POWER CONVERTERS FOR INTEGRATION OF RENEWABLE SOURCES TO MICROGRID

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RESEARCH LAB
(ESTABLISHED YEAR IN 2014)

Group:

- Faculty=2;

  Ph.Ds =5(awarded) +7(ongoing)+

  M. Tech=17 Completed + 2 On-going) +

  B.Tech = 16 (Graduated)

Funding:

- SERB, GUJCOST, SVNIT GRANT

Research Area

- ➢ Control Algorithm for Power Filter Technology
- ➢ Improved Power Converter for EVs /PHEVs Battery Charging
- ➢ Power Converters for Micro-grid/Nano-grids applications

Publications since (2014)

- Transactions: 41 (published)
- Conferences: 11

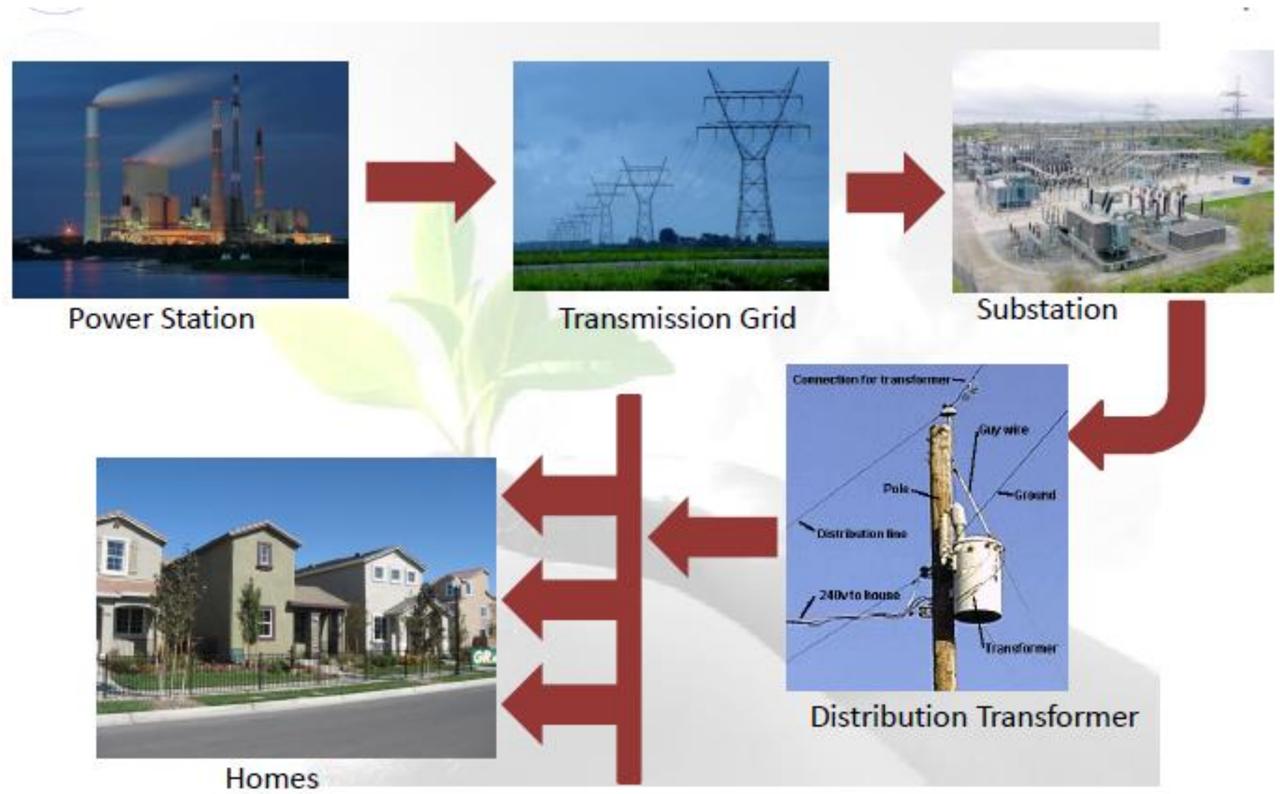
OUTLINE

- Introduction-Need of Micro-grid
- Renewable Energy Sources and DC Microgrid
- DC-based Microgrid Architecture
- Power Converters for RES Integration
- A Sample Research Highlight
    - Uninterrupted DC Power (UDC)
    - Improved Power Converter for EVs/ PHEVs battery charging
- Conclusion

SMART GRID VISION FOR INDIA

"Transform the Indian power sector into a secure, adaptive, sustainable and digitally enabled ecosystem that provides reliable and quality energy for all with active participation of stakeholders"

