Integration of Renewable Energy Power Stations with Remote Monitoring and Control system for Smart Grid Applications

Jiju K.
Senior Engineer

Aby Joseph
Joint Director

Power Electronics Group
Centre for Development of Advanced Computing
Thiruvananthapuram – India

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Agenda

- What, Why, How Power Electronics?
- What is Smart Grid?
- Grid Interactive Renewable Energy Source Power Conditioning Unit
- Importance of Remote Monitoring and Control of Power Stations

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What, Why, How Power Electronics?

What?

Solid-state electronics for the control and conversion of electric power

Why?

To use power efficiently you need power electronics

How?

- Applications of PE
- Power Generation
- Power Transmission
- Power Distribution

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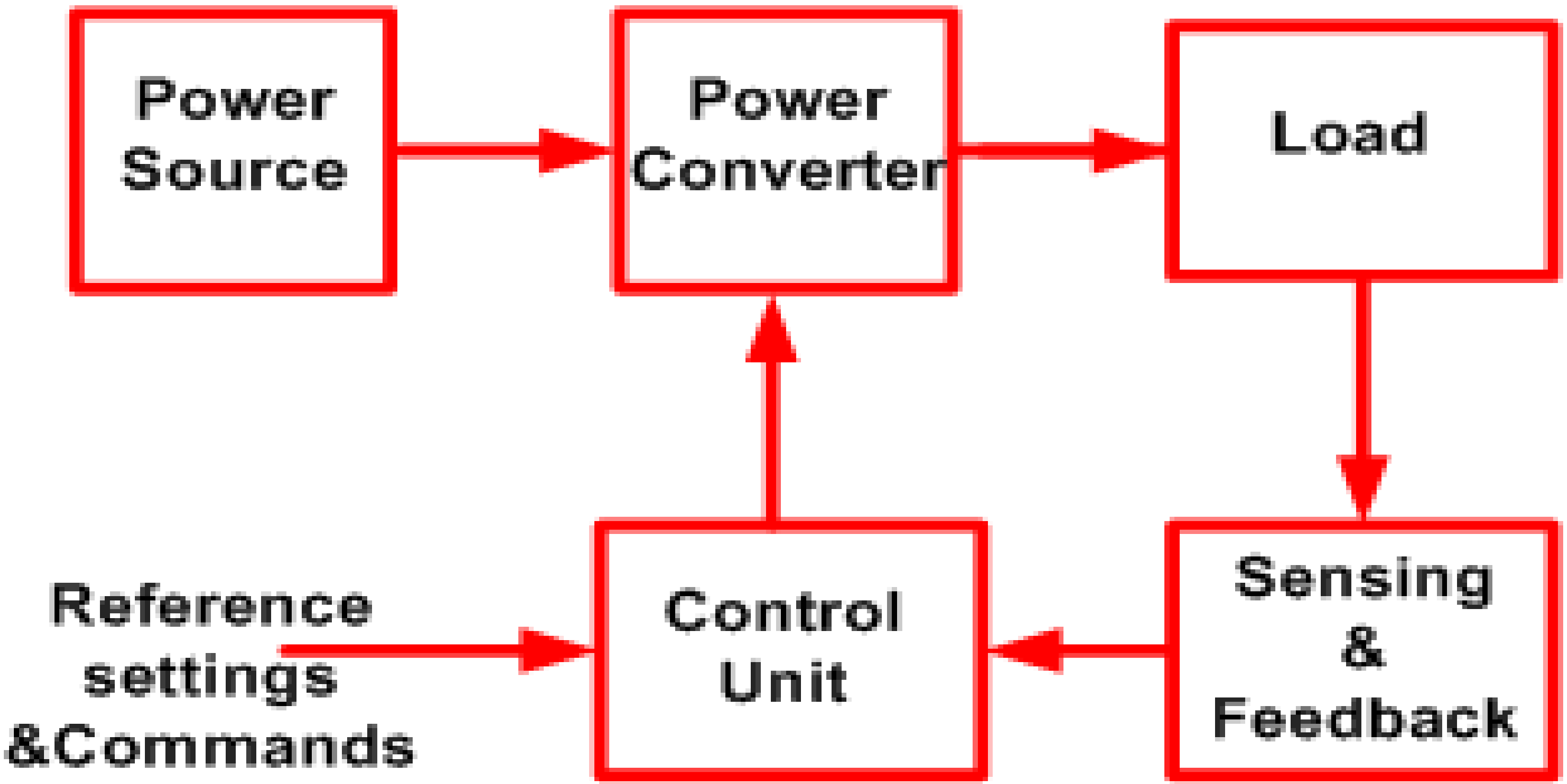
PE System



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PE System

- ❑ AC –DC Converters (Rectifiers)
- ❑DC- AC Converters (Inverters)
- ❑DC –DC Converters (Choppers)
- ❑AC –AC Converters (Cyclo Converters)
- ❑AC Regulators

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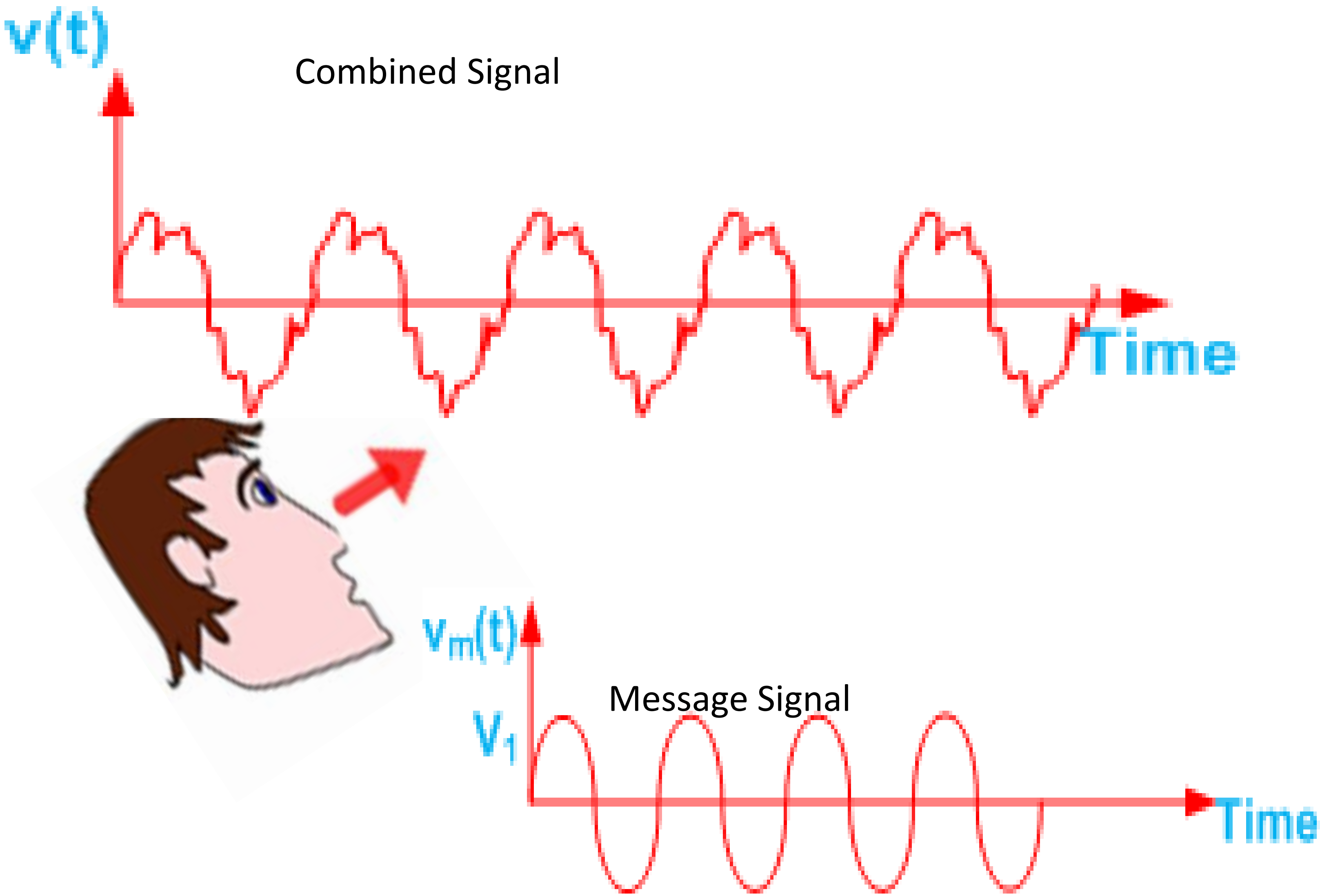
Some facts



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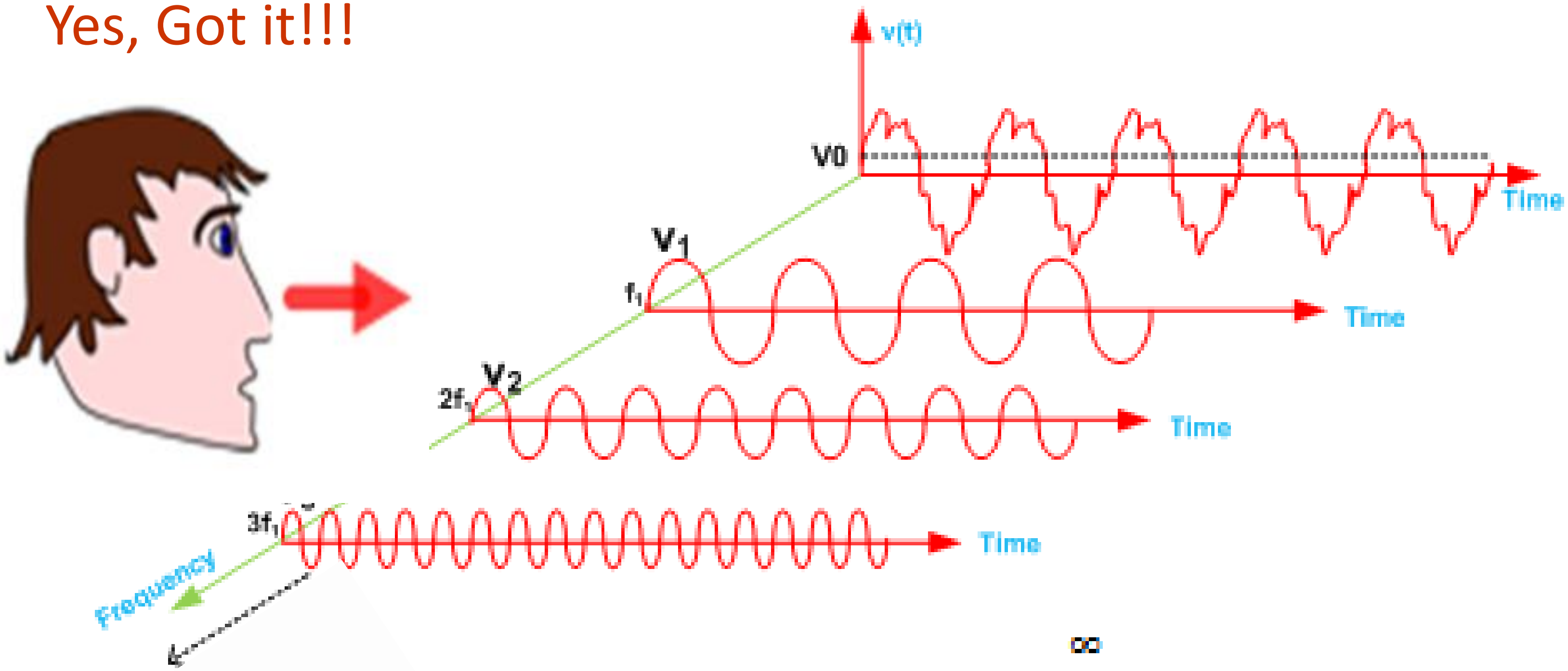
Yes, Got it!!!



$$v(t) = a_0 + \sum_{n=1}^{\infty} (a_n \cos n\Omega_0 t + b_n \sin n\Omega_0 t)$$

$$\Omega_0 = \frac{2\pi}{T} \text{ ; } T = \text{Period}$$

$$V_o = \frac{1}{T} \int_{<T>} v(t)\, dt$$

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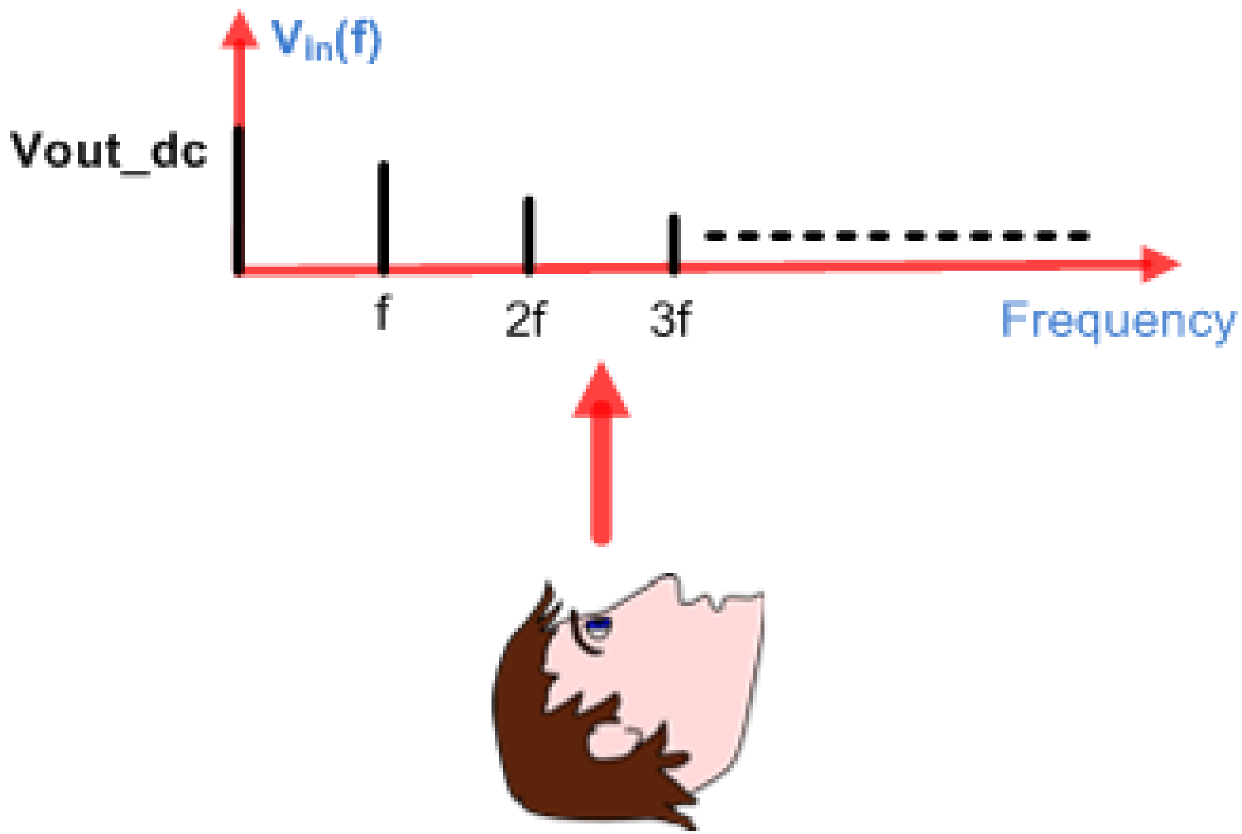
Spectrum

- Side View is called Spectrum



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Frequency

- *Information is coded Inside the Frequency*
- Need to extract the required frequency
- All systems are doing filtering

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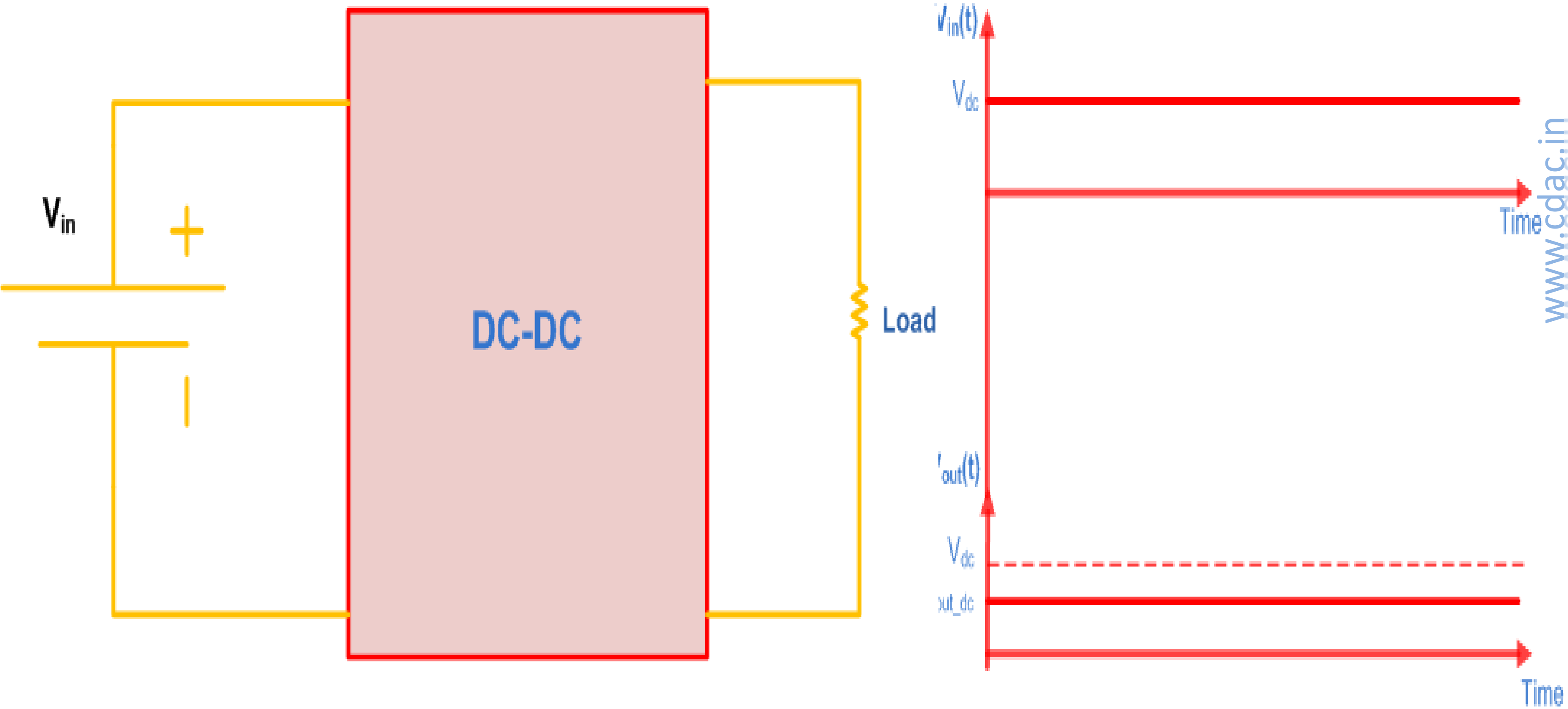
DC - DC



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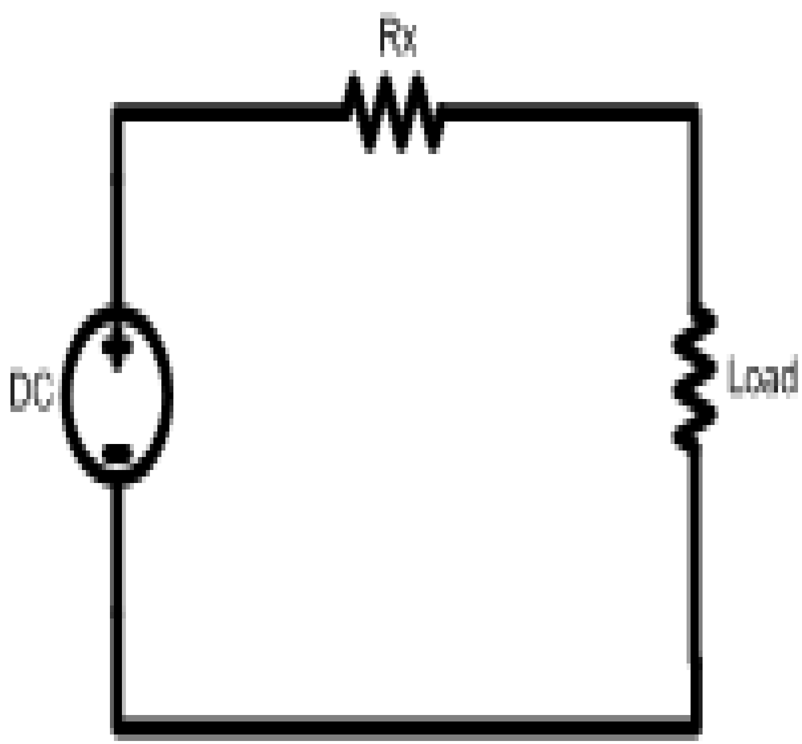
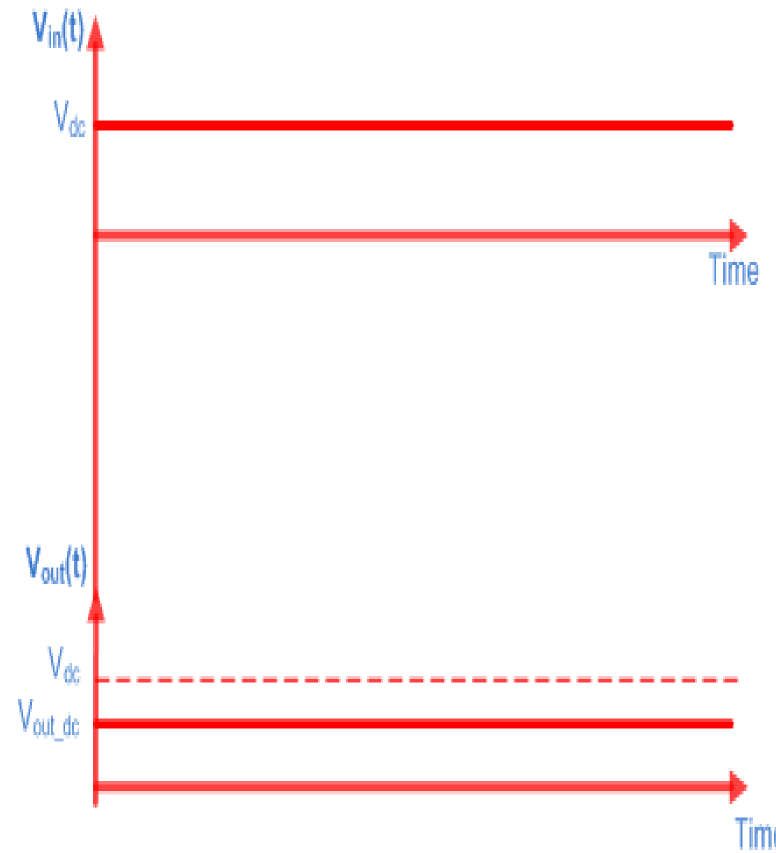
Voltage Divider





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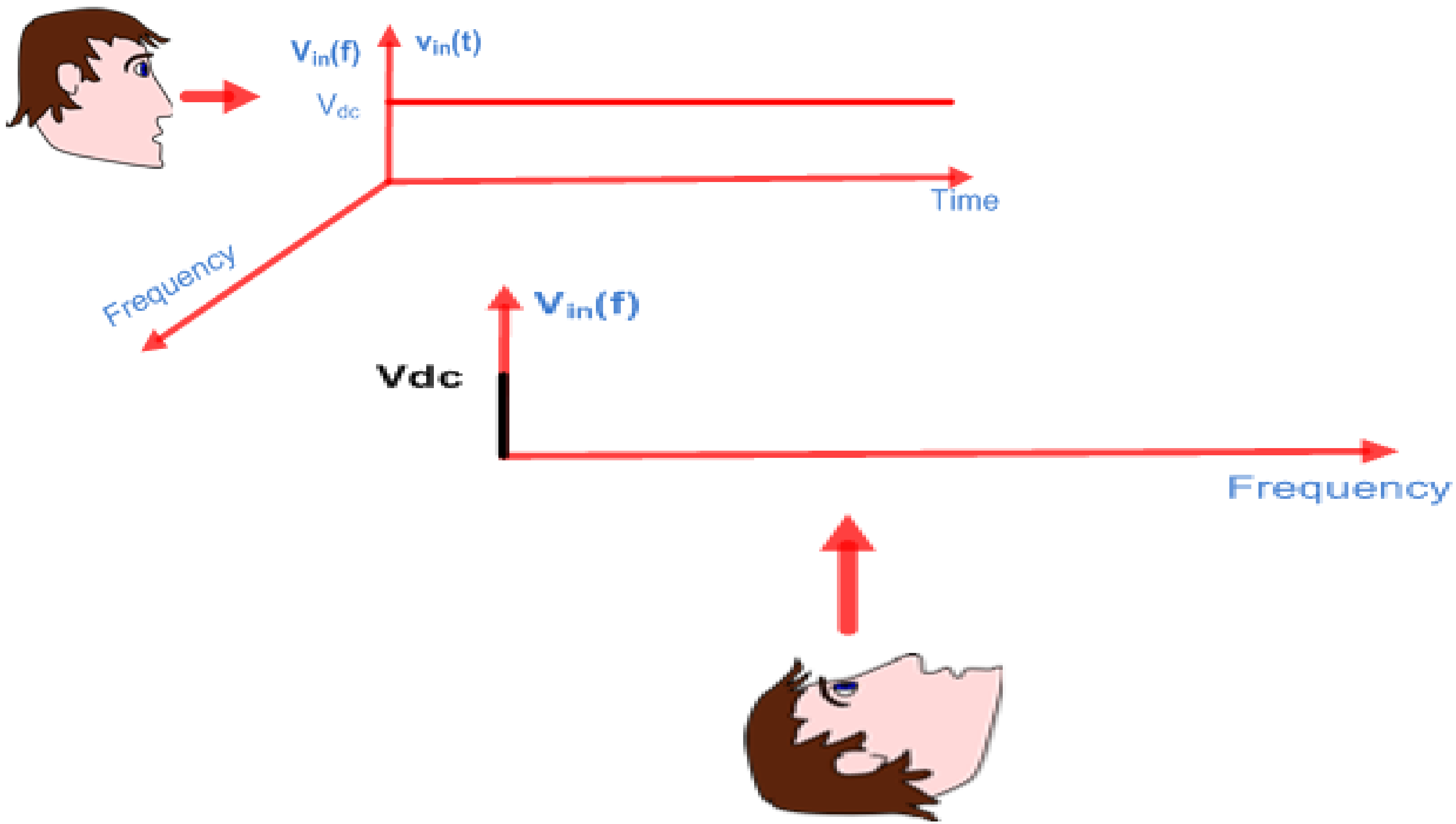

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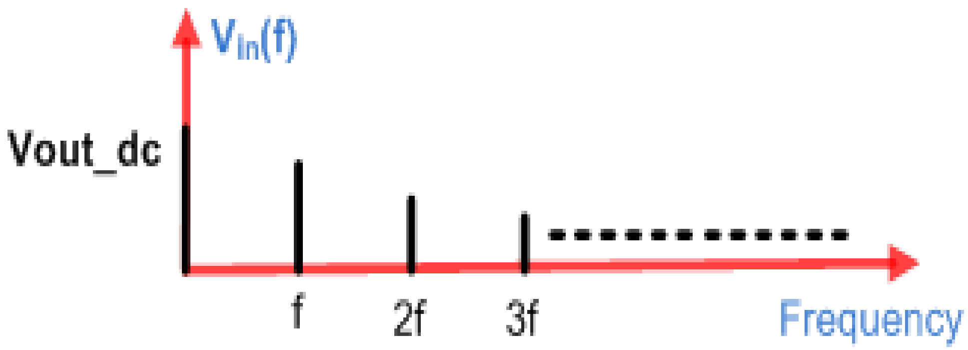

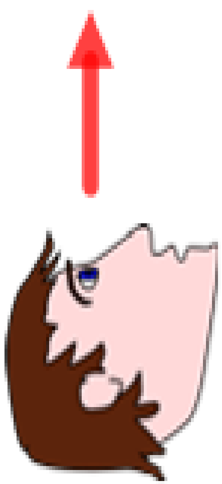

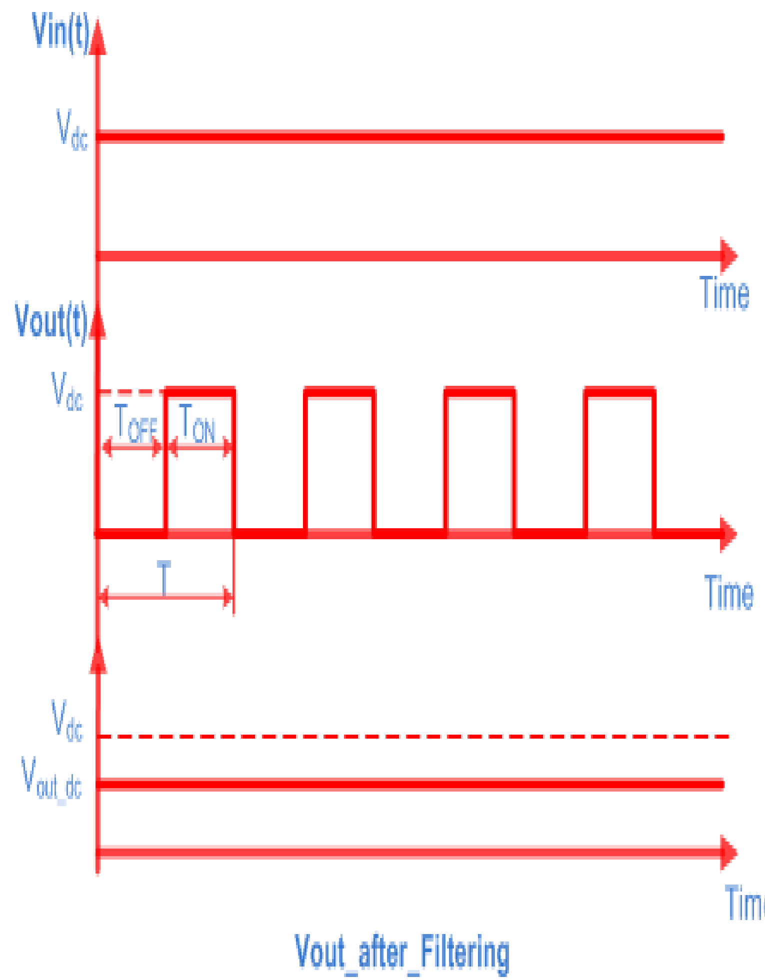

$$V_{0=a_0} = \frac{1}{T}\int_{\langle T\rangle} v(t)\,dt = \delta\, Vdc\,;\ \delta = \frac{T_{ON}}{T}$$

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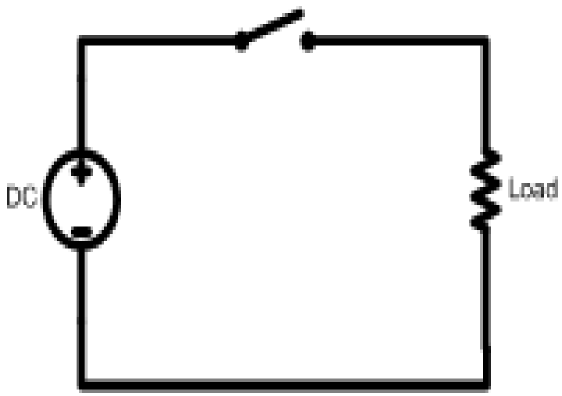

