Inverter Application Note

Voltech

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Forward

- Direct Current conversion to Alternating Current Inverters (DC/ AC) are the subject of much research and development in recent years because of the growth in Green Energy sources of power in particular Solar Photo Voltaic (PV) cells. The engineering task is to take the DC power from these cells and convert the power into a useful AC power at either 50 or 60Hz Line frequency that can be distributed on National Power Grids. In this application note we will look at how this can be achieved and the various methods employed to achieve a clean undistorted AC sinusoidal wave form and at the same time ensuring that the conversion process is as efficient as possible . We will look at the internationally agreed standards that govern connection of inverters to their local grids and the use of power analyzers to help engineers meet the design criteria of low voltage and current distortion on the inverter outputs and meet the increasing pressure to develop more efficient inverters at lower costs.

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- Types Of Inverters
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  - Grid Tie Solar
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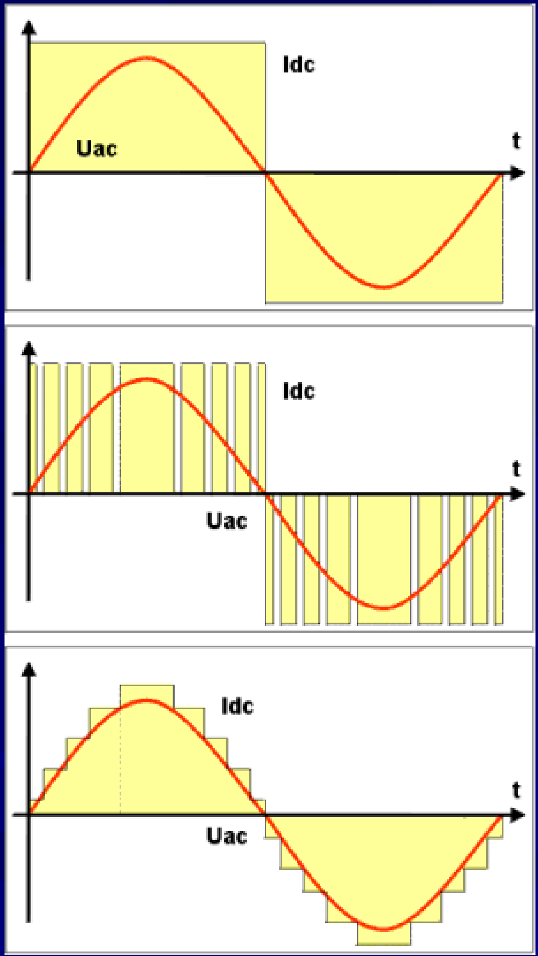
  - Transformer less design
- International Standards
  - IEEE519
  - IEEE1547
  - EN50530
  - EN61000-3-2/3
- **Test Equipment**

Producing a Sine Wave Output

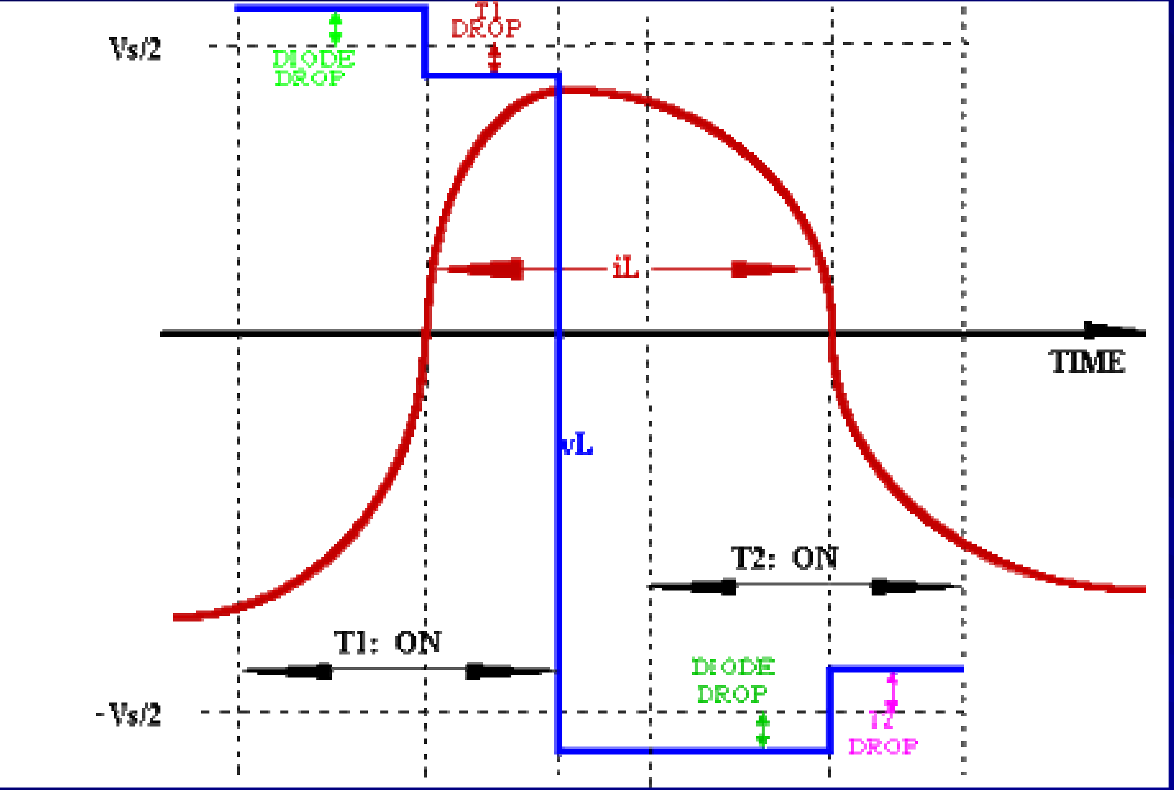


Voltage and current in line-commutated

PWM self commutated inverters

Cascade inverters

Principles of Operation



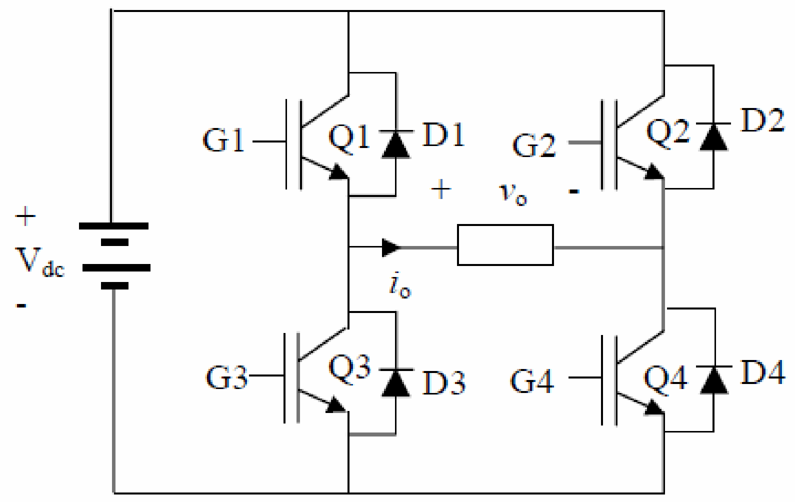
Half Bridge Inverter

With T1 ON and drawing positive load current iL the load voltage will be less than Vs/2 by the ON-STATE voltage drop of T1. When the load current reverses, the load voltage will be higher than Vs/2 by the voltage drop across D1.

Normally the ON-STATE voltage and diode drops are ignored and the centre tapped inverter is represented as generating the voltage + Vs/2 or - Vs/2.