INTRODUCTION

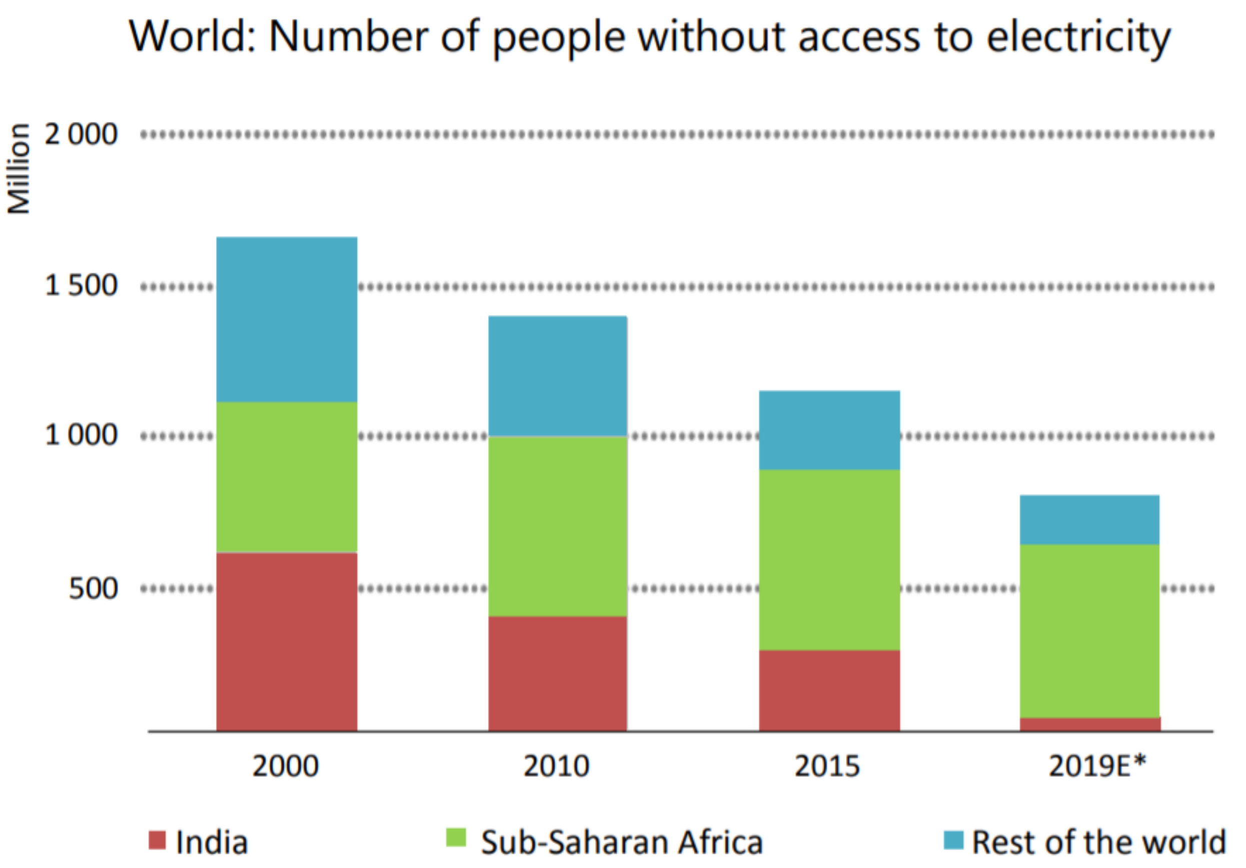


Power system in earlier days

Power system in earlier days

- The Conventional power grids that connect homes, businesses, and other buildings to central power sources - allowing us to use appliances, HVAC systems, electronics, etc. - typically have a centralized generating station with a very large power generation capacity.
- While this system has its benefits, unfortunately, it also means that when part of that grid has to be repaired, *everyone* on the grid is affected.
- How can we combat this to provide more reliable energy to the places it matters most?

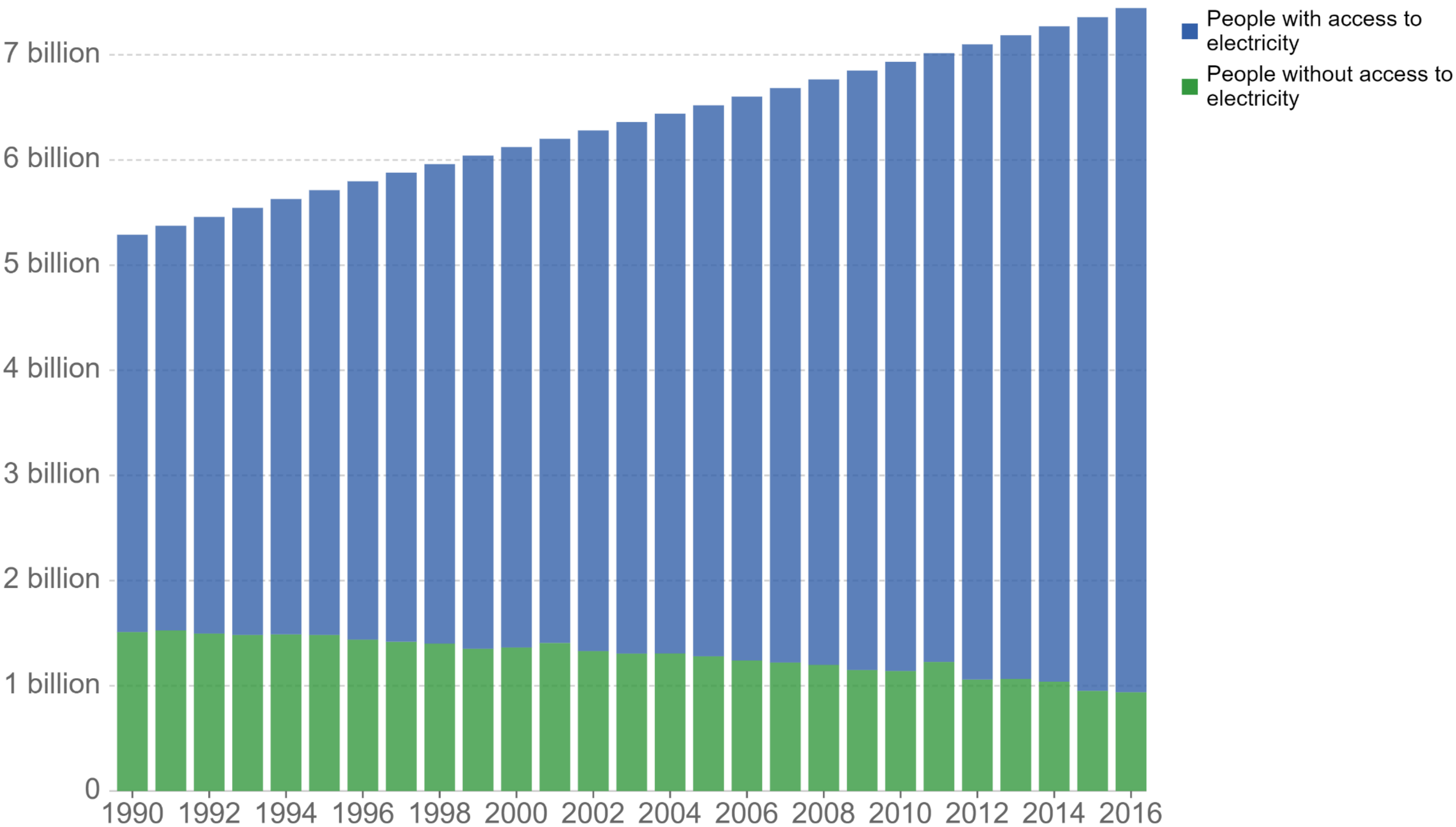
World: Number of people without access to electricity