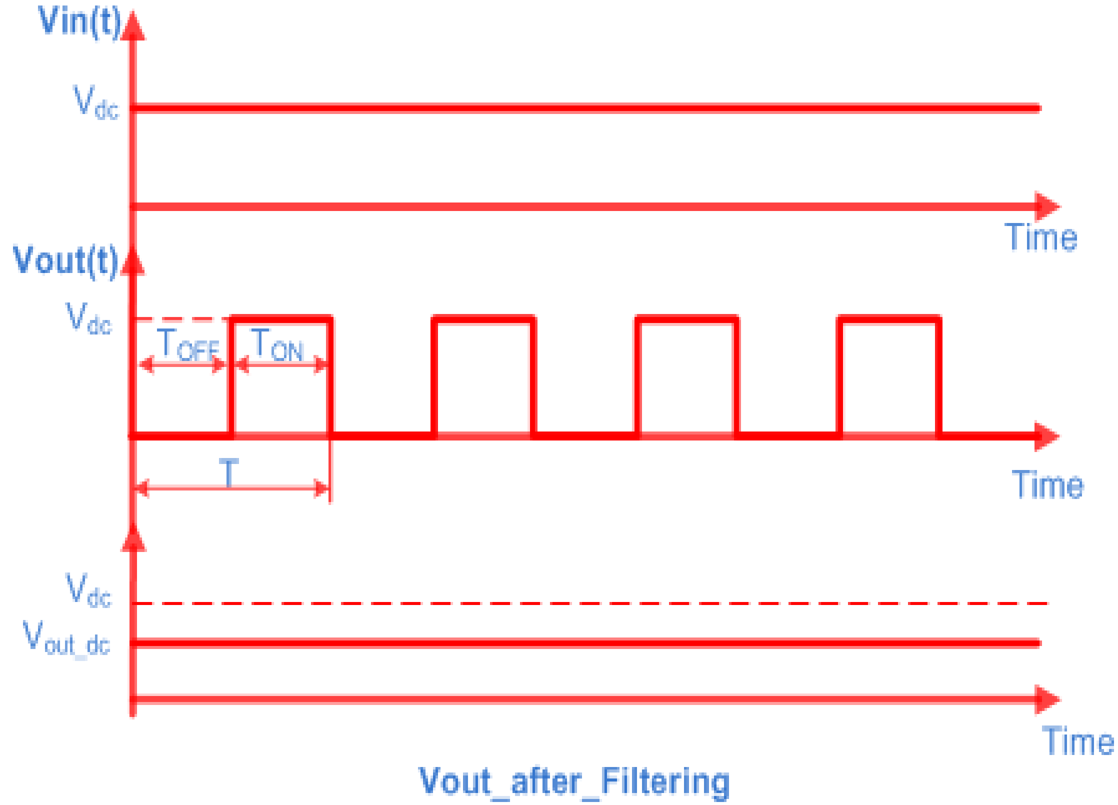

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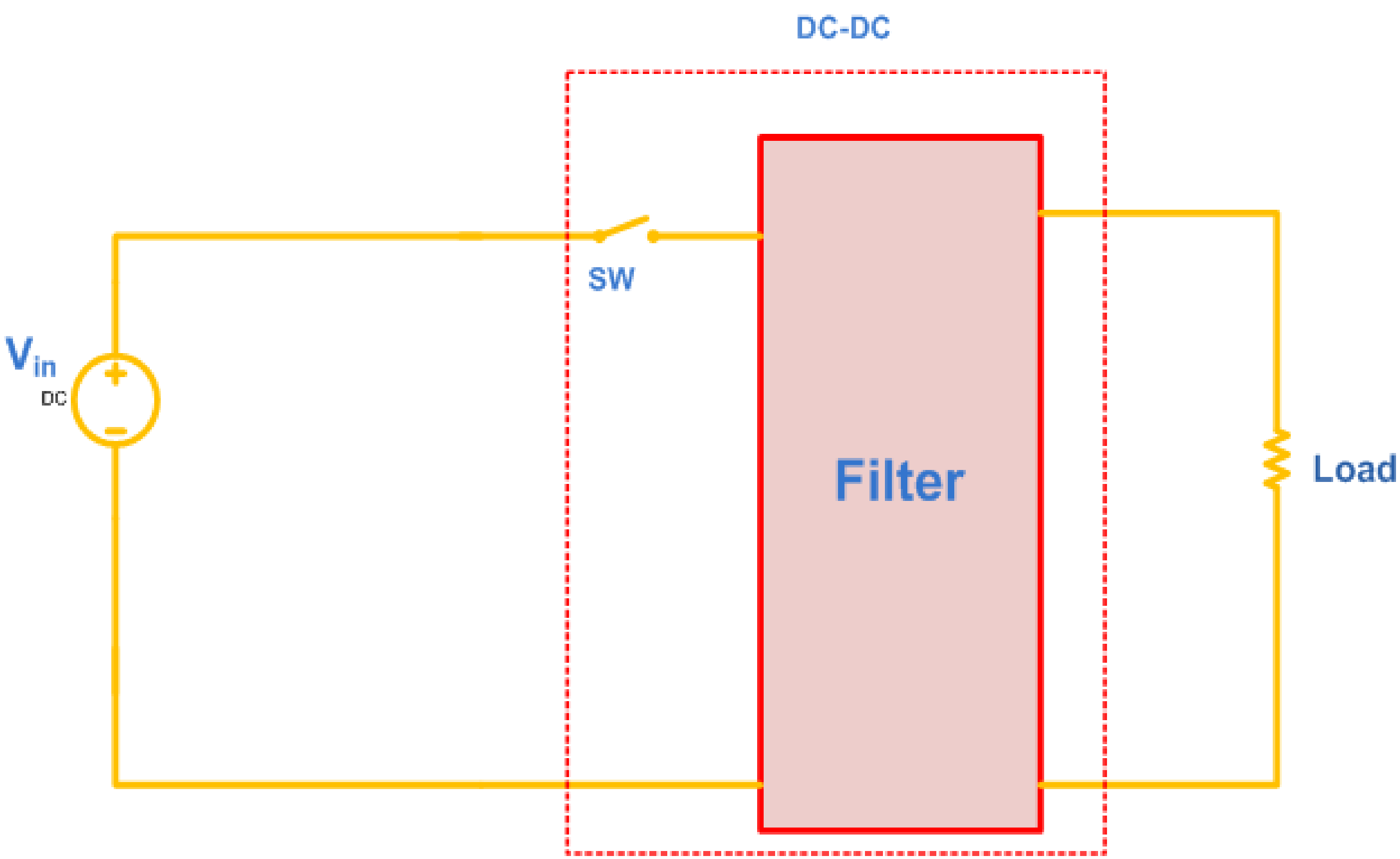
DC-DC



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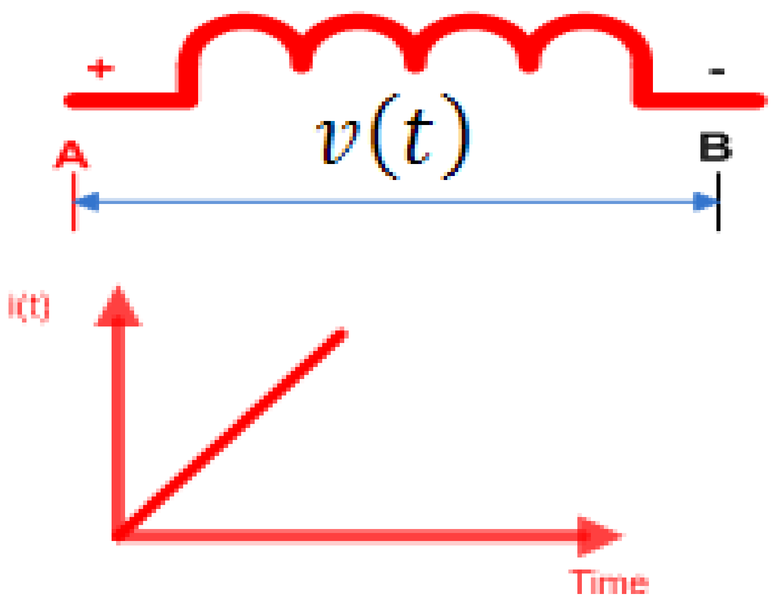
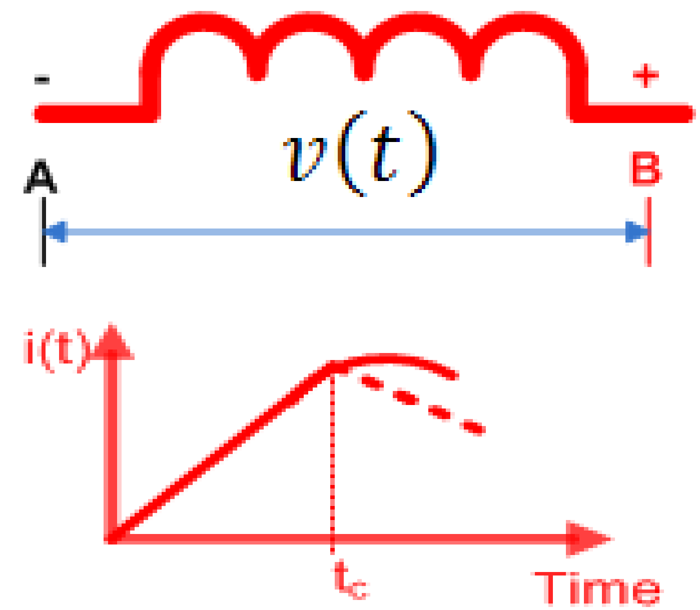
Inductor





$$v(t) = L\frac{di(t)}{dt}$$

$$i(t) = \int v(t)\,dt$$

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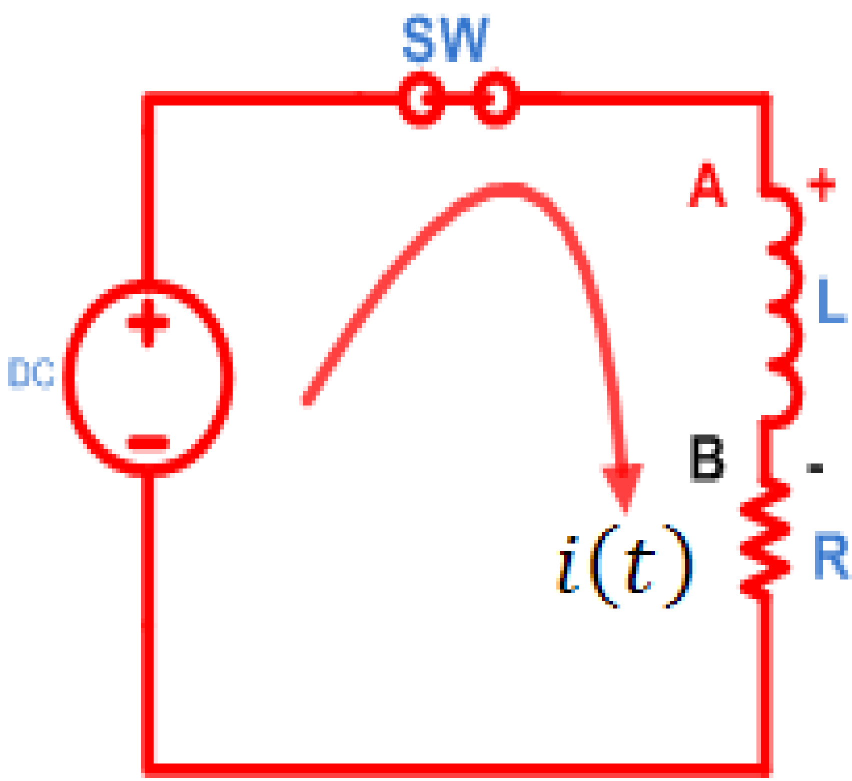
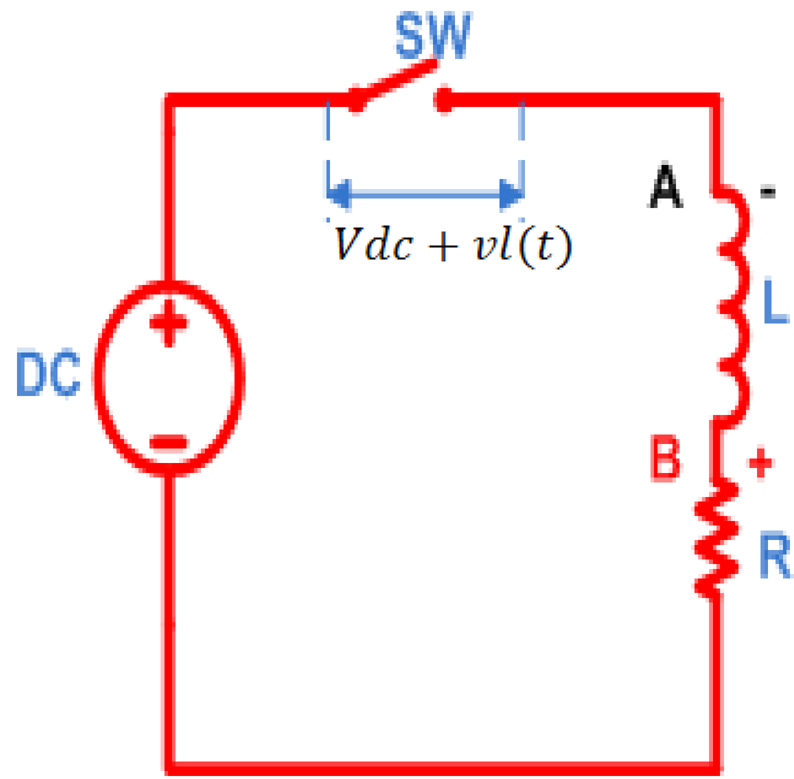
Inductor



SW ON



SW OFF

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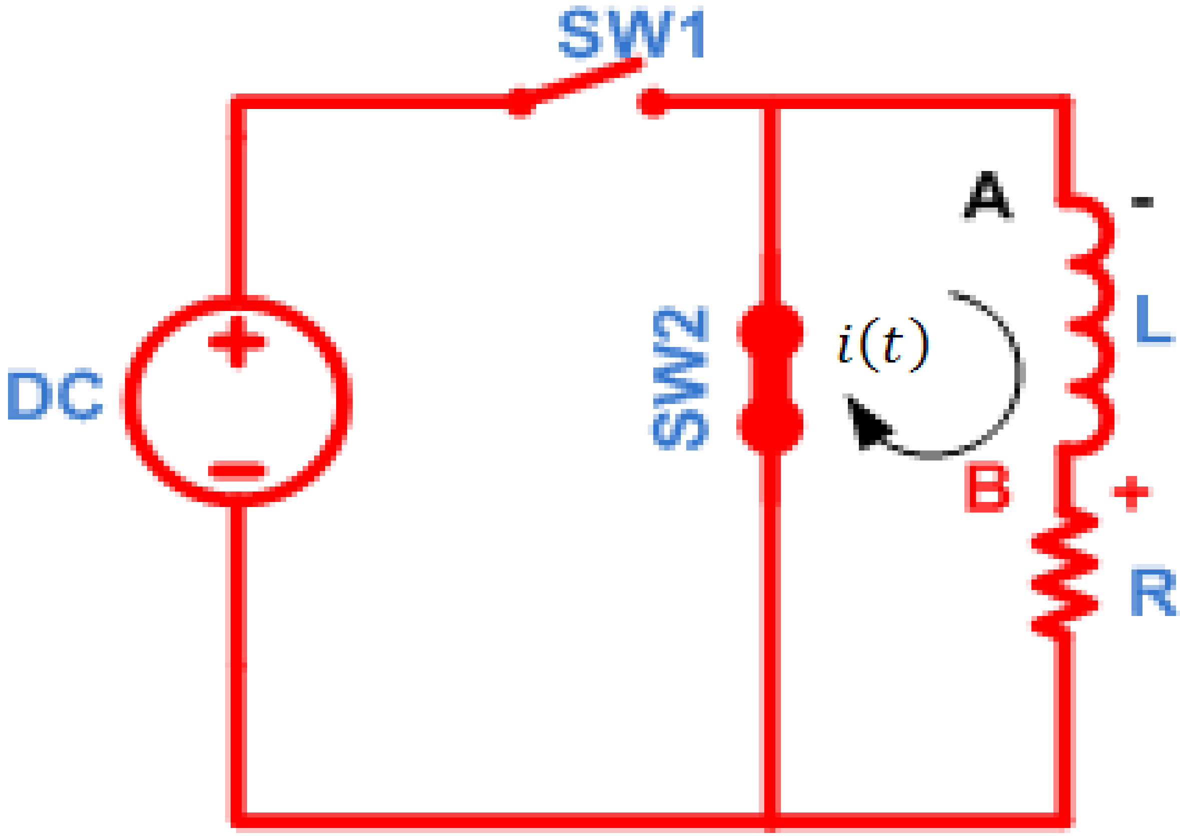
Solution



SW1 OFF and SW2 ON

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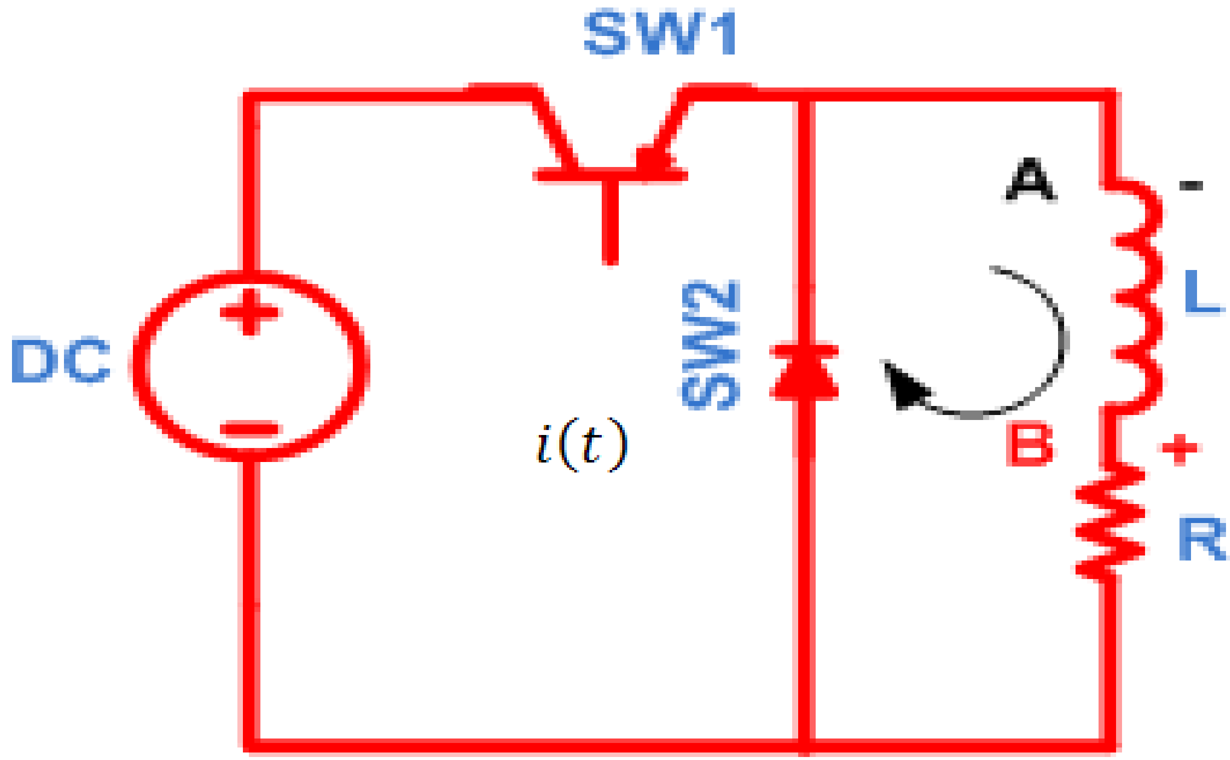
Switch ????



SW1 OFF and SW2 ON

$$V_{0=a_0} = \frac{1}{T}\int_{<T>} v(t)dt = \delta Vdc \,; \delta = \frac{T_{ON}}{T}$$

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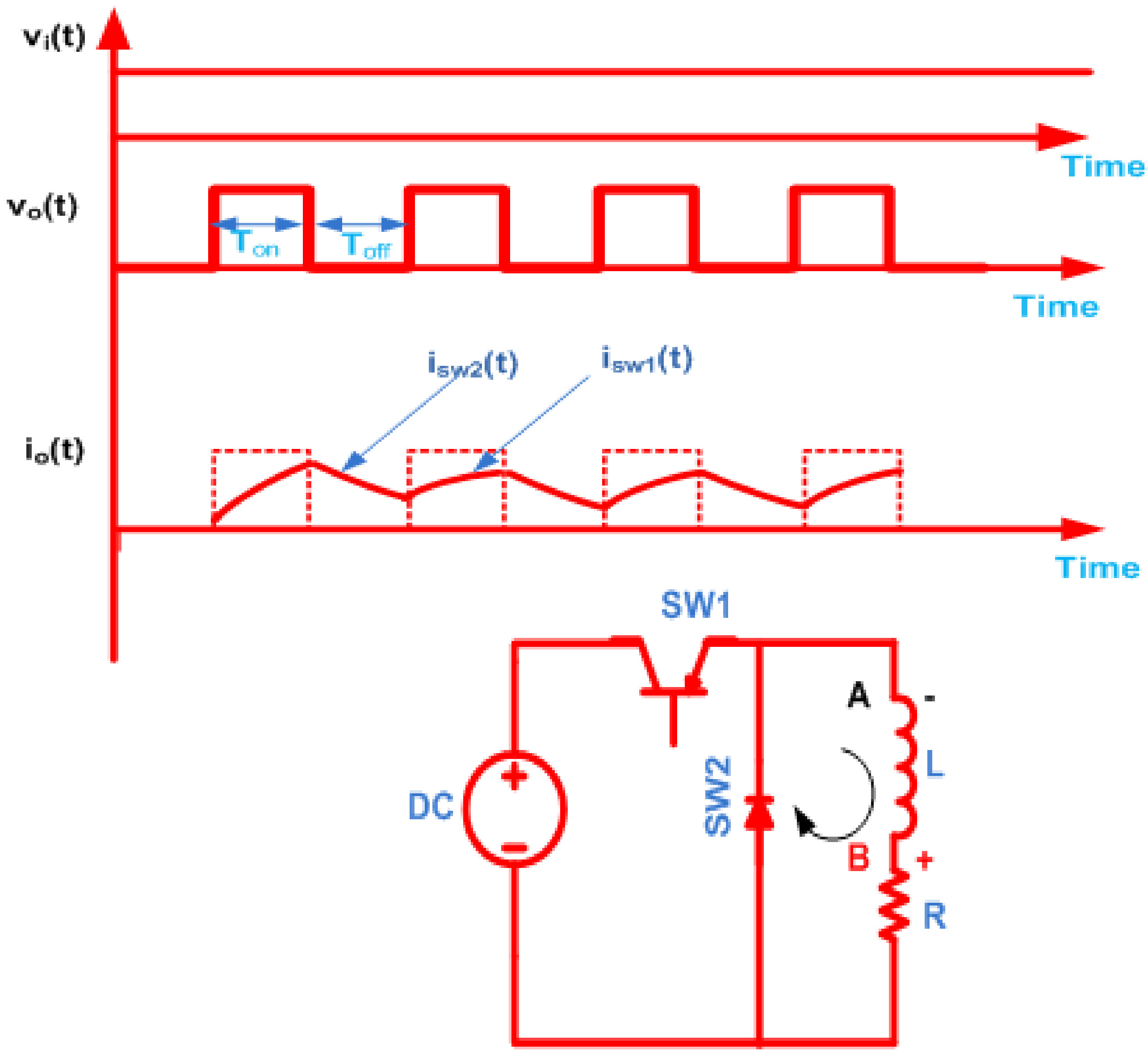
Waveforms

Voltage and Current Waveform



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Boost ???

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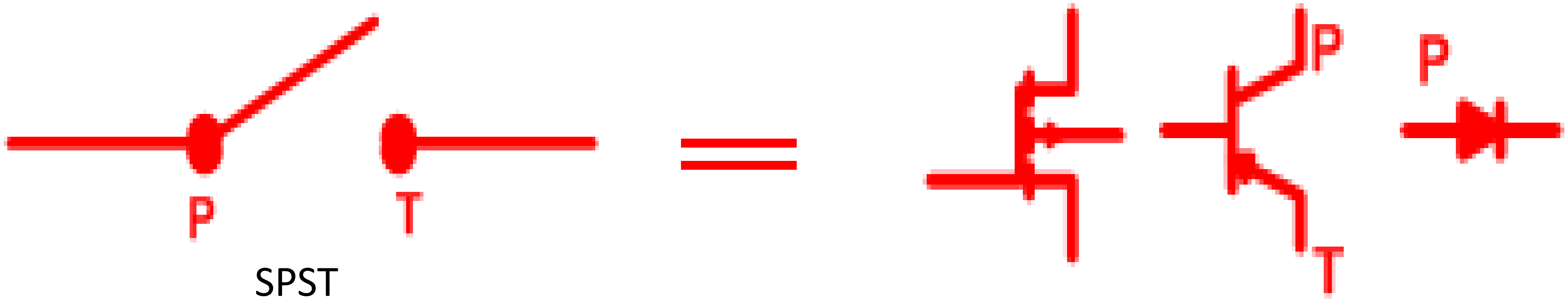
SWITCH



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Ideal Switch

- $R_{on} = 0$, $R_{off} = \infty$
- When ON Should withstand up to Infinite current and Von = 0
- When OFF Should pass zero current and withstand up to Infinite Voltages
- Zero delay on switching ; ie Ton = 0 ; Toff = 0;
- No losses
- ON – OFF is Fully controllable
- No Power to drive the Switch

There is no Such Switch in Practices

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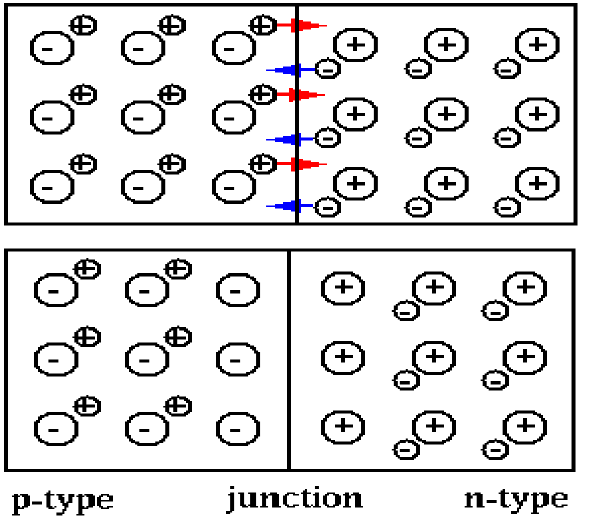
Drift and Diffusion In Semi Conductors

- Motion of Carriers Under the influence of an electric filed

- Motion of carriers from Higher concentration to lower Concentration

Ton < Toff



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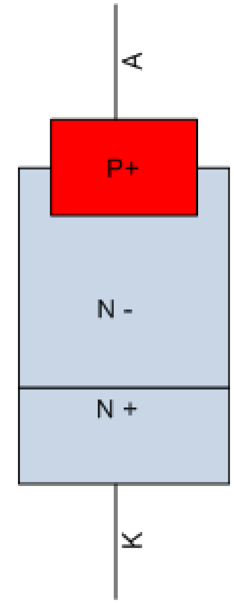
Power Diode



- Conductivity Modulation
- Drift Region
- Present in almost all Power Semiconductor Devices

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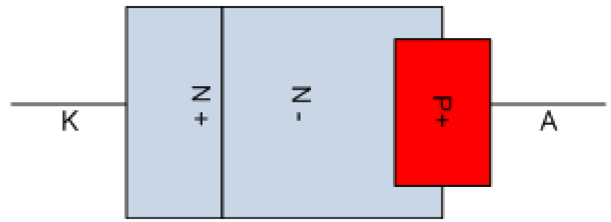
Types Power Diode



- General purpose
- Fast Recovery
- Schottky

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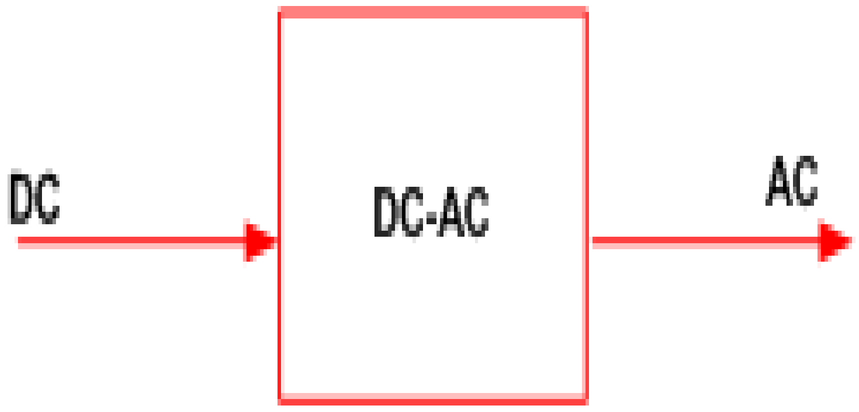
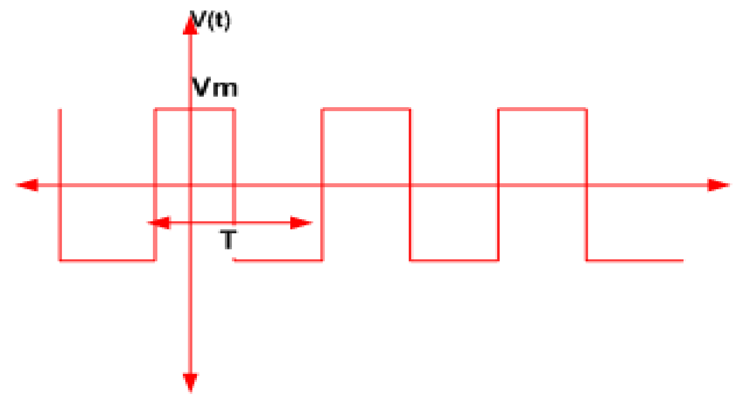
DC-AC





$$v(t) = \frac{4}{n\pi}\cos n\Omega_0 t$$

$$n = 1, 3, 5 \ldots\ldots$$

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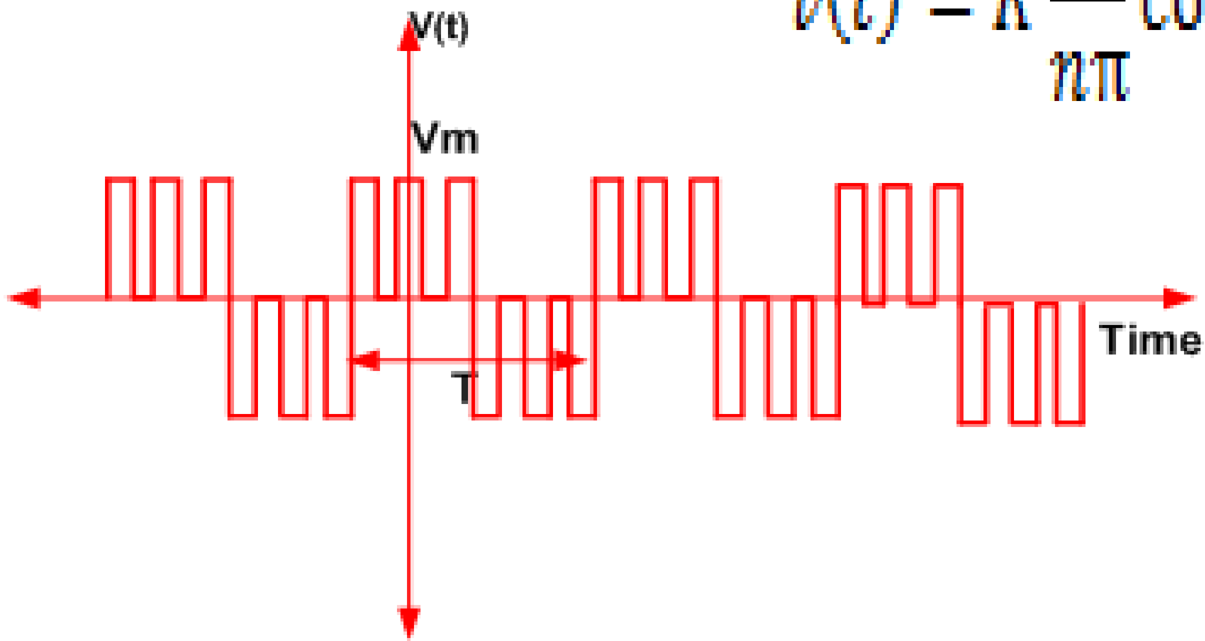
PWM

$$v(t) = K\frac{4}{n\pi}\cos n\Omega_0 t$$



K = Voltage Modulation Index , K<1

Lowest other than fundamental 2p – 1 Harmonics

p= m/2 m = fc/f Freq :modulation ratio

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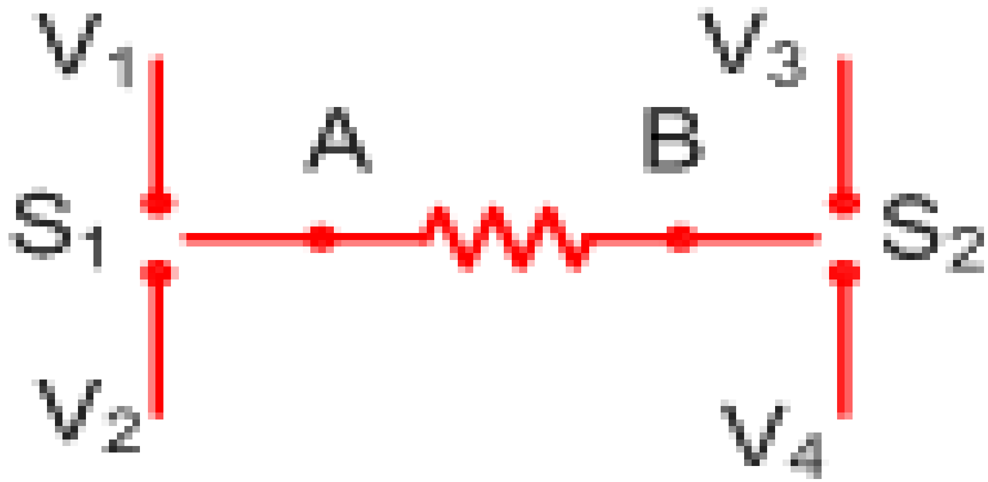
Topology