Principles of Operation

- The " H " Bridge

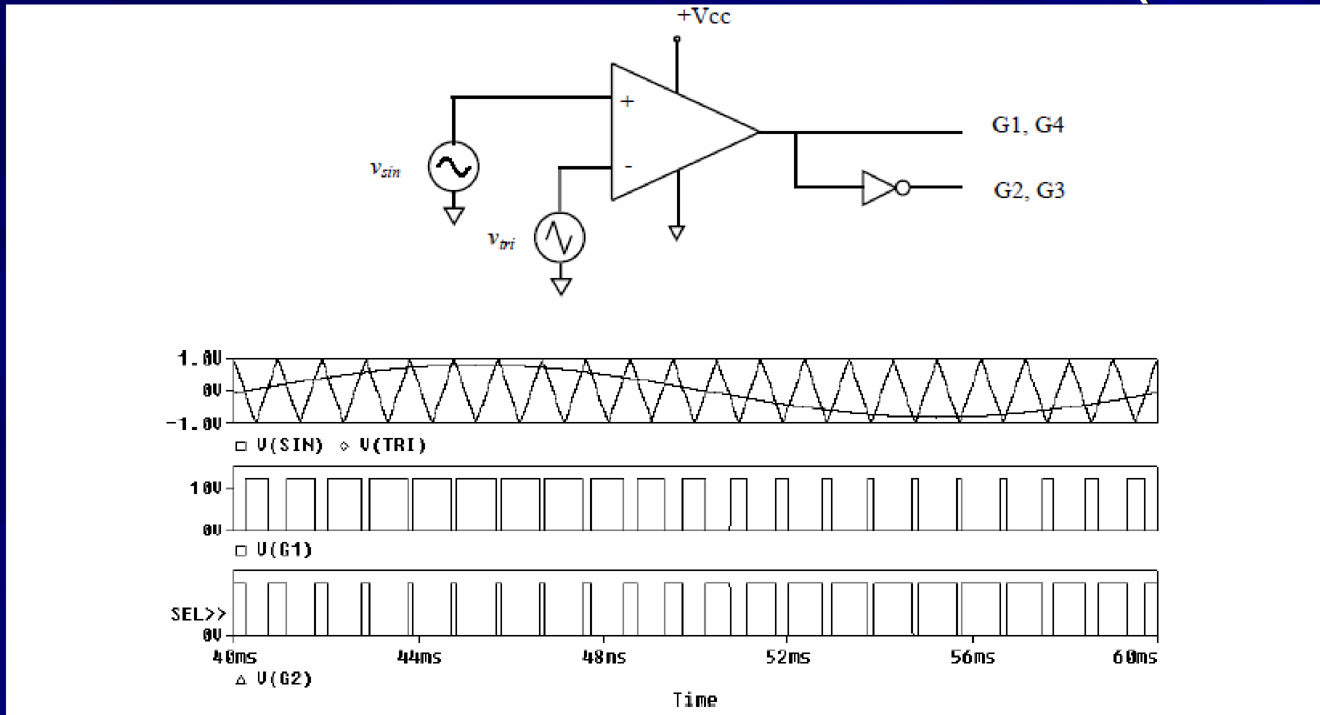


(b)

The H Bridge users MOSFETs or IGBT s to switch the DC input "Vdc "backwards and forwards across the output " Vo" to produce a bi-polar square wave.The sequence of switching the 4 devices is controlled by logic signals sent to the 4 Gates G1-G4 .

Principles of Operation

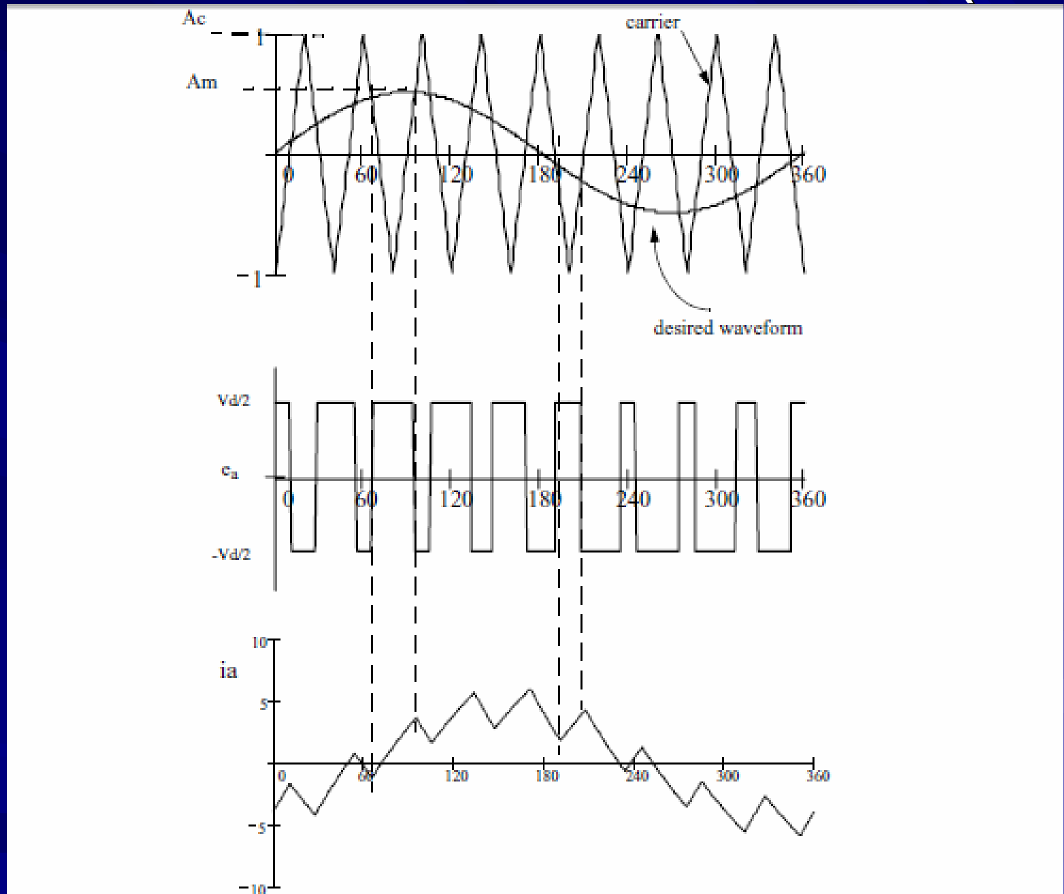
- Pulse Width Modulation Control (PWM)



The H Bridge Gates G1-G4 are fed by the combined signals from the Sine and Triangle Wave generators .The sine wave will be at 50/60Hz and the Triangle wave at the Chopping or Carrier frequency (5kHz -100kHz). This produces the variable mark space pulse output in phase with the controlling Sine Wave.

Principles of Operation

- Pulse Width Modulation Control (PWM)



As can be seen the output can be highly distorted and is dependant upon the Triangle wave Chopping or Carrier frequency.

