DC	12V DC
Output frequency	45-55 Hz	50 Hz 0.1%	48 -52 Hz	48 - 52 Hz
Low volt shutdown	10 V spec- not fixed	10.5V DC	11.2V DC	10.5 V DC
Topology	Forward QS	Flyback QS	Forward QS	Forward QS
Reverse polarity	YES - Relay	Yes- fused	Yes- Fused	Yes- Fused
Input Filter	No	No	Yes	Yes
Input capacitor	2200uf 16V	2200uf 16V	2 x 1000UF 16V	2 x 1000UF 16V
Line inductor	No	No	Yes	Yes
DC link Capacitor	100UF 400V	100UF 400V	68UF 350V	68UF 400V
H Bridge protection	not good	Current fold back	DC link current f old back	Link fold back, plus Series 10W Resistor
Human Interface	LED	LED	Buzzer	Buzzer
Peak output power	120W	300W 3 seconds	400W 10 sec	200W 10 sec
Waveform	Mod Sine	Mod Sine	Mod Sine	Mod Sine
Packaging	Metal enclosure	Heatsink Extrusion	Heatsink Extrusion	ALU Mould
Size	120x60 120mm	80 x 40 x 70 mm	70 x 50 x 140mm	96 x 42 x 116 mm
Output Plug	2 Pin USA	2 Pin USA	3 Pin Eastern	3 Pin Eastern
Input connections	1M x 2.5mm wire with Crock clips	1 meter 2.5mm wire with cigarette lighter	1meter x 2.5mm with Crock clips	50 cm x 2.5mm with Cigarette lighter plug
Input over voltage protection	Shutdown but damage does occur after a while	Shutdown but damage does occur after a while	Shutdown but damage does occur after a while	Shutdown but damage do occur after a while
Input / Output isolation?	Yes	Yes	No	No

Table 2 Inverter comparing

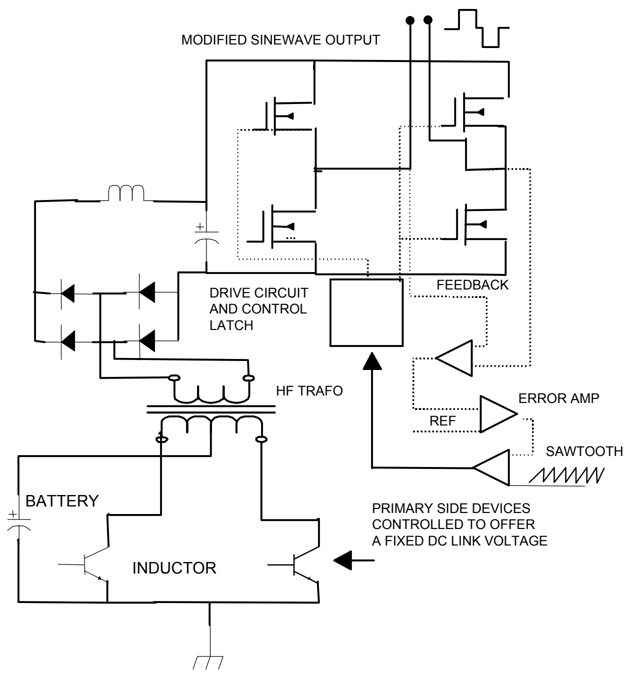


Figure 1 Inverter Topology

Suggested solution

An over voltage shutdown is implemented to shut the main DC to DC converter down. All the capacitors and components that "see" the input voltage have a rating of 35V minimum.

D. Thermal shutdown?

Inverters are abused and placed in positions where they are not well ventilated. All of the tested inverters do have thermal protection [Table 2 Inverter comparing]- e.g. Thermal shutdowns were implemented with a 4 to 7 NTC -

E. Low battery voltage shutdown

Batteries are a high cost items. Most low cost inverters available do not offer sufficient low battery voltage protection. In permanent PV installations the suggested low voltage cutout level is 11.4V. The battery is then expected to recover up to at least 12.3V before the inverter will reconnect. In mobile applications NO predetermined set voltages are given, but 10.5V seems to be the accepted, low voltage cut out point. (This is 1.75V per cell, allows sufficient power to restart the vehicle). Another critical specification is that the inverter does not shutdown when the battery goes lower than this voltage for short periods. i.e when a vehicle starts the battery voltage can drop down to 8.8V (1.45 V/cell this is the suggested suppliers "cranking" voltage). If the vehicle is started and it takes 10 seconds, the inverter should still continue to supply the load. (Audi and Volkswagen suggest a voltage of down to 6.5V for 2 seconds.[10]). All the tested inverters failed to do so [Table 2 Inverter comparing], Only some industrial high cost inverters [3] comply to this specification.