S1 Connected to	S2 Connected to	O/P Voltage
V1	V4	V1 – V4
V1	V3	V1 - V3
V2	V4	V2 – V4
V2	V3	V2 –V3

4 Level Inverter

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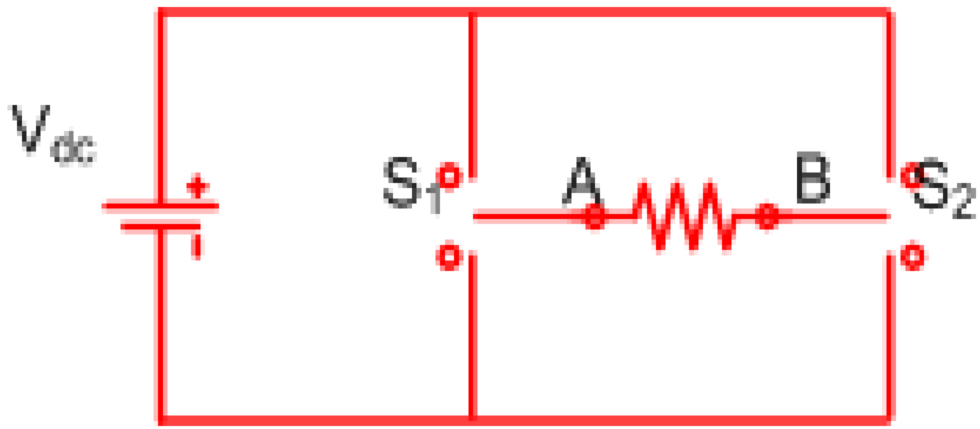
Topology



V1 = V3 = Vdc & V2 = V4 =0

S1 Connected to	S2 Connected to	O/P Voltage
Vdc	0	Vdc
Vdc	Vdc	0
0	0	0
0	Vdc	-Vdc

3 Level Inverter

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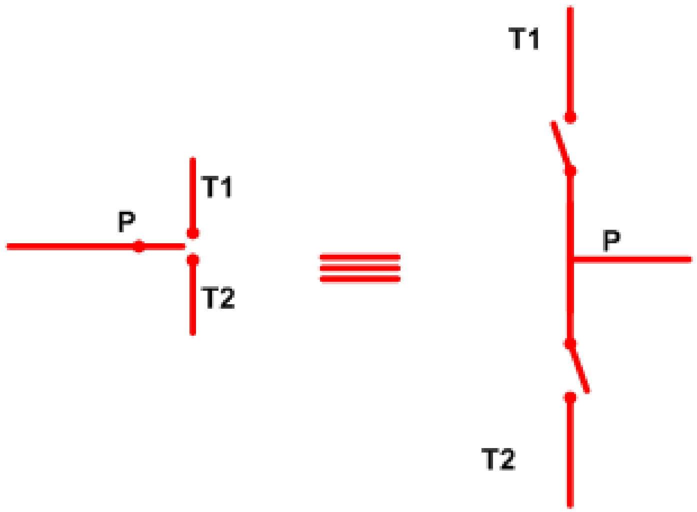
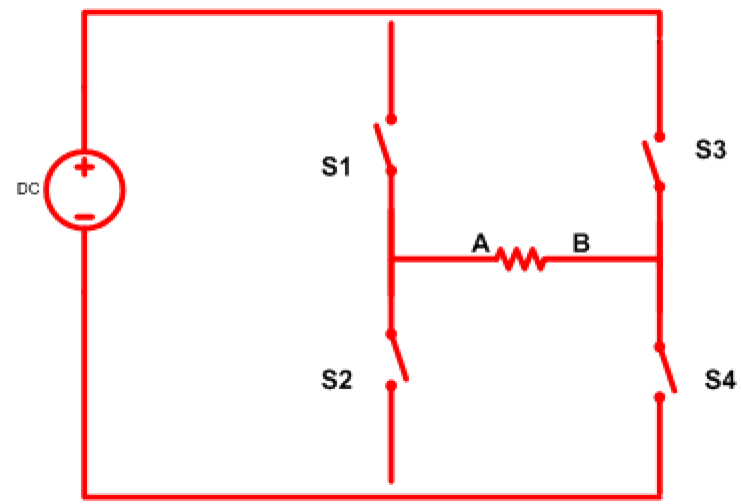
Realization



SPDT to SPST



H – Bridge

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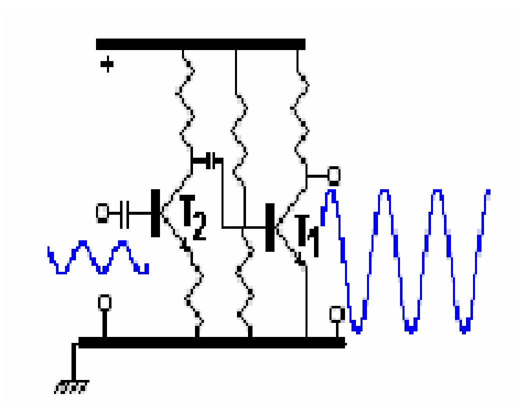
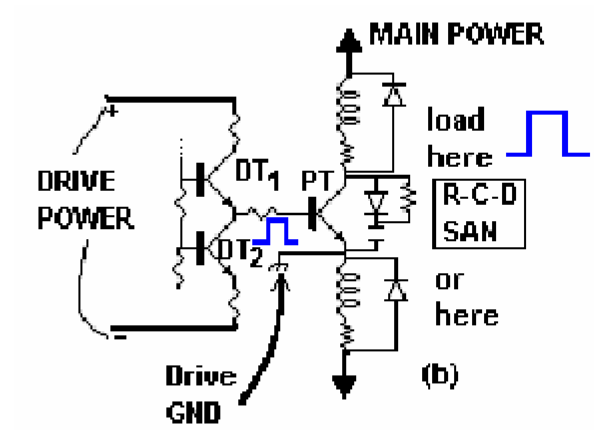
How is Power electronics distinct from linear electronics?

	
Typical Bipolar transistor based linear (common emitter) (voltage) amplifier stage	Switching (power) amplifier

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How is Power electronics distinct from linear electronics?

Linear operation	Switching operation
Active zone selected: Good linearity between input/output	Active zone avoided : High losses, encountered only during transients
Saturation & cut-off zones avoided: poor linearity	Saturation & cut-off (negative bias) zones selected: low losses
Transistor biased to operate around quiescent point	No concept of quiescent point
Common emitter, Common collector, common base modes	Transistor driven directly at base - emitter and load either on collector or emitter
Output transistor barely protected	Switching-Aid-Network (SAN) and other protection to main transistor
Utilization of transistor rating of secondary importance	Utilization of transistor rating optimized

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How is Power electronics distinct from linear electronics?

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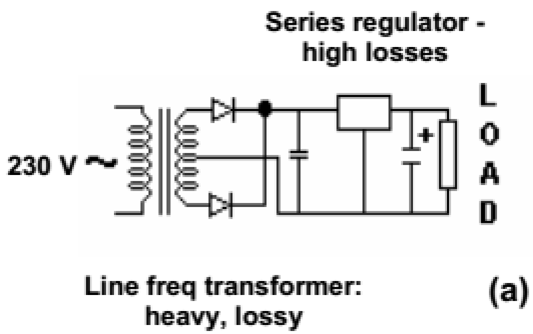
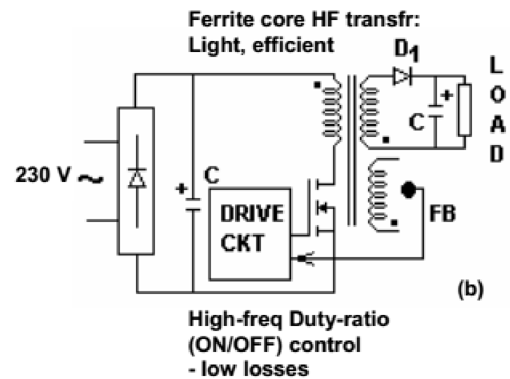
<tr>
<td></td>
<td></td>
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<tr>
<td>A Linear regulator</td>
<td>A switching regulator</td>
</tr>
</table>

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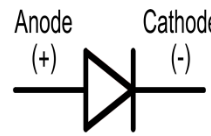
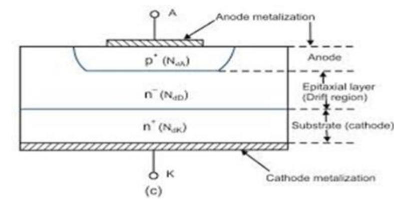
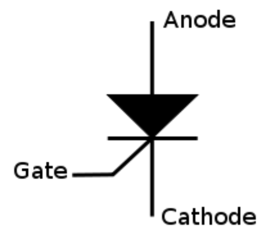
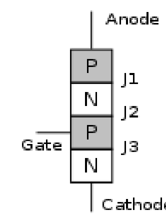
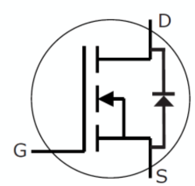
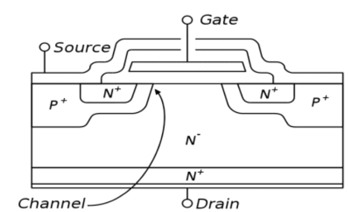
Overview of PE Devices

<table>
<tr><th>Device</th><th>Symbol</th><th>Structure</th></tr>
<tr><td>Power Diodes</td><td>
</td><td>
</td></tr>
<tr><td>Silicon Controlled Rectifier (SCR)</td><td>
</td><td>
</td></tr>
<tr><td>Power MOSFET</td><td>
</td><td>
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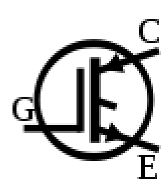
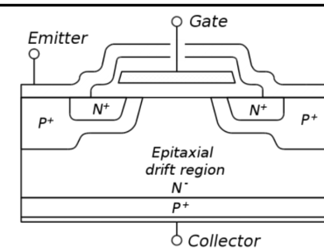
<tr><td>Insulated Gate Bipolar Transistor (IGBT)</td><td>
</td><td>
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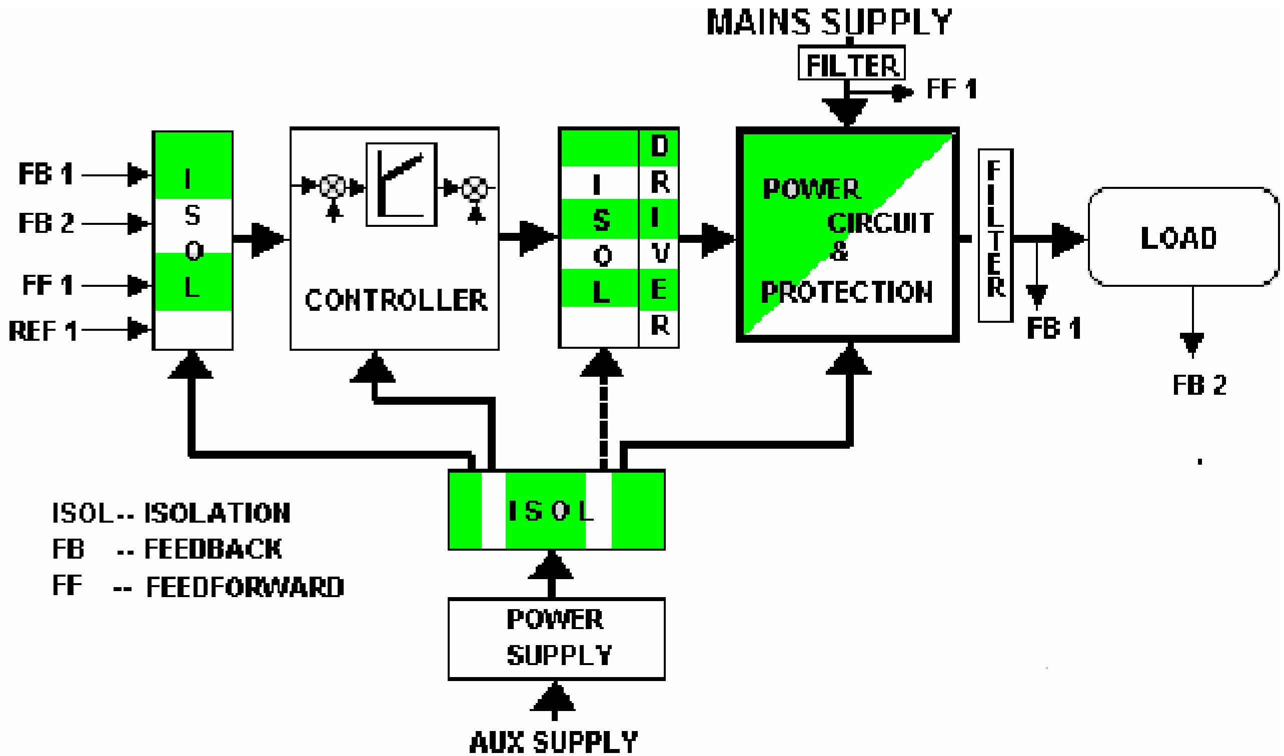
Typical Power Electronic Converter



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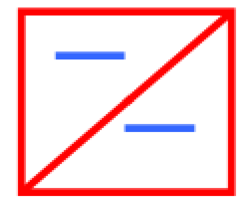
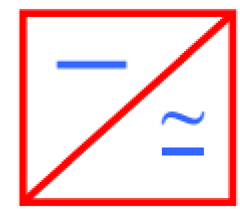
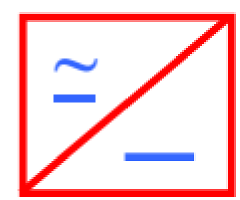
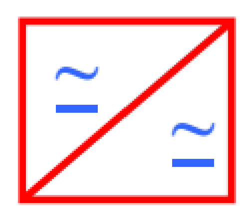
Power Converter Topologies

Conversion FROM/TO	Name	Function	Symbol
DC to DC	Chopper	Constant to variable DC or variable to constant DC	
DC to AC	Inverter	DC to AC of desired voltage and frequency	
AC to DC	Rectifier	AC to unipolar (DC) current	
AC to AC	Cycloconverter, AC-PAC, Matrix converter	AC of desired frequency and/or magnitude from generally line AC	

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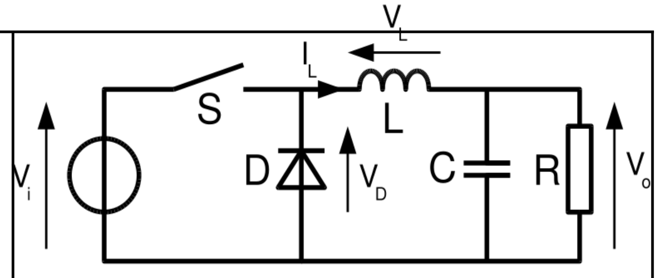
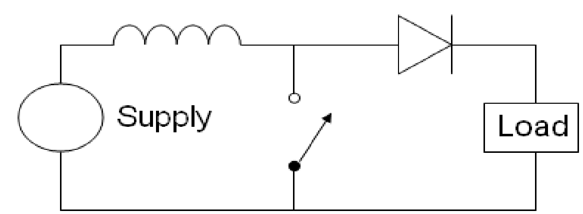
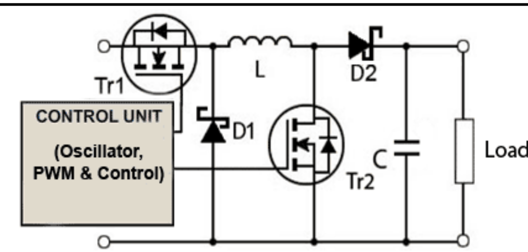
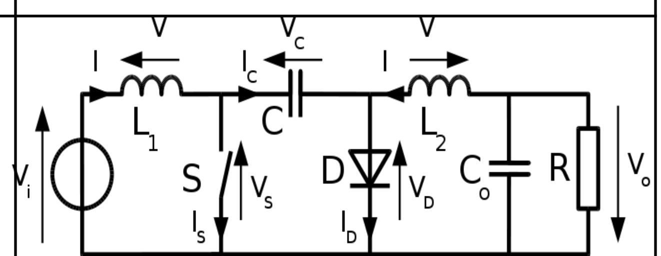
DC-DC Converters

Non-Isolated

Step-down (Buck) $V_o = DV_i$ $D = Duty\ ratio$ $= Ton/T$	
Step-up (Boost) $\frac{V_o}{V_i} = \frac{1}{1-D}$	
Inverting (Buck-Boost) $\frac{V_o}{V_i} = \left(\frac{-D}{1-D}\right)$	
Ćuk $\frac{V_o}{V_i} = \frac{-D}{1-D}$	

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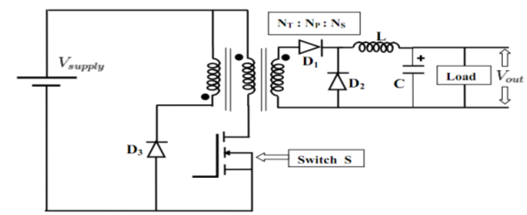
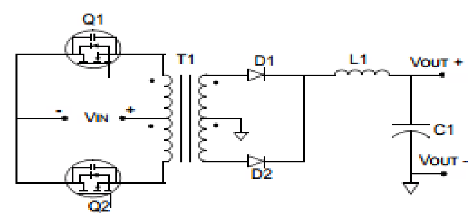
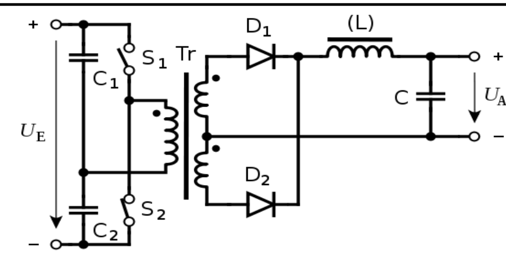
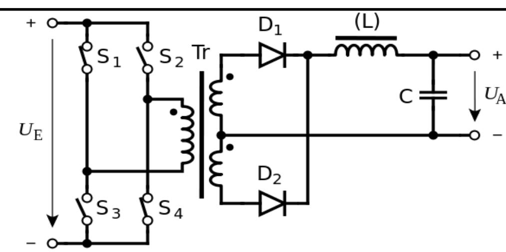
DC-DC Converters

Isolated

Forward $$V_{out} = D \cdot \frac{N_S}{N_P} \cdot V_{supply}$$ Power Levels (Typical):100W	
Push–pull $$V_{out} = D \cdot \frac{N_S}{N_P} \cdot V_{supply}.2$$ Power Levels (Typical):150W	
Half bridge $$V_{out} = D \cdot \frac{N_S}{N_P} \cdot V_{supply}.2$$ Power Levels (Typical):200W	
Full bridge $$V_{out} = D \cdot \frac{N_S}{N_P} \cdot V_{supply}.2$$ Power Levels (Typical): ~200W	

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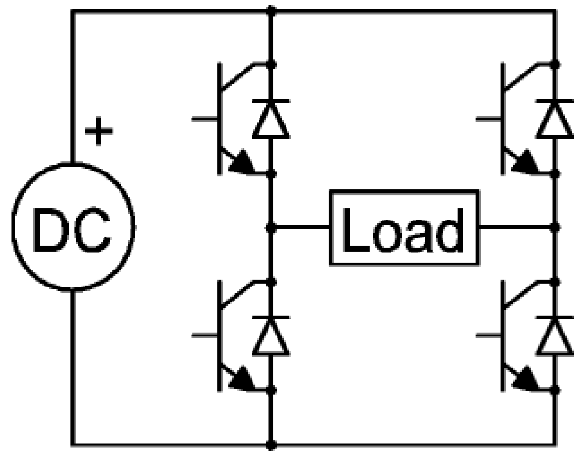
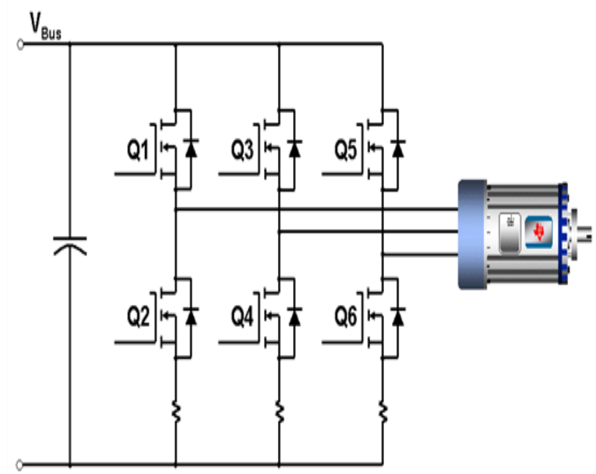
DC-AC Converters(Inverter)

Single Phase Inverter



Three Phase Inverter



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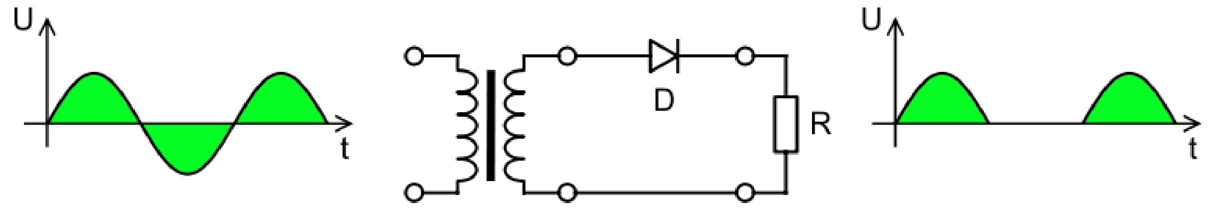
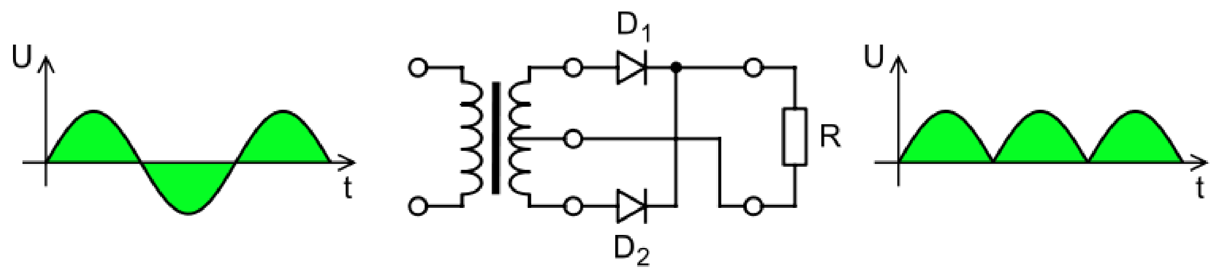
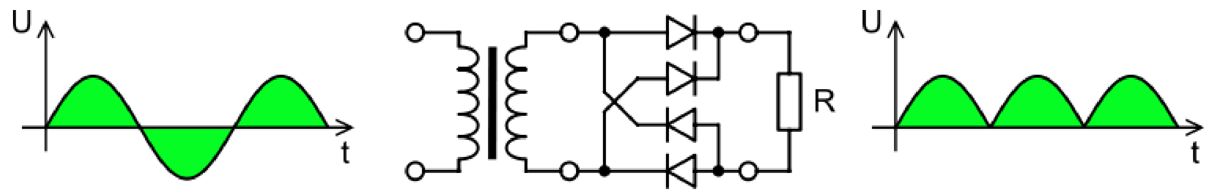
AC-DC Converters(Rectifier)

Half-wave rectification	$V_{\text{rms}} = \frac{V_{\text{peak}}}{2}$ $V_{\text{dc}} = \frac{V_{\text{peak}}}{\pi}$	
Full-wave rectification	$V_{\text{rms}} = \frac{V_{\text{peak}}}{\sqrt{2}}$ $V_{\text{dc}} = V_{\text{av}} = \frac{2V_{\text{peak}}}{\pi}$	
Full-bridge	$V_{\text{rms}} = \frac{V_{\text{peak}}}{\sqrt{2}}$ $V_{\text{dc}} = V_{\text{av}} = \frac{2V_{\text{peak}}}{\pi}$	

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AC-AC Converters

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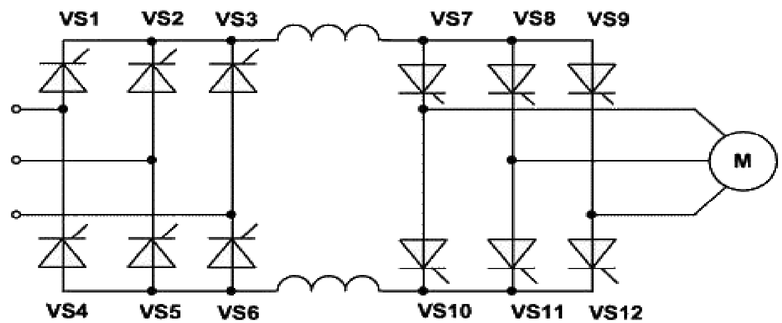
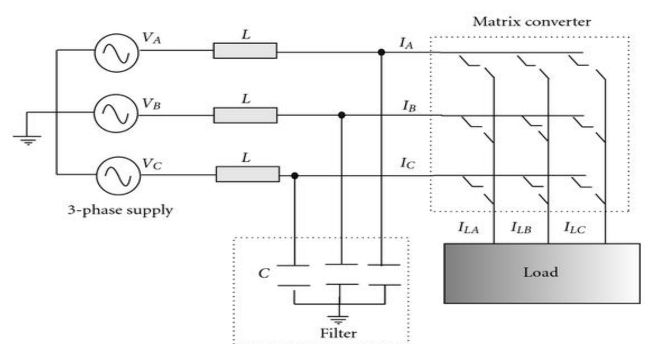
<tr><td>Cycloconverter</td><td>
</td></tr>
<tr><td>Matrix Converter</td><td>
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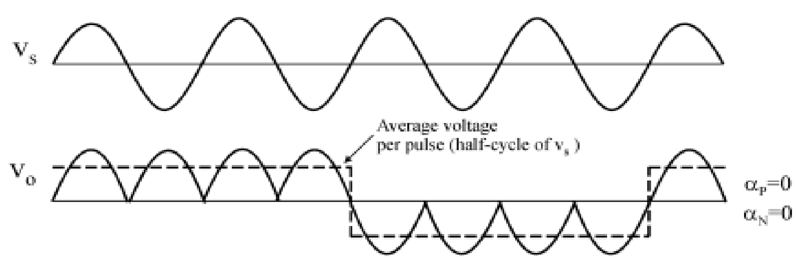
<tr><td>Output waveform</td><td>
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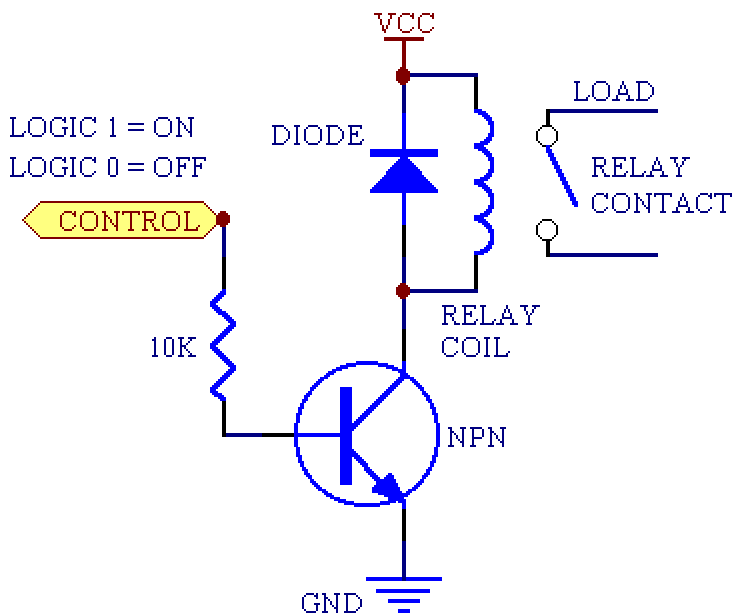
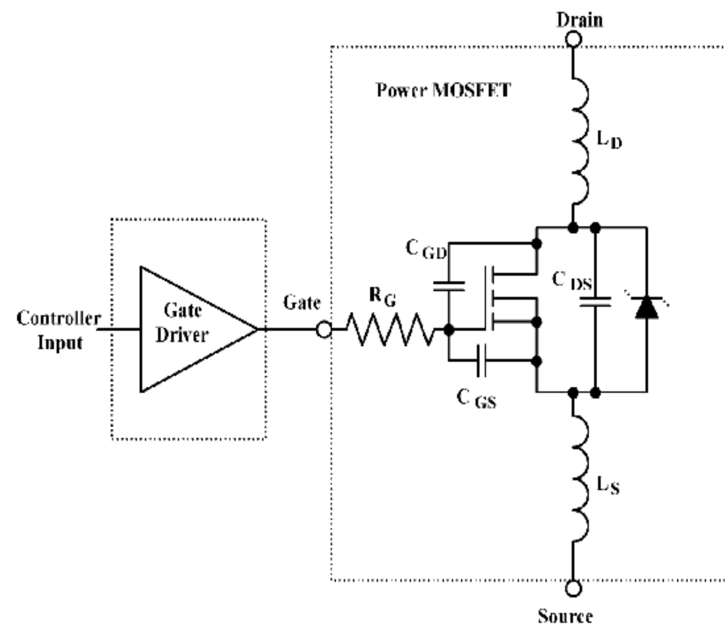
Switch Drivers