- Almost 750 million people gained access to electricity in India since 2000

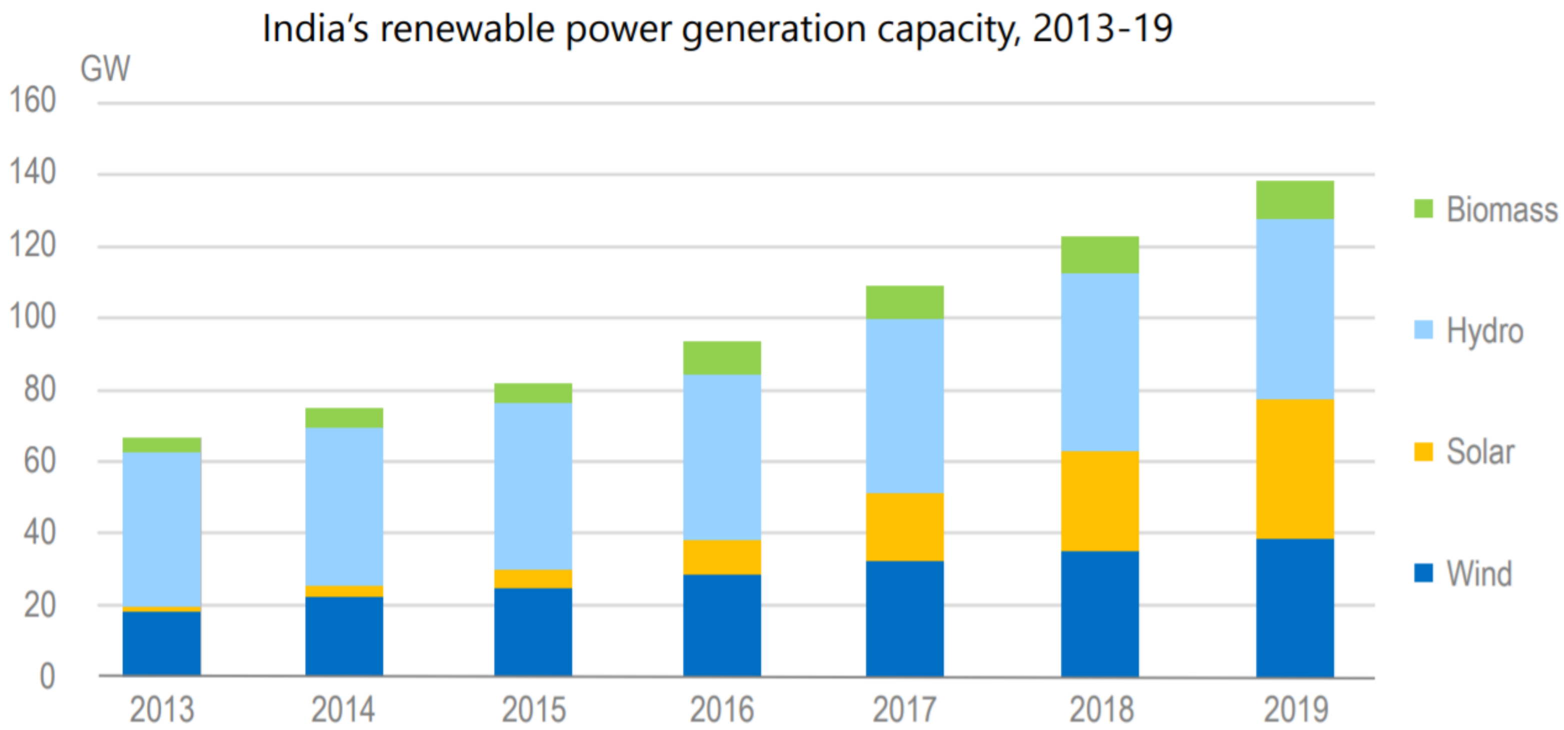
Number of people with and without electricity access, World

The number of people in a given population with and without access to electricity.