Suggested solution

A "slow" low voltage cut-out circuit was implemented, with effective voltage feedback to supply power to the control circuit under all conditions.

F. Output frequency - RC clock or Crystal?

RC (resistor capacitor) clocks must be set during manufacturing. It has the tendency to loose synchronisation with time and temperature. Inverters are often used to run small items like bed alarms, which depend on the voltage source frequency for keeping time. A crystal clock on the other hand guarantees continuous time synchronisation, but at a higher cost.

Suggested solution

An inverter with a lifetime of minimum 5 years can not be reliable if the frequency in 5 years time is unpredictable. The availability of low frequency crystals is a problem. For this reason an 4060, 4040 and a 3.2768 Mhz crystal is used.

G. Output voltage regulation - PWM or fixed duty cycle with DC link control ?

Option1 – If the DC to DC converter is designed to have a fixed duty cycle, then the output DC link voltage will increase and decrease as the input battery voltage fluctuates. The I^2R losses in such a case should be a minimum. Controlling of the H Bridge with PWM that does the output voltage regulation.

Option 2 - is to control the DC link voltage to a set voltage i.e. 265V DC and then drive the secondary H Bridge with a fixed duty cycle. Experience gained [5] [Table 2 Inverter comparing] indicates working from a fixed 265V DC link voltage with a predetermined pulse width, offers the best solution. Tests done on starting of single-phase induction motors support this approach.

Suggested solution

The DC to DC converter controls the DC link at 265V DC. Output H Bridge is then switched at a fixed duty cycle of approx. 80%.

H Input - Output isolation or not?

Input - output optic and mechanical insulation is always a discussion point. In fixed installations, the input and output must be isolated to enable the earth leakage protection units. When the input/output is not isolated, and a battery terminal and/or output cable (Live or Neutral) is touched, electrocution is possible. If the input/output is isolated, the output would be floating and the only possible way of getting electrocuted is by touching both live and neutral. With the investigated inverters [Table 2 Inverter comparing], an output line filter and/or MOV configuration referenced the output voltage to ground. Isolation has a increased cost factor. The possible options are as follows:

a) Completely isolate the Input / Output and pay the cost price - this will add at least an estimated 1.5 - 2 $US to the inverter's price.
b) Don't do input output isolation. Inform the user of the inverter and reduce the cost to gain quality on another point.
c) Add electronic earth leakage protection to inverter. This option was left out due to legal complications.

Suggested solution
Cost, remains the main issue. The inverte r output is referenced to chassis ground due to surge and lightning protection. This range of inverters would not be used in large permanent installations. Thus input output insulation does not have purpose in this inverter range and is therefore left out.

I Input switching device protection

For maximum MTBF it is essential to drive all the components within its safe operating parameters and then also protect those components when driven beyond such parameters. Protection of the MOSFETs on the primary s ide of the inverter, means protection against over voltage, overheat and over current. The devices on the primary side of the inverter switches high current. IRFZ44N MOSFETs will be used, RDS on = 24 mOHM, DC current = 20A at 100C and pulsed rain current at 100C is 120A, maximum power dissipated at 35W.

Suggested solution
The primary devices are protected in all three ways. Thermal protection is done by the general thermal protection, the NTC is mounted right next to these. The current being switched in the primary is measured across "0 Ohm" resistors and when the continuos limit is exceeded the inverter will shutdown. The inverter over voltage protection will not allow the unit to work at 24V. Thus protecting the devices against over voltage

J Power transfer topology - Feed forward or Flyback converter topology?

For a power rating of up to 300W, either a feed forward or a Flyback converter principle can be used. The Flyback converter requires larger volume ferrite material, for the same power transfer [6]. The feed forward converter would require a rectifier DC inductor. One tested inverter [2] makes use of a Flyback converter principle. The other 3 inverters investigated, make use of a forwa rd converter. In a Flyback converter all the energy is stored in the magnetic material and then transferred when the switching device is off, thus short period overload is not possible. A feed forward converter offers an "unlimited" (up to a point), short period overload ability.