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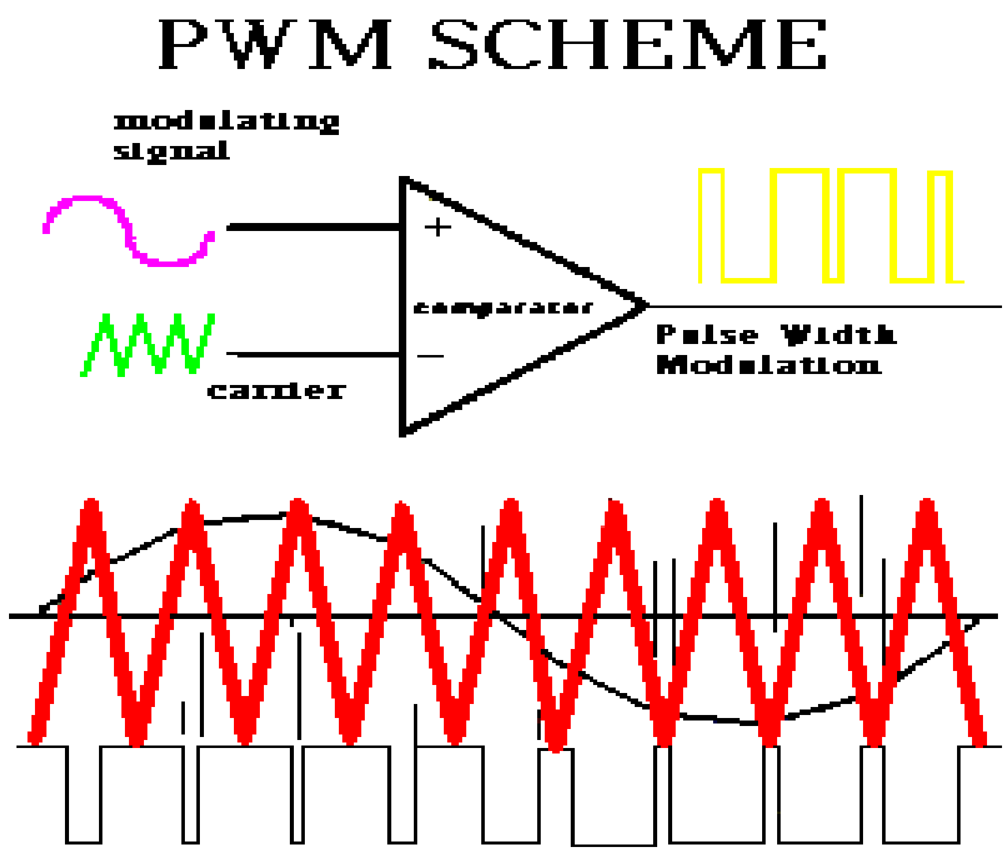
PWM



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Applications of Power Electronics Circuits

DC-DC

DC Voltage Regulators, DC Power supply, Battery Charger, SMPS, DC Drives

DC-AC

Solar Inverters, Fuel Cell Inverter, AC Drives

AC-DC

SMPS, DC Power supply, Battery Charger, DC Drives

AC-AC

Wind Electric Generators, AC Drives

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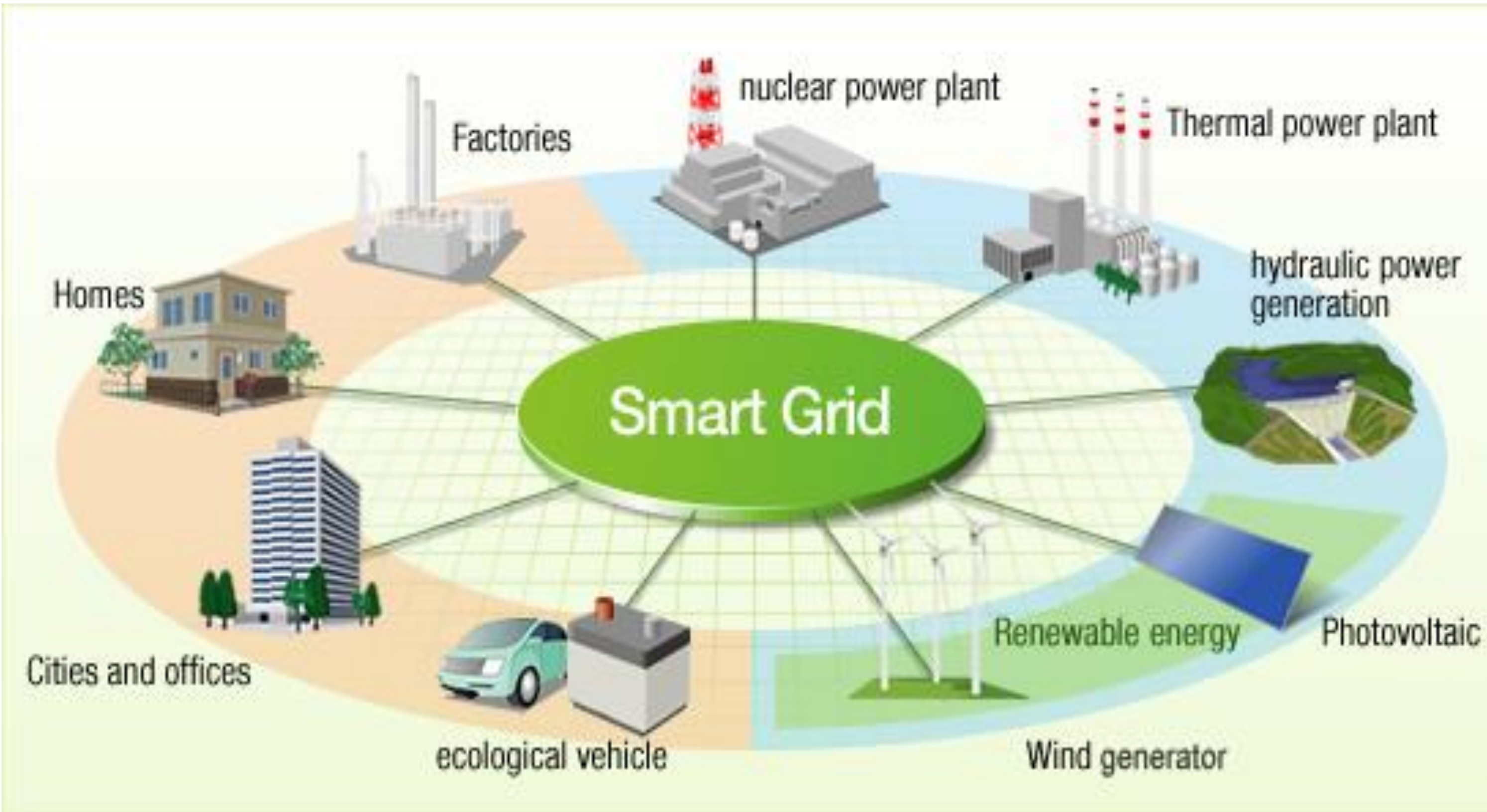
Smart Grid



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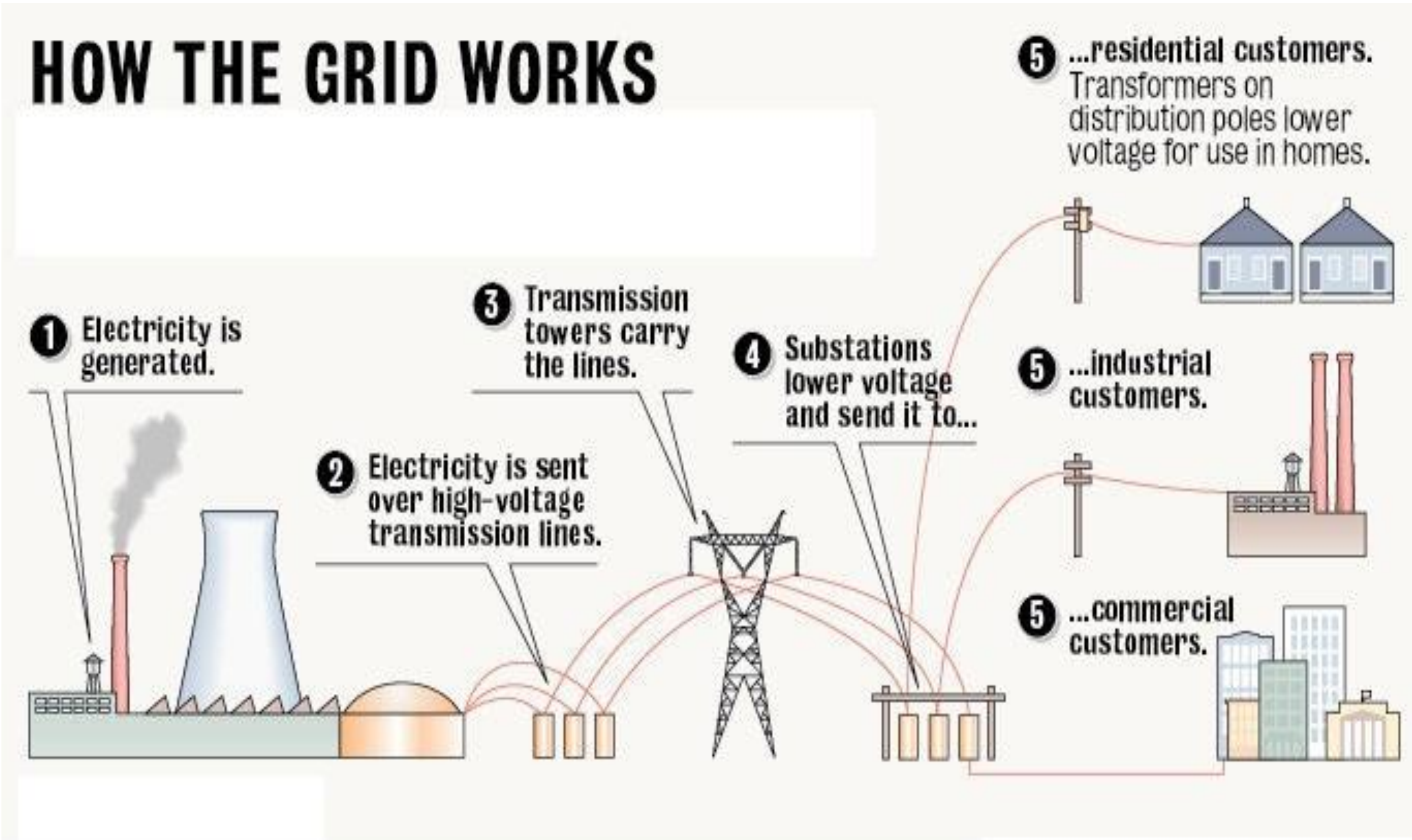
Smart Grid



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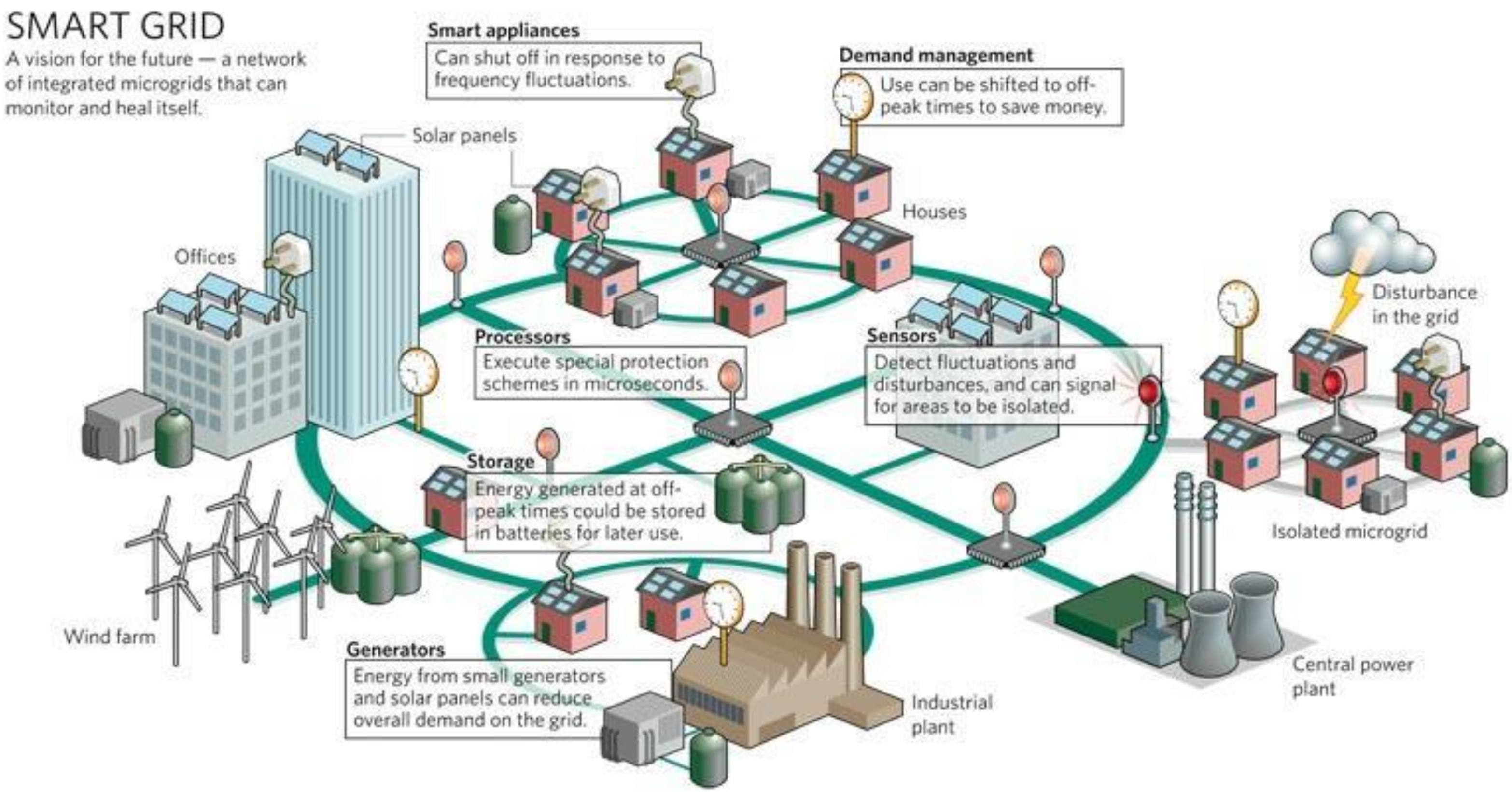
Smart Grid



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What is Smart Grid?

An electricity supply network that uses digital communications technology to detect and react to local changes in usage (or simply Grid+Communication+Sensors).

Existing Grid	Smart Grid
Electromechanical	Digital
One-way communication	Two-way communication
Centralized generation	Distributed generation
Few sensors	Sensors throughout
Manual monitoring	Self monitoring
Manual restoration	Self healing
Failure and blackouts	Adaptive and islanding
Limited control	Pervasive control
Few customer choices	Many customer choices

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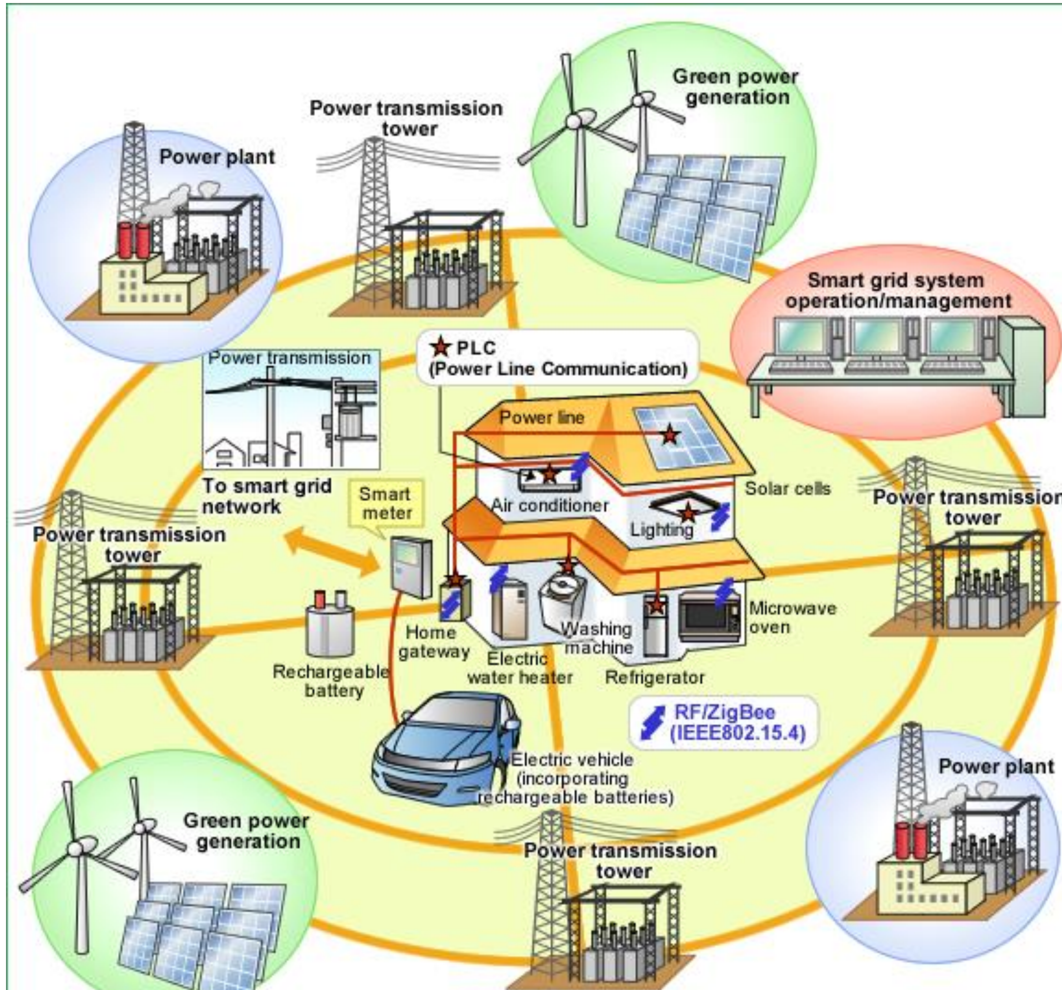
Potential Application Areas

- Electricity Distribution
- Electricity Markets
- Renewable Energy
- Energy Storage
- Transport
- Industrial Energy Efficiency
- Building Energy Efficiency



Source: http://www.renesas.eu/ecology/eco_society/smart_grid/

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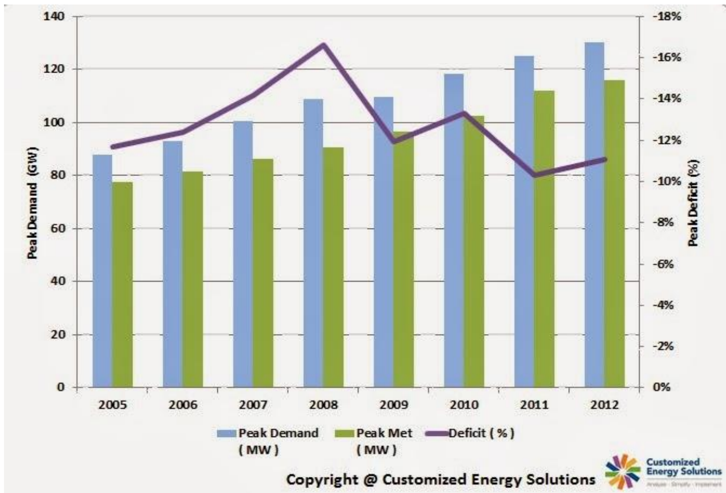
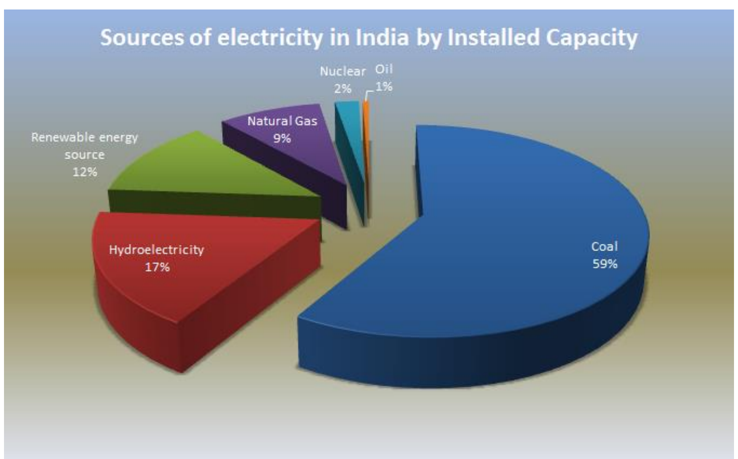
India’s Electricity Needs





DEMAND – **210000** Mega-Watt(appx.)
(Central Energy Authority(CEA)– Ministry of Power)

PRODUCTION – **182,200** Mega-Watt(MW)

INSTALLED CAPACITY – **225,133** Mega-Watt(MW)
(Central Energy Authority(CEA)– Ministry of Power)

DEFICIT – **10.2%**

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Smart Grid Components

- Smart Meter
- Phasor Measurement
- Communication devices/ Information transfer
- Distributed generation

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Smart Meter

- An electrical meter that records consumption of electric energy in intervals
- Essential technical features and cost
- Bi-directional communication
- Demand Side Management

Why Smart Meter?

- Next generation of electricity metering
- Provide greater choice in energy tariffs and services
- Real-time information

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Phasor Measurement

- A device with unique ability to sample analog voltage and current waveforms in synchronism with a global reference signal(eg:GPS) and compute its phasor values and frequency information

- Communicates the time-stamped computed information to PDC/SCADA etc. in near real-time

  - *1st prototype of PMU – 1988 (Virginia Tech)*
  - *1st PMU – 1992 (Macrodyne)*

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Communication devices/ Information transfer

- Communication modules in smart grid
- Communication protocols and standards
- Wired Communication method (Ethernet, PLCC etc.)
- Wireless Communication methods (GSM, GPRS, Wi-Fi, RF etc.)

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Distributed generation

- Distributed generators and loads in the neighborhood can form micro grids which can work parallel to grid or operate in islanded mode providing UPS services
- The Microgrid can be assumed as a cluster of loads and micro sources operating as a single controllable system that provides power to its local area

Advantages

- Standby / Backup power to improve the availability and reliability of electric power
- Peak load shaving
- Sales of power back to utilities or other users
- Free energy input, zero operational costs (except diesel gensets), minimal maintenance
- Power quality, such as reactive power compensation and voltage support
- Reduction in environmental pollution
- Reduction of distribution losses in the grid.

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How Smart Grid?

- Analyze energy demand and supply
- Manage load according to supply
- Power outage and power quality monitoring
- Centralized data management system
- Remote monitoring and control of loads
- Bidirectional communication

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Why Smart Grid?

- Improve efficiency of grid
- Reduce green house gases
- Automated control of distribution
- Provide infrastructure for electricity business
- Support micro generators
- Self healing

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Grid Interactive Solar Photo-Voltaic (GISPV) Power Plant

- **GISPV -OVERVIEW**
  - System Architecture
  - SPV array sizing & specifications
  - Photographs
- **POWER HARDWARE**
  - Power conditioning Unit - Single Line diagram
  - Topology Comparisons
  - Practical Hardware Scheme
  - Basic Interface Module (BIM)
  - Photographs (BIM, Hardware Panel)
  - Thermal management, DC/AC Filters
  - Specifications
- **CONTROL HARDWARE**
  - Digital Controller requirements
  - Block diagram – controller card
- **CONTROL ALGORITHM**
  - Multi phase Interleaved DC-DC Converter, MPPT control
  - Grid side Controller
  - Experimental Results

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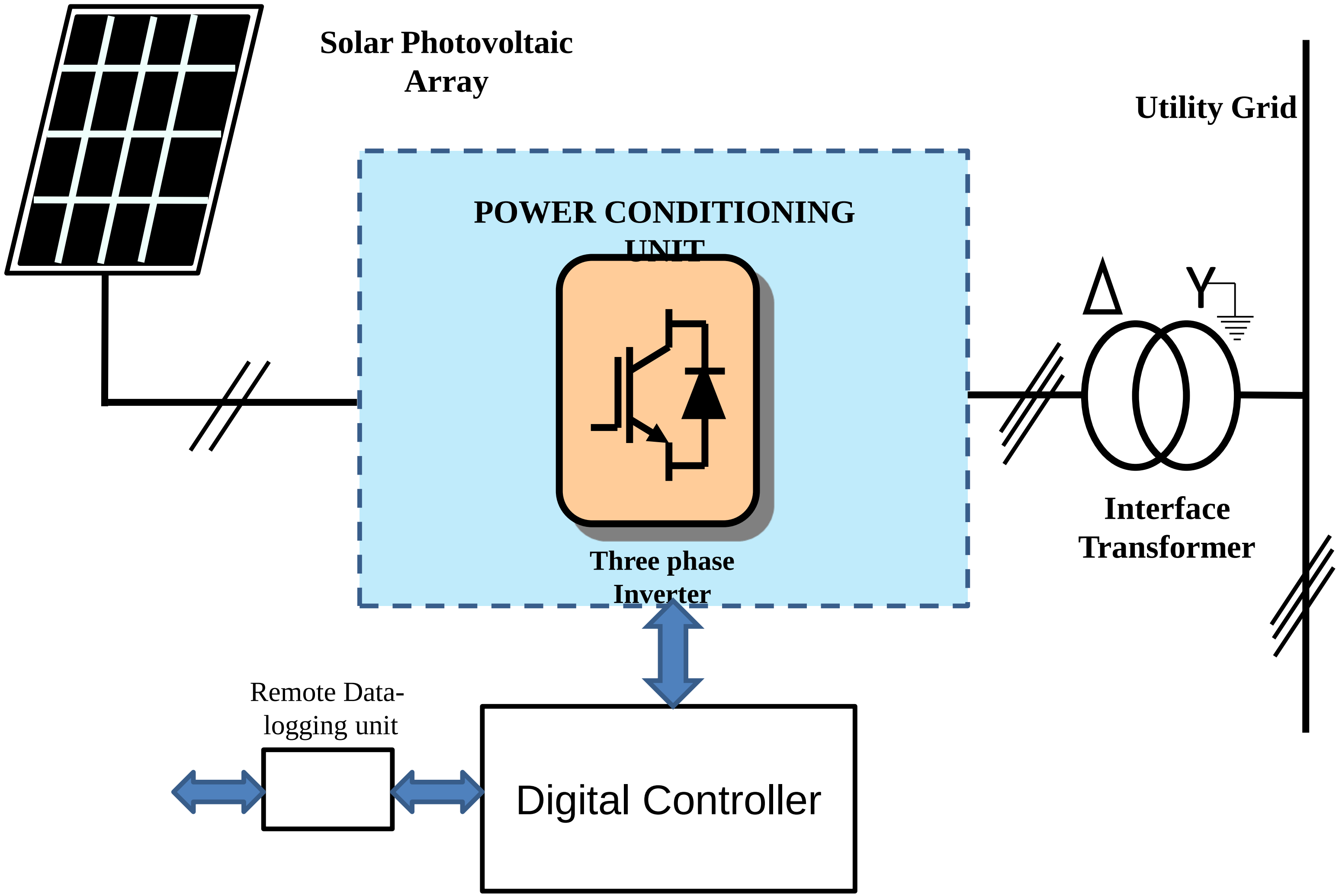
GISPV - scheme



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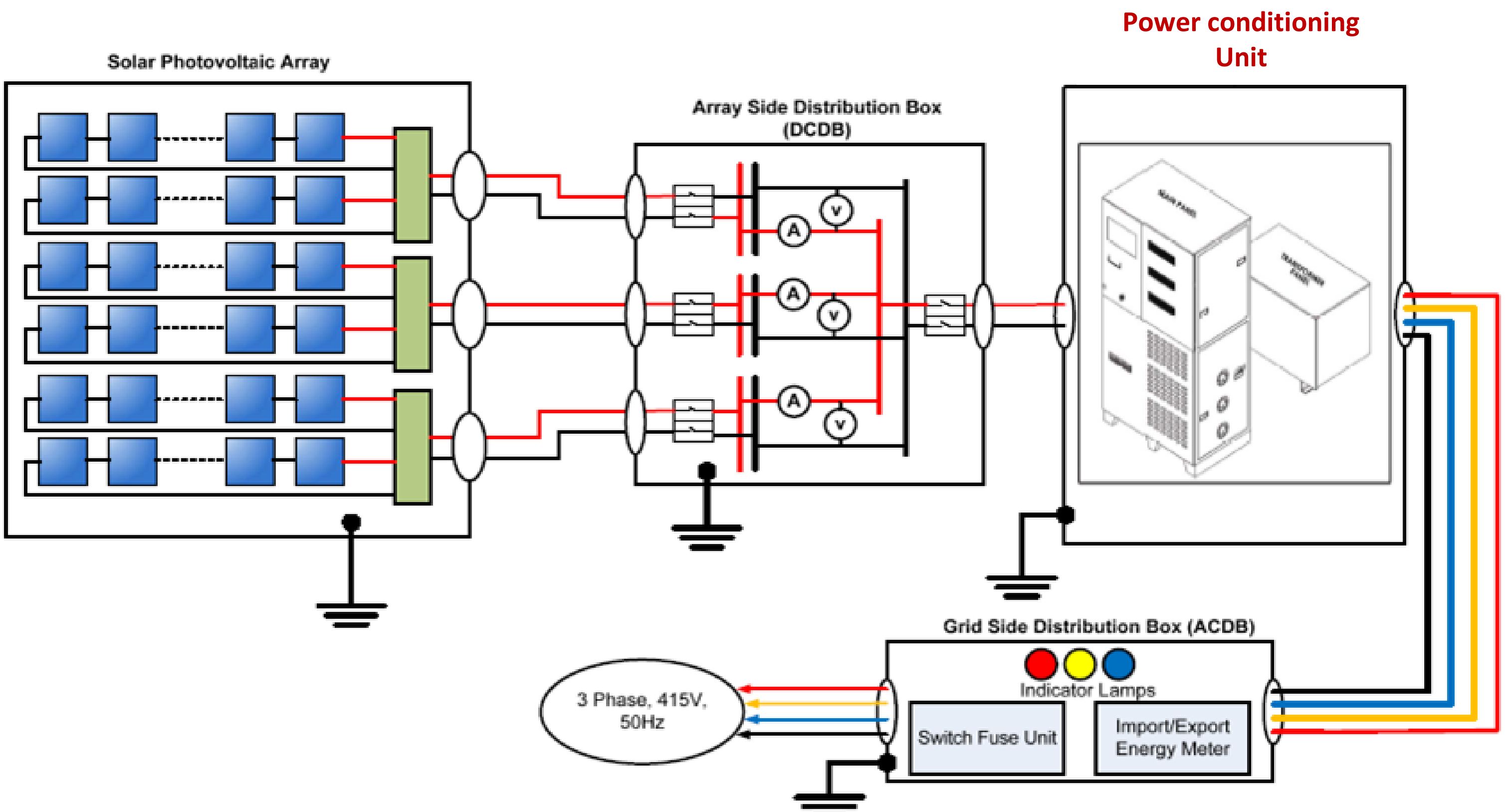
System Architecture – GISPV Power Plant (25kWp)