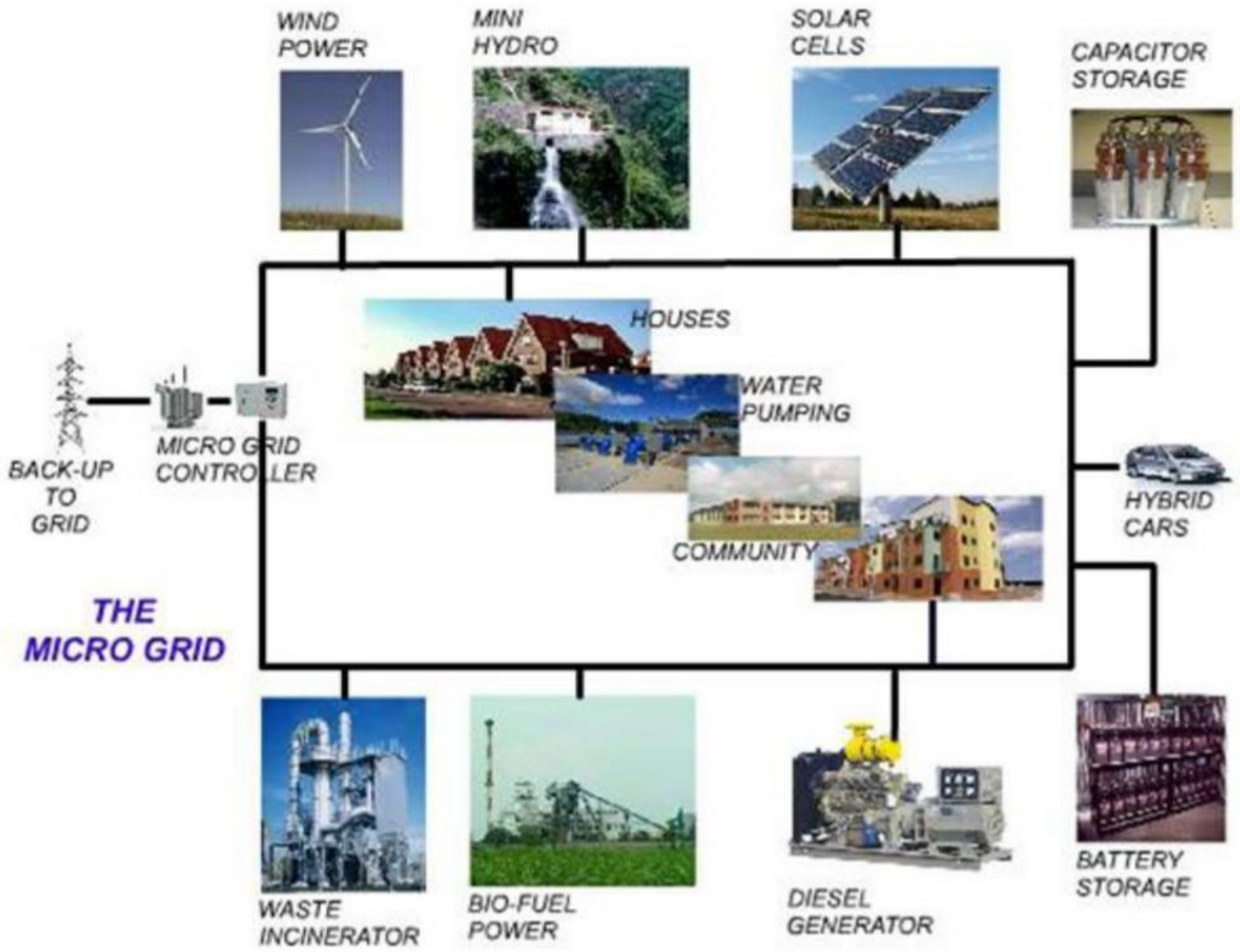
Source: The World Bank, World Development Indicators (WDI) and UN Population Prospects
OurWorldInData.org/energy-production-and-changing-energy-sources/ •

India has seen rapid growth in renewables



- ❑ Onshore wind and Solar PV have seen strong growth.
- ❑ To reach 175 GW by 2022 and 450 GW, system integration becomes a priority.

https://niti.gov.in/writereaddata/files/175-GW-Renewable-Energy.pdf


WIND POWER
MINI HYDRO
SOLAR CELLS
CAPACITOR STORAGE
HOUSES
WATER PUMPING
BACK-UP TO GRID
MICRO GRID CONTROLLER
HYBRID CARS
COMMUNITY
THE MICRO GRID
WASTE INCINERATOR
BIO-FUEL POWER
DIESEL GENERATOR
BATTERY STORAGE

Energy efficiency improves, but needs to accelerate

- **Strong programmes based on the National Energy Efficiency Mission**
  - Green public procurement of LEDs (UJALA)
  - Industry scheme Perform, Achieve and Trade (PAT)
  - Cooling Action Plan
- **Recent energy efficiency programmes introduced since 2000 have allowed India to:**
  - Cut expected energy demand by 15%
  - Reduce oil imports by 8% and gas imports by 12%
  - Lower CO_2 emissions by 300 MT (or 14% of current emissions)
  - Reduce local pollution (SO_2 and NOx) by more than 15%