Principles of Operation

Cascaded H bridge

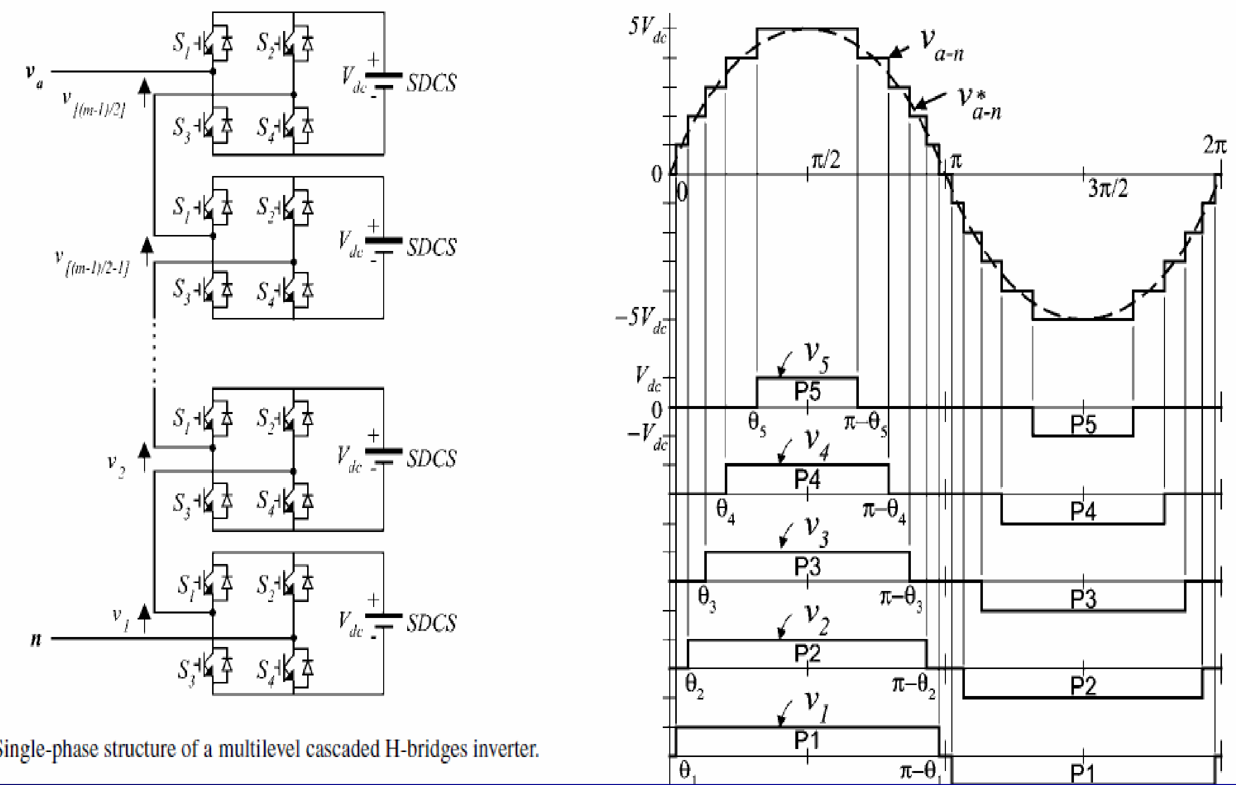


Fig. 1. Single-phase structure of a multilevel cascaded H-bridges inverter.

By Cascading H bridges a sine wave with less distortion can be generated . With an increasing number of levels (above example has 5) a better approximation of a pure sine wave can be achieved, but at the expense of more switching losses.

Principles of Operation

Cascaded H bridge

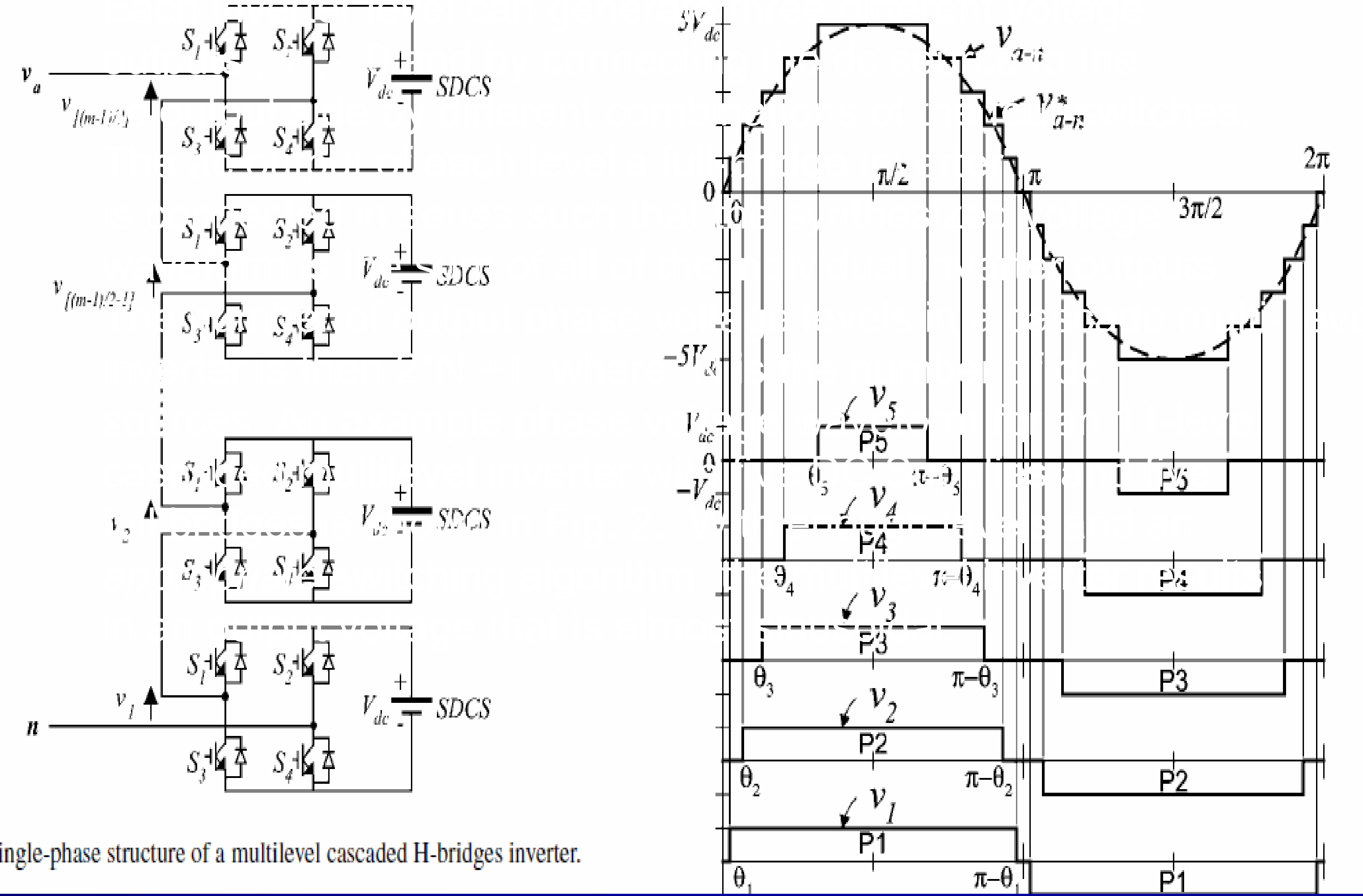


Fig. 1. Single-phase structure of a multilevel cascaded H-bridges inverter.

Types of Inverters

- DC-AC.
- Direct Current input with fixed frequency Alternating Current output
- **Low Power** (<1KW) 12Volt DC battery input with standard 115 Volt at 60Hz or 230 Volt at 50Hz output designed to power common household devices from a car battery

Types: Grid Tie Solar Inverters

- DC-AC **Medium Power** >1KW <100KW
- They can convert the 250V-600 V DC from many Solar panels wired in series to 115V 60Hz or 230V 50Hz and they can feed energy back into the distribution network because they produce alternating current with the same wave shape and frequency as supplied by the distribution system. For safety they can also switch off automatically in the event of a blackout. A sub group are Micro-inverters that convert direct current from individual solar panels into alternating current for the electric grid

Types: Grid Tie Solar Inverters

- A **maximum power point tracker** (or **MPPT**) High efficiency DC-DC converter

This presents an optimal electrical load to a solar panel array and produces a voltage suitable for the load.
PV Cells have a single operating point where the values of the current (I) and Voltage(V) of the cell result in a maximum Power output. These values correspond to a particular load Resistance which is equal to V/I as specified by Ohm's Law. A PV cell has an exponential relationship between current and voltage, (Fig1) and the maximum power point (MPP) occurs at the knee of the curve, where the resistance is equal to the negative of the differential resistance (V/I = -dV/dI). Maximum power point trackers utilize some type of control circuit or logic to search for this point and thus to allow the converter circuit to extract the Maximum Power available from a cell.
Traditional solar inverters perform MPPT for an entire array as a whole. In such systems the same current, dictated by the inverter, flows through all panels in the string. But because different panels have different IV curves, i.e. different MPPs (due to manufacturing tolerance, partial shading, etc.) this architecture means some panels will be performing below their MPP, resulting in the loss of energy. Some companies are now placing peak power point converters into individual panels, allowing each to operate at peak efficiency despite uneven shading, soiling or electrical mismatch.