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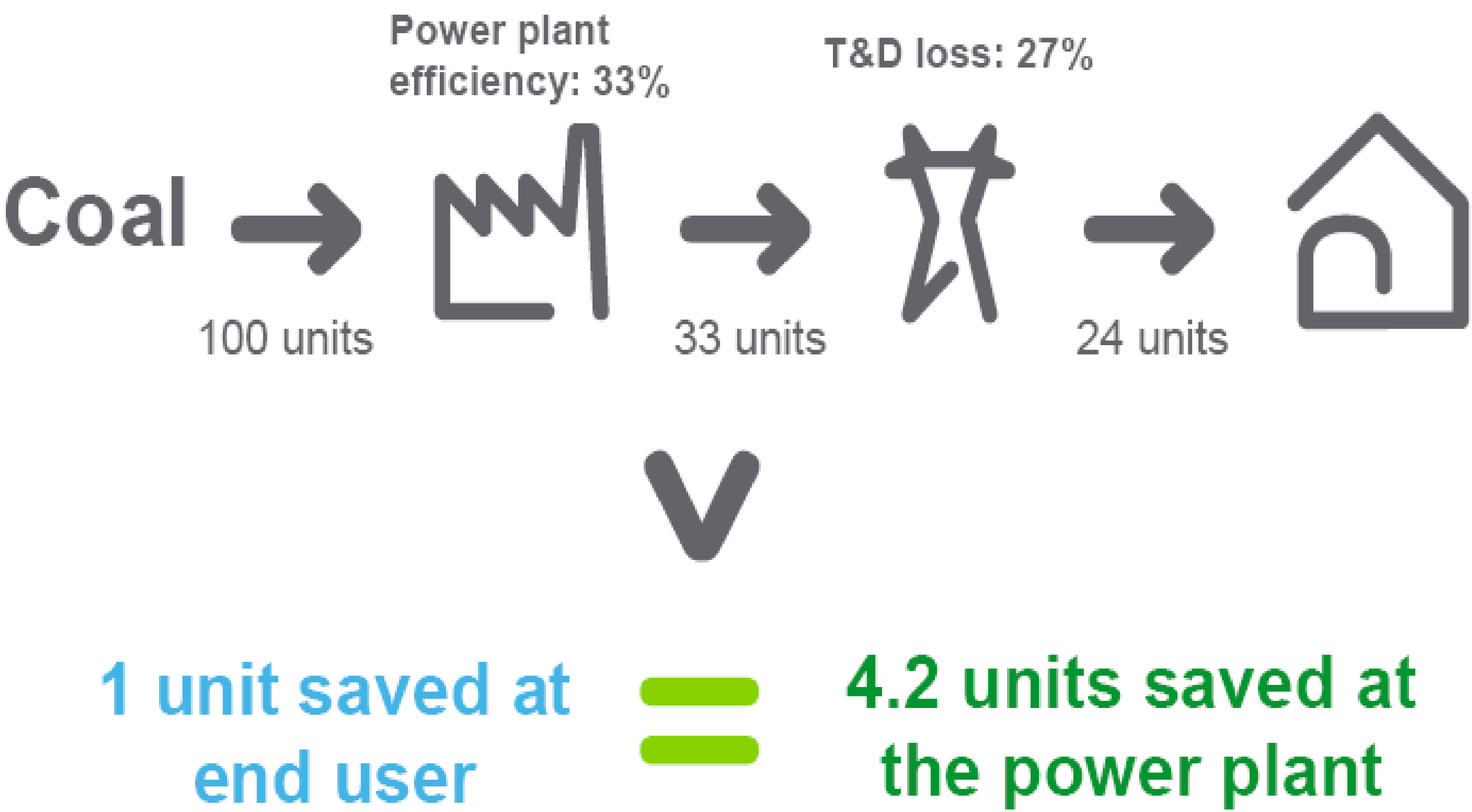
Energy efficiency-the solution



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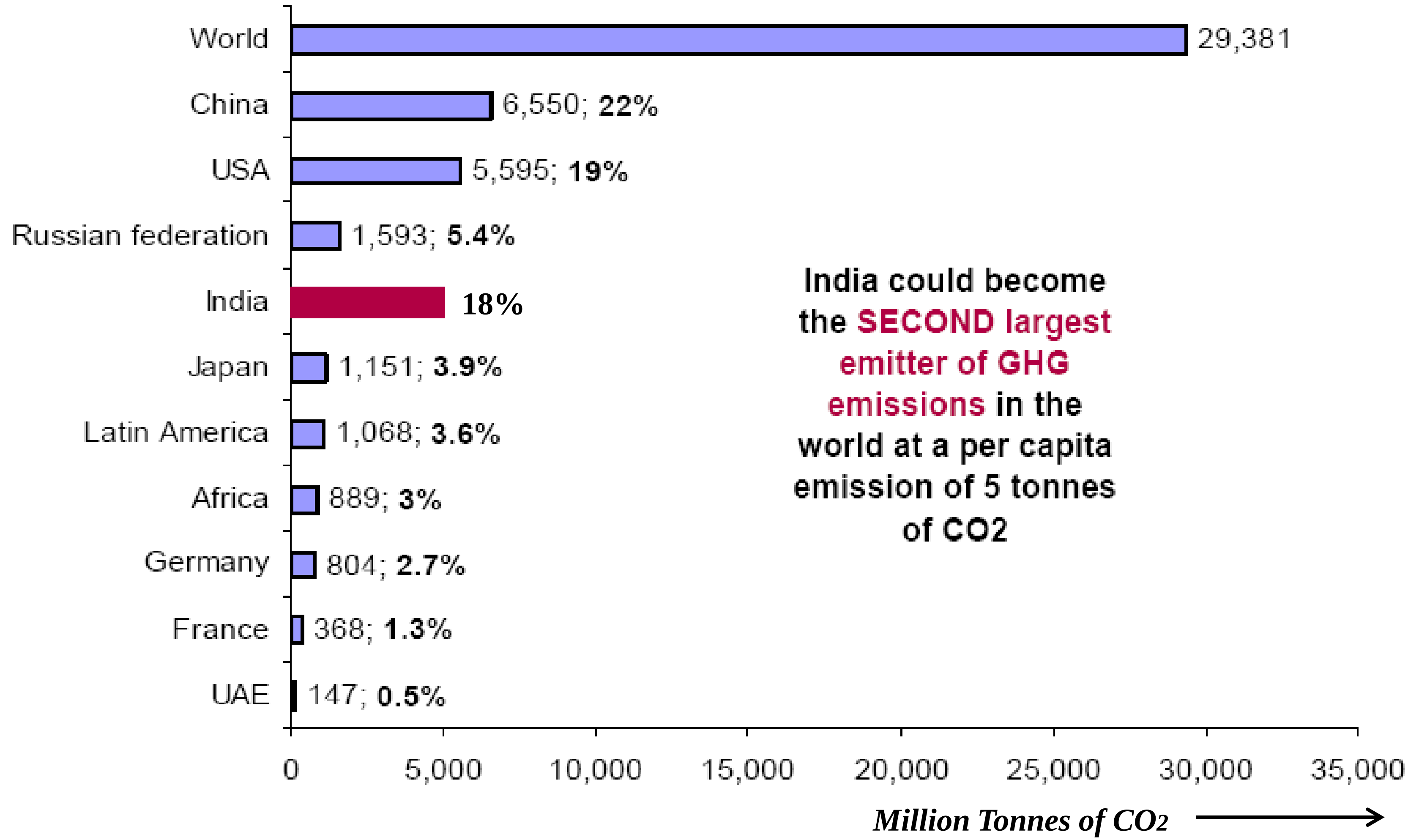
Energy Challenge in India



India could become the SECOND largest emitter of GHG emissions in the world at a per capita emission of 5 tonnes of CO_2

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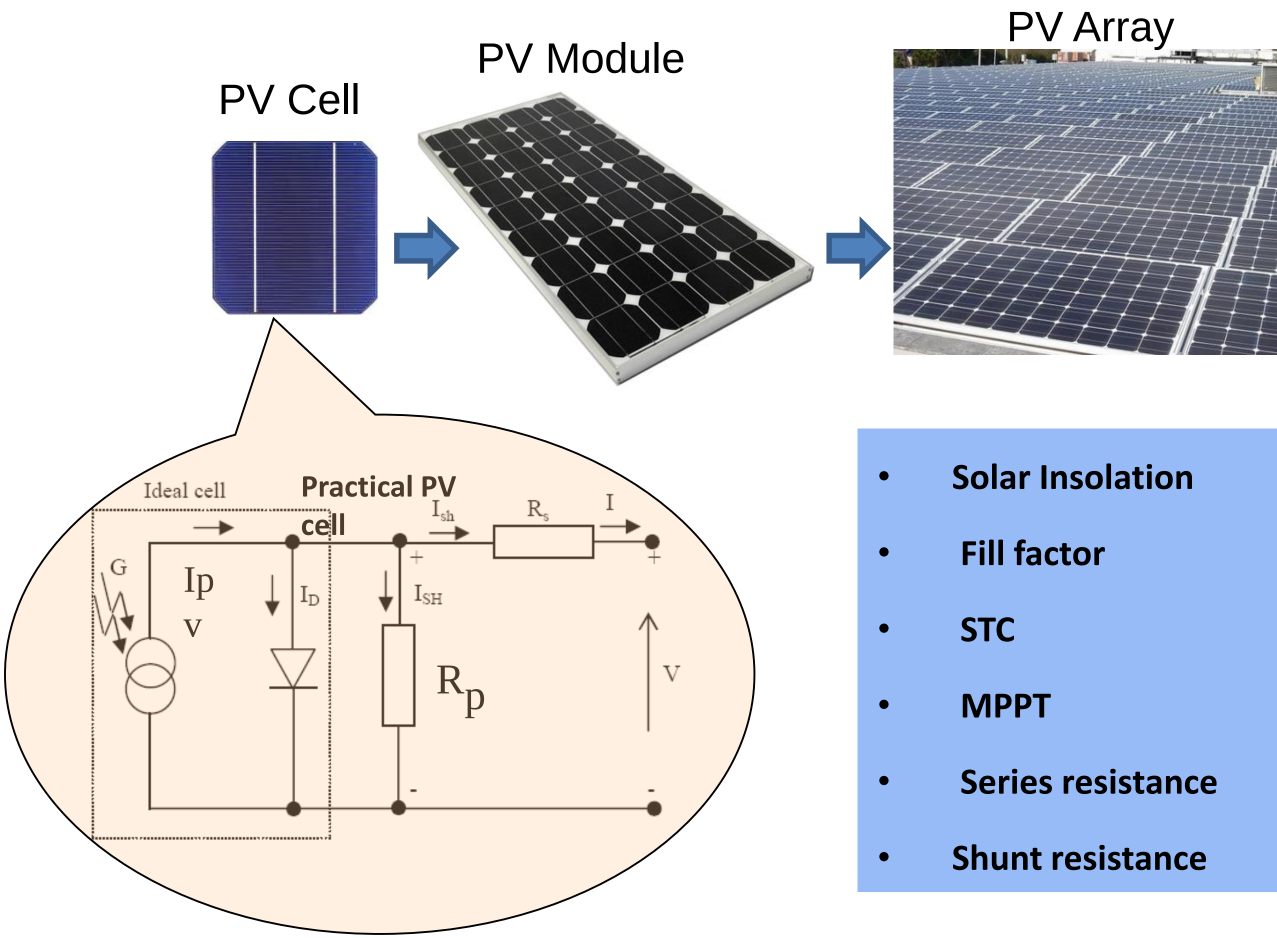
Important terminologies



- Solar Insolation
- Fill factor
- STC
- MPPT
- Series resistance
- Shunt resistance

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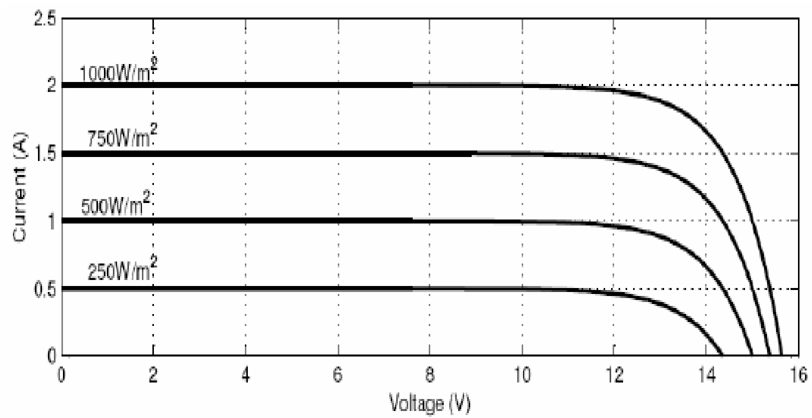
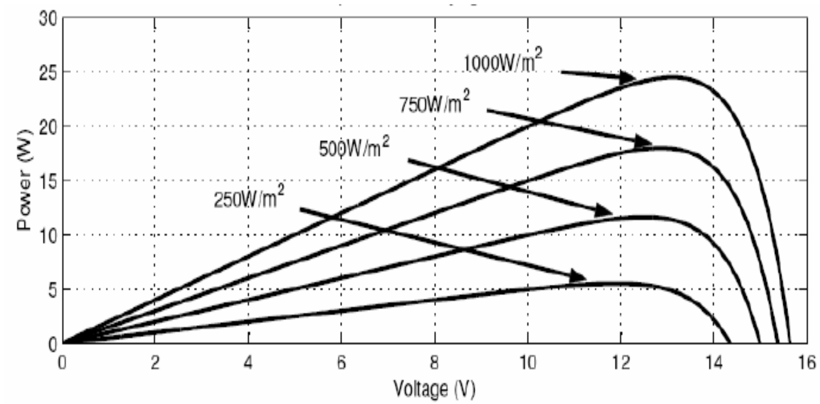
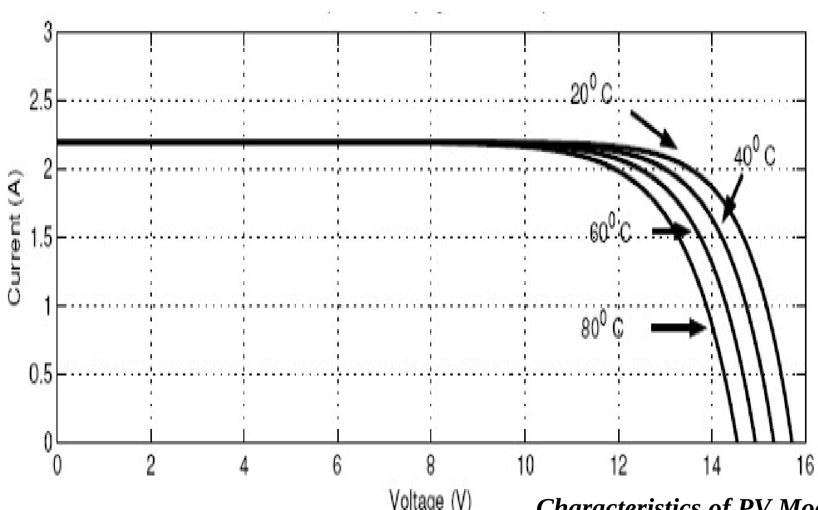
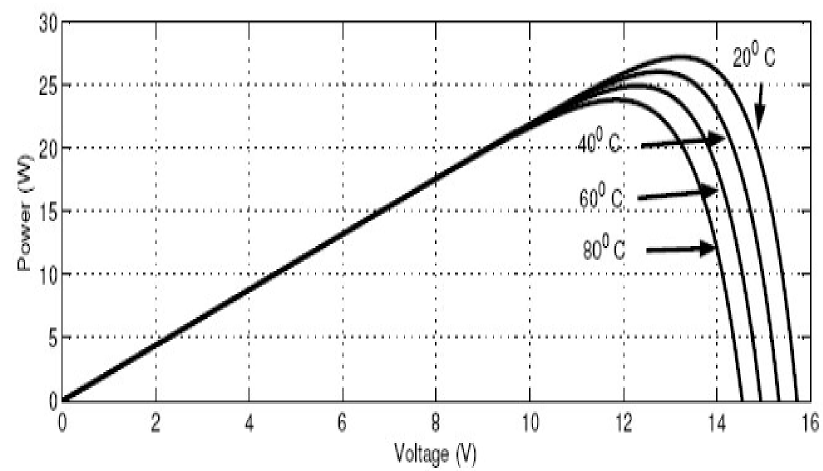
I-V and P-V Characteristics





Characteristics of PV Module for different insolation conditions





Characteristics of PV Module for different temperatures

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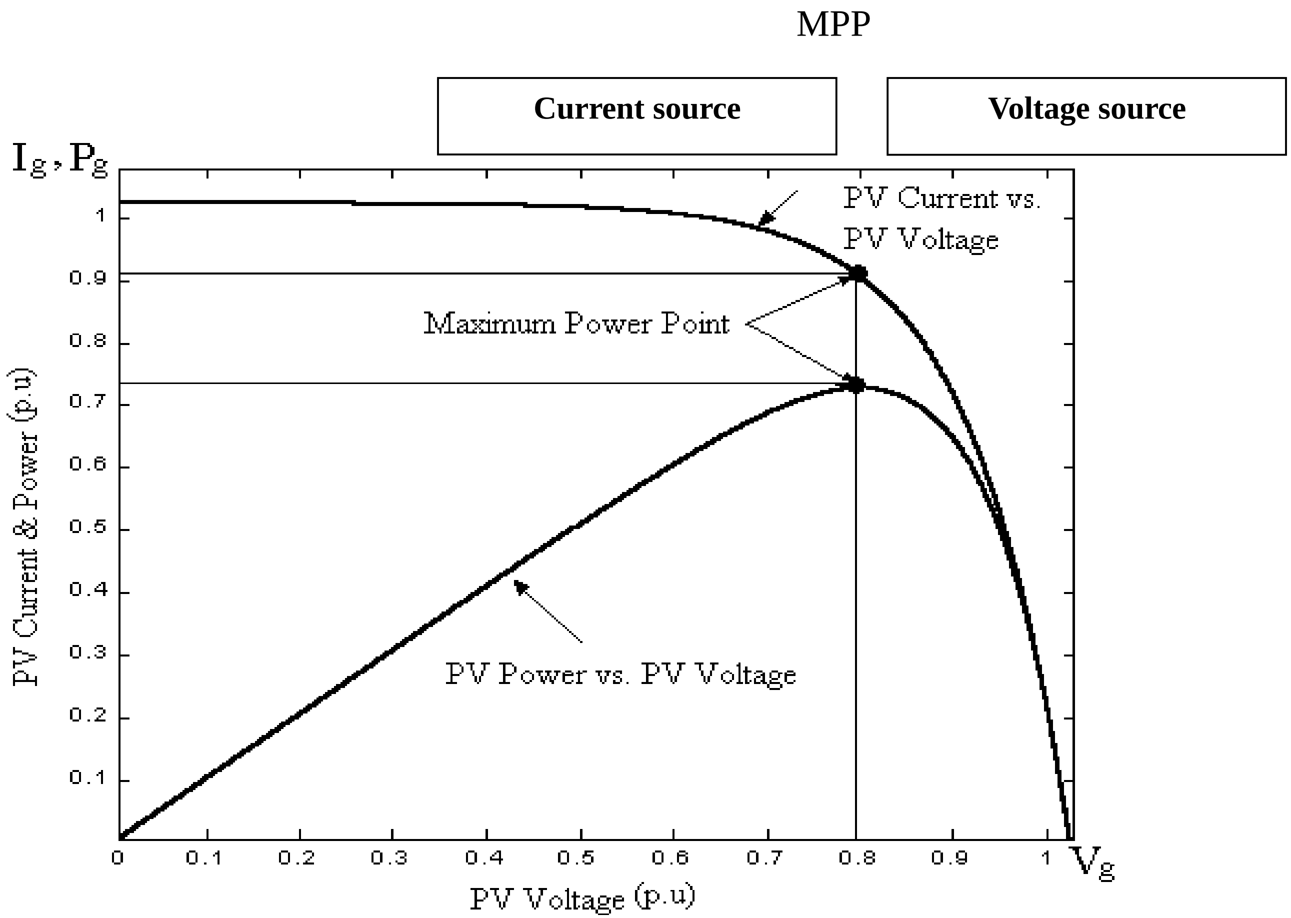
Parasitic Resistances



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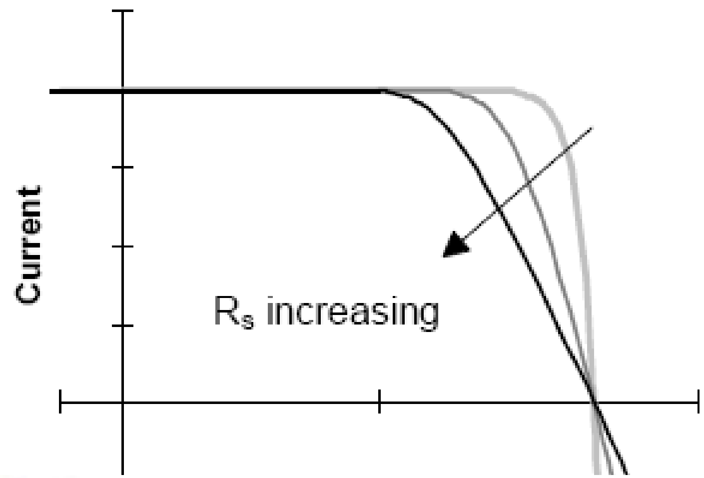
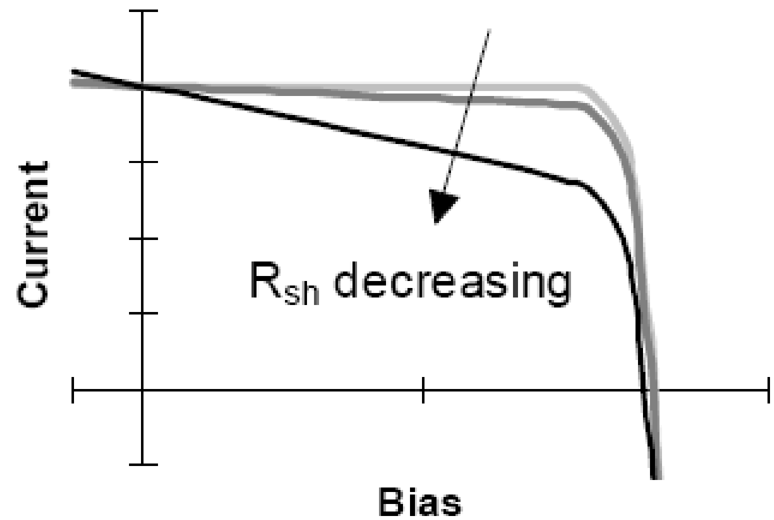
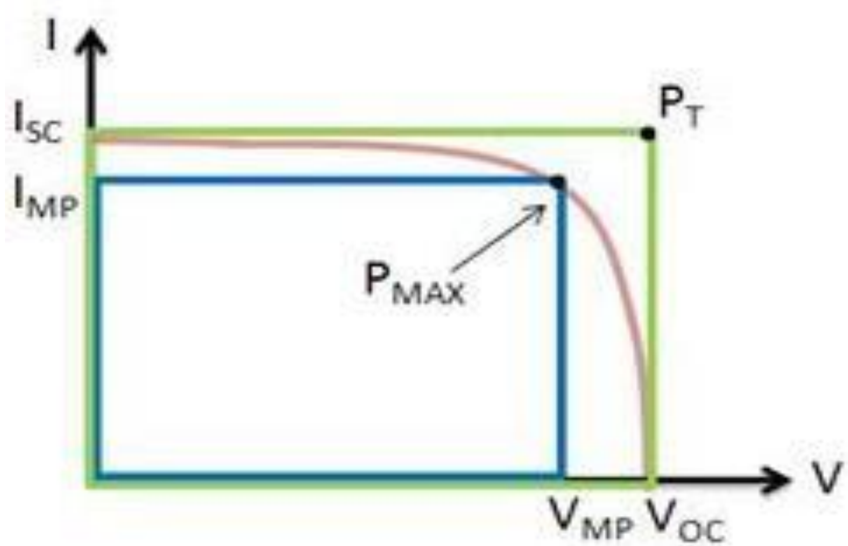
Effects of Parasitic resistances







$$Fill\ \ factor = \frac{V_{max}.I_{max}}{V_{OC}.I_{SC}}$$

$$R_s < \frac{0.01V_{OC}}{I_{SC}}$$

$$R_p > \frac{100V_{OC}}{I_{SC}}$$

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Specifications of Solar PV Module

ELECTRICAL CHARACTERISTICS	
RATED POWER	**280 Wp**
OPEN CIRCUIT VOLTAGE (Voc)	44.50 V
MAXIMUM POWER VOLTAGE (Vmp)	35.00 V
SHORT CIRCUIT CURRENT (Isc)	8.50 A
MAXIMUM POWER CURRENT (Imp)	8.00 A
MODULE EFFICIENCY (%)	14.17
OUTPUT TOLERANCE (%)	±3
CELLS	72
CELL LAYOUT	12x6
MAXIMUM SYSTEM VOLTAGE	1000 VDC

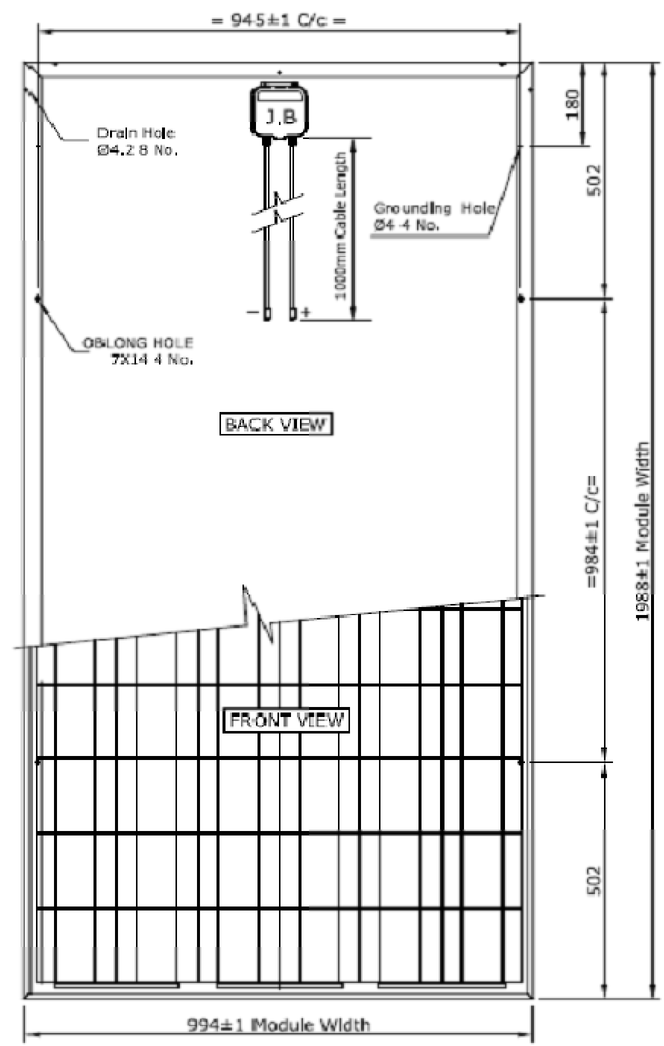
ELECTRICAL CONNECTION	
JUNCTION BOX	IP 65 / IP 67
OUTPUT TERMINAL	1000mm,4mm^2 Cable;MC4 / HA3 Type / Compatible Connectors
PROTECTION	SCHOTTKY BYPASS DIODES

MECHANICAL CHARACTERISTICS	
MODULE DIMENSIONS (mm)	1988 x 994 x 46
WEIGHT (KG, APPROX)	28

ABSOLUTE MAXIMUM RATINGS	
OPERATING TEMPERATURE	-40^{0}C to +85^{0}C

GENERAL	
FRAME	ANODISED ALUMINIUM

TEMPERATURE CO-EFFICIENTS		
α_{Isc} %/˚C	β_{Voc} %/˚C	γ_{Pmp} %/˚C
+0.05	**-0.34**	**-0.45**
NOCT	**45±2℃**	



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Specifications of PCU

Peak Power of SPV array	25kWp
Nominal power	30 kW
Voc Solar PV Array	400.5 V
V_{MPP}	315 V
Grid Voltage	415 V ± 10% , 3ϕ AC
Grid Frequency	50Hz ±0.5 %
Power factor	> 0.95
I_{THD}	< 5% at full load as stipulated by IEEE 1547-2003
Efficiency	97 %
Converter	IPM based voltage source inverter
User Interface	Android Tablet GUI, Remote data access through Internet
Protections	Over voltage, over current, temperature at source and load side, Anti islanding

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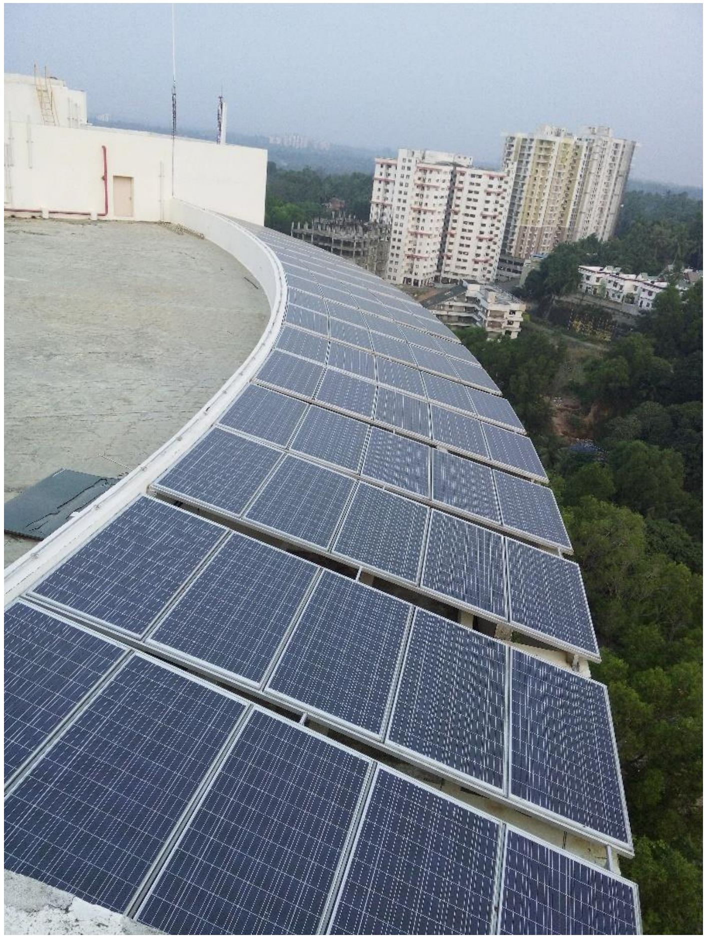
SPV Power Plant – Photographs



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Outline

- GISPV -OVERVIEW
  - System Architecture
  - SPV array sizing & specifications
  - Photographs
- **POWER HARDWARE**
  - **Power conditioning Unit - Single Line diagram**
  - **Topology Comparisons**
  - **Practical Hardware Scheme**
  - **Basic Interface Module (BIM)**
  - **Photographs (BIM)**
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  - Grid side Controller
  - Experimental Results