With ambitious energy efficiency policies, up to 2040 India can avoid:

- USD 200 billion per year of energy imports and building 300 GW of new power generation

Renewables and Smart Grids

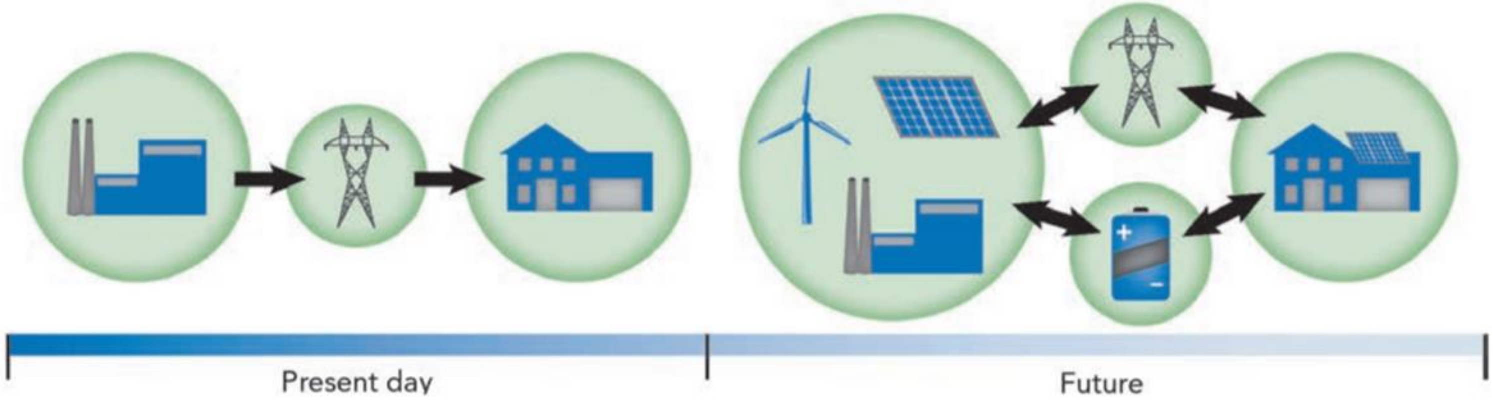
- In 2012, in the context of the "International Year for Sustainable Energy for All" (SE4ALL), the International Renewable Energy Agency (IRENA) launched a global renewable energy roadmap for doubling the share of renewables in the global energy mix by 2030.

- The aspirational target of this roadmap—called REMAP 2030—is derived from the SE4ALL initiative, which is currently chaired by the United Nations–General Secretary and the World Bank President.

- The initial results of REMAP 2030 concluded that the share of renewables in the electricity sector will have to double from 20% today to at least 40% to achieve this aspirational target.

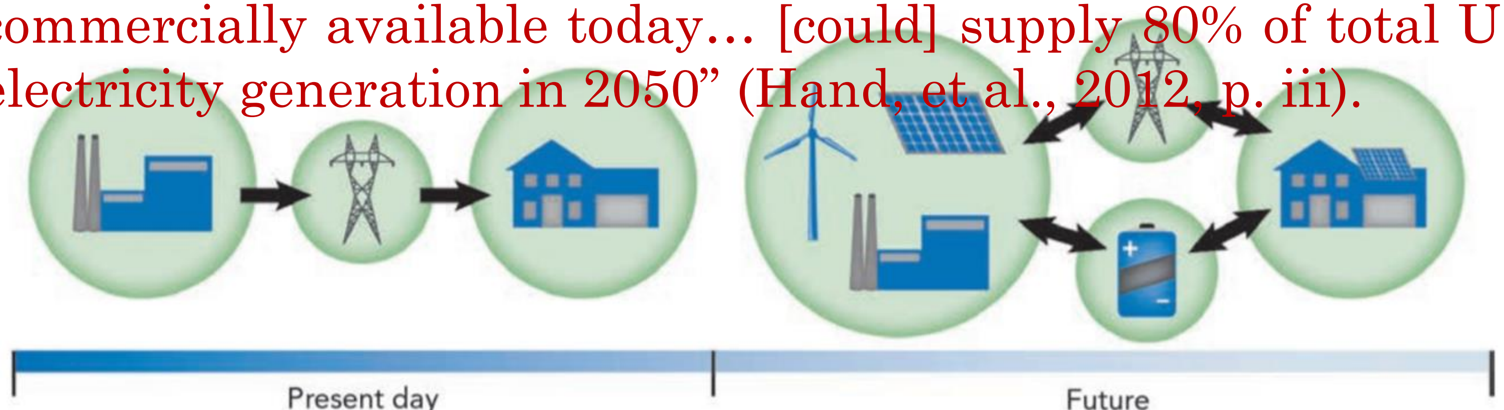
- This means that in many countries the renewable share of electricity generation has to increase substantially. For developed countries, transforming the electricity sector to absorb more renewables requires upgrades and modernised extensions of old grid systems, while also opening opportunities for introduce new, innovative solutions.