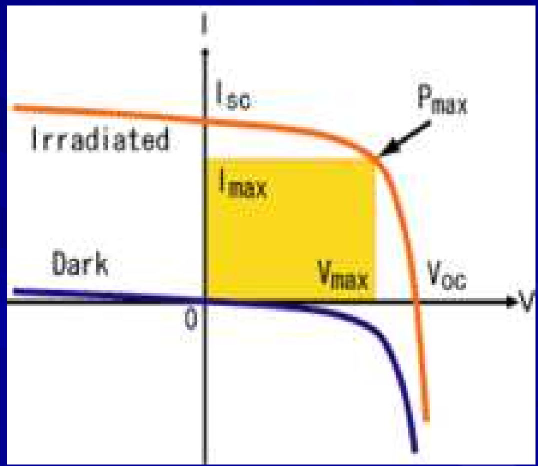


Fig 1

PV Inverter System

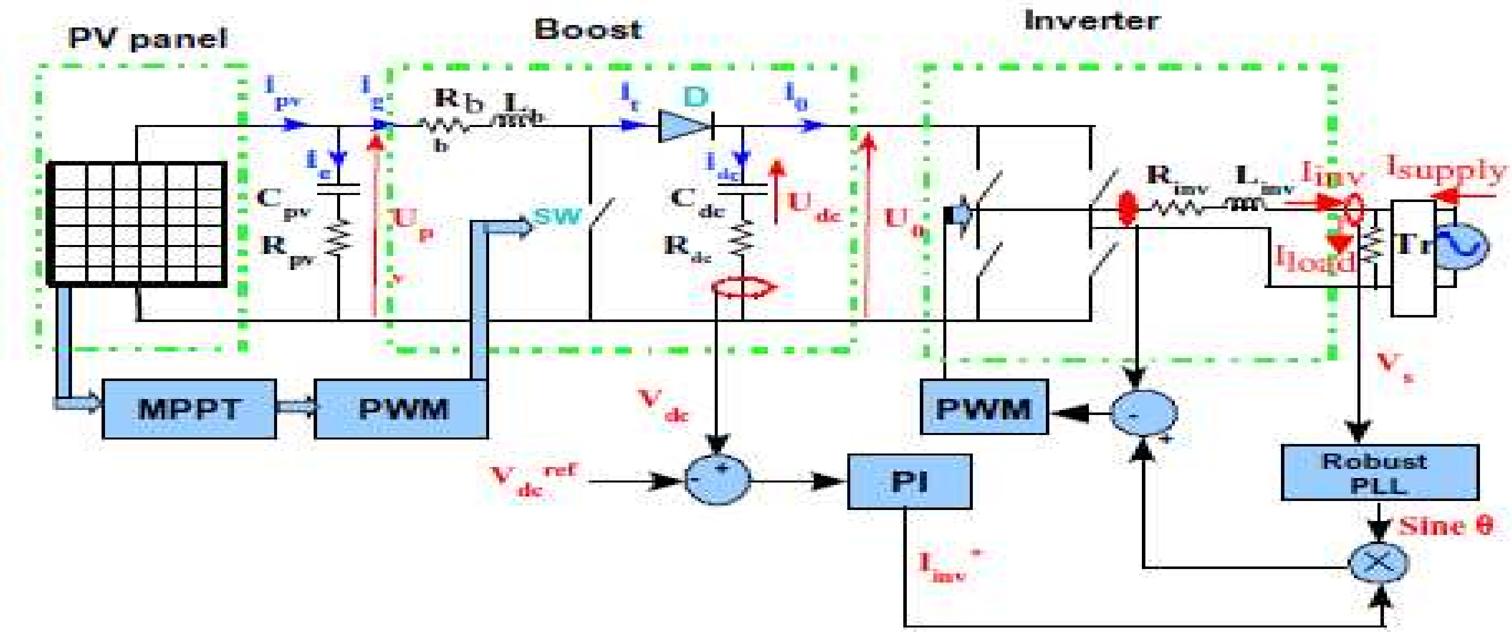


Figure 1. Power circuit of the PV system

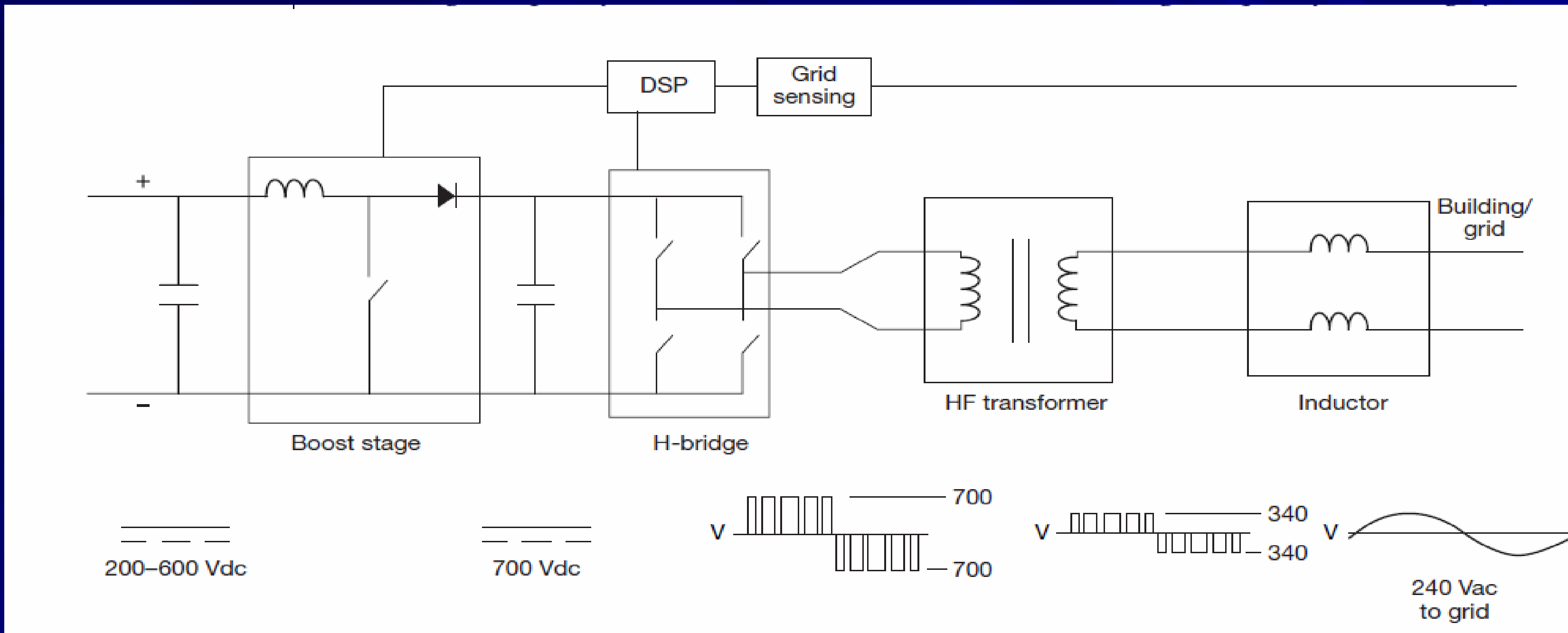
PV panel output controlled by Max Power point tracker (MPPT) .