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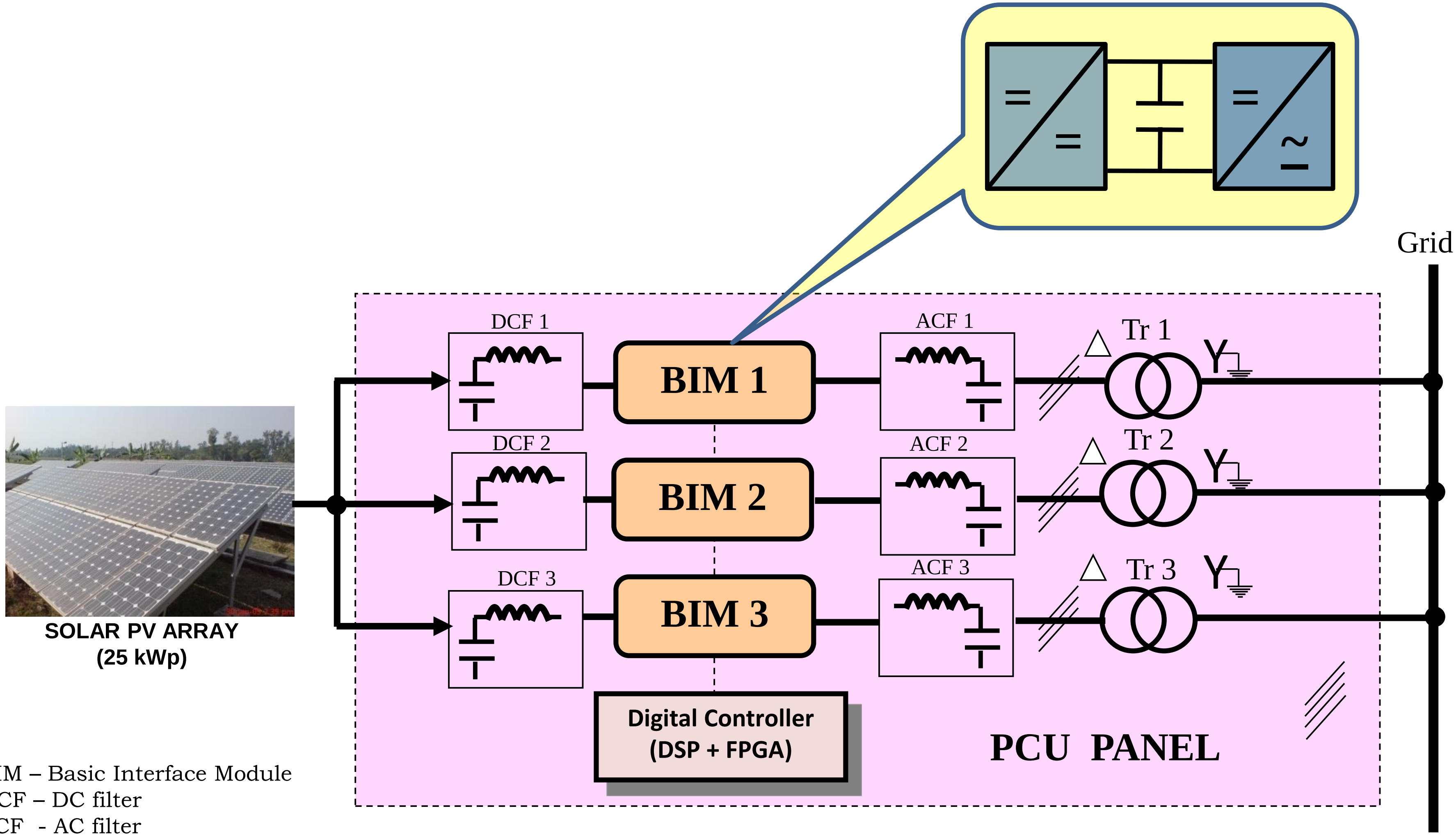
Single line diagram of PCU



BIM – Basic Interface Module
DCF – DC filter
ACF - AC filter
Tr 1-Tr 3 – Interface transformers

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Inverter Configurations available

Topology 1 – with Split DC Link capacitors

Topology 2 – with Four leg inverter

Topology 3 – with Three leg inverter +

coupling transformer

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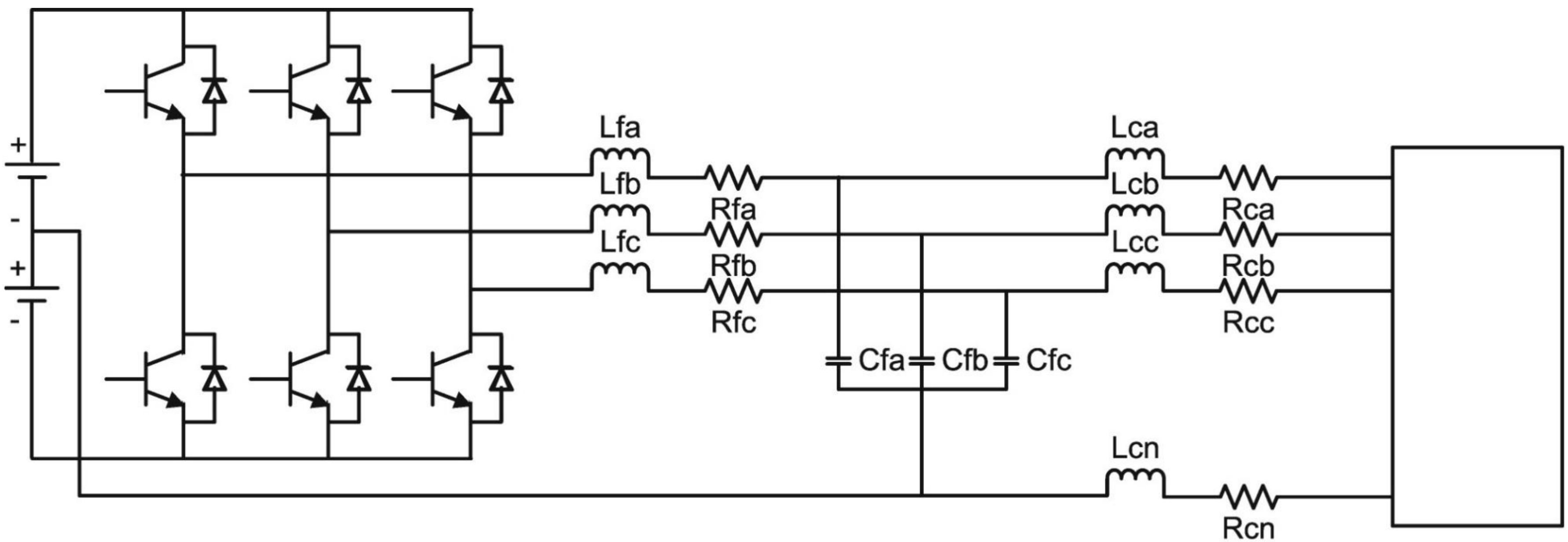
Topology 1



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Drawbacks

- DC Bus voltage equalization
- Zero sequence current handling
- Control complexities
- No Isolation

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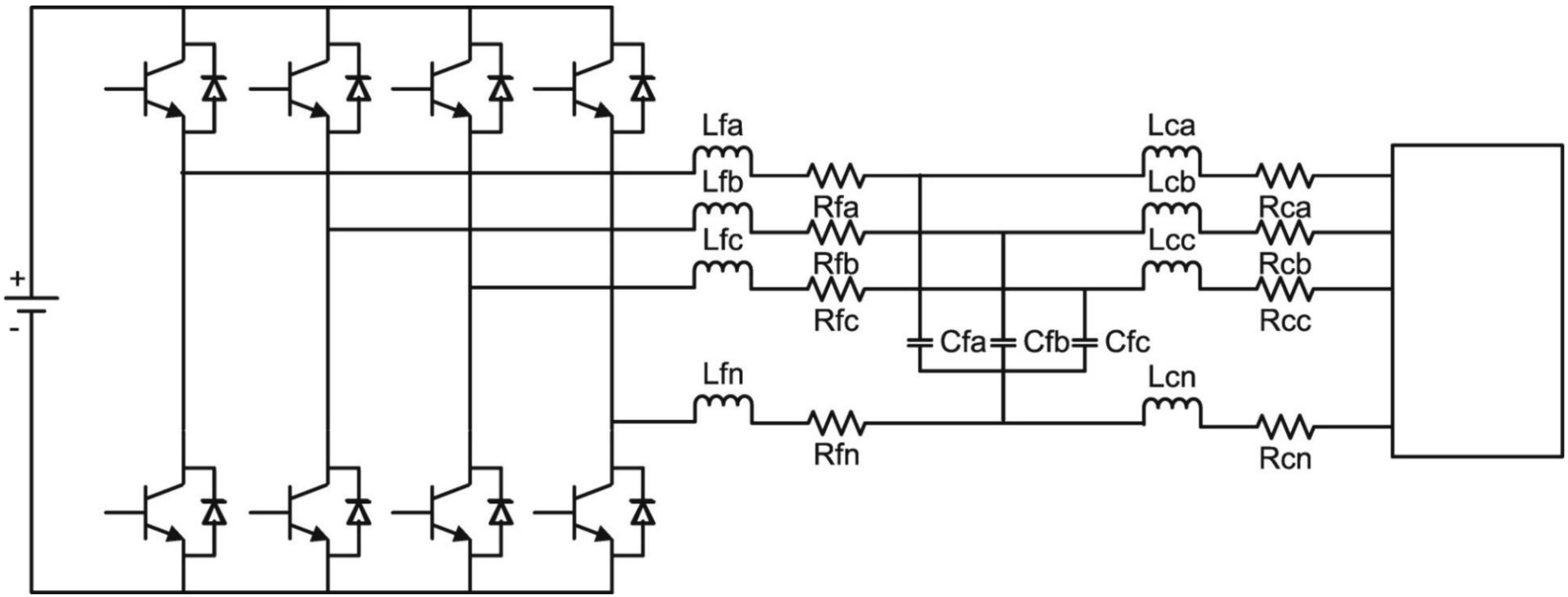
Topology 2



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Drawbacks

- Higher semiconductor cost
- Control complexities
- No isolation

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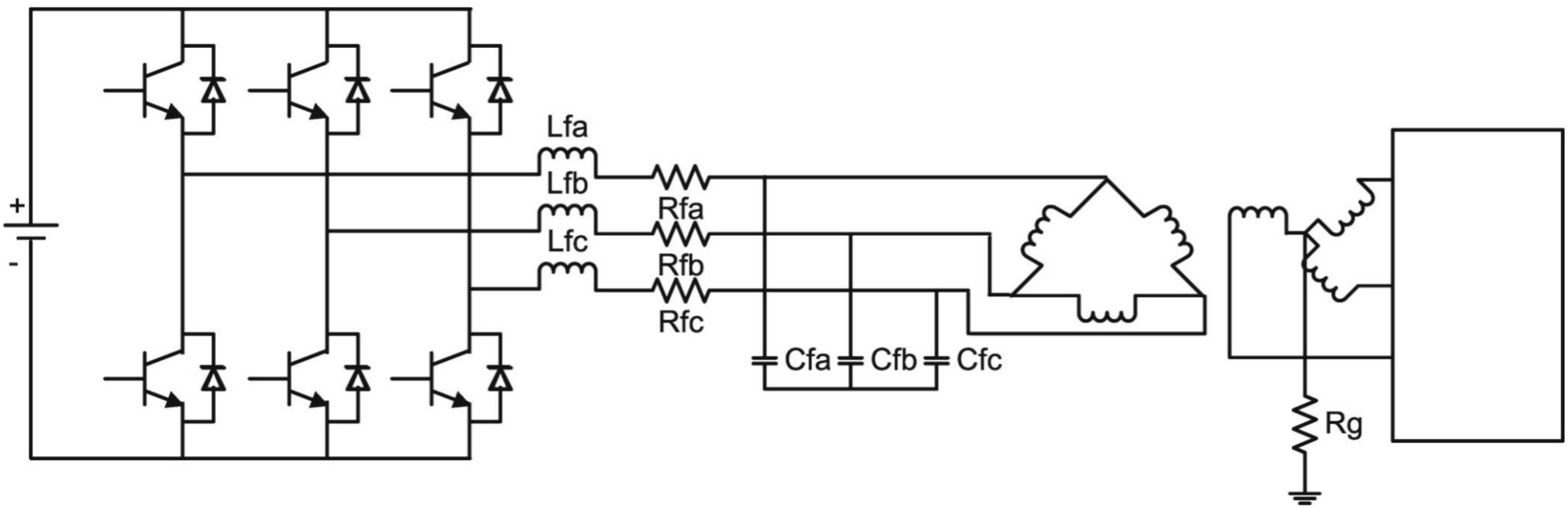
Topology 3



Advantages

- Low voltage power electronics module
- Limits inrush currents
- Limits DC injection current
- Leakage inductance acts as filter inductor
- Local expertise available

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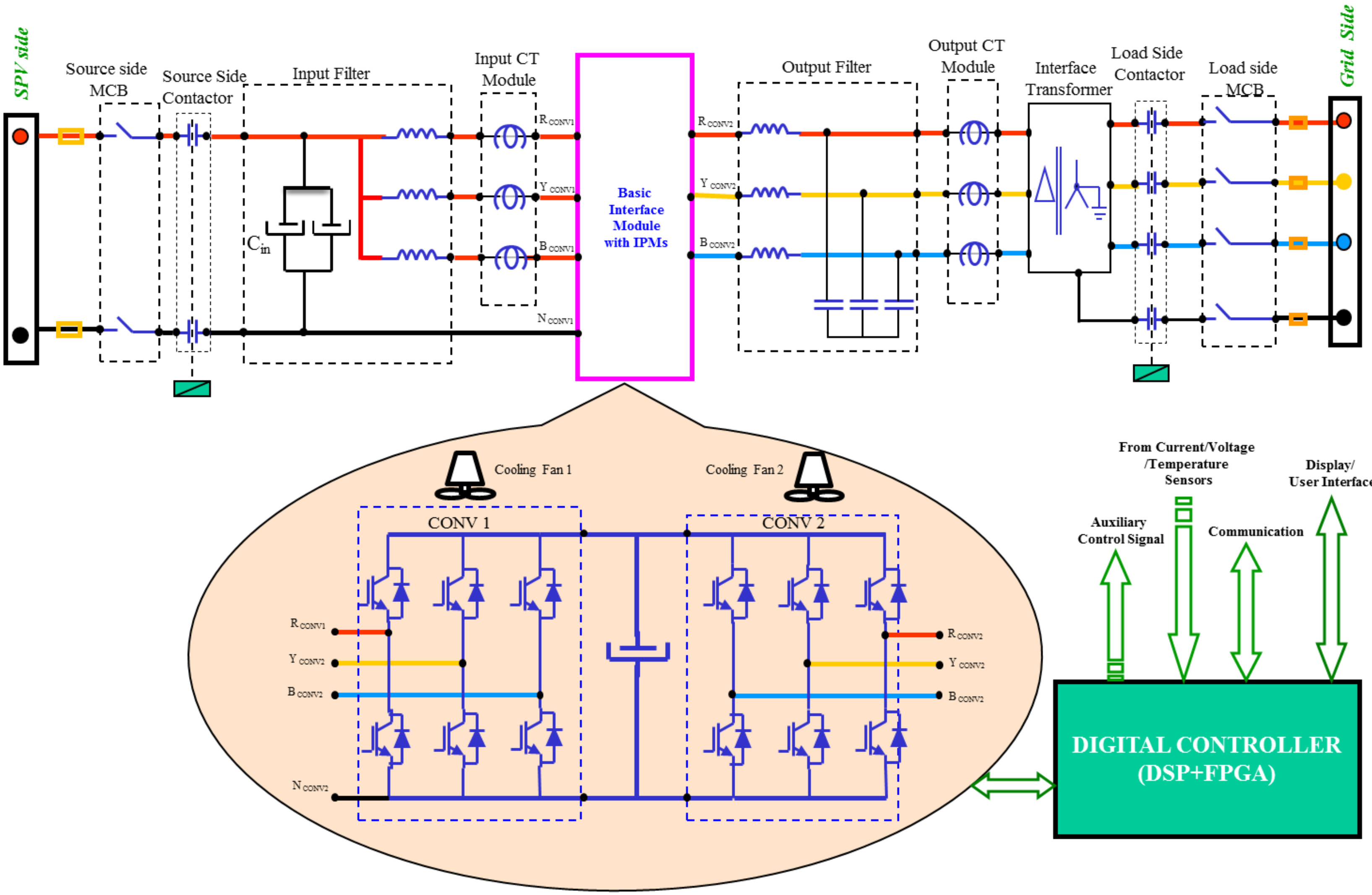
Detailed Hardware schematic diagram



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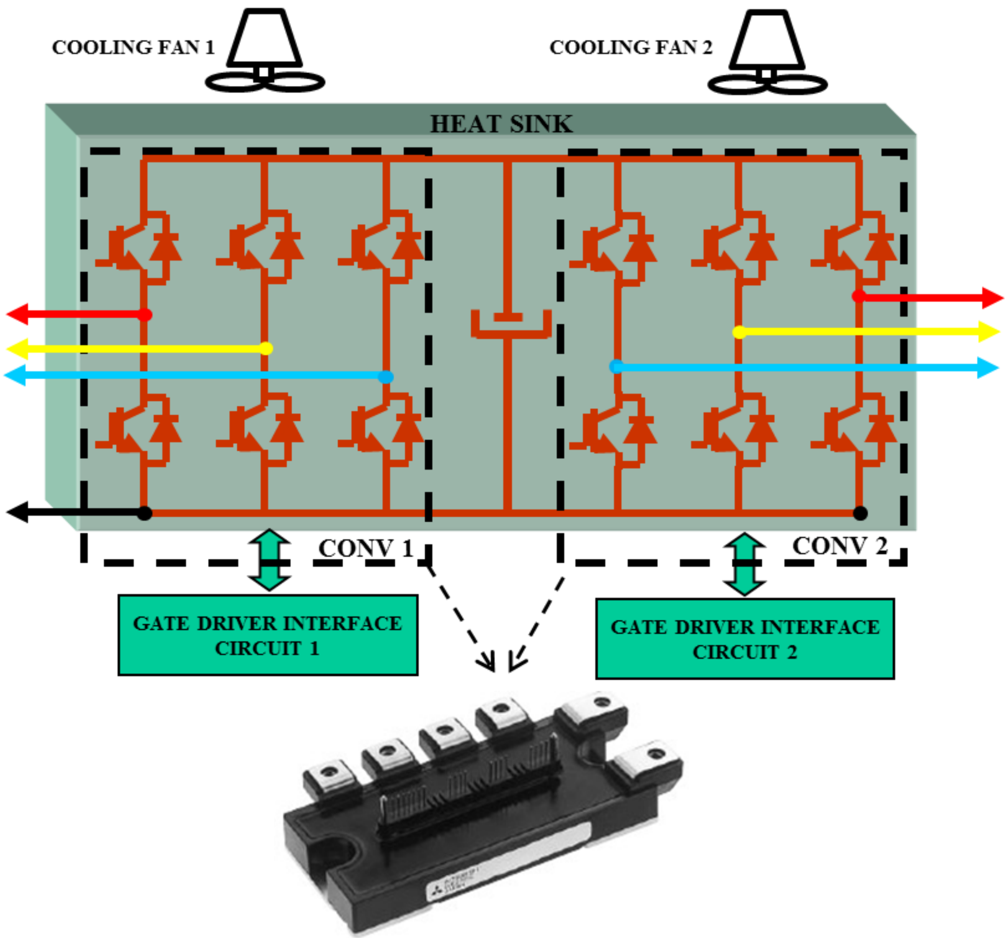
Basic Interface Module (BIM)



Specification

Rated power	10 kVA
DC Bus voltage	400V Max
AC Voltage	200V l-n nominal, 3 phase, 50 Hz
Switching frequency	10 kHz
Switching devices	IGBT/IPM *600V, 150A Mitsubhisi make*
Protections	SC, DC O/V, Overload, over temp.
Cooling System	Forced air cooling

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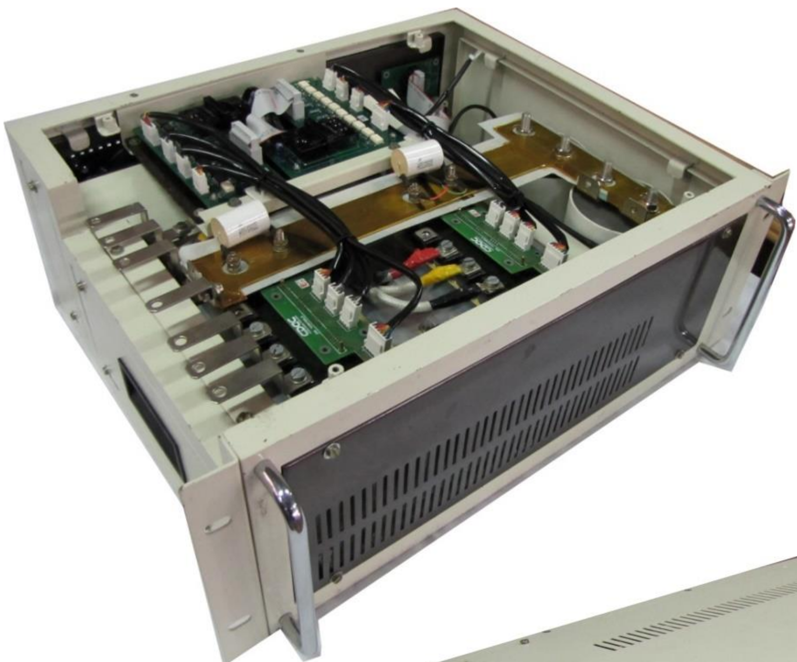
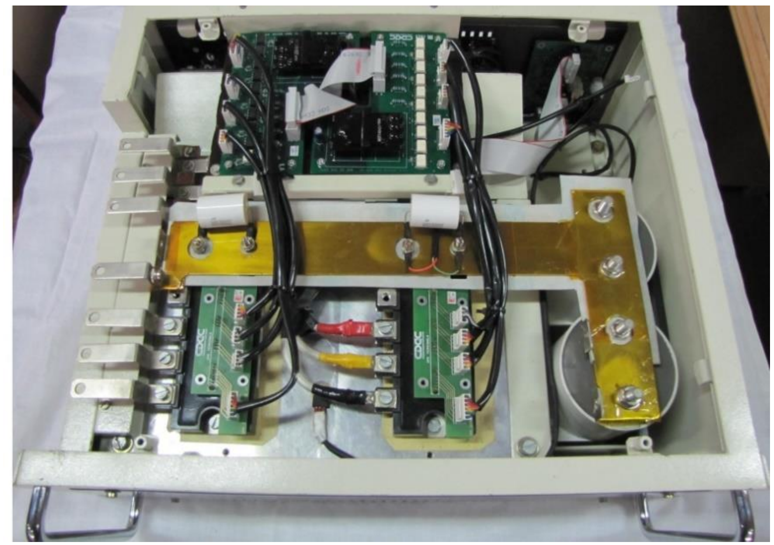
BIM - Photographs





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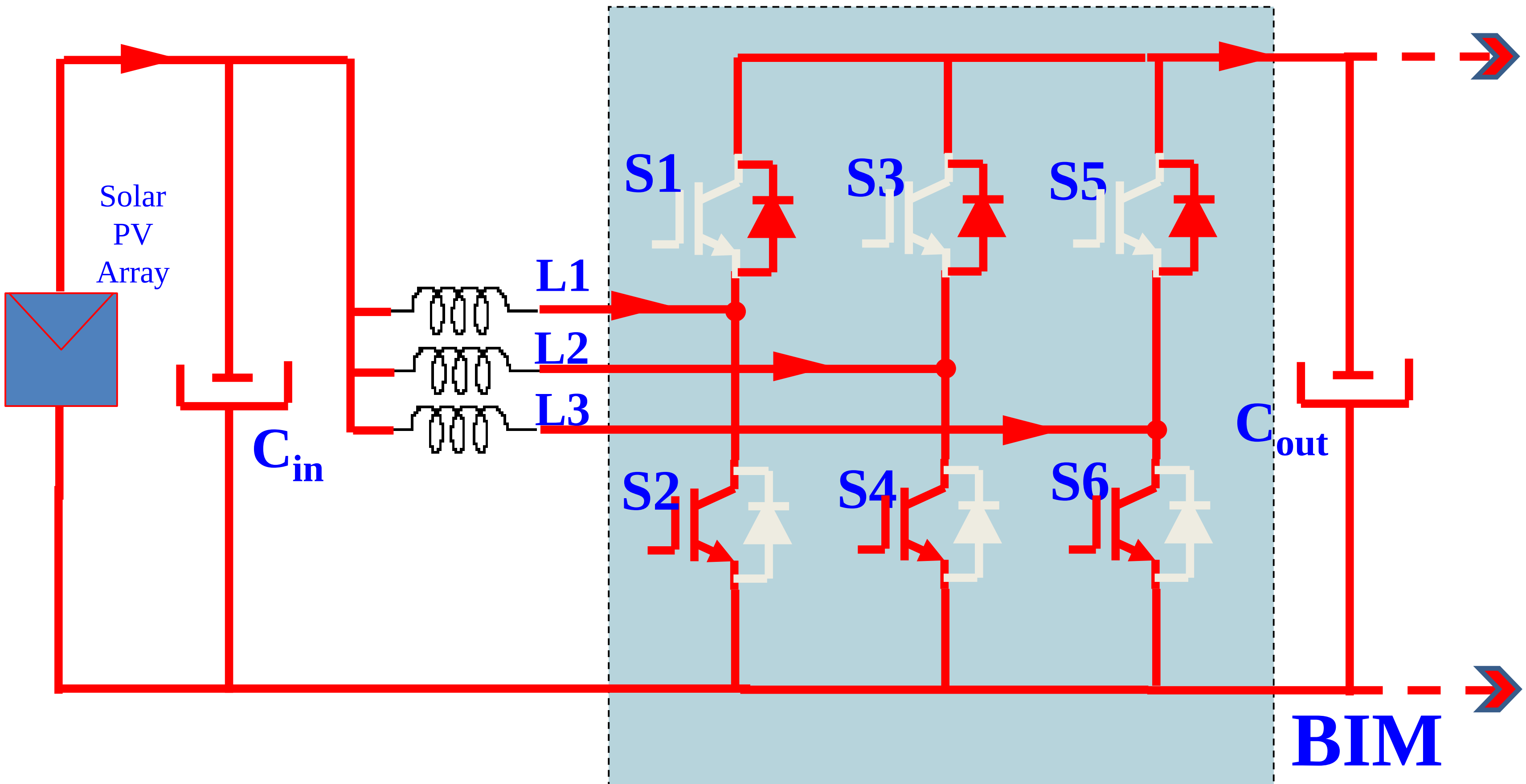
Multiphase Interleaved Boost converter



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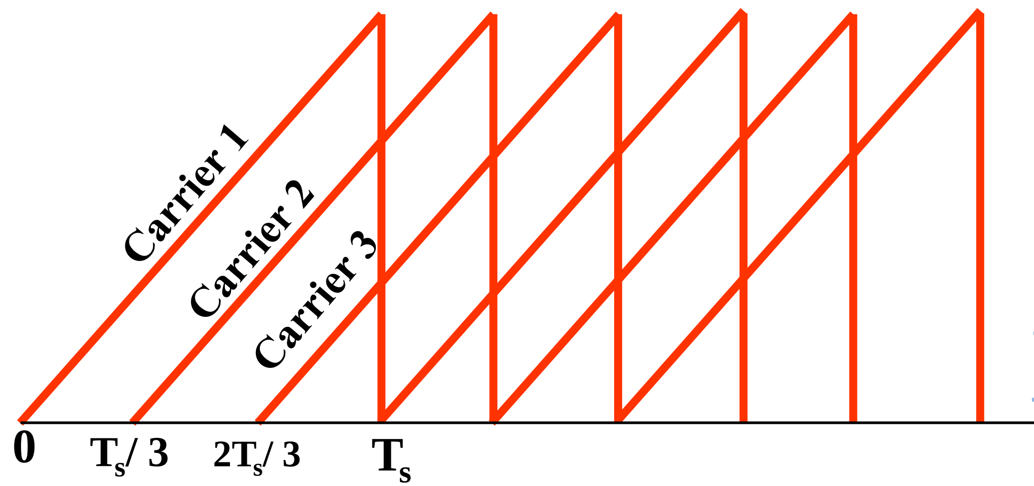
DC choke Selection Criteria

CASE 1

$$L = \frac{V_{pv} \times D \times T_s}{\Delta I}$$



Phase Shifted Carriers generated using FPGA

CASE 2

Fix L = 2.5 mH

Without interleaved carriers,

Total Ripple for 3 phase DC-DC converters $=\Delta I_i = 11A$

With interleaved carriers,

Total Ripple for 3 phase DC-DC converters $=\Delta I_i = 6A$

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AC filter Selection Criteria

CASE 1

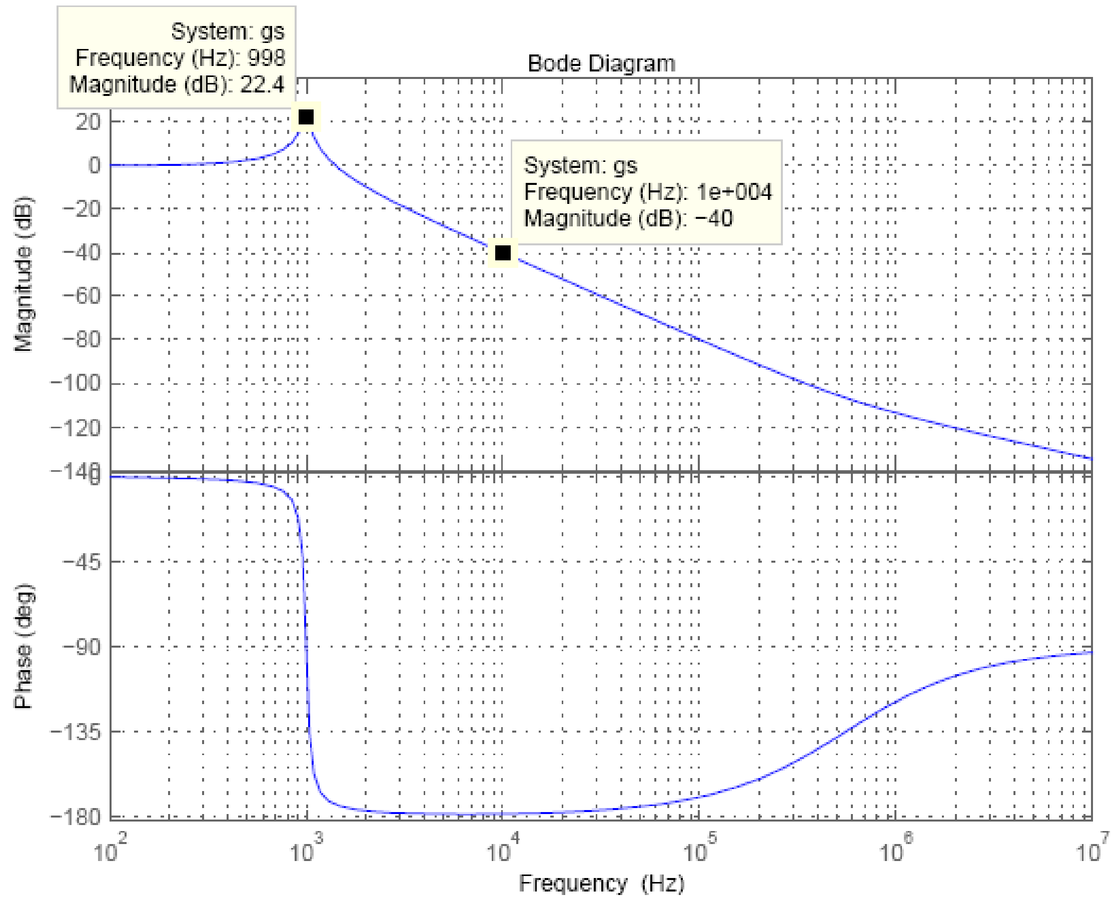
$$f_c = \sqrt{f_{sw} f_s}$$

f_c = 707 Hz

CASE 2

If dB = 40 dB,
C = 47 μf
then, f_c = 1000 Hz

L = 540 μH



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Outline

- GISPV -OVERVIEW
  - System Architecture
  - SPV array sizing & specifications
  - Photographs
- POWER HARDWARE
  - Power conditioning Unit - Single Line diagram
  - Topology Comparisons
  - Practical Hardware Scheme
  - Basic Interface Module (BIM)
  - Photographs (BIM)
  - Thermal management, DC/AC Filters
  - Specifications
- **CONTROL HARDWARE**
  - **Digital Controller requirements**
  - **Block diagram – controller card**
- **CONTROL ALGORITHM**
  - Multi phase Interleaved DC-DC Converter, MPPT control
  - Grid side Controller
  - Experimental Results

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Functional Requirements of Digital controller

DSPs

- Reads various voltage, current signals
- Source-side converter control with maximum power point tracking in the case of solar and wind power conversion
- Battery management
- Communication of critical parameters to/from the central Controller for coordinated operation
- Converter / System level protections
- Supervisory Control
- Remote monitoring and control