- For emerging or to developing countries, the priorities are to avoid lock-in with conventional energy sources, to attract new streams of investment, and to accommodate a range or energy sources to meet rising electricity demand



TRANSFORMATION OF THE ELECTRICITY SECTOR TOWARDS RENEWABLES

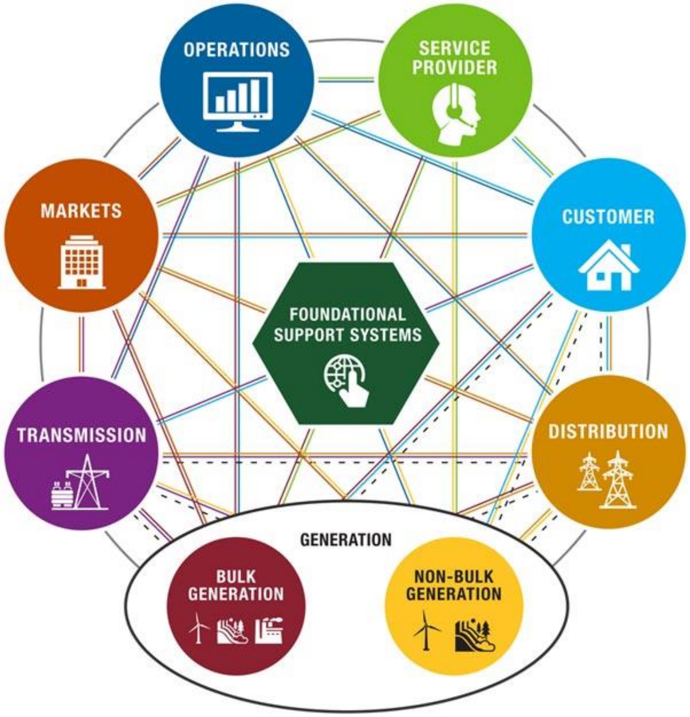
- The many studies show that a transformation of the electricity sector towards renewables is already happening, but several studies suggest that even higher shares of renewable energy power generation are foreseen. For example:
- The International Energy Agency's (IEA) "sustainable future" scenario shows renewables providing 57% of world electricity by 2050 (IEA, 2012, p. 10).
- A comprehensive analysis of the United States (U.S.) electricity system by the U.S. Department of Energy concluded that "Renewable electricity generation from technologies that are commercially available today… [could] supply 80% of total U.S. electricity generation in 2050" (Hand, et al., 2012, p. iii).



SMART GRID ?

- Overall Objective:
  Smart/best/optimal utilization of all available Resources.

- Smarter
  - Generation
  - Transmission
  - Distribution
  - Customer participation
  - Operations
  - Markets
  - Service providers



CONVENTIONAL GRID VS SMART GRID

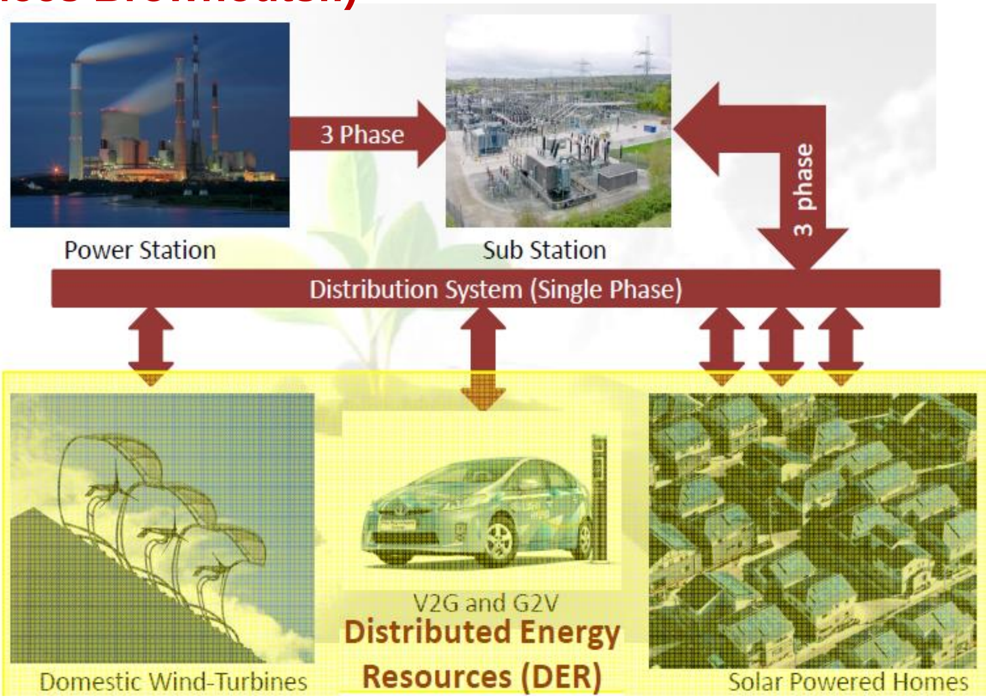
What?

❖ The application of intelligent, co-operative resources to create a flexible electric power system is referred to as smart grid.

- ❖ Two-way flow of power and info in distribution grid
- ❖ Information technology is used to improve grid function
- ❖ Interconnection of high number of automation devices

Why?

- ❖ Increases penetration of renewable energy sources
- ❖ Enables active participation of consumers
- ❖ Improved Reliability
- ❖ Optimizes power quality (Reduces Brownouts!!)