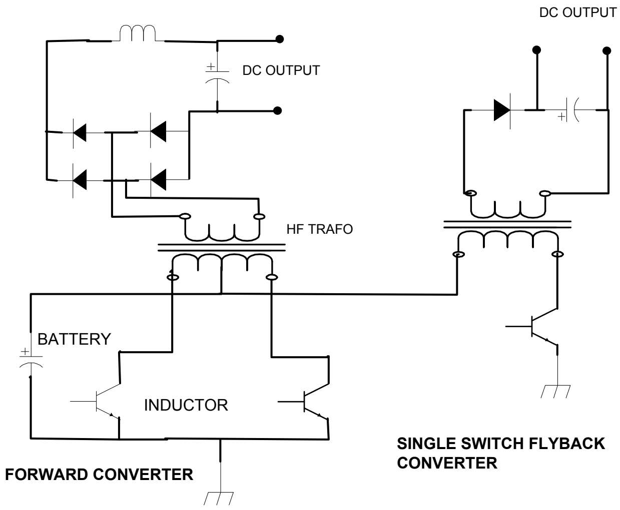


Figure 2 Feed forward or fly back

Suggested solution
A feed forward converter topology was chosen for the following reasons:

- The inverter must be capable of producing up to 3 times the maximum continuos rated power.
- The cost of the magnetic material for the Flyback converter for a 150W inverter that is capable of supplying 450W for 5 seconds is +-$6 US and that of a feed forward converter is $ 3.2 US.
- A push pull configuration was chosen to limit the cost of the drive circuit. The magnetic material is optimally used.

K Output H bridge protection

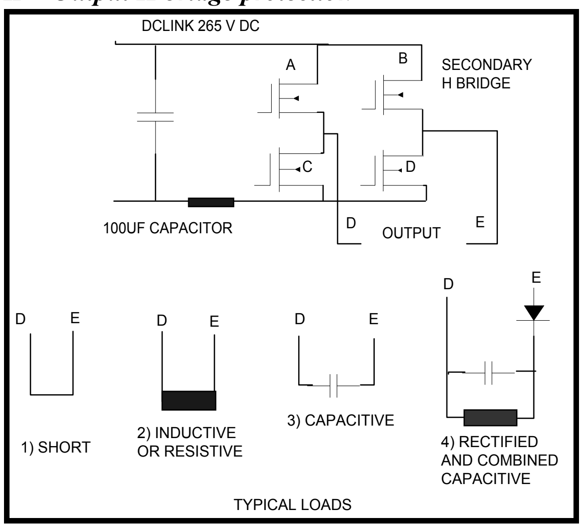


Figure 3 – Load configurations

The H bridge is the last active part of the inverter. The output d evices (when switched on), produce a low output and impedance between the 265V DC link and the load. If the load is a short circuit or a low impedance, such as a capacitive load, [loads 1, 3 and 4 Figure 3 – Load configurations] no or very limited control is offered over the rise of the load current.
Load 4 [Figure 3 – Load configurations]is very common. Typical load examples are electronic ballast fluorescent light [11W etc], televisions, video machines, computers etc. All capacitive loads must be driven **. It is therefore**

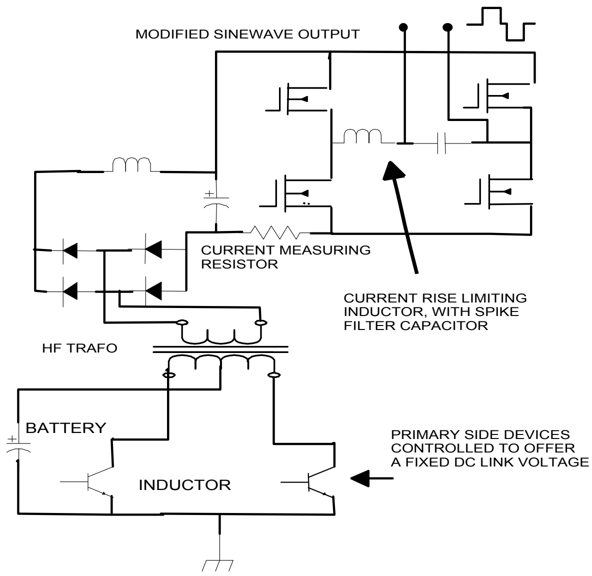
important to control the current instead of simply shutting it down. A power factor of 0.6 pF is equivalent to a capacitor value of 20uF in load 4, and a resistive load of 320 Ohm.(Figure 3 – Load configurations)

Suggested solution
The solution is very much a combination of options.