DC bus Voltage boosted.

DC-AC inverter output power controlled with Pulse Width Modulation (PWM) and phase controlled by Phase locked loop (PLL)

Output to load via Transformer (Tr)

Inverter Topologies
High frequency, Transformer-based

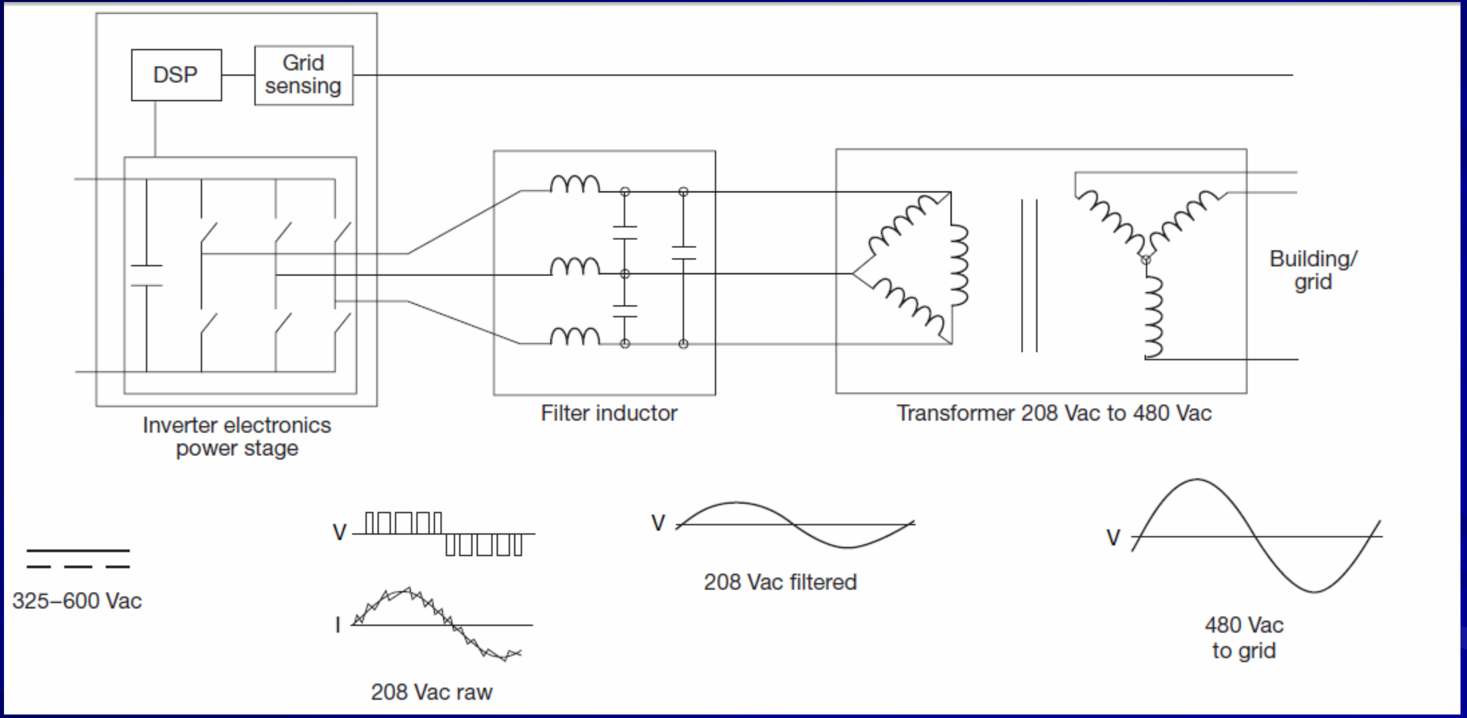


Advantage : HF transformer size and weight reduction to 20% of 60Hz Transformer.

Inverter Topologies

Solar Grid Tie High Power Inverter

- **High Power >100KW DC Input - 3 Phase AC output**



Large 3-phase inverter for commercial and utility scale grid-tied PV systems .Inverters that target commercial applications are often compatible with 208, 240, 277, and/or 480VAC.

International Standards

- PV Inverters EN50530
- European Standard for measuring the over-all efficiency of PV inverters. The new testing introduced in the document provides the basis for a comprehensive characterization of the performance of PV inverters.
- The prEN 50530 introduces the definition of the *overall efficiency*, taking into account both, *conversion efficiency* as well as the *Maximum Power Point Tracking* (MPPT) efficiency.

International Standards

- IEEE519
- Harmonics cause problems in power systems
- • IEEE Std 519-1992 provides a basis for limiting Voltage supply harmonics by controlling current harmonics of the inverter connected to the grid at the point of common coupling (PCC).
- The objectives of the current limits are to limit the maximum individual frequency voltage harmonic to 3% of the fundamental and the voltage THD to 5% for systems without a major parallel resonance at one of the injected frequencies."

International Standards

- IEEE519
- Voltage Harmonic limits

Harmonic Limits

Voltage Distortion Limits

Bus Voltage at PCC	Individual Voltage Distortion (%)	Total Voltage Distortion THD (%)
69 kV and below	3.0	5.0
69.001 kV through 161 kV	1.5	2.5
161.001 kV and above	1.0	1.5

NOTE: High-voltage systems can have up to 2.0% THD where the cause is an HVDC terminal that will attenuate by the time it is tapped for a user.

International Standards

- IEEE519
- Current Harmonic Limits

Harmonic Limits

Current Distortion Limits for General Distribution Systems (120 V Through 69000 V)

Maximum Harmonic Current Distortion in Percent of I_L						
Individual Harmonic Order (Odd Harmonics)						
I_{sc}/I_L	<11	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h$	TDD
<20*	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

Even harmonics are limited to 25% of the odd harmonic limits above.

Current distortions that result in a dc offset, e.g. half-wave converters, are not allowed.

* All power generation equipment is limited to these values of current distortion, regardless of actual I_{sc}/I_L.

Where

I_{sc} = maximum short-circuit current at PCC.

I_L = maximum demand load current (fundamental frequency component) at PCC.

TDD = Total demand distortion (RSS), harmonic current distortion in % of maximum demand load current (15 or 30 min demand).

PCC = Point of common coupling.

International Standards

- IEEE519

Harmonic Limits

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- TDD = Total demand distortion (RSS), harmonic current distortion in % of maximum demand load current (15 or 30 min demand).
- PCC = Point of common coupling.

- Current harmonic limits vary
  - System short circuit vs. load size (I_{SC}/I_L)
    - Larger load: stricter limits
    - Weaker system: stricter limits
  - Higher order current harmonics
    - Stricter limits for higher order harmonics
  - Even order current harmonics
    - Stricter limits: 25% of odd harmonics
  - Dc offset
    - Not allowed

International Standards

- AC Current Harmonics (IEEE 1547 limits)

Table 3. Maximum Harmonic Current Distortion in Percent of Current[a] (I)						
Individual Harmonic Order h (Odd Harmonics)[b]	$h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h$	Total Demand Distortion (TDD)
Percent (%)	4.0	2.0	1.5	0.6	0.3	5.0

(a) I = the greater of the Local EPS maximum load current integrated demand (15 or 30 min) without the DR unit, or the DR unit rated current capacity (transformed to the PCC when a transformer exists between the DR unit and the PCC).

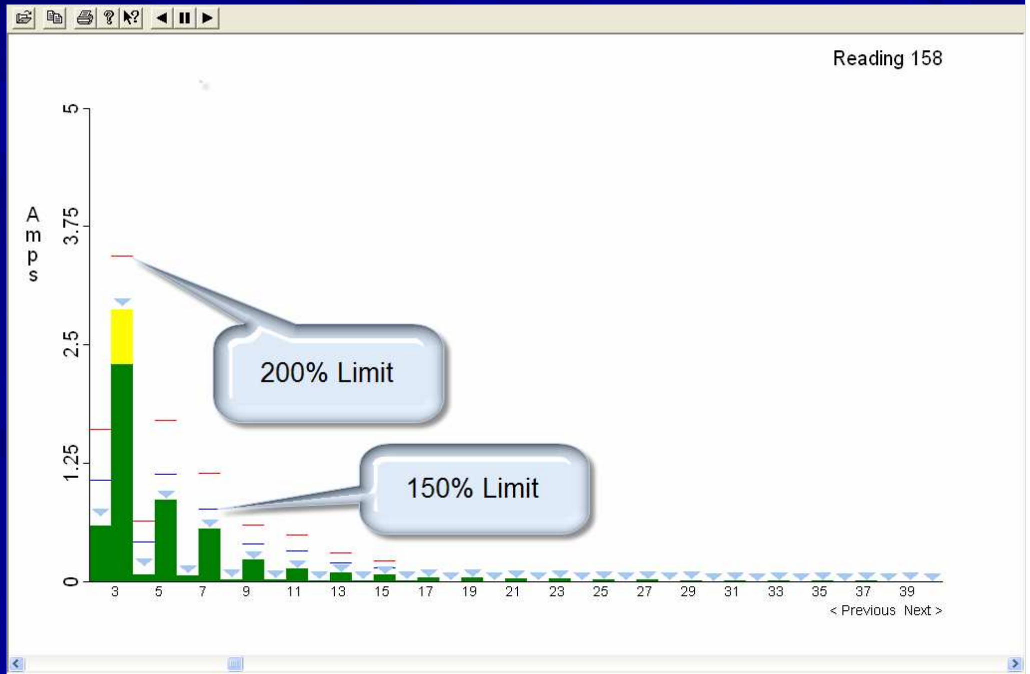
(b) Even harmonics are limited to 25% of the odd harmonic limits above.

- Flicker shall not cause irritation to humans or cause equipment mis-operations.

International Standards

- IEC61000-3-2 Harmonic limits for Systems up to 16A .
- IEC61000-3-12 Harmonic limits for systems up to 75A

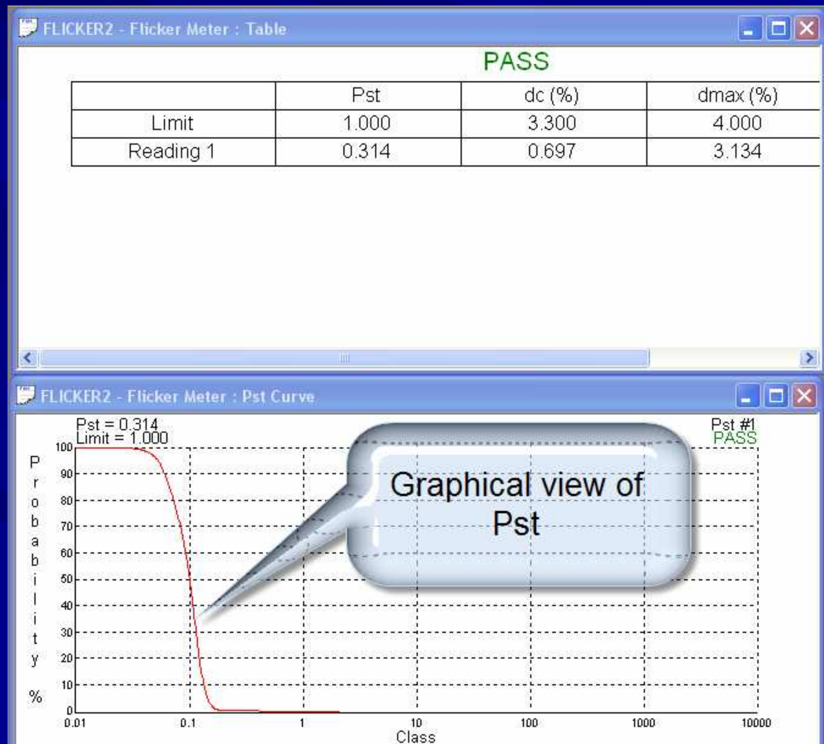
Voltech's fully compliant software for Harmonic and Flicker measurements



International Standards

- IEC61000-3-3 Flicker Limits for systems up to 16A
- IEC61000-3-11 Flicker Limits for systems up to 75A

Sample from Voltech's Flicker Software



Test Equipment

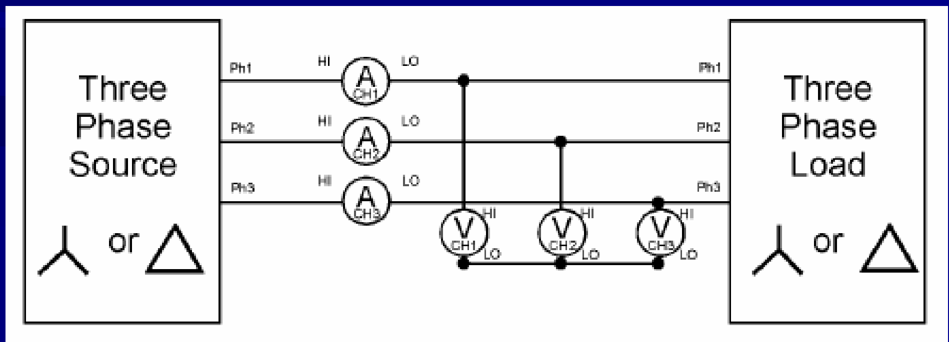
Voltech's PM6000 Power Analyzer

Can measure 3phase input and 3phase output Power Simultaneously

10MHz Bandwidth;- Ideal for Inverter measurements

PM6000:-Connectivity

Rear of PM6000 .Direct input 2kV peak & 30A RMS or extended current range via Current Transformers

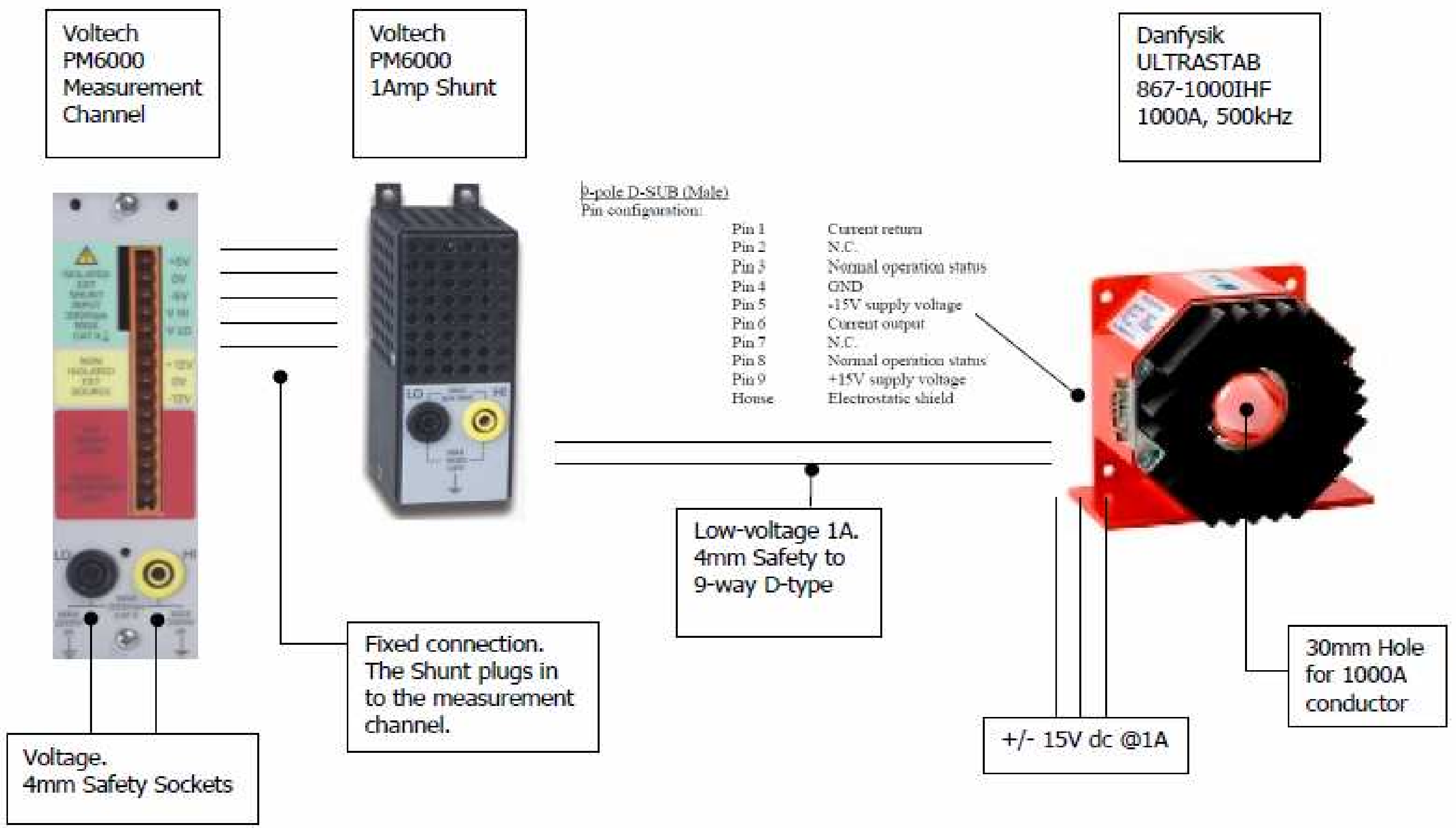


CL1000 converts 1000A to 1A

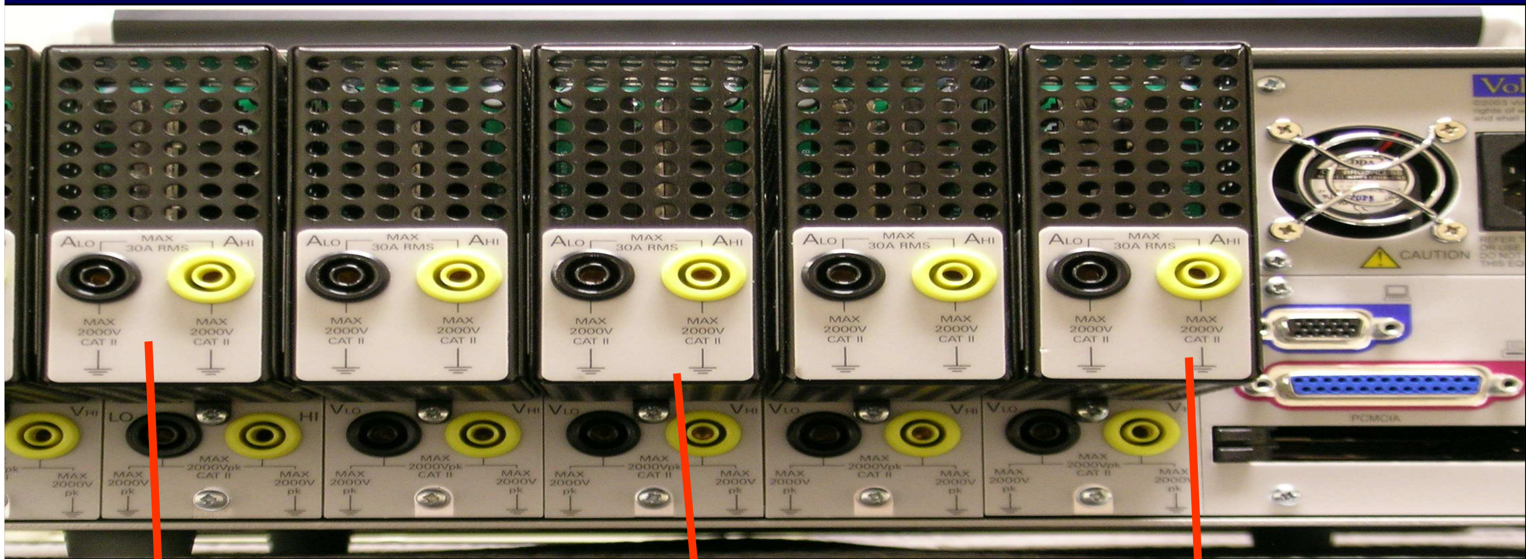
High Bandwidth CTs from Danfysik

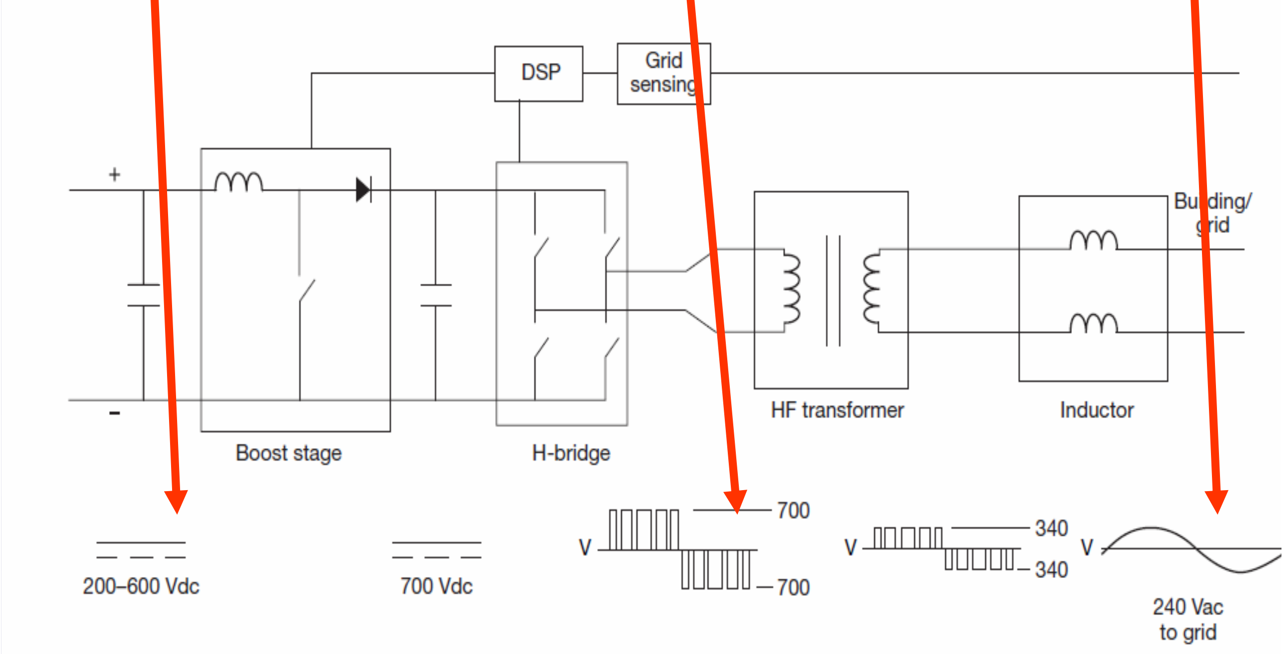
For High Bandwidth Current Measurements above 30A use Danfysik CTs

Connections for Danfysik Current Transducers to a Voltech PM6000 Power Analyser.



DC-AC Inverter measurements





Power & Efficiency can be measured across the whole system In real time With Voltech'sPM6000

Ch1 240v AC Output

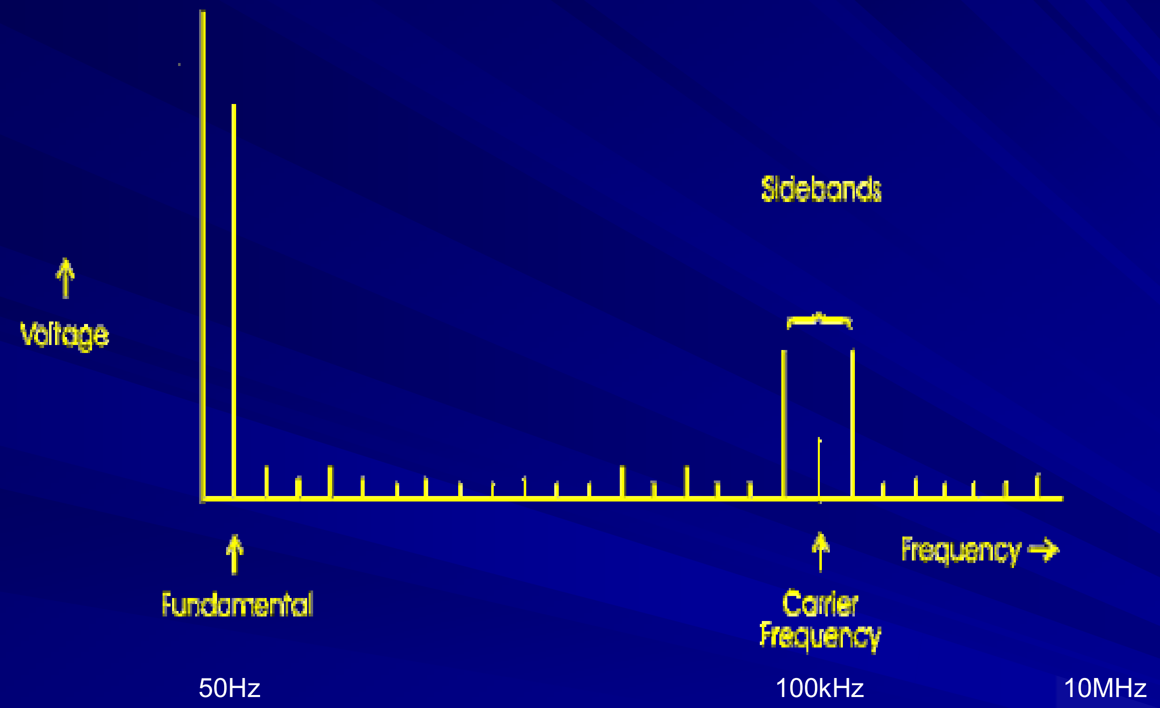
Ch2 PWM 340V

Ch3 PWM 700V

Ch4 DC Bus 700V

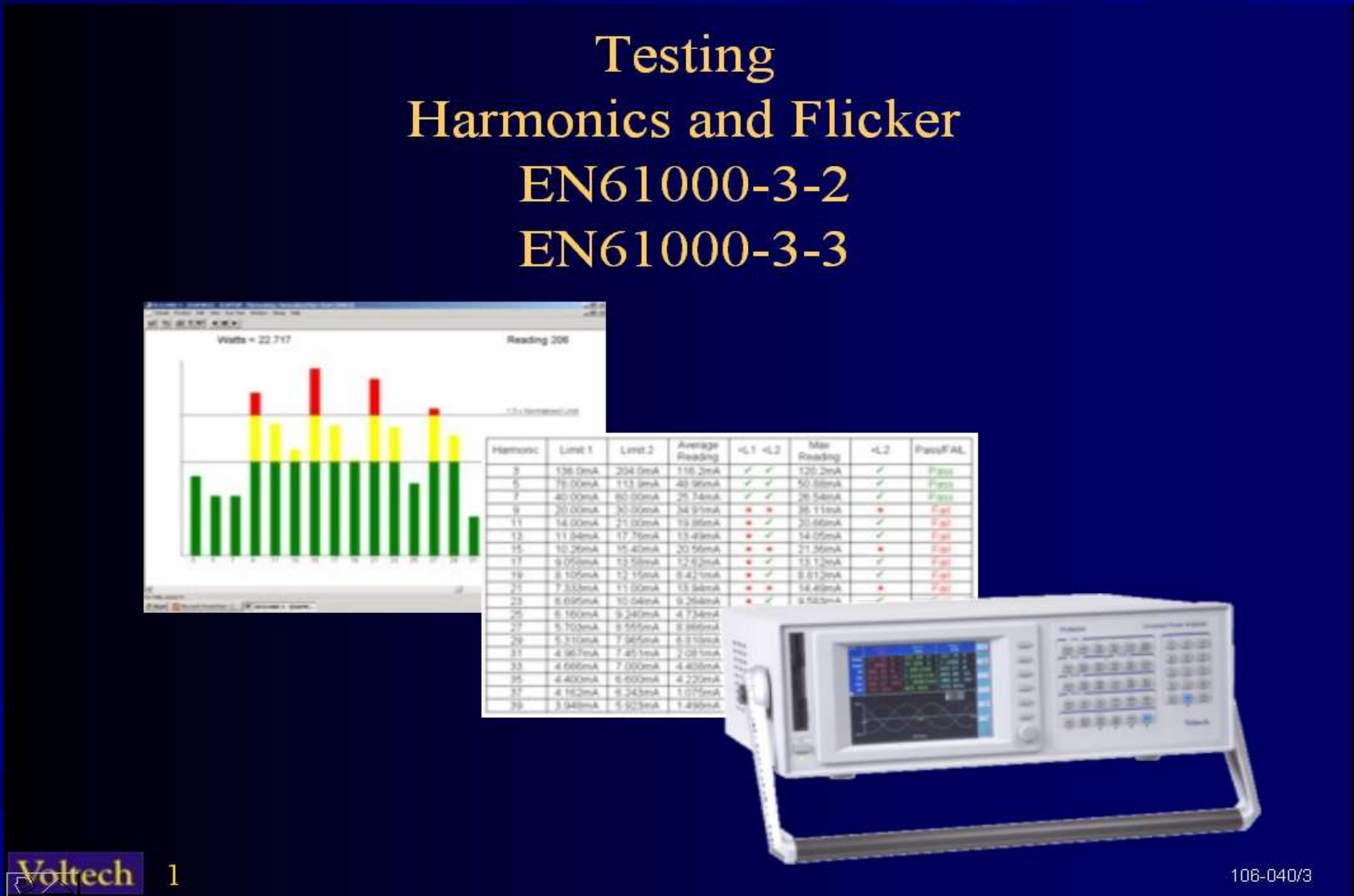
Ch5 DC Input

PM6000 PMW Measurements



Voltech's PM6000 Power analyzer has a special mode for measuring Pulse Width Modulated waveforms . With the carrier frequency at 100kHz it can measure up to the 99th Power, voltage or current harmonic in real time with the highest industry accuracy possible

Inverter Transformer Testing



PM6000 and IEC software for full compliance testing