What is smart grid?...contd

- Definition by National Institute of Standards and Technology (NIST), USA:
  - **A modernized grid that enables bidirectional flows of energy and uses two-way communication and control capabilities that will lead to an array of new functionalities and applications.**
- IEEE:
  - **Smart grid is a large 'System of Systems', where each functional domain consists of three layers:**

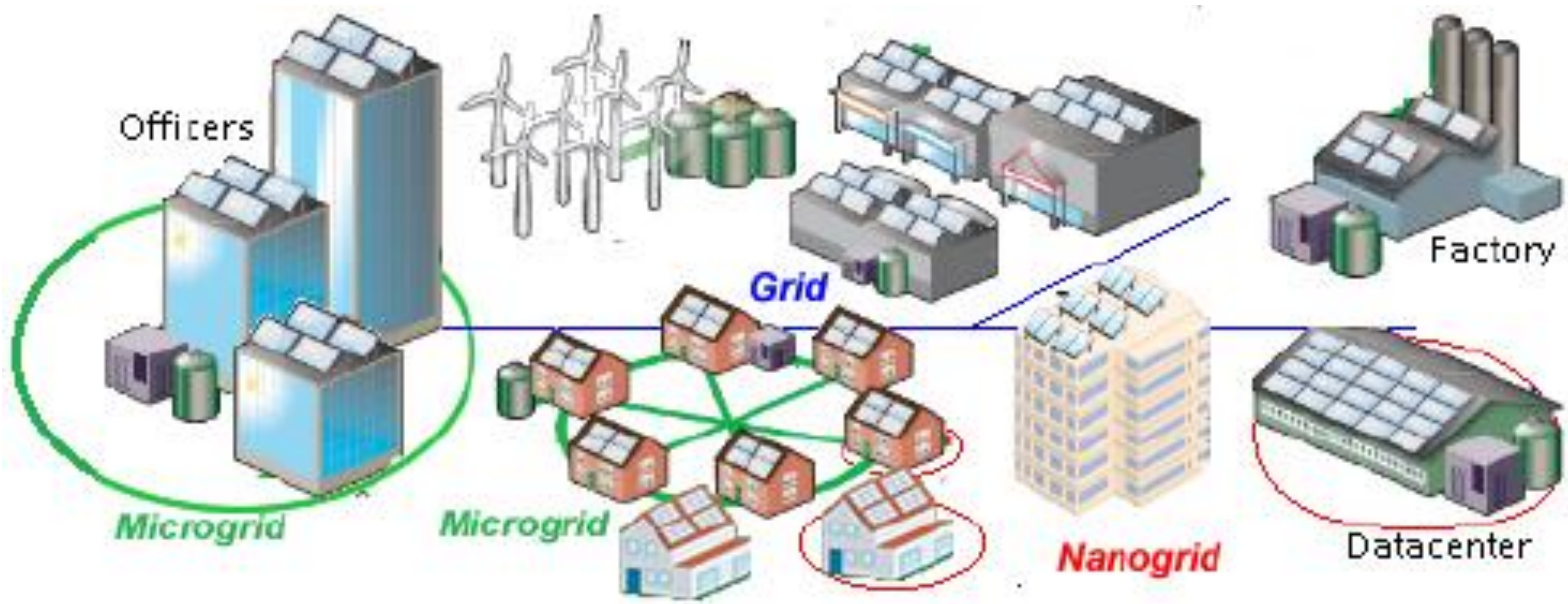
(i) **the power and energy layer,**

(ii) **the communication layer, and**

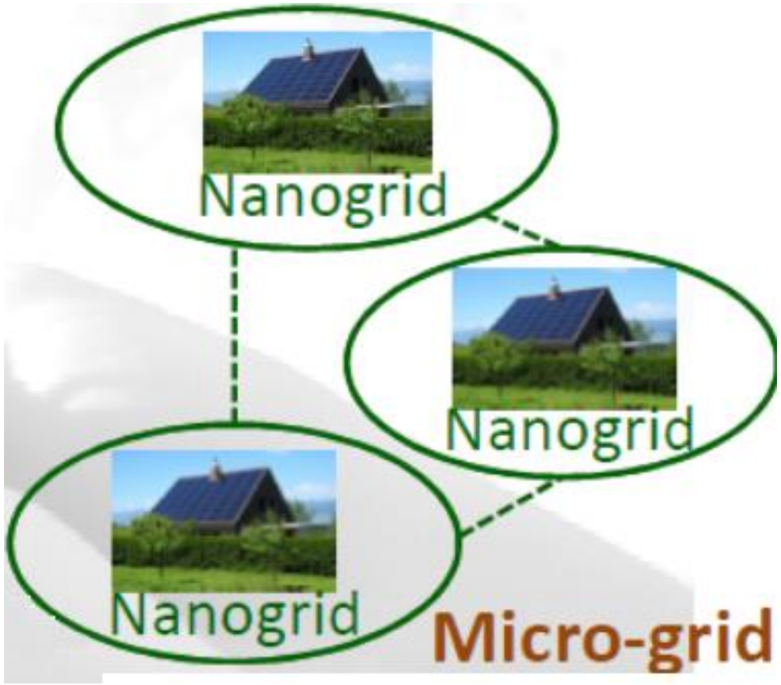
(iii) **the IT/computer layer.**

  - **Layers (ii) and (iii) above are the enabling infrastructure that makes the existing power and energy infrastructure 'smarter'.**