- To add a series resistor reduces the efficiency of the inverter as used in inverter 4. (Table 2 Inverter comparing)
- If a inductor is added, the rise of current is limited, but it is still required to limit the absolute current peak.

An combination of current rise limitation and current peak "chop" is offered. The total protection chopped circuit consist of a series L and parallel small capacitor to limit voltage peaks, and an electronic control circuit. (Figure 4)

It allows 60 uS for the current to go to 0A and then switch the devices on again. If a short is still present it will just shut down with time. If however it is a capacitive load such as load 4, the load will be pulsed with a 3.3 A current peak



until the capacitor is fully charged and then the devices would stay on.

Figure 4 GZZ BZZ Cicuit

L3 is determined, by the maximum pulsed current rating of the MOSFET, and the delay caused by the control electronics.

L *Overload protection- specifications*

Setting the levels

The specifications on inverters power rating differ. Manufacturers speci fy input power, some specify output power. It was decided to specify the true output power for this inverter. This is however difficult to measure and three methods were chosen to measure and limit the output power.

a) Method 1 is the chopped current limiting, which is set to 3.3A peak independent of load type (capacitive or inductive).
b) Method 2, is the measurement of the average H - bridge current, this level is set at 150W/0.6 = 250VA. The line voltage and current is not always in phase and modified sinewave output could add to load current distortions.
c) Method 3, is by measuring and filtering of the DC input current , this is unfortunately the only way to determine the power used. A estimated inverter efficiency of 90%, will set this level at 14A DC input.

M *Other added essential functions*

The following essential circuit blocks were added to make the inverter very versatile :

a) Output disable until DC link is 265V DC (required to drive small motors)
b) The PCB was split between power and control to reduce total size
c) A self -reset circuit was added, when inverter shutdown into overload, the inverter will reset itself after a 40 second predetermined period. A separate switch Sw2 is also supplied to offer reset function
d) Only on single LED is used as the human interface.

III) EXPERIMENTAL WORK AND RESULTS.

