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An Investigation into Power Electronics Used in Photo Voltaic Power Systems

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ABSTRACT

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Power electronics are used anywhere where there is a need to process electrical energy. It could be for changing currents, voltages and/or frequency. Power electronics is different from general electronics in a sense that it deals with processing energy instead of information. The most important metric in power electronics is efficiency. The use of power electronics is growing rapidly in the area of renewable power generation. This change is because of increasing supply and demand gap of power, prospect of cost savings from electric bills, scarcity of fossil fuels, excess CO2 emissions, unavailability of capital to build traditional power plants are few of the challenges that power electronics is helping to solve. This paper discusses the basic power electronic devices, their usage and commercial power electronic systems being used in renewable PV energy generation and consumption.

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GLOSSARY

Photo Voltaic:	A semiconductor device that converts photons in light to current flow
Micro-controller:	Micro processor with other features like memory etc that can helps in automation of a process
Efficiency:	Measure of how well a system converts one form of energy to another
Solid State:	Characteristic of a system where there are no mechanically moving devices, term is usually used for semiconductor devices.
MPPT:	Phenomenon used to extract maximum amount of power from a PV array
Total Harmonic Distortion:	Measure of quantifying the weight of unwanted signals in a waveform

LIST OF ABBREVIATIONS

PV	Photo Voltaic
CO2	Carbon Dioxide
AC	Alternating Current
DC	Direct Current
FET	Field Effect Transistor
IGBT	Insulated Gate Bipolar Transistor
MPPT	Maximum Power Point Tracking
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
THD	Total Harmonic Distortion

HISTORY OF POWER ELECTRONICS

The era of power electronics began in early 1900s but the real development has occurred in the past 60 years. In 1892, German researcher L. Arons invented the first mercury arc vacuum valve. In 1906, J.A. Fleming invented the first vacuum tube and L. Forest patented the vacuum tube. The development of electronic amplifiers started in 1927 when feedback amplifier was invented by H.S. Black. In the early 20th century, main electronic equipments were based on vacuum tubes, such as mercury arc rectifiers etc. In 1930s they were replaced by more efficient mercury equipment. The vacuum tube had a set of disadvantages. Its life was limited to few hours before its filament burned out. It was bulky and gave off heat that raised the internal temperature of electronic equipment too high. Because of vacuum tube technology, early electronic devices were very expensive and consumed large amount of power.

Semiconductors devices started to come out in 1947 when American scientists from “Bell Labs” invented the germanium transistor. This invention earned them a Nobel Prize. From 1952, General Electric manufactures the first germanium diodes. In 1954 Texas Instruments produced the first silicon transistor which became way more popular than germanium transistor because of its increased performance and reliability. Integrated circuits were invented by Texas Instruments in 1958 and started the era of solid state electronics. The era of high power rating of these solid state electronic devices started from 1956 when silicon based thyristor was invented. The second era of power electronic devices started from 1975 till 1990, the metal oxide semiconductor field-effect transistors, bipolar npn and pnp transistors were developed. The era of third generation of power electronic devices started after the invention of insulated gate bipolar transistor (IGBT) [7].

INTRODUCTION

Power electronics is a very broad field and some say it is the hardest of electrical disciplines because of its inter-disciplinary nature. Power electronics combine power systems, power electronics, microcomputers, digital signal processing, magnetics, and control systems to name a few. Power electronics can process electrical energy from few mili watts like in cell phones to several mega watts in HVDC applications. The driving force in power electronic equipments is availability of high speed and high power transistor. Control semiconductor devices like transistors are used in power electronic converters. Depending on their application power electronics can be divided in four general blocks.

- Rectifier (AC to DC)

  In a rectifier, AC input voltage is rectified to produce a DC output voltage.
- Inverter (DC to AC)

  In an inverter a DC input voltage is transformed into an AC output voltage of controllable magnitude and frequency.
- DC to DC Converter

  In a DC–DC converter, the DC input voltage is converted into a DC output voltage of different magnitude and sign.
- AC to AC Converter

  An AC-AC converter, the converts input AC voltage of a specific frequency to an output AC voltage which can be of different magnitude and frequency than the input voltage.