Nano grid, Micro grid and Power Grid



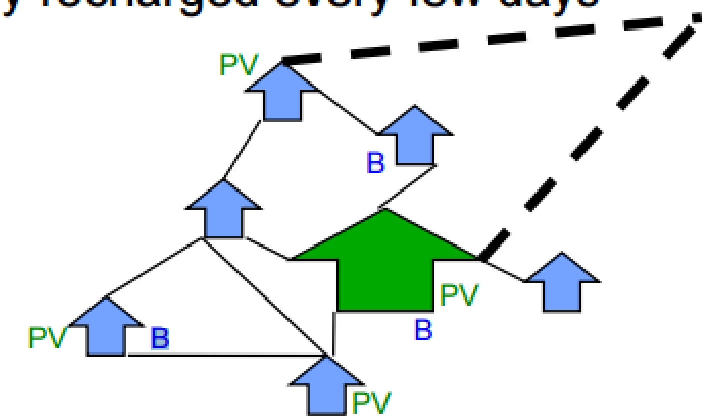
NANO-GRIDS : DEFINITIONS



- Nano-grids consist of small DC grids of low power typically less 1kW @ 100V, or 48 V DC, typically serving a single building or a single load.
- Navigant Research has developed its own definition of a Nano-grid as being 100 kW for grid-tied systems and 5 kW for remote systems not interconnected with a utility grid.

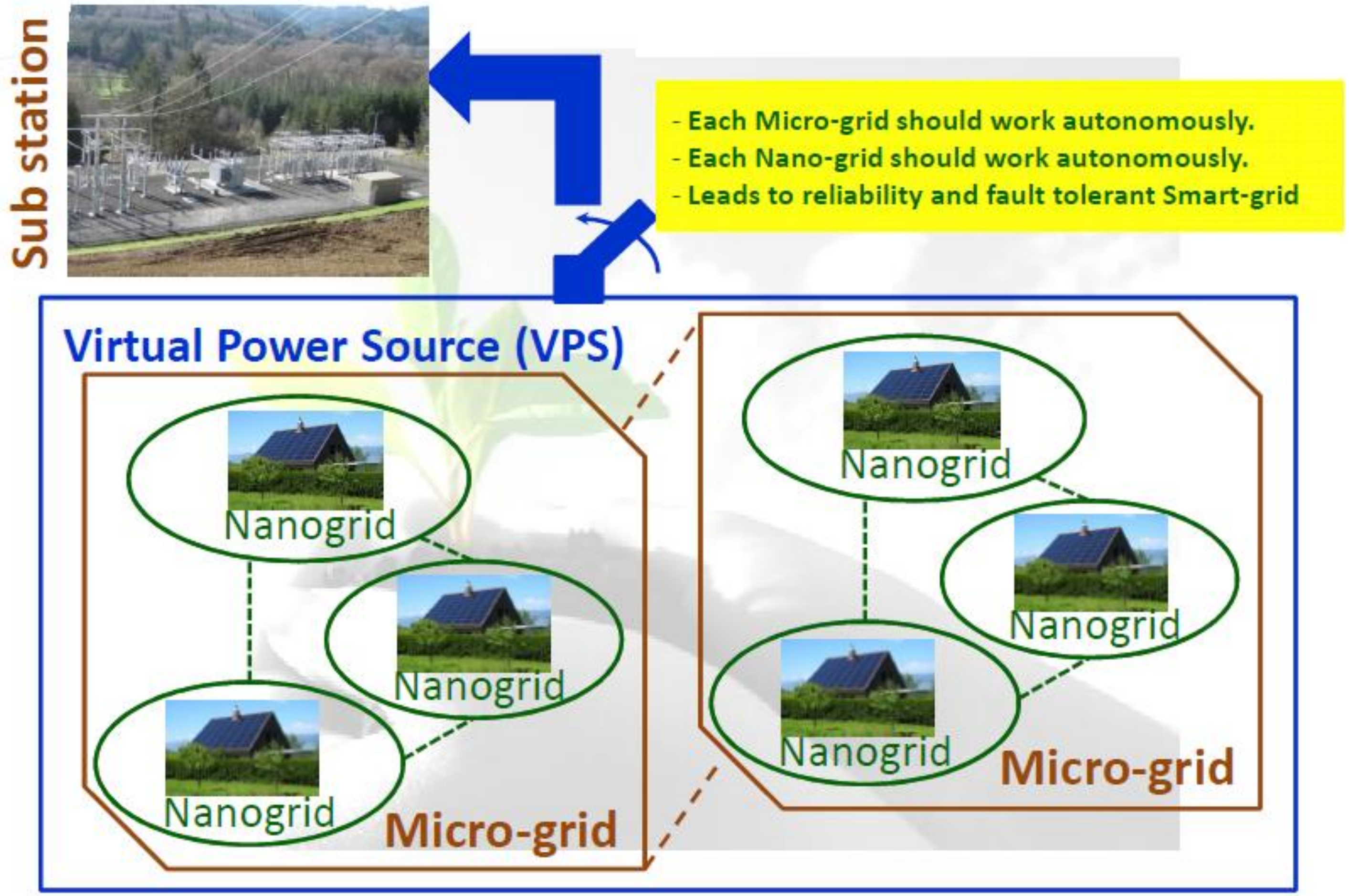
VILLAGE: EXAMPLE

- Start with single house – car battery recharged every few days
  - Light, phone charger, TV, …
  - Add local generation – PV, wind, …
- Neighbors do same
  - Interconnect several houses
- School gets PV
  - More variable demand
- Eventually all houses, businesses connected in a mesh
  - Can consider when topology should be changed
- Existence of generation, storage, households, and connections all dynamic
- Can later add grid connection(s)