FPGA

- Shifted carrier generation for both source side and Grid side converters
- Generation of PWM Signals(36 Nos)

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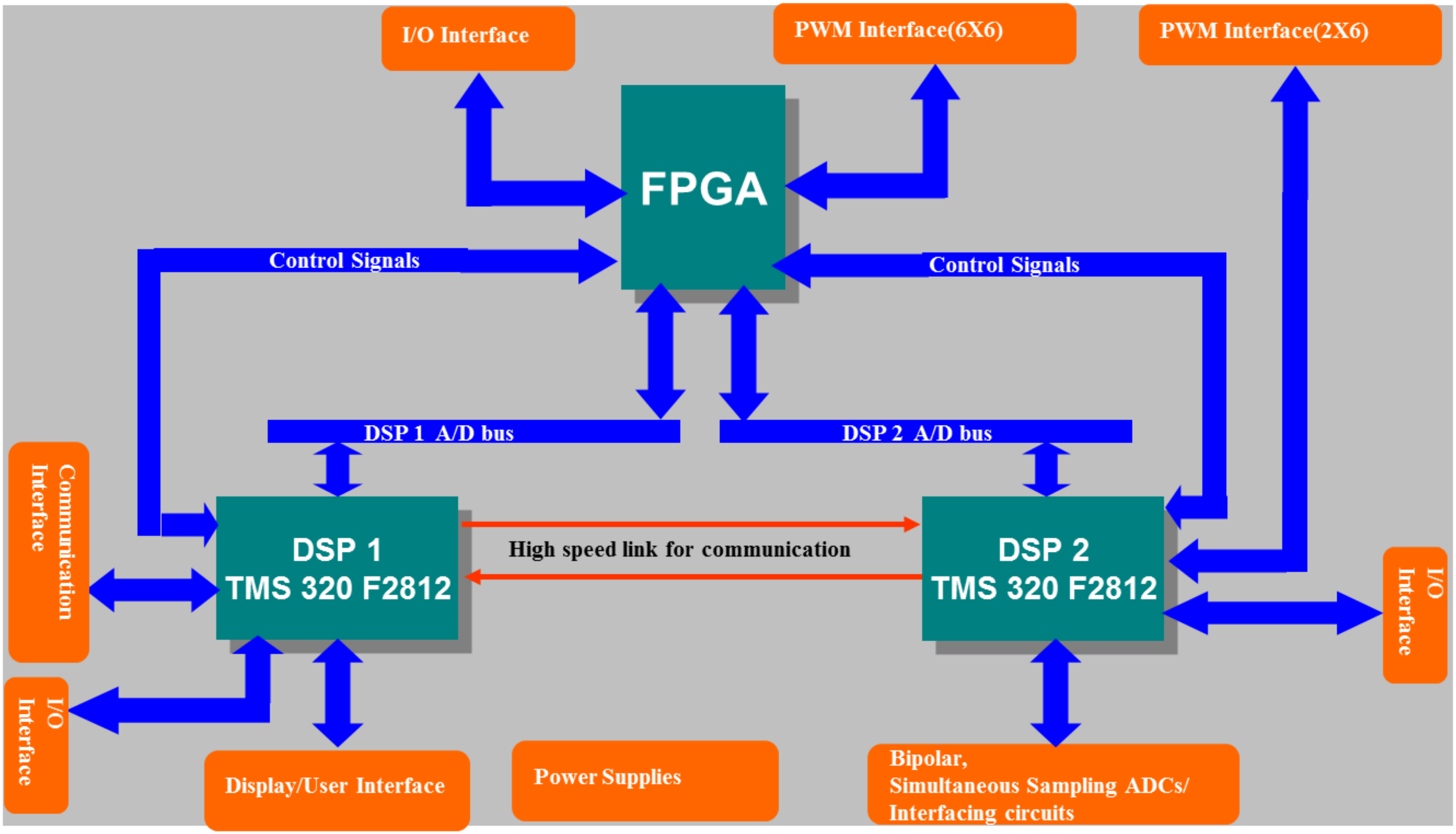
Digital controller Block diagram



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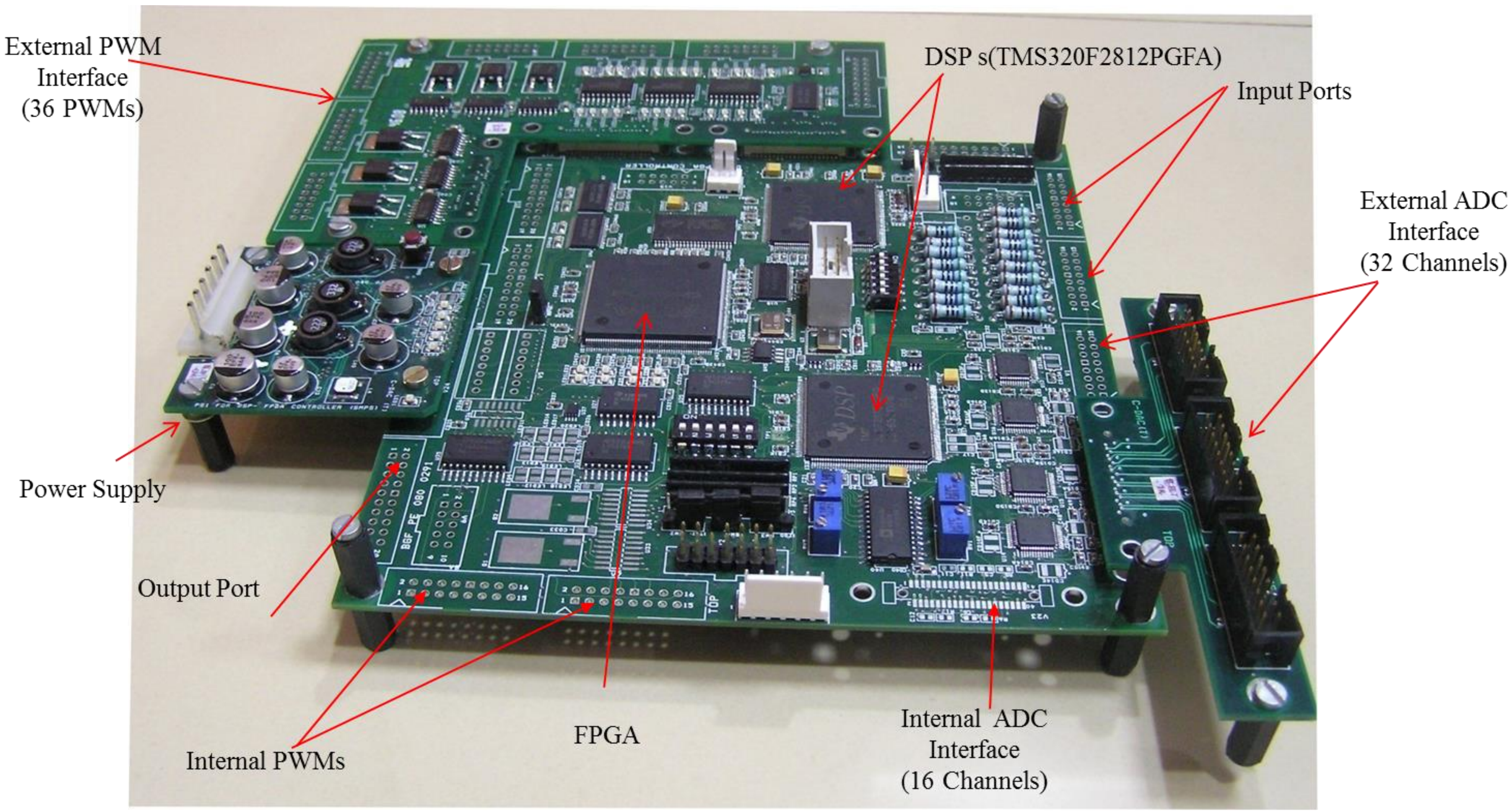
Digital controller - Photograph



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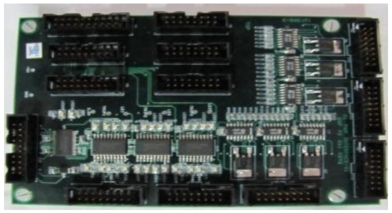
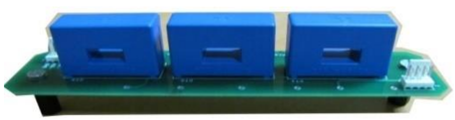
Auxiliary circuits- Photograph



PWM Interface Circuit

SMPS for the Digital Controller



Current sensor PCB

Voltage sensor PCB

Power supply

Gate Driver Interface PCB

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Outline

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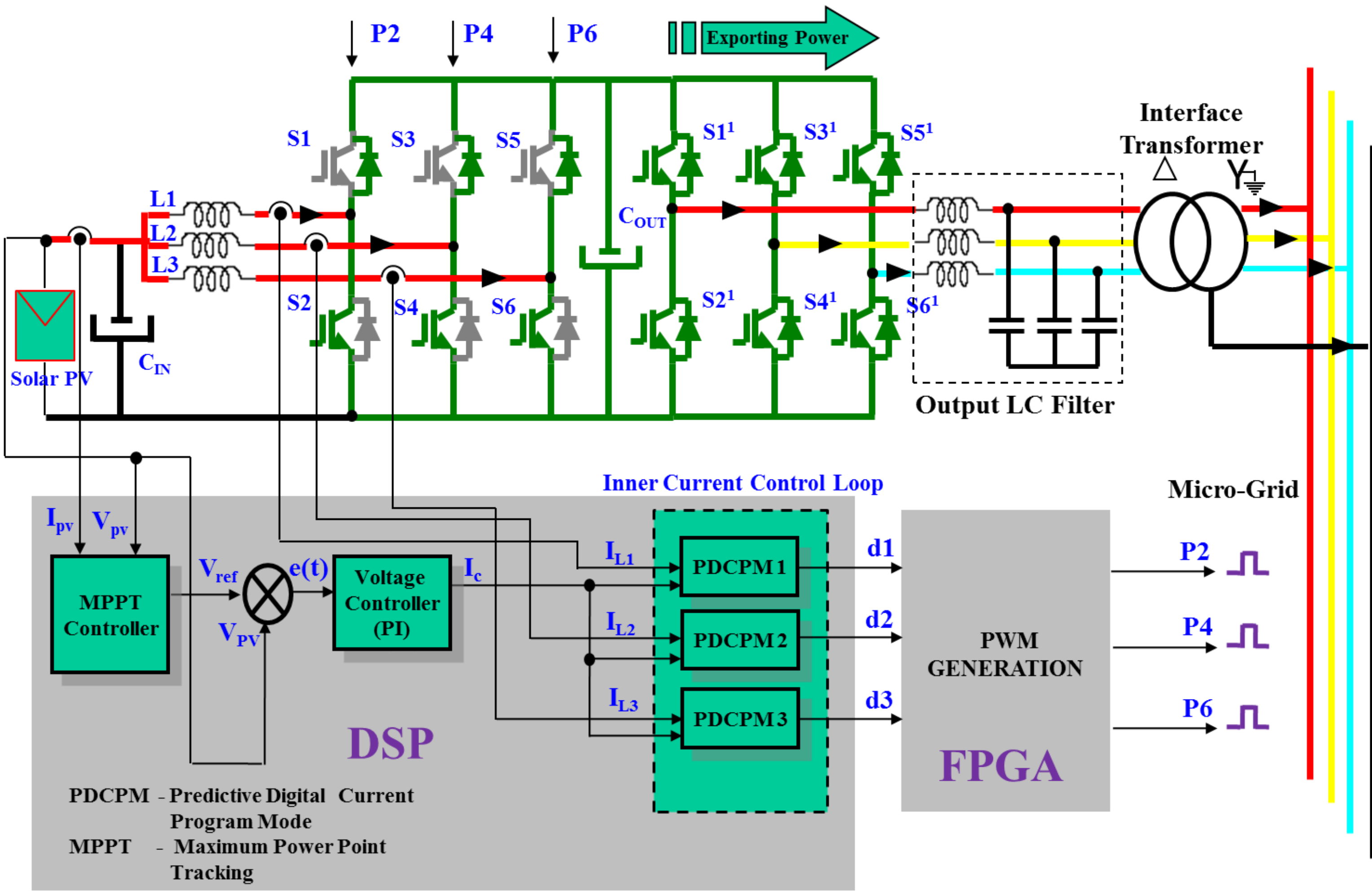
Solar PV System(Boost mode)



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Why MPPT ?

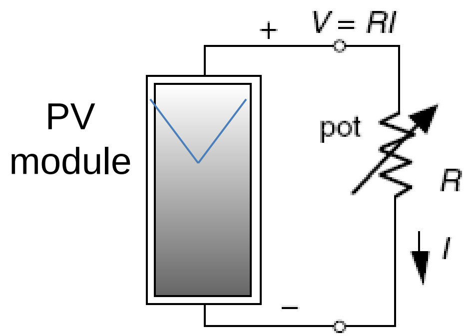

Fig 1

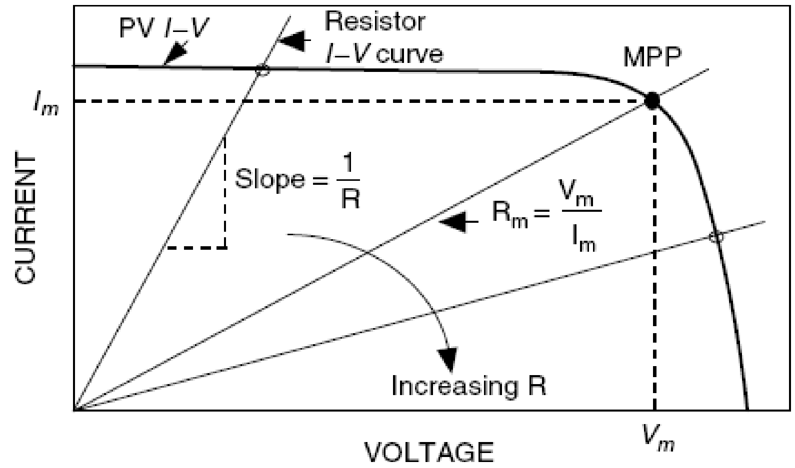

Fig 3

At R_m, Maximum Power $= V_m . I_m$

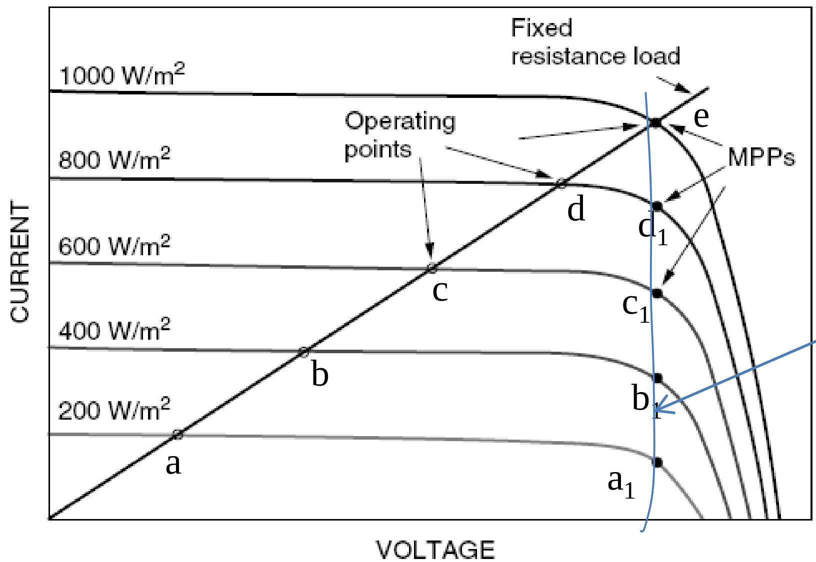

Fig 2

Maximum power point trajectory

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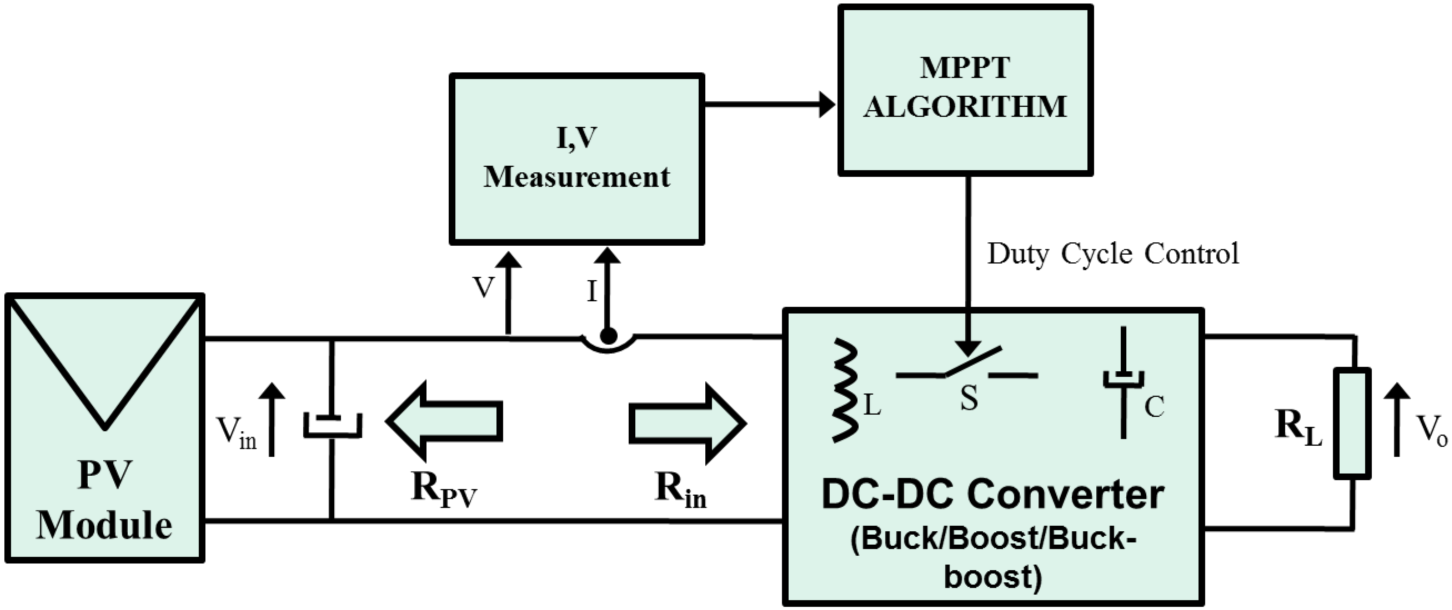
MPPT- Principle of operation



R_{in} – Input side Impedance/Reflected R_L

R_L – Load Impedance

R_{PV} – Impedance of Solar PV module

For maximum power transfer
$R_{PV} = R_{in}$

For Buck : $R_{in} = \frac{R_L}{d^2}$

For Boost : $R_{in} = R_L(1-d)^2$

For Buck-Boost : $R_{in} = R_L\left(\frac{1-d}{d}\right)^2$

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Conventional MPPT Techniques

- Perturb & Observe(P&O)/Hill climbing Method
- Incremental Conductance(IC) Method
- Constant Voltage Method(CV) Method

Advanced MPPT Techniques

- Artificial Intelligence techniques(Fuzzy logic, Neural networks, genetic algorithms)
- Multi-dimensional MPPT /Particle swarm Optimization (PSO) Method

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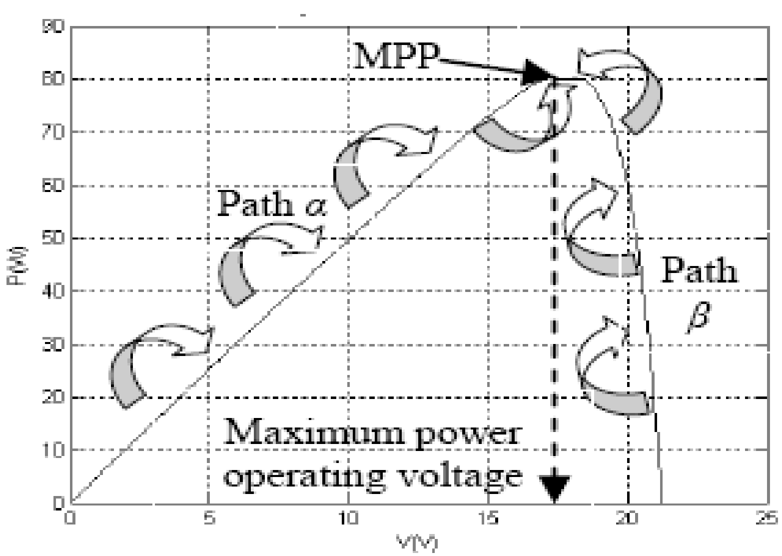
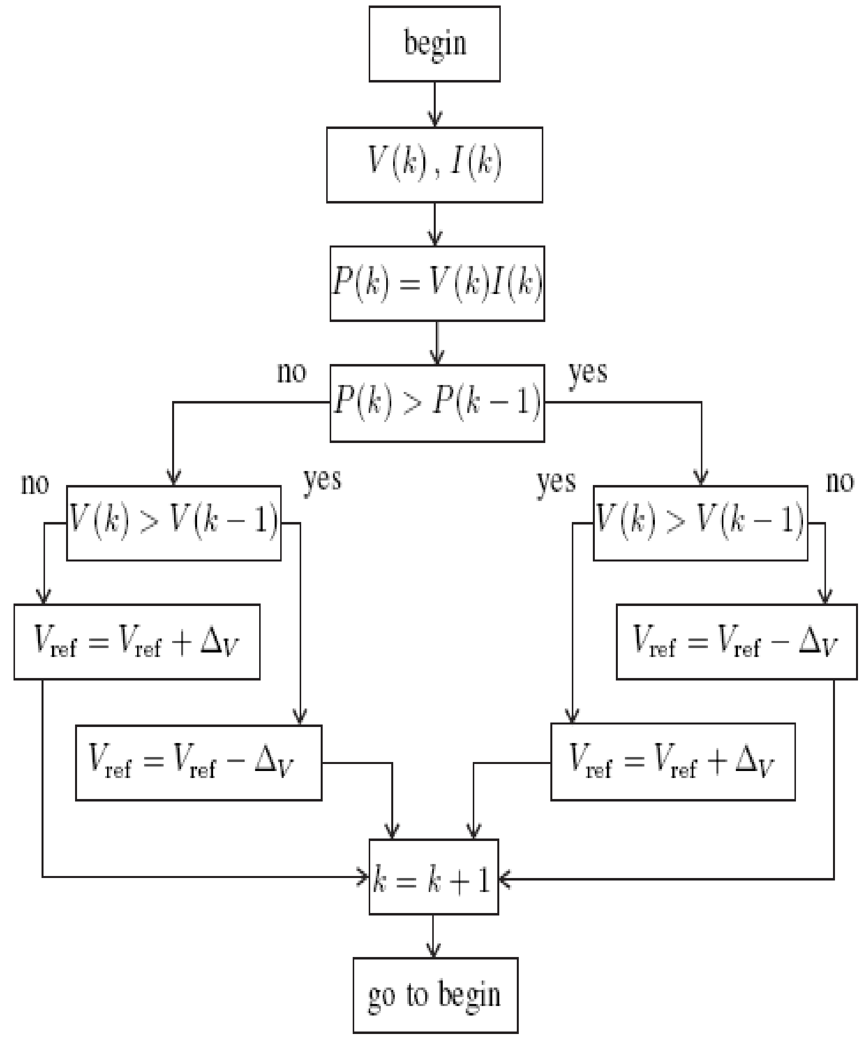
MPPT-Perturb & Observe method

Advantages

- Simple structure & easy to implement
- Generally used for wide range of applications





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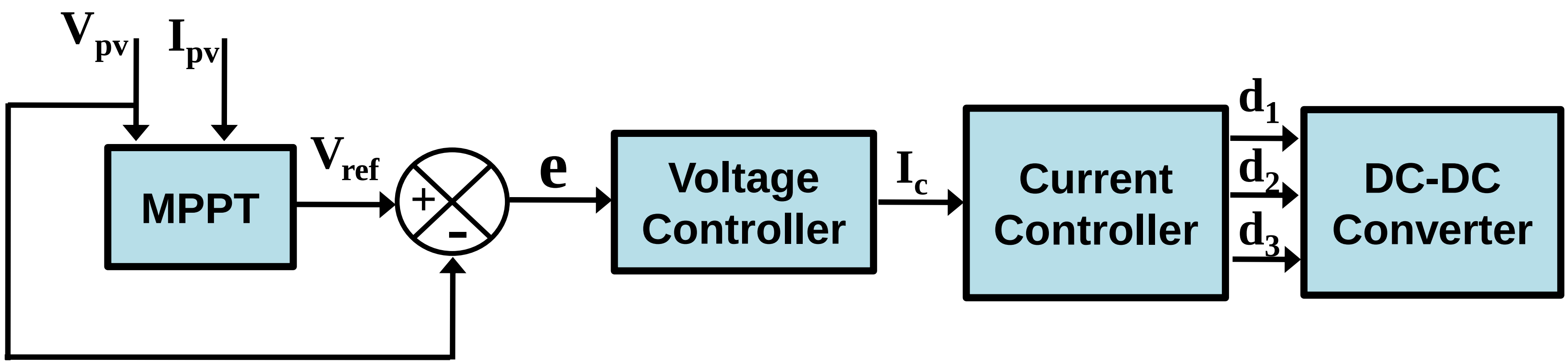
Voltage Controller



Simple closed Loop system

$$e[n] = V_{ref}[n] - V_{pv}[n]$$

Voltage Control Law

$$I_c[n] = I_c[n-1] + k_1 e[n] + k_2 e[n-1]$$

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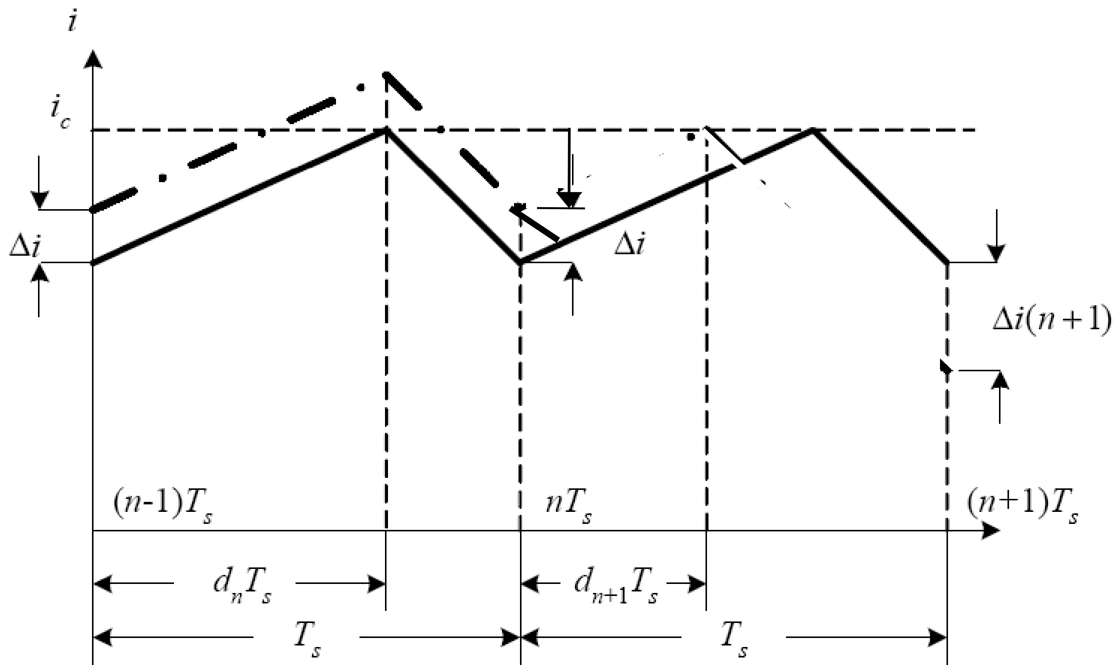
Current Controller



Inductor current with perturbation

Current Control Law

$$d_{[n+1]} = \frac{L}{V_{dc}[n-1]T_s}\left(I_c[n] - I_L[n-1]\right) + 1 - \frac{V_{pv}[n-1]}{V_{dc}[n-1]}$$

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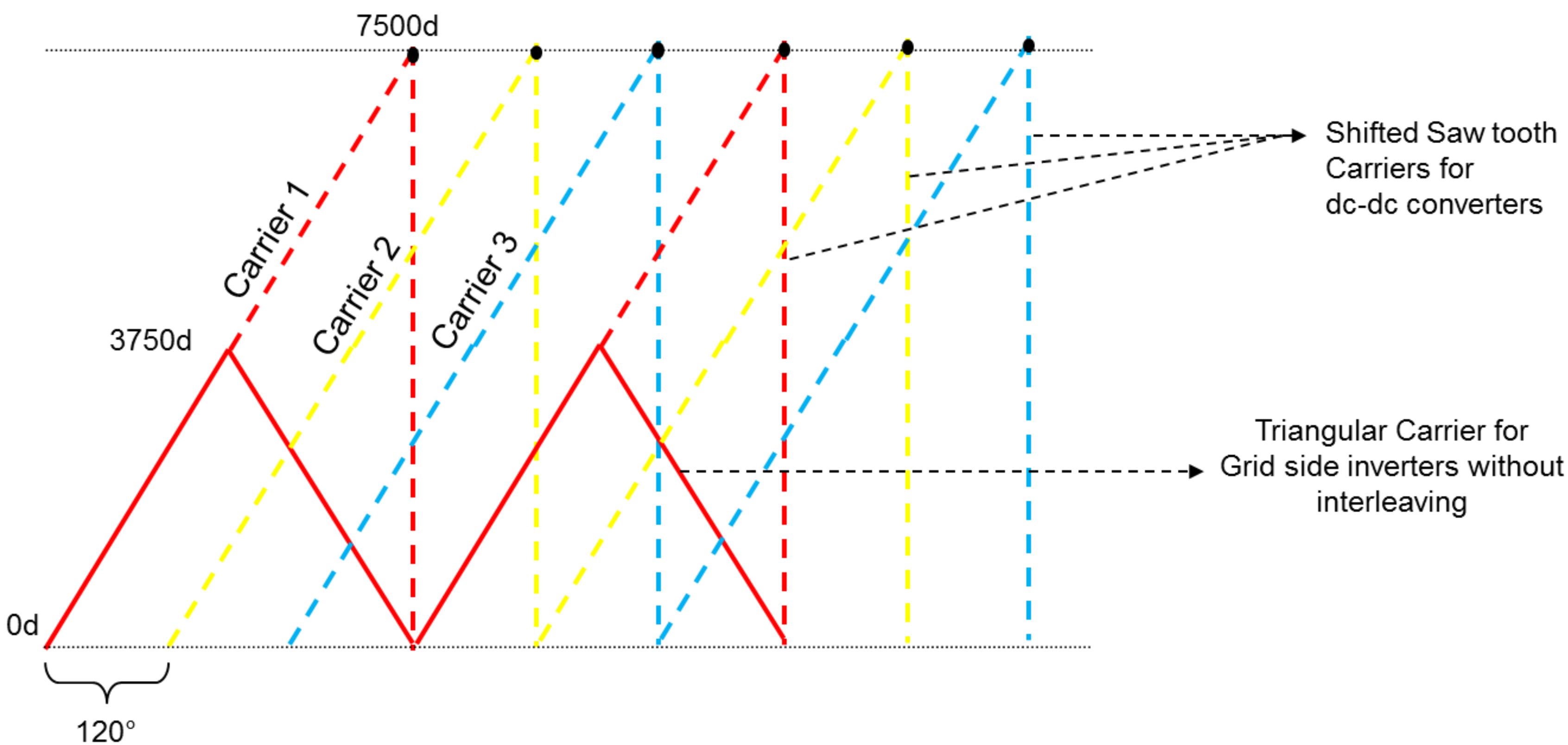
Phase shifted carrier generation