A controller is a very important part of any power electronic device because input voltage and current waveforms will not be always stay constant and therefore the output will not be as expected. A controller looks at the output and changes the input parameters to have a desired output.

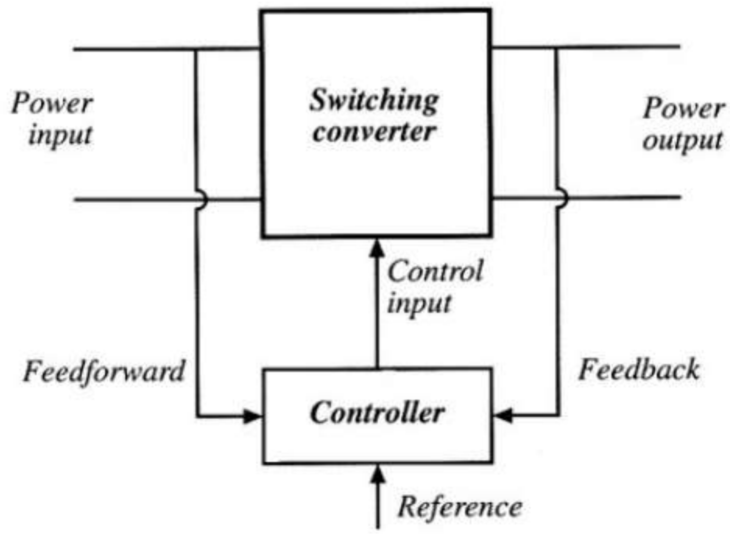

Figure 1 Closed Loop Converter with a Controller Block

Also the components used in the construction of converter will have different behavior at different current, voltages and temperatures.

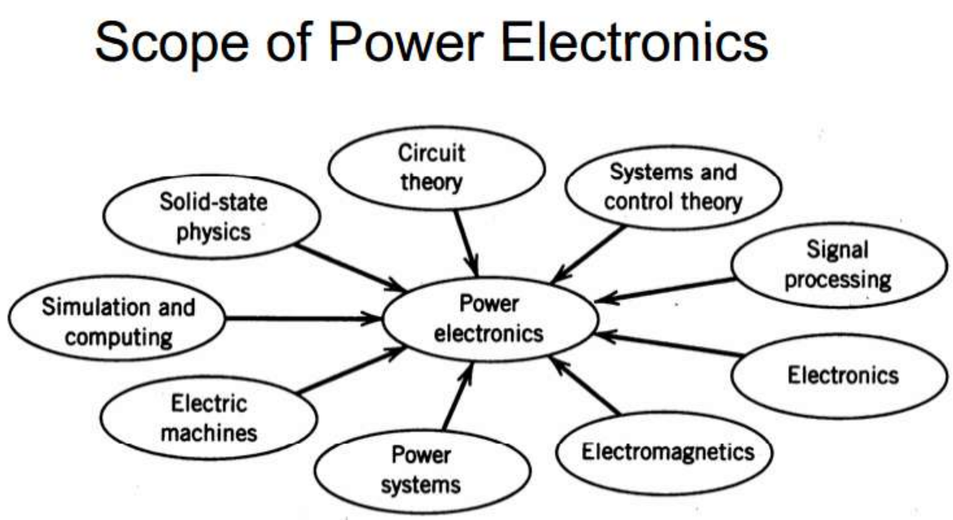

Figure 2 Scope of Power Electronics

CONVERTER EFFICENCY

High efficiency in power converters is very important because if converter is not efficient, then very large amount of power will be wasted as heat and converter will need to operate at a very low output power in order to keep the temperature manageable. Efficiency in a power electronic converter is defined as

$$\eta = \frac{P_{out}}{P_{in}}$$

The power lost in the converter as heat is defined as

$$P_{loss} = P_{in} - P_{out} = P_{out}\left(\frac{1}{\eta} - 1\right)$$

Plotting converter efficiency with power loss shows that if a converter has efficiency of 50% then P loss / P out =1 This means that at 50% efficient converter will waste as much energy in heat as its output power. Therefore at high output powers it may be impossible to adequately cool the converter. Efficiency is a very important parameter and can be used to tell the success of a given power converter design.

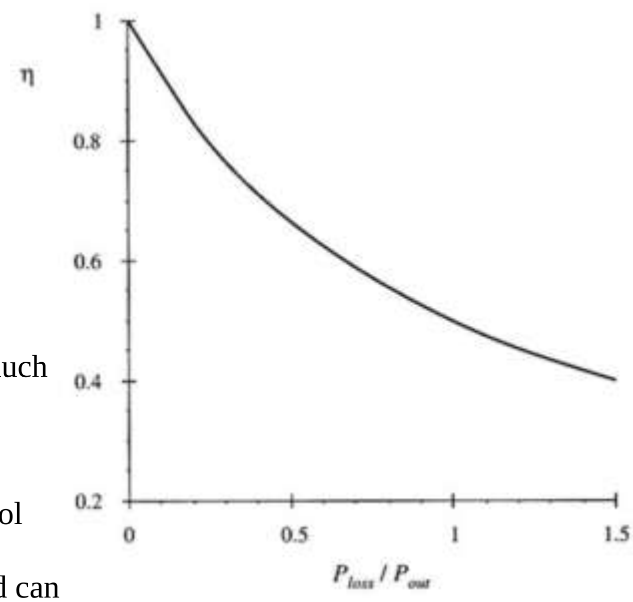

Figure 3 Efficiency Graph

High efficiency converter can be packaged in smaller, light weight packages with high density and high power output, which is a very desirable trait. In power electronics inductor, capacitors are used very often because ideally they consume no real power and for the same reason switching devices like transistors are operated in either saturation or cutoff regions. That is because when switching device is in cut off region its power dissipated is ideally zero and when it is in saturation region the voltage drop across it is very small and hence power usage is also ideally zero [1]. For example to reduce the input voltage one can think of using a voltage divider, this method is not ideal because the voltage is reduced by wasting power on the voltage divider resistor and hence switching converters are needed.

POWER ELECTRONICS IN PHOTOVOLTAIC (PV) SYSTEMS

PV systems are different from other sources of electricity generation is a sense that they have no moving parts and are completely solid state. All that is required between source and the load are electric and electronic equipment. PV is also very modular and scalable technology. One of the most important components that are present in all type of PV system is what called an inverter and in this a report, research has been done on the theory and usage of inverters in regards to renewable energy [5]. The main reason photovoltaic (PV) energy systems are not as widespread as they should be is because of their installation cost. Initial start up cost is very high because of high cost of components of a PV system.

The system costs more than an average house hold would like to pay because of high cost of solar panels, batteries and power electronics. The price of these components is going down relatively and there are thousands of different types of products for each category. Cheaper and more efficient solar panels are being developed by numerous R&D centers around the world [2]. PV systems are particularly more attractive at places where the utility does not have enough power to provide its customers and load shedding is frequent like in numerous parts of the developing world. Reliable solar power can become a reality if the systems are analyzed in a simpler fashion without extra details so that general public can appreciate them.

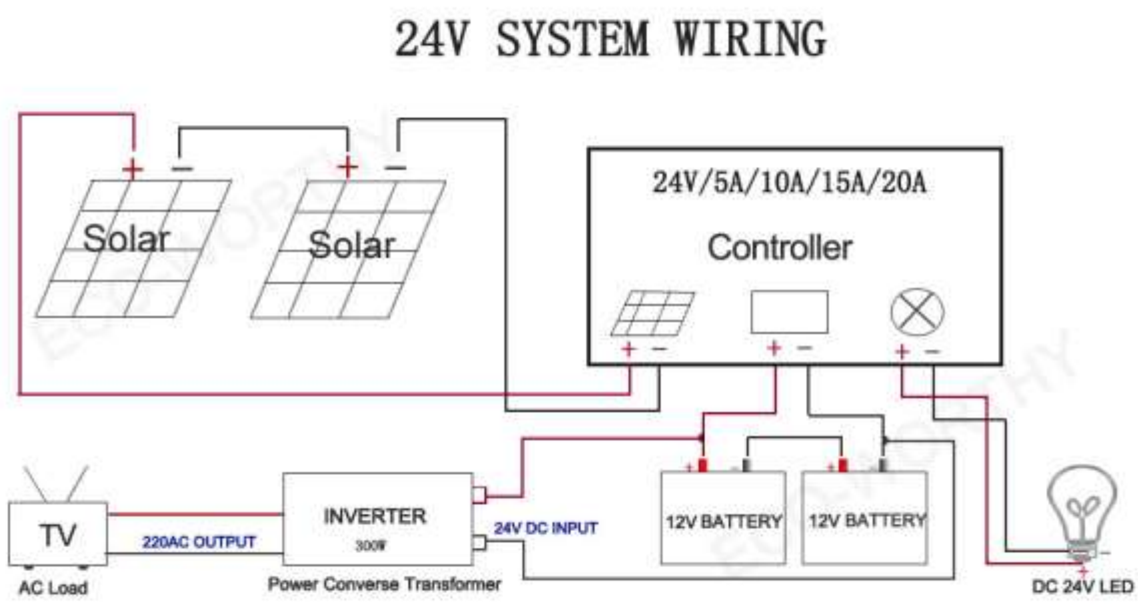

Figure 4 A Stand Alone PV System with Inverter [8]

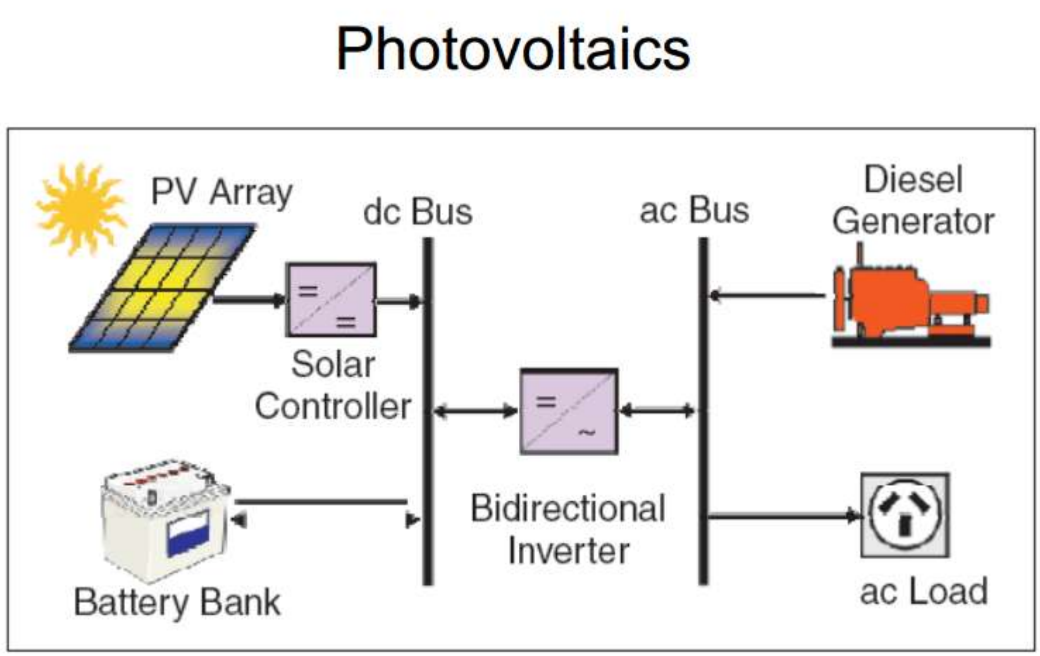

Figure 5 A Hybrid PV System with Bidirectional Inverter

SOLID STATE INVERTERS USED IN PHOTOVOLTAIC SYSTEMS

A solar inverter is a crucial component in any PV power system. Its job is to convert stored DC voltage in batteries to AC voltages whose magnitude and frequency is user defined typically 50 or 60 Hz. That is because house hold appliances are designed to run utility grade AC power therefore a PV system should provide the same type of power to be useable. The output of that inverter can be supplied to electrical grid or off –grid electrical network. New inverters are becoming increasingly advanced with extensive microprocessor based control algorithms, maximum power point tracking (MPPT), Anti-Islanding Protection (AIP) to name a few. There are three different types of inverters.

- Off-Grid

  In Off-Grid PV applications an additional DC-DC converter is required between PV array and batteries and an inverter with a built-in charger to charge the batteries.

- Grid- Interactive

  There are two general types of grid interactive systems.

  1. Basic Grid Tie
  2. Grid Tie with battery back up

1. Basic Grid – Tie System

A basic grid tie system generates electricity when the photovoltaic cells are producing power. The power produced by PV goes to power the home and excess power is sold to utility. DC power produced by PV cells is converted to AC by a grid tie inverter which is sent to the main power panel to be used by appliances in home. Any excess power goes back to the utility through "net metering" to reduce the electric bill.

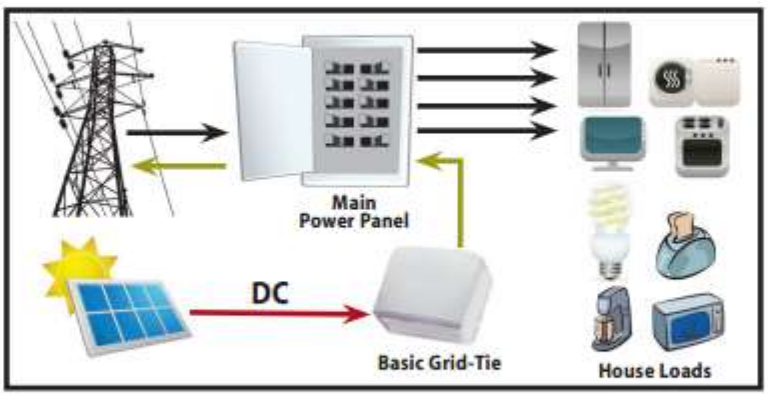

Figure 6 Basic Grid Tie System with no Battery Back Up

This type of grid tie system is relatively simple and inexpensive to install since there is no storage of electricity and fewer power flows. A disadvantage of this type of system is it does not provide power when utility power goes out for safety regulations and uses Anti Islanding Protection which is built in the inverter.

2. Grid – Tie with Battery Back - Up

Grid tie with battery back-up does more than just providing power when the sun is shining and selling excess power to the utility, it provides power even during the power outages. Charged batteries are part of the system and they provide power to the house when the gird power is out, at the same time PV panels charge the batteries if sun is shining. This system does not sell power to utility during a grid outage again for safety regulations.

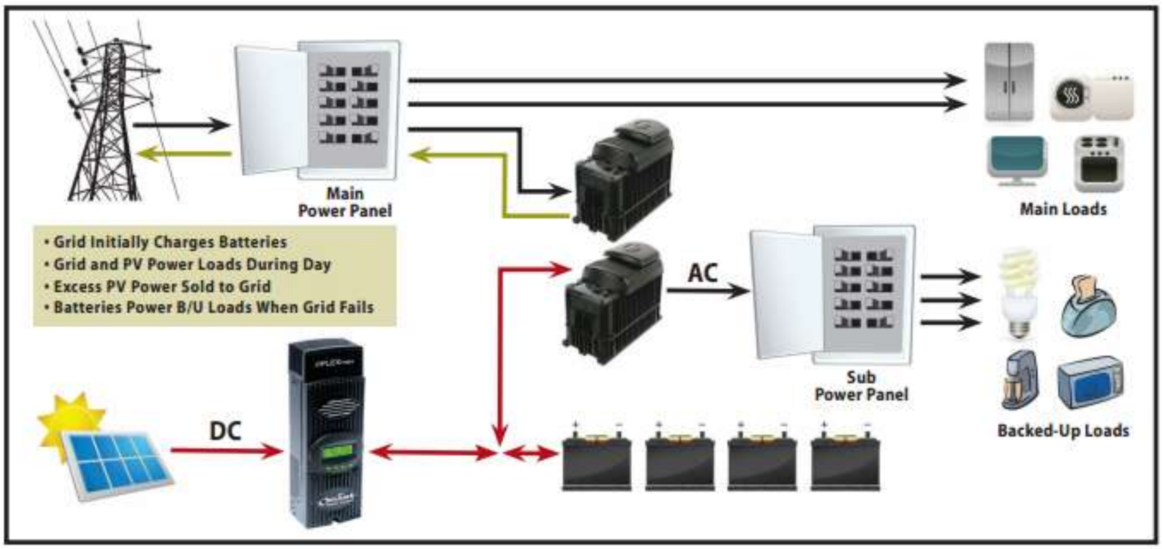

Figure 7 Grid Tied System with Battery Back Up

When the grid power comes on, inverter/ charger charge the batteries.

In grid-tied applications all that is needed between a solar array and the grid is smart inverter that can supply power to the grid in a safe manner and shuts off during emergencies. Features that a grid tied inverter should have are [6].

- Inversion
- Maximum Power Point Tracking
- Grid Disconnection

Solid State Inverters (SSI) have no moving parts and can be found in small electronic power supplies to utility grade high power HVDC links. Maximum Power Point Tracking (MPPT) feature is crucial to maximize the output of a PV system. The PV maximum power is dependent on the operating conditions and varies from moment to moment due to temperature, shading and time of day so tracking and adjusting for this maximum power point is a continuous process.

A SIMPLE INVERTER

An earlier technique to convert DC voltage to AC voltage is by connecting a DC motor to an AC generator but this technique is now replaced by power electronic inverters [3]. A very simple electronic inverter is called a square wave inverter; it works by supplying DC voltage at its output terminals for half cycle like shown below.

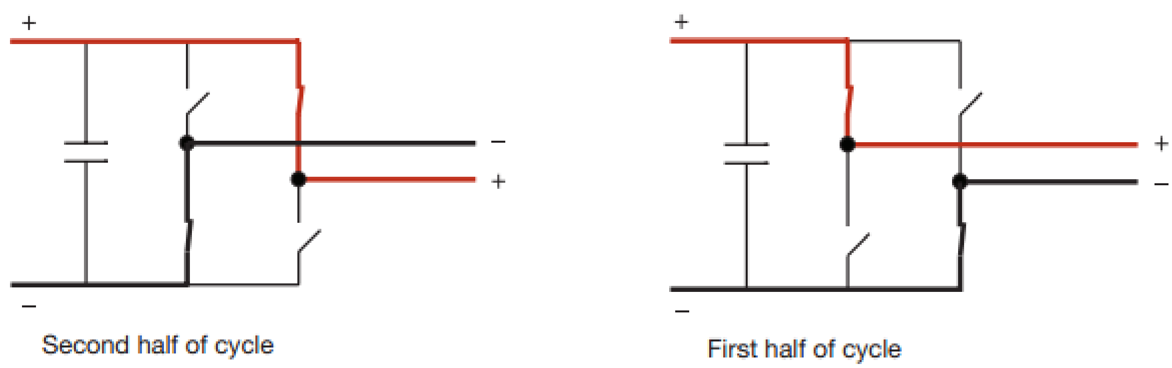

Figure 8 A Simple Square Wave Inverter [5]

In the next half cycle the other two switches closes and the voltage polarity at output terminals changes sign.

This is a very crude type of inverter, converting DC Voltage into AC. Some devices like light bulbs can work with this type of voltage but most device cannot therefore a better inverter is needed [5].

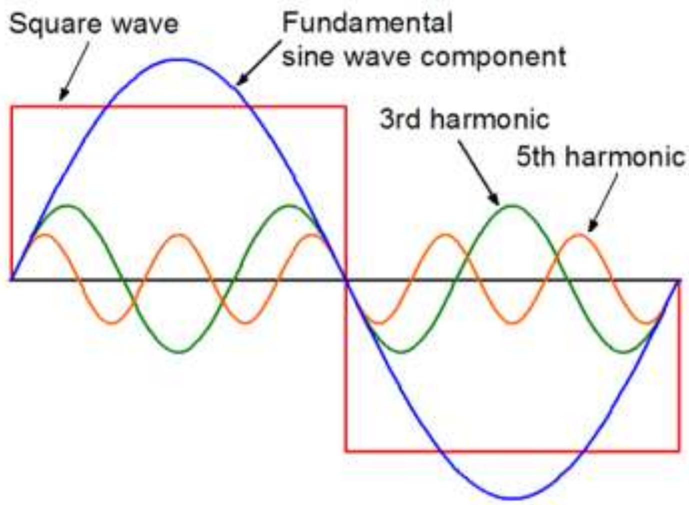

Figure 9 Square Wave Inverter and its Harmonic Contents [9]

As can be seen the voltage made using a simple inverter is rich in other harmonics and 60 or 50 Hz component is very small. Switches in an inverter are usually MOSFETs and BJTs.

GENERAL KNOWLEDGE ABOUT INVERTERS

Power transmission uses pure sine wave because naturally that's what comes out of a generator but creating a pure sinusoidal voltage and current waveforms from DC source is an expensive process and for this reason many power inverters create what is known as modified sine wave. The most basic and inexpensive way to create a sine wave is by switching DC from positive to negative but a modified sine way is designed so it resembles closely with a pure sine wave in terms of carrying the energy in 60 Hz or 50 Hz component. This practice makes most AC devices think that they are supplied with a pure sine wave. A modified sine wave is positive for some time then zero for some time and then become negative for some time and become positive again and the cycle continues. The pause at zero volts is what puts the maximum amount of power at 60 Hz component. It is to be noted that simple modified sine wave inverters are not suitable for all application for example medical equipment, battery chargers and digital clocks.

The sizing of inverter is an important calculation in any design and many factors must be taken into account before buying an inverter. Inverter should be able to provide all the power that is required by appliances connected to it in steady state and in transient state for example during start up. Inverters at high voltage are comparatively cheaper than low voltage inverters because $P = V*I$ for a constant power requirements, and decreasing the voltage will result in increasing the current as a result inverter will need to have parts like MOSFET, IJBTs, and Diodes rated for higher currents which in result increases the size and cost of inverter [4].

LIST OF REFERENCES

[1] Fundamentals of Power Electronics Second Edition Robert W. Erickson, Dragan Maksimovic

[2] Single Stage Converters for Low Power Stand-Alone and Grid-Connected PV Systems Luigi G. Junior, Moacyr A. G. de Brito, Leonardo P. Sampaio, Carlos A. Canesin São Paulo State University – UNESP - Power Electronics Laboratory – Electrical Engineering Department Av. Prof. José Carlos Rossi, 1370, 15385-000, Ilha Solteira, SP, Brazil *canesin@dee.feis.unesp.br

[3] Design and analysis of a simpler dc to ac power transfer circuit for residential size photovoltaic panels Wicks, F. ; Martino, J.P. ; Dept. of Mech. Eng., Union Coll., Schenectady, NY

[4] http://www.powerstream.com/inFAQ.htm

[5] How Inverters Work, By James Worden and Michael Zuercher-Martinson, What Goes on Inside the Magic Box Floriani, Juan Carlos A.

[6] http://www.outbackpower.com/pdf/brochures/Grid_Interactive_Systems_2.pdf

[7] Power Electronic Converters – Valery Vodovozov, Raik Jansikene

[8] http://www.ebay.ca/itm/10W-12V-solar-panel-home-use-battery-charger-photovaltaic-solar-panel/170813664535?pt=LH_DefaultDomain_0&hash=item27c549ad17#ht_3451wt_1163

[9] http://en.wikipedia.org/wiki/File:Squarewave01CJC.png