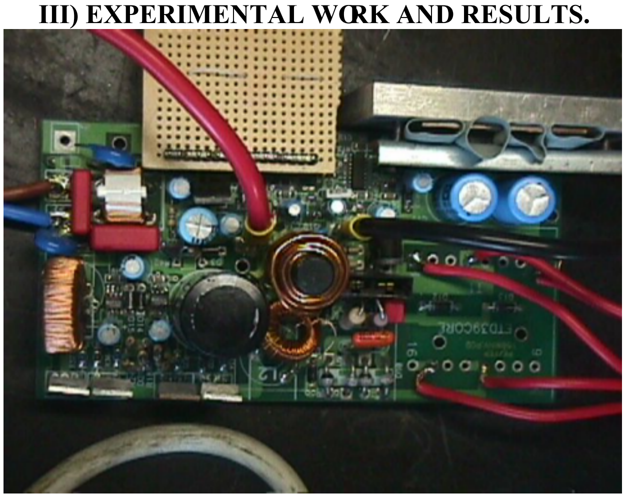


Figure 5 Working proto inverter

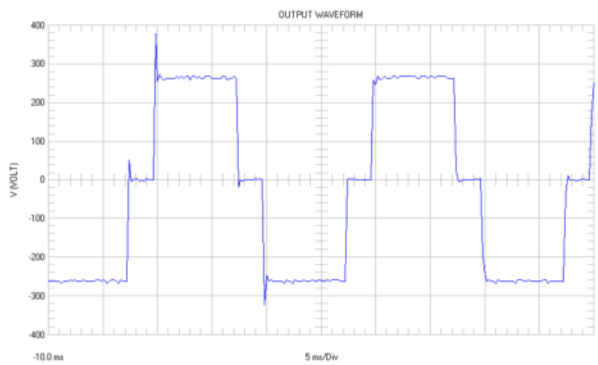


Figure 6 Inverter output waveform

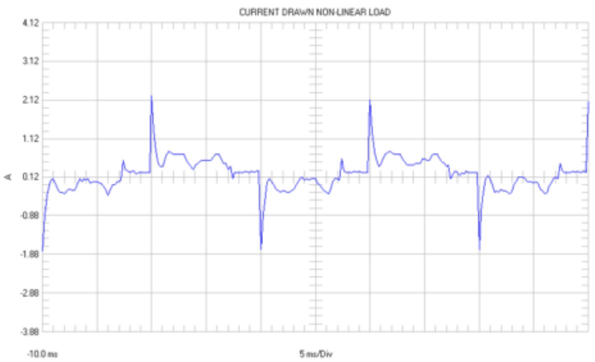


Figure 7 Current non-linear load

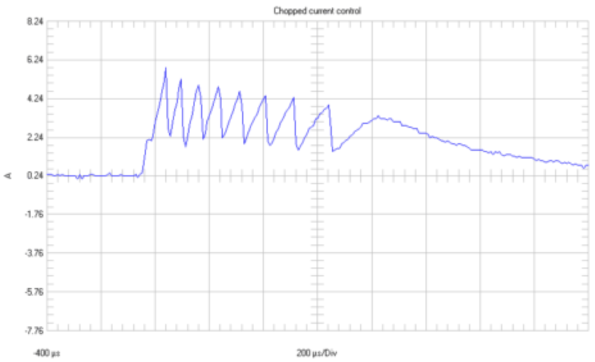


Figure 8 Chopped current control

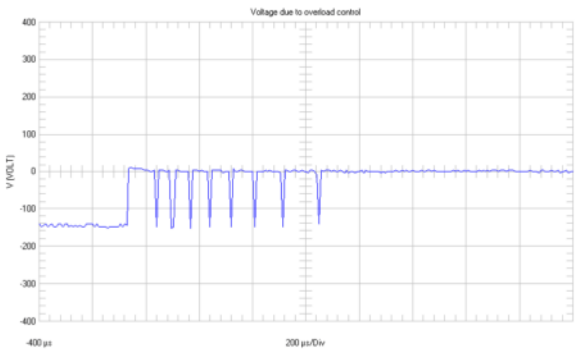


Figure 9 Output voltage during current control

Figure 5 shows the layout of the experimental inverter. Figure 6 shows the output waveform of the inverter, the peak voltage which is regulated at 265V DC is clearly visible. Figure 7, shows th e current drawn by a typical non-linear load. This load used is electronic ballast fluorescent lights – total of 160 VA. The high current peak drawn by the load is highly visible.

The load shown in Figure 7 is a typical non-linear load, which is in daily use. Other examples of such loads are TV, Computers etc. The input stage of such a load is typical as load 4 in Figure 3, a full bridge rectifier as input stage , followed by a capacitor bank . Due to the voltage shape of a typical modified sine wave inverter, these kinds of loads is often a problem. The proposed inverter, compensate for this problem, by a method of current pulsed control (Figure 8 Chopped current control). If the load current exceeds a certain value, the inverter will shut the output down, but only for a short period and then restart it. This allows for a current build up. Figure 8 and Figure 9 shows this effect. Figure 8 clearly shows, how the current is pulsed. The input stage of the load is then charged up to the working level.

Figure 9 shows the output voltage at this stage. It is clearly visible from th e voltage waveform, how the output is controlled.

IV CONCLUSION

A 150W high frequency inverter was designed for mobile as well as PV applications. Preliminary production runs indicate a production cost of around 0.5 $/W which is within our goal. The current pulsed control is effective and solves a major problem, for the lifetime of the inverter as well as the life time of the typical non linear loads, which are in use. All the designed functions such as battery low protection, overvoltage, overload, o verheat etc was found satisfactory

Further tests are still being done and more attention is given to reduce the production cost even more.

REFERENCES

[1] Photocomm, Inc , Solar Electric Products Catalog, 6 th edision p24-34

[2] Statpower internet website, at http:/www.statpower.com

[3] Traceengineering internet website at http:/ traceengineering.com

[4] Simon Roberts; "Solar Electricity - a Practical guide to designing and installing small photovoltaic systems"Great Britin, University Press, Cambridge, 1991, P 125 to 131

[5] E.E Landsman; "Static Inverters for use in PV power systems", copyright American Chemical Society, 1979

[6] G.J Van Der Merwe " Internal report 07, optimal design of 150W Inverter for Solar Home systems", RAU, Lab for Energy, 1997

[7] 150W inverter MODEL SV3, made in Taiwan.

[8] Powersaver invert supplied for testing by Zebenza Radio and TV

[9] 100W Inverter supplied by Kaohiang, Electronics CO.Ltd

[10] Specifications of EMI for cars, as per Technical Supply Specification, Control Unit for Electronic Ignition, Functional Requ irements, 7the Revision, Dated 01/89 (Sec.2.7 'Climatic Durability' deleted.