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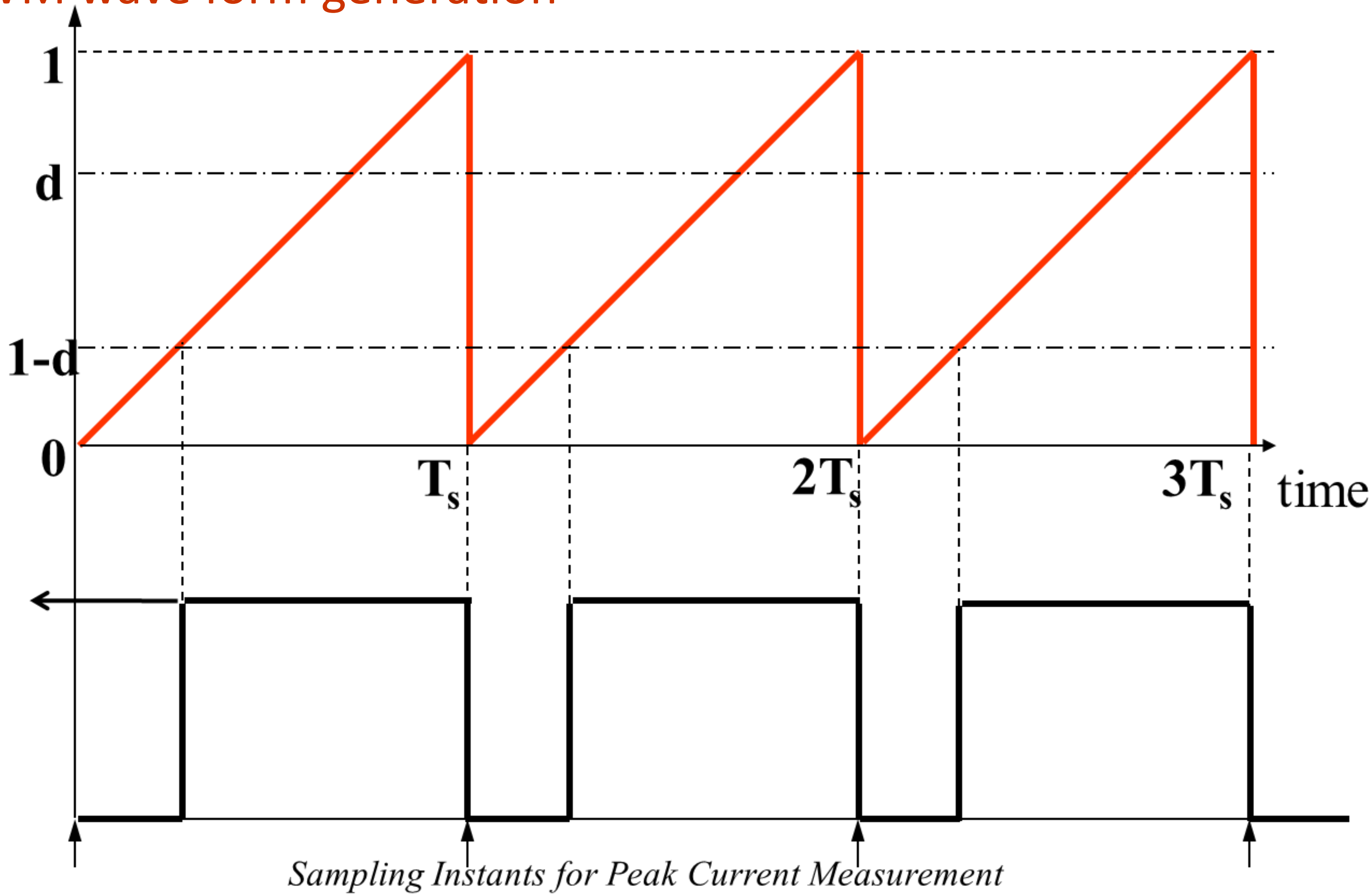
PWM wave form generation



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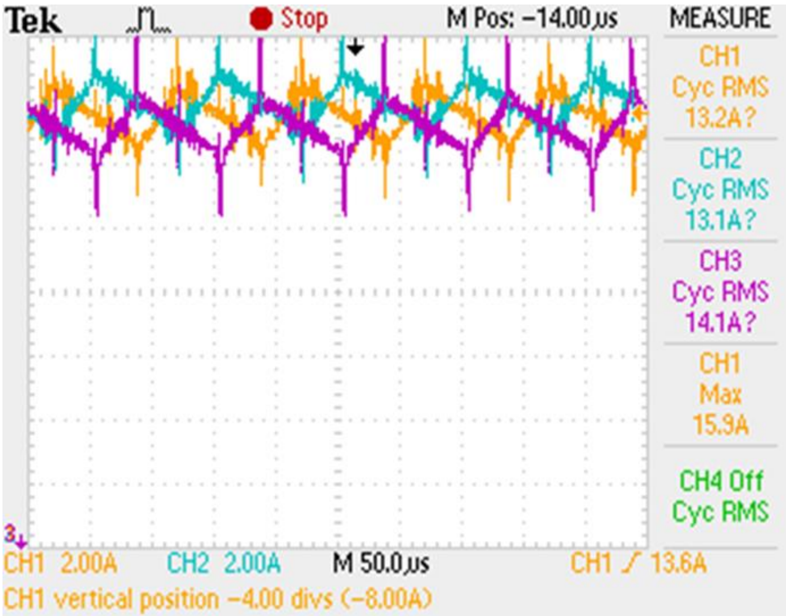
Test Waveforms for DC-DC Converter



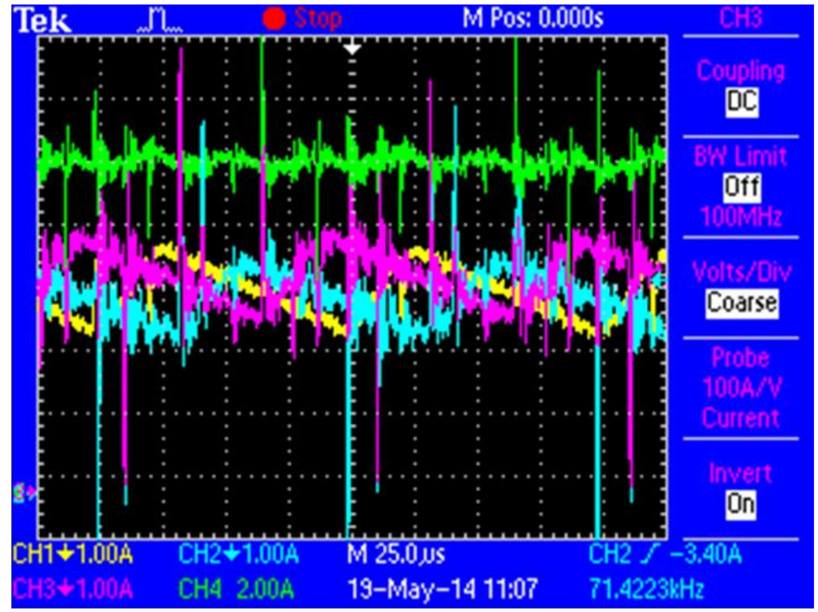
<u>Test condition</u>

Vdcin: 290 V

Vdclink : 400 V

Pin: 9.78 kW

Iin : 33.67 A



<u>Test condition</u>

Vdcin: 340 V

Pin: 3049.5 W

Iin : 9.5 A

Vdclink : 400 V

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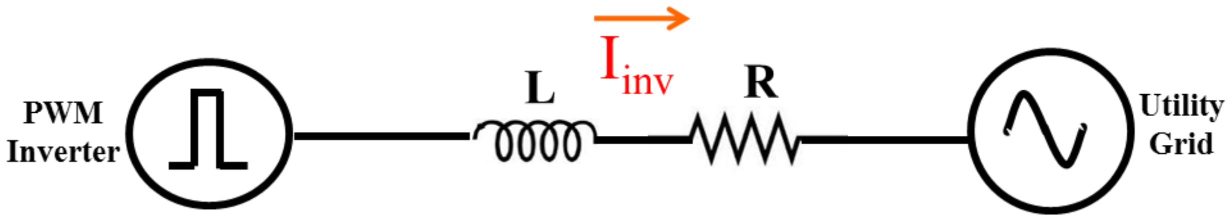
Grid side Controller – Control Law



$$\vec{V}_{inv} - R.\vec{I}_{inv} - L\frac{\vec{d}_{inv}}{dt} - \vec{V}_{grid} = 0$$

$$V_{inv} = \left(V_{inv(d)} + jV_{inv(q)}\right)e^{j\theta}$$

$$V_{inv(d)} = I_{invd}R + L\frac{dI_{invd}}{dt} - \omega L.I_{invq} + V_{gd}$$

$$V_{inv(q)} = RI_{invq} + L\frac{dI_{invd}}{dt} - \omega L.I_{invd}$$

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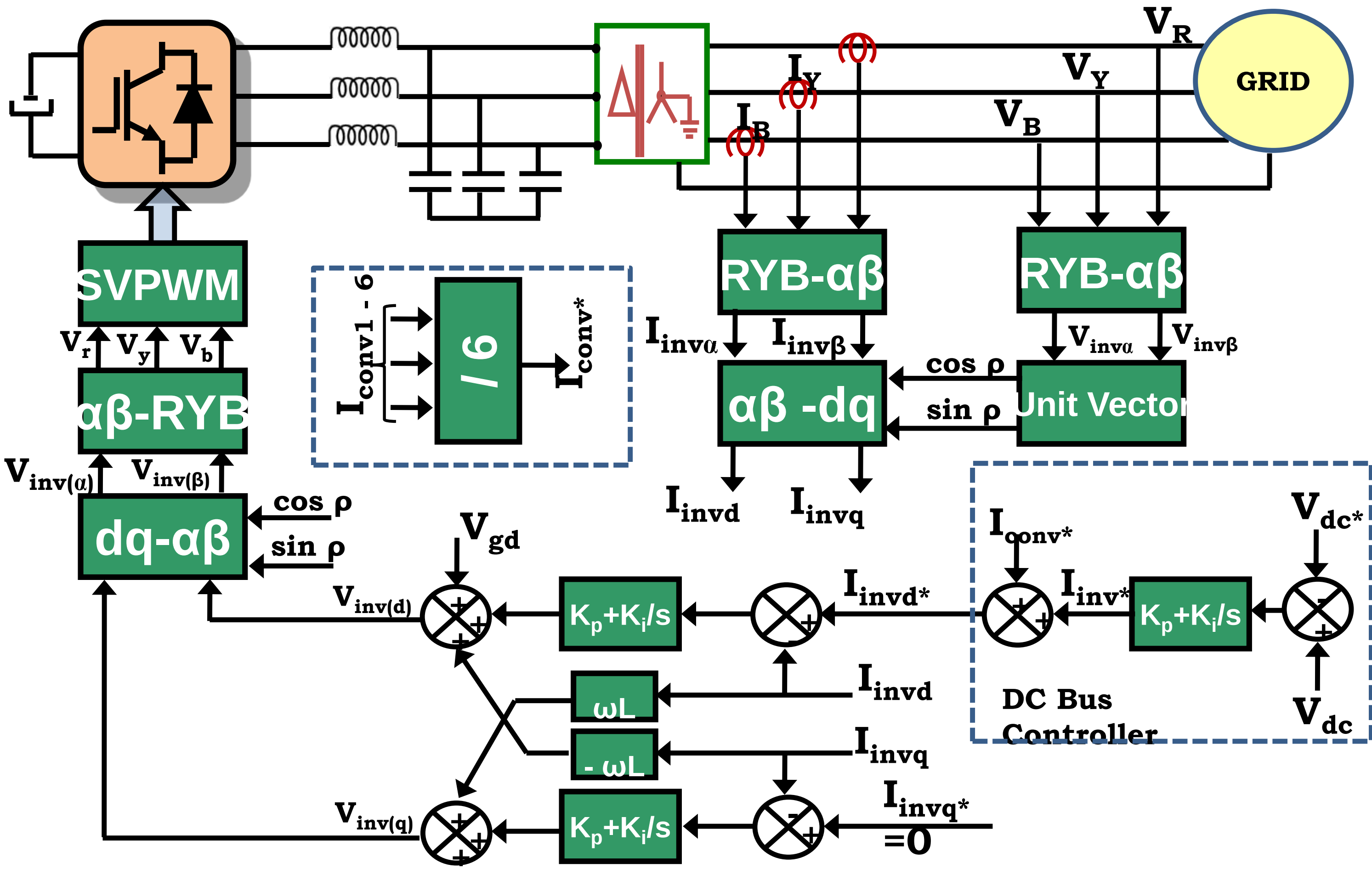
Controller Implementation Block Diagram



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Protections

- Input Over current protection
- DC bus protection
- Grid over current protection
- Grid over / under voltage protection
- Anti-islanding during grid failures(IEEE 929:2000)
- Over temperature protection

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Important Standards

List of PV Inverter Standards/Regulations	Reference No.
Photovoltaic systems – Power conditioners – Procedure for measuring efficiency	IEC 61683:1999
Semiconductor convertors - General requirements and line commutated convertors - Part 1-1: Specifications of basic requirements	IEC 60146-1-1:1991
Low Voltage Ride Thorugh(LVRT) Tests	IEC 61400-21
Balance-of-system components for photovoltaic systems – Design qualification natural environments	IEC 62093:2005
Test procedure of islanding prevention measures for utility-interconnected photovoltaic inverters	IEC 62116:2008 modified
Photovoltaic(PV Systems)-Characteristics of the utility interface	IEEE 1574 , **IEC 61727(2004-12)Ed.2.0**
Electrical installations of buildings-Part 7: Requirements for special installations or locations-section 712:Photovoltaic power supply systems	IEC 60364-7-712
Photovoltaic system performance monitoring - Guidelines for measurement, data exchange and analysis	IEC 61724:1998
Overvoltage protection for photovoltaic (PV) power generating systems - Guide	IEC 61173:1992
Safety of power converters for use in photovoltaic power systems – Part 1: General requirements	IEC 62109-1:2010
Safety of power converters for use in photovoltaic power systems – Part 2: Particular requirements for inverters	IEC 62109-2:2011
Protection against lightning - Part 3: (Physical damage to structures and life hazard - Supplement 5: Lightning and overvoltage protection for photovoltaic power supply systems)	IEC 62305-3:2010-12 Edition 2.0
Solar photovoltaic energy systems - Terms, definitions and symbols	IEC/TS 61836:2007
Grid connected photovoltaic systems - Minimum requirements for system documentation, commissioning tests and inspection	IEC 62446:2009

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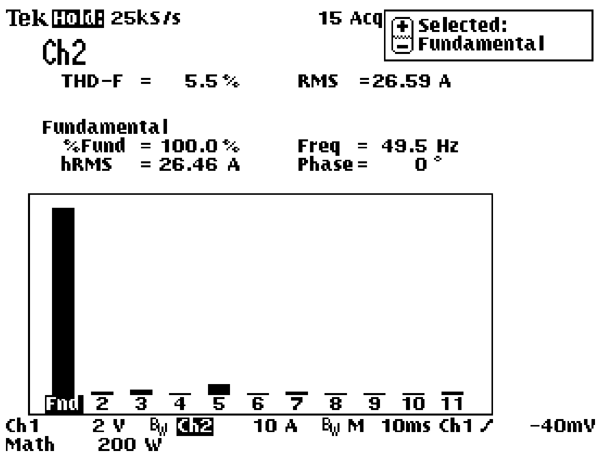
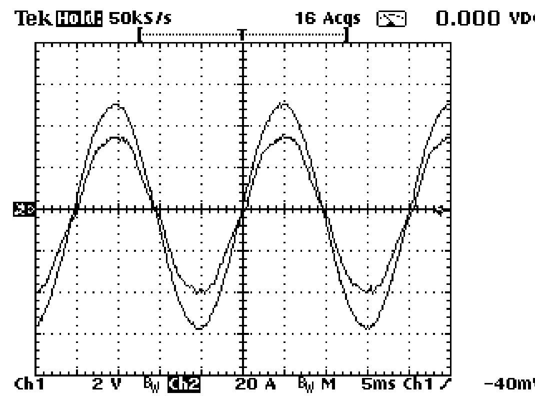
Test Results

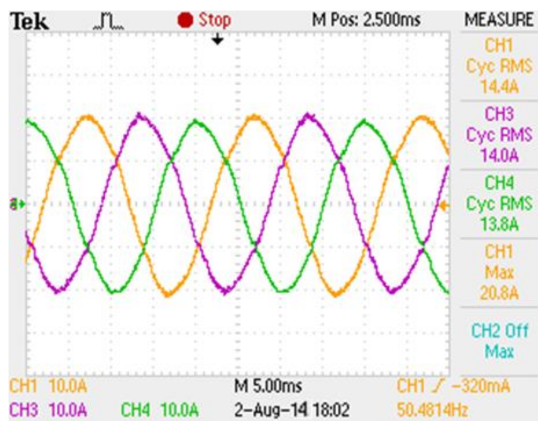
Delivers about 70 units per day on sunny days



THD(I_R)



V_{RN} versus I_R



Inverter current Y side

THD

I_{R}_inv =5.03%

I_Y-inv =4.31%

I_B-inv =5.54%

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Photographs – installed at Technopark, Trivandrum

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Photographs – installed at NEHU

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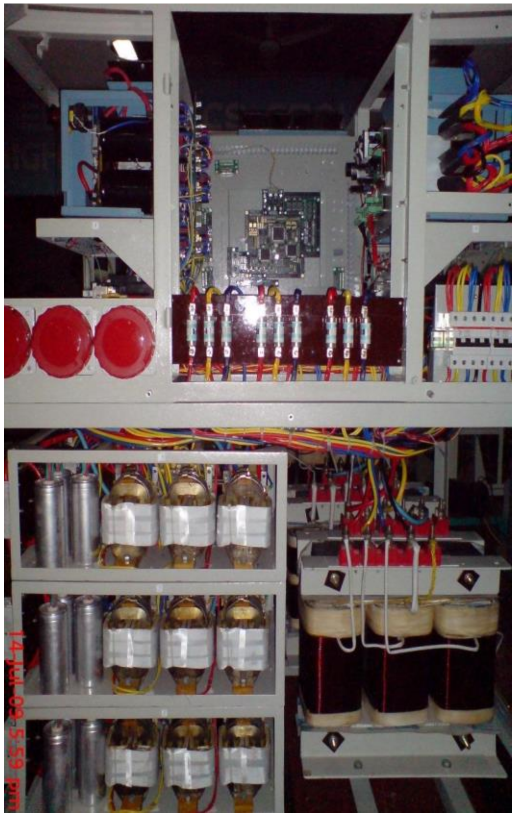
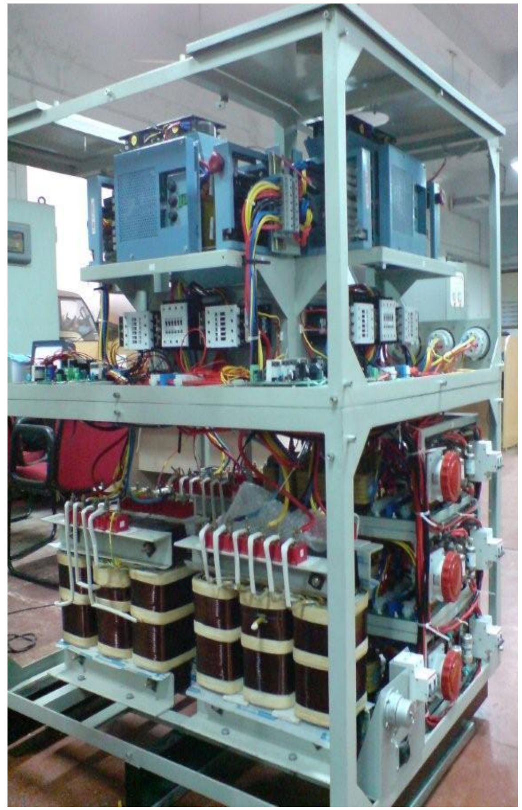
Photographs – installed at WBREDA





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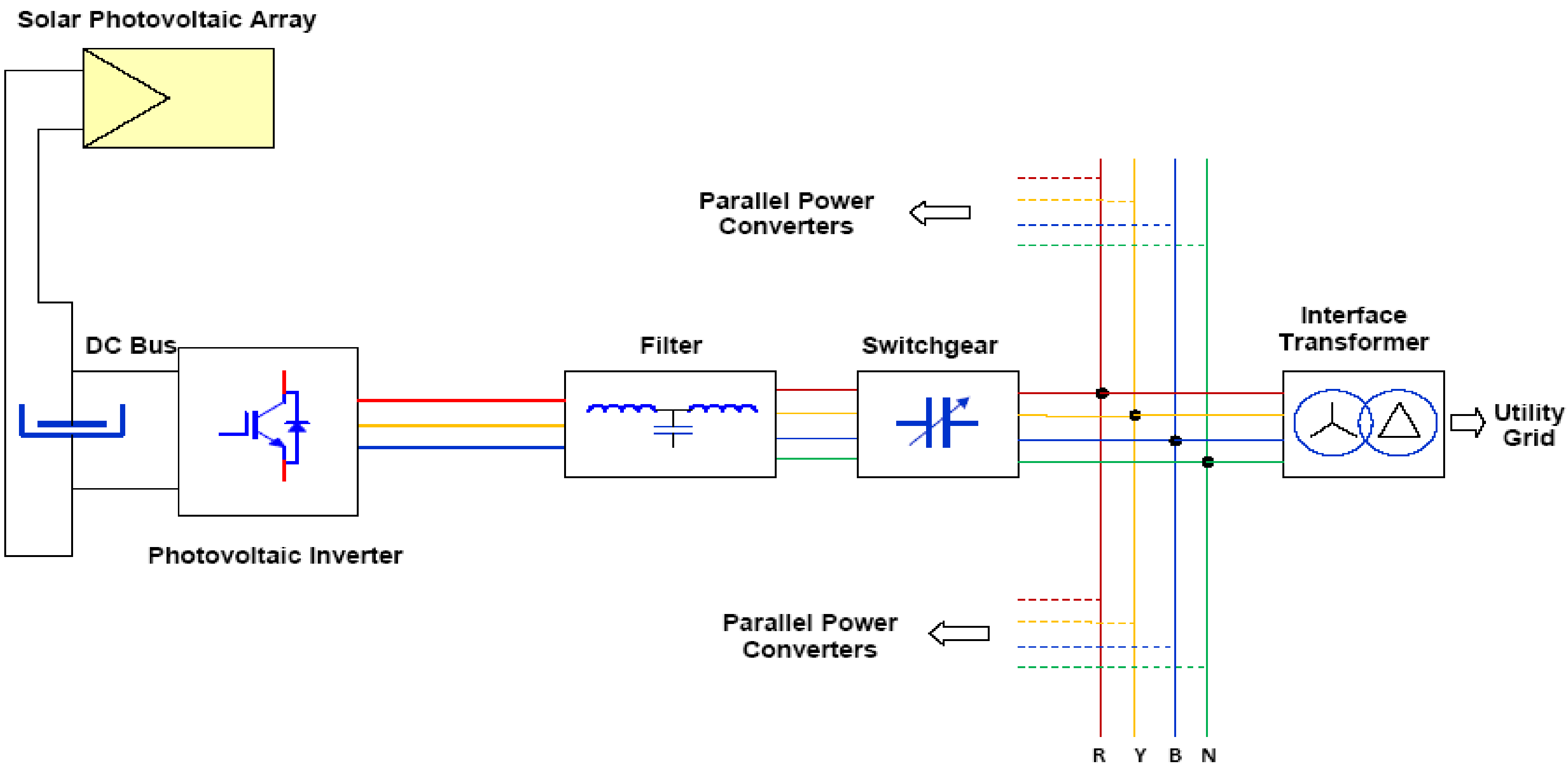
On going activity

Development of 1MW grid connected PV power plant at Jamuria, a 2MW power plant which is the first MW level power plant in India (August 2009)



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Specifications of MW Power Plant

Specification of Solar PV array	
Rated Peak power per set	1250 kW x 2
Array Tilt Angle	20^0
Bus Voltage	670 – 800 V
Module Rating	240 / 225 W
Specification of Power Conditioning Unit	
Nominal Power	1 MW (4* 250W)
Grid Voltage	415 ± 10 %, 3 Φ
Grid frequency	50 Hz ± 0.5 %
Power factor	> 0.95 above 10% of installed capacity
I_{THD}	< 5%, at full load as stipulated by IEEE 1547 – 2003
Efficiency	97 %
Converter	IGBT based voltage source Inverter

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Photographs - 2 MW Power Plant






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Future Scope

- Mode transition control strategies
- Single chip solution(FPGA)
- Improve power density
- Standardization & Commercialization
- Advanced communication infrastructure

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Remote Monitoring and Control of Renewable Energy Source Power Plants

The major objectives of the development:

Development of reliable and cost effective solution for remote monitoring and control of Renewable Energy Source Power Conditioning Units

- Remote monitoring is an essential feature of Distributed Power Generating Station
- Tablet replaces Graphical LCD, Matrix keypad and wireless internet modem
- Cheap and easily upgradable

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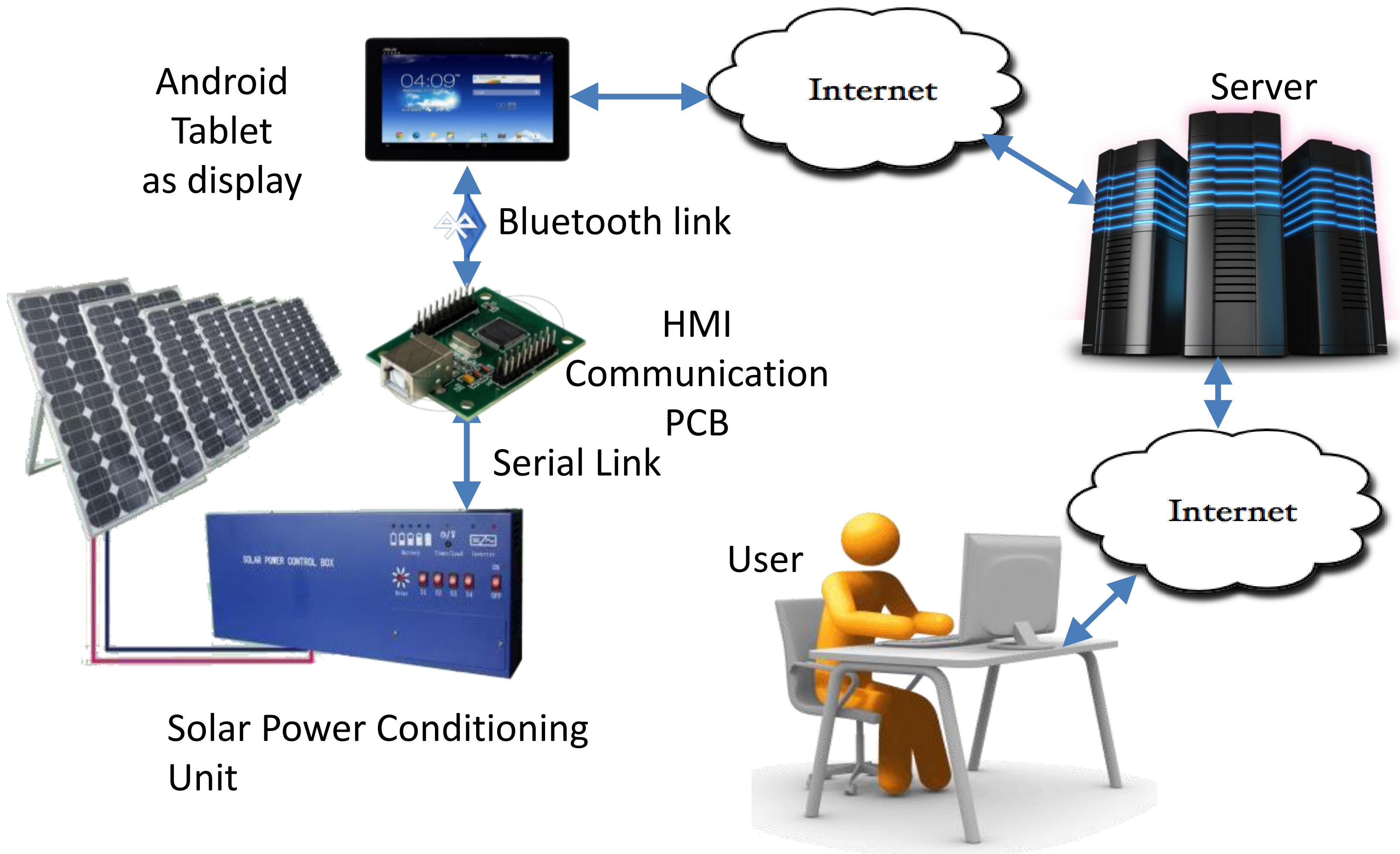
Remote Monitoring and Control of Renewable Energy Source Power Plants



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Remote Monitoring and Control of Renewable Energy Source Power Plants

- Demands an android tablet running Android OS 3.1 or latter having
  - ✓ Bluetooth interface
  - ✓ Internet connectivity
- DSP-FPGA based controller card in the PCU with having UART interface
- Communication between Tablet and PCU through Bluetooth PCB
- On-line monitoring of System parameters
- Same android tablet can be used as local HMI – better graphical visibility to an operator

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Software Environment

- Android application development :- Free downloadable Android Development Tool (ADT)
- Eclipse based IDE
- Java is used for application development
- Code development in PCU – Embedded C
- Server posting method is used for web-enabling the system
- Communication between android tablet and web server is by PHP file in the web server
- Javascript and html coding used for web updation

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Technical Features

- **Android Tablet**
  - Decipher PCU parameters
  - Act as local UI as well as wireless modem
  - Furnish Bluetooth, USB, SD card and wireless networking
  - Can be used as a local storage infrastructure for logging of important events and data for post analysis
- **Webserver**
  - Store online UI
  - Offer duplex communication with PCU and remote monitoring & control device
  - Log measured parameter and system status with time

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Technical Features

- **User Interface Controller Board**
  - Inbuilt communication interface such as UART, USB and Bluetooth
  - Facilitates Bi- directional data exchange between PCU and Tablet

- **Remote Monitoring & Control Device**
  - Networked PC, Laptop or Mobile phone

  "Authorized user can remotely switch ON/OFF the system"

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User Interface Screen

Local UI in Android Tablet	Remote UI as a Web page (www.greenpowerlab.in)
	

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Comparison between conventional & Proposed solutions for Remote monitoring and control

Parameters	Conventional Online Monitoring System	Proposed Android Tablet based Online monitoring System
Communication link between RES PCU and Ethernet	Can be achieved through Rabbit core processor (RCM3000) cost ` 8,000	Serial to Bluetooth converter module(HC-04/HC-05/HC-06) cost ` 600
Establishment of internet connection	Requires internet modem with public IP address approximate cost ` 6,000 per annum	The Existing webserver inbuilt with Public IP can be utilized thereby avoiding the use of internet modem
Other maintenance cost	Renewal of Public IP every year and each system need unique IP, so this cost will get multiplied while number of system increases	Since server posting method is used with unique login gateway /unique domain name, Cost won't change irrespective of number of system

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Comparison between conventional & Proposed solutions for local HMI

Item Resources	Conventional GLCD System	Proposed Android based system
Display device	Graphical LCD 128x64 (CFAG320240CX-YMI-T) cost ≅ ` 6,200	Cheap android tablet cost ≅ ` 6,500
Keypad	16WAY Keypad(GS160201) cost ≅ `5 ,000	Utilizing tablet's touch pad

* For the conventional system, the total cost is evaluated as `25,200(Approx.) whereas the proposed android based monitoring system is only `7,300(Approx.).

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Scope of the Work

- Grid integration of large RES power plants can be triggered by on-line monitoring & control of RES PCUs
- As higher capacity RES plants are being installed, complete shut down of RES power plants in case of grid failure can be avoided
- Can be integrated as a part of Wide Area Monitoring in Smart Grid technology

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Photo of Installed system

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