

Inverters – The investigation to the optimal topology to the designing of a Sinewave inverter range for the use in static as well as mobile applications

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Abstract – 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. At the same time, the need for a range of inverters covering a wide range of power and applications are becoming a salient issue. Currently there are various types of inverters on the market, ranging from square wave, modified sinewave, pure sinewave, lightweight high frequency inverters (sine or modified sine), heavy 50Hz transformer topology inverters etc. Often the choice of inverter is prescribed by the application, but in all applications the first choice of waveform is always sinewave. An investigation into the optimum, single frequency, sinewave technology was undertaken with the view of designing a range of said inverters.

I. INTRODUCTION

A wide range of sinewave inverters are in existence [1,...11]. The topologies used by these inverters are wide spread. **The most common (popular) topology is high frequency switching in the primary using a Toroidal transformer with an output filter (as per Figure 5). Other popular options are the high frequency switching with a DC link in the secondary (as per Figure 6), and CVT (as per Figure 1) etc.** Some suppliers use methods of switching two or three transformers in a matrix configuration [1], (Figure 8). Although all these methods seem to offer the same result, (which is a sinewave output). The output waveform as well as the efficiency of the inverter often gets completely distorted due to certain critical loads. Typically, such loads are fluorescent lights with electronic ballasts, computers, televisions, microwave ovens etc.

A. Objective

The Objective is to describe and explain the difference in the design of various Sinewave Inverter topologies. This includes topology description, advantages and disadvantages. Topologies that will be discussed is as follows:

- Inverter using CVT (Constant Voltage Transformers)
- Inverters with 50 Hz Toroidal or silicon steel, EI transformers, with a variation.
- Inverter with High frequency isolated converter and separate secondary inverter control bridge.
- Inverter with more than one transformer configured in series or matrix configuration.

II. INVERTER TOPOLOGIES

A. Inverter using CVT (Constant Voltage Transformers or often referred to as Ferroresonant transformers)

CVTs are one of the most commonly used methods used for the generation of “clean sinewave”. A typical application of CVT is, as line conditioners. Where it would offer voltage regulation as well as filtering of the line mode spikes [14]. The mentioned advantages make it ideal for UPS applications. At the moment a very big percentage of the UPS population are still being designed using a CVT. A CVT (or Ferroresonant transformer) is a self-oscillating unit, consisting of a transformer, capacitor bank and a saturable inductor combined into one. Due to the fact that all these passive components carry the full load capacity, and they are designed for the applicable frequency, which is 50 Hz. The size and weight of a CVT is excessive (up to twice that of a normal 50 Hz transformer of the same rating).

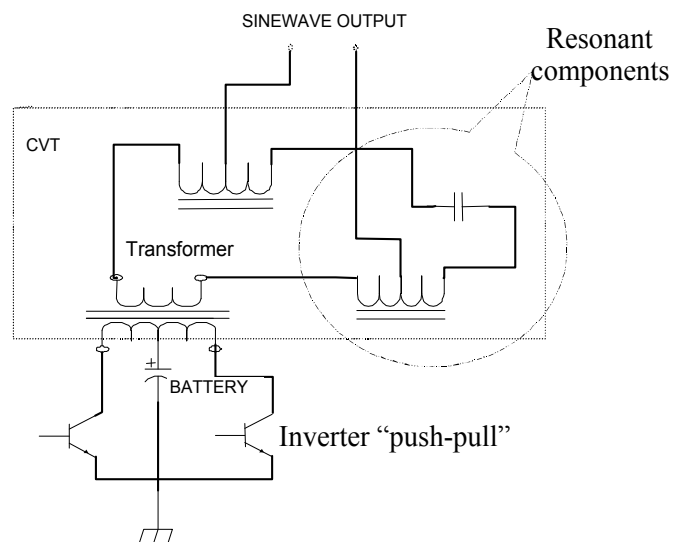


Figure 1 CVT

Advantages of CVT's

- Generating a sine wave from a simple drive system is simple, only high accuracy on the frequency is necessary.
- CVT is self “short circuit” protected.
- As long as the frequency is stable, the CVT does its own output voltage regulation, with an accuracy of up to 2%. Voltage distortion is typical <3% (with linear loads).

Disadvantages of CVT's

- Due to the saturation affect of some of the magnetic components of the CVT, the efficiency is very low. It could vary between 40 % and 80%.
- CVT is limited to motor start application, and needs to be overrated at least 2.5 times.
- Some non-linear loads, such as a thyristor choppers “confuse” a CVT and leads to instability.
- Due to the passive components such as the saturable inductor and resonant capacitor bank, the CVT is up to 2 times bigger and heavier than a normal 50 Hz transformer of the same rating.

B. Inverter designs with 50 Hz transformers.

Most of the commonly used Inverters on the market are designed using these topologies.

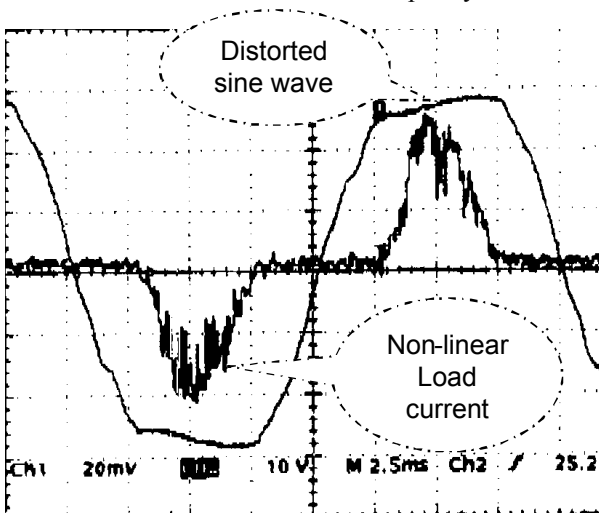
The principle is that an “overrated” 50Hz transformer is used - either EI, UI or Toroidal cores. All the control and power switching is done on the primary side of the Transformer. A current limit element i.e. inductor is placed in series with the output filter capacitor either on primary side, or the secondary side.

Voltage feedback is done using an isolation transformer, or direct, if isolation is not required.

The switching frequency varies from topology to topology. But for silicon EI steel, it would typically be ± 6 kHz and for Toroidal cores. It could however go as high as 20 kHz. The PWM strategy could also vary from bi-polar PWM, to Uni-polar PWM.

Advantages of 50 Hz transformer topology

- Only one energy conversion stage from DC (Battery) to AC.
- Relatively “clean” sine wave can be generated, with very simple and limited control.
- Due to isolation and electronic simplicity the



reliability is good.

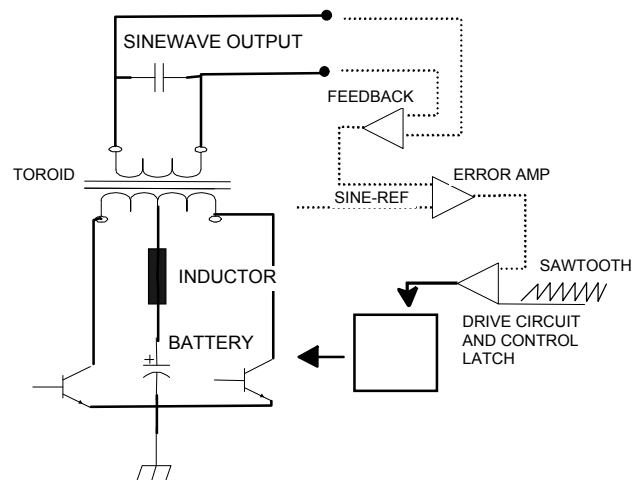
Disadvantages of 50 Hz transformer topology

- Inverter units are heavy compared to high frequency units.
- The transformer needs to be “overrated” to compensate for EDDILOSSES and high efficiency.
- When EI silicon steel is used the switch in frequency is limited to below 10kHz.
- The current in the switching devices is the same “shape” as the load current, but amplified by the transformer ratio.
- Non-linear loads such as computers, Electronics, Fluorescent lights, etc. often cause waveform distortion. (Figure 2)
- Units bigger than 1000VA have restricted mobility.

Figure 2 Wave form distortion due to nonlinear load

Figure 3 Push-Pull topology

OPTION 1



Advantages of Option 1.

- All MOSFET are referred to ground, thus simplifying the control and reduce cost.
- Bi-polar PMW ensures that there is always a current flow path for inductive loads.
- The primary devices are protected by the series line inductor.

Disadvantages of Option 1.

- Push-pull topology often leads to “skewing” of the transformer, which leads to device destruction. Additional control and protection is required to compensate for this.
- Due to energy in the inductor, voltage overshoot on the MOSFET is high, therefore additional snubbers are required.

- No, or very limited control over energy stored in the inductor.
- MOSFETs need to be voltage overrated. This leads to unnecessary conduction losses i.e. For a typical 12V application, a IRFP054 on resistance $14\text{ m}\Omega$ can be used, but due to this topology a MOSFET IRFP150 with a resistance of $54\text{ m}\Omega$ must be used. The later has a 4x higher conducting resistance.

OPTION 2 (50 Hz - Figure 4)

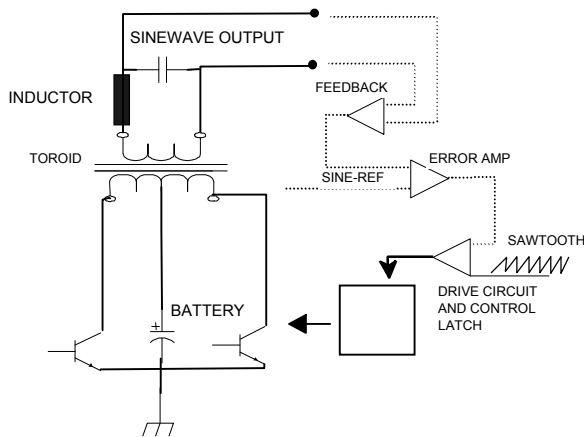


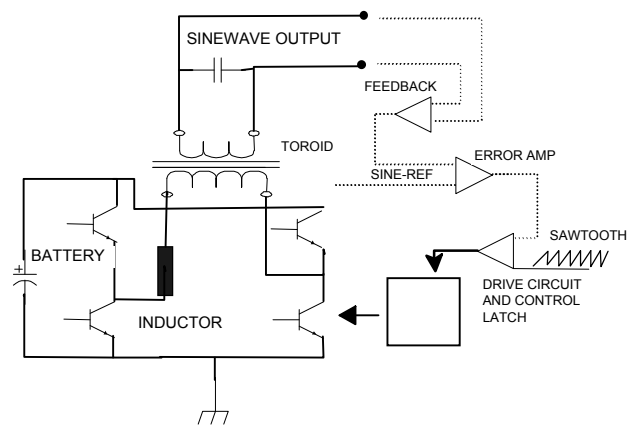
Figure 4 Push-pull with inductor in secondary

Advantages of Option 2

- All MOSFET are referred to ground, therefore simplifying the control and reducing cost.
- Bi-polar PWM ensures that there is always a current flow path for inductor boards.
- The primary devices are protected by the series line inductor.
- Current rating of inductor is smaller and the value higher.
- Manufacturing of inverter is simpler and smaller.

Disadvantages of Option 2

- Push-pull topology often leads to “skewing” of the transformer, which leads to device destruction. Additional control and protection is required to compensate for this.
- Due to energy in the inductor, voltage overshoot on the MOSFET is high, therefore additional snubbers are required to protect against this.
- No, or very limited control over energy stored in the inductor.
- MOSFET needs to be voltage overrated. This leads to unnecessary conduction losses i.e. For a typical 12V application, a IRFP054 on resistance $14\text{ m}\Omega$ can be used, but due to this topology a MOSFET IRFP150 with a resistance of $54\text{ m}\Omega$ must be used. The later has a 4x higher conducting resistance.



OPTION 3 (50 Hz- Figure 5)

This is the most successful and most popular “50 Hz” transformer topology used in the industry.[3][4][7][9] It offers the best control and cost effectiveness.

Advantages of Option 3

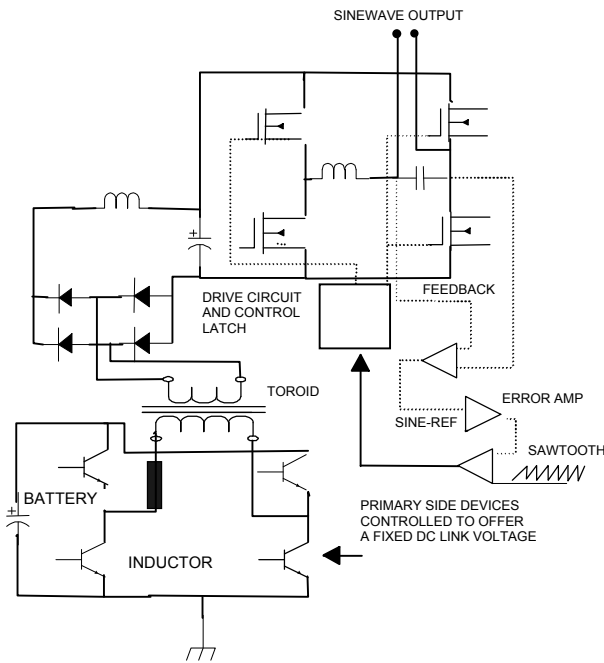
- The full bridge switch configuration in the primary, ensure that no voltage overshoot occur on the MOSFETs.
- The lower voltage rated MOSFETs can be used for applications up to 36Vdc. This limits product and production cost.
- Uni-polar as well as/or Bi -polar PWM control is possible, depending on the application. In both cases a free path is offered to any inductive load.
- Full control of the line inductor is offered. Excessive energy can be “dumped” via adequate control of the MOSFETs in the primary side.
- Due to the flexibility of choice between Uni -polar and Bi-polar PWM controls, the switch frequency can be controlled and varied. It can be a high as 20 kHz.

Disadvantages of Option 3

- The MOSFETs are not referenced to ground, thus the gate drive is more complex.
- The current drawn by the load is directly amplified by the transformer ratio on to the primary. Thus with a ratio of 25. A current pulse of 4A in the secondary, would become 100A pulse on the primary side.
- Units bigger than 1kva are not portable.
- Due to relative high impedance between primary and secondary (transformer & inductor), non-linear loads do cause voltage distortion on the output. (Figure 2)

Figure 5 Full H-bridge in primary side of transformer

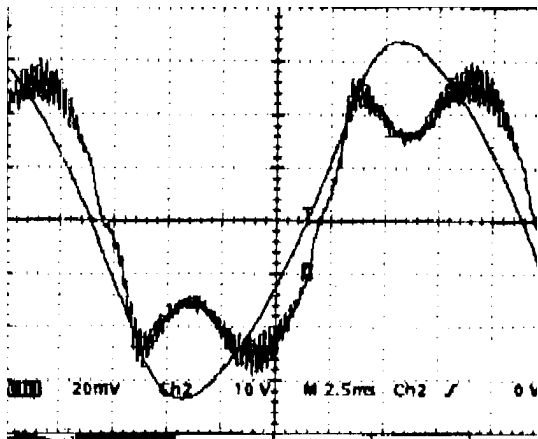
C. Inverter design with High frequency isolated



converter and separate secondary inverter control bridge (Figure 6)

Figure 6 High frequency isolated sine wave inverter

This topology is widely used in inverters for mobile applications. It has some cosmetic advantages, but the main advantage is mobility. Non-linear loads do not influence the efficiency of such an inverter as much as it



does with the other topologies.

Figure 7 Output wave form of high frequency inverter with non-linear load

As a general rule the output voltage regulation is much better than that of 50 Hz topology inverter.

The topology offers the use of Bi-polar and/or Uni-polar, PWM control, this method offers major efficiency advantages.

The first stage, steps the battery voltage up to a fixed DC linked voltage of approximately 350 VDC. This step of DC to DC conversion must be able to “handle” 100 Hz pulsed loads of up to 6 times the continuous rating.

The step-up converter would typically switch at a frequency of above 20 kHz. This reduces size of the first power stage.

The second stage of the inverter converts the 350 V DC link into a pure sine wave by high frequency PWM switching and control. The passive components, such as the in-line inductor and capacitor, filters out the PWM sine wave. It is thus ideal that the filter components are as small as possible.

In a well designed high frequency inverter, the current switched by the primary devices, is only the average DC current, drawn by any non linear load. This unfortunately, adds to both the price and physical dimensions of the inverter, but offers major efficiency advantages.

Advantages of Option C

- Units can be small mobile and modular[5][6][8][9].
- A well-designed unit’s efficiency is not influenced by the non-linear load.
- Direct control of the secondary Hbridge leads a better sine wave control.
- High system efficiencies are possible.
- Both Uni-polar and Bi-polar, PWM control strategies are possible.

Disadvantages of Option C

- Inverters are complex and thus more expensive to manufacture.
- Increased component count leads to reduced MTBF.
- Only short period overload rating possible. This can be increased but at a higher price.
- Additional EMI and RFI filtering components required, which increases the price.

D. Inverter design with more than one series transformer.(Figure 8)

The series configuration as shown in the figure above, offers another topology to generate a sine wave, from a battery source. The topology is a combination of a 50 Hz transformer topology and high frequency switching.

Although this method is complex, with a high “component count”, it offers a topology, that can be used for power ratings of up to 10kw [1].

The example showed in Figure 8 consists of three separate inverters, of different power ratings. Inverter A is a normal square wave inverter, with up to 80% duty cycle. B and inverter C only “assists” by filling in of the detail. Thus transformer B and C will work in the “dead time” of A.

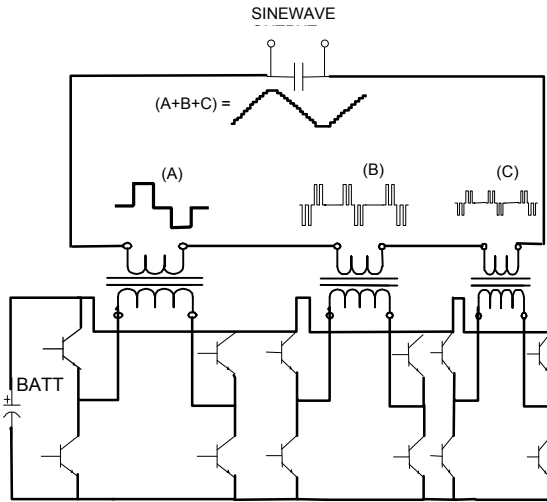


Figure 8 Inverter with more than one series transformer

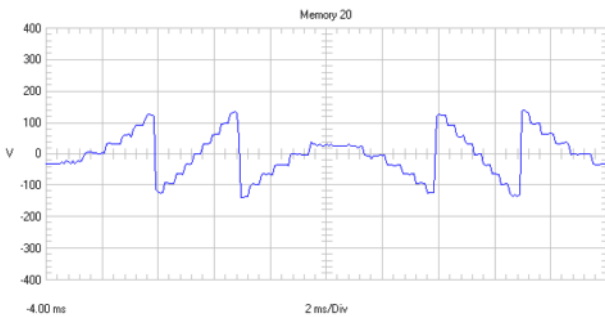


Figure 9 Typical wave form across transformer B (Figure 8)

The result of the output is a multi “stepped” sine wave, which is the sum of the output of the three different small inverters. All the “inverters”, can add or subtract to the wave form output. Inverter A will switch at 50 Hz. The transformer’s output voltage would be approximately 320V peak. Inverter B will switch at a frequency of approximately 500 Hz. This transformer’s output is approximately 150V peak. Inverter C will switch at a frequency of approximately 1500 Hz. This transformer’s output will be approximately 75V peak.

Advantages of inverters with more than one series transformer.

- With good control a multi “stepped” sine wave output with low voltage distortion can be achieved.
- Due to the fact that there is no additional series components such as current limiting inductors, the output and overload characteristics are good. These inverters can typically be overrated for short periods up to 6 times the nominal rating [1]

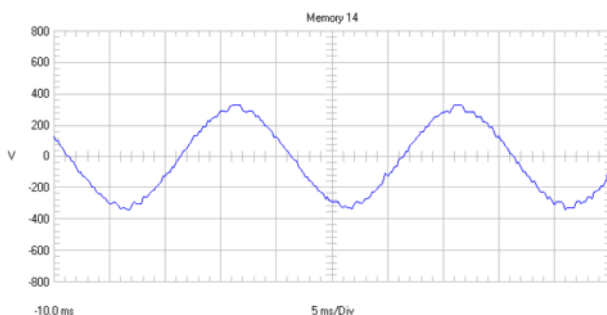


Figure 10 Multi “Stepped” sine wave output

- This inverter offers major advantages for motor start up applications.
- Inverters B and C in Figure 8 can also be driven as current source units, which offer major advantages to stack inverters in parallel.
- It is easy to configure inverter as a bi-directional inverter.
- Output voltage regulation is good.

Disadvantages of Inverter with more than one series transformer

- Inverter is complex to manufacture.
- Inverter is heavy and bulky.
- Control strategy is complex.
- Output wave is not pure sine wave, but a combination of small steps.

E. Other Inverter Topologies

The above mentioned inverter topologies cover a wide range of inverters in manufacture today. Although new “topologies” are developed and advertised almost daily, these so called “new” topologies will fit in with one of the above mentioned topologies. Other topologies will consist of:

- Single switch step up converter
- 3 to 8 stepped inverter
- Quasi Sine inverter of various topologies
- Controllable CVT inverters
- PWM inverter
- Utility interaction inverter

III. CONCLUSION

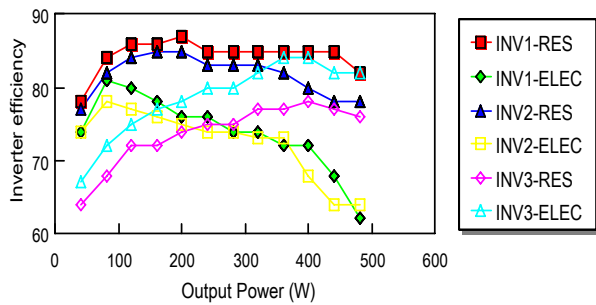
Three different types of sinewave inverters. All three are rated at 600W. The measurements were done using a 24V battery bank, and input and output power was measured by making use of Fluke 41 and Fluke 99 measuring instruments. Two different loads were tested, load one in each case was a resistive load and load 2 was fluorescent lights with electronic ballast. INV1 and INV2 is based on the topology indicated in Figure 5, 50 Hz toroidal transformer with line inductance, INV3 is an inverter with high frequency insulation between primary and secondary. (Figure 6)

The following observations can be made:

- INV1-RES – maintains a good efficiency over the

Efficiency of three types of Sinewave inverter

Load 1 = resistive, Load 2 = Electronic ballast



range with resistive load.

- INV1-ELEC – efficiency drops down as a result of the current drawn by the load.
- INV2-RES – maintains a good efficiency over the range with resistive load.
- INV2-ELEC – efficiency drops down as a result of the current drawn by the load.
- INV3-RES – maintains a constant efficiency over the range with resistive load, but tapers down a little at the end indicating under design.
- INV3-ELEC – efficiency increases – this is in contrast with the results of INV1 and INV2.

The previous graphs indicate that a significant difference exist between various topologies of sine wave generation. It is easy to note the effect that the wrong inverter can have on a system design.

A thorough investigation with results, showed the difference between various inverters. It was indicated that although such a wide variety of inverters topologies do exist, the application can vary. Inverter Option D, was not tested at 600W as such an inverter using the topology is not commonly available. It is clear that there is not much difference between Topology B (50Hz) and Topology C (high frequency). In weight and physical dimensions, Option A and D can not compete in the power range 1000VA. Option B offers cost and reliability advantage due to the reduced component count. Option C – although at a high price offers systems advantages, which could be critical for PV applications.

IV. REFERENCES

- [1] Advertising pamphlets, Instructions manuals and advertising on the Internet at <http://traceengineering.com>, by TracEngineering.
- [2] Advertising pamphlets, Instructions manuals and advertising on the Internet at <http://www.statpower.com>, by Statpower
- [3] ASP, Hauptsitz, Hauptstrasse 36b, CH -8637 Laupen/ZH- advertising package
- [4] Siemens technology advertising pamphlets, Sinewave Inverter SWR600 dated 10/95
- [5] EXELTECH, 2225 East Loop 820 North, Fort Worth, Texas 76118, e mail : info@exeltech.com - Product information catalogue
- [6] Mastervolt, Lemelerberg rd 23, 11010 A.J Amsterdam, P.O. Box 22947, 1100 DK A'DAM

- [7] Vallve X, Feixas E; “ Stand Alone PV modular Power conditioning station”; 12th European Photovoltaic solar energy conference, 11 -15 April 1994, Amsterdam Netherlands. Pg 1651
- [8] Invertomatic Victron UK Ltd, member of IMV group, Wheatfield Way, Hinkley Fields, Hinkley - marketing and technical manuals.
- [9] Boglietti A, Ferraris P, Lazzari M...” Effects of different modulation index on the Iron Losses in soft magnetic materials supplied by PWM inverter”IEEE Transactions on Magnetics, 1993, vol 29, Iss 6, pp3234-3236, JD bib no 118/51
- [10] Onduleur sinus, Serie SI, Sinuswechselrichter, Studer Innovative Technik, Ecosol, Zi Les vernedes, 83480 Puget/Argens, advertising pamphlets 1997
- [11] L'indépendance Asolue existe, Twinpower, ondulateurs SINUS haute performance, Ecosol, Zi Les vernedes, 83480 Puget/Argens, advertising pamphlets 1997
- [12] An Internet publication of Jademountain of tests done with different fluorescent lights, with various inverters. Web site : www.jademountain.com,
- [13] N.M Chivelet, F Chenlo;”Analysis and modelling of DC/AC Inverters with resistive and reactive loads for stand alone PV systems”, 12th European Photovoltaic solar energy conference, 11 -15 April 1994, Amsterdam Netherlands. Pg 1631
- [14] Mohan, Undeland, Robbins, Power Electronics: Converters, applications and design.
- [15] High Efficiency DC -AC Inverters for Solar application, K.H. Edelmoser & F.A. Himmelstoss; Technical University Vienna, Power Electronics Section, Gusshausstr 27-29, A-1040 Wien, Austria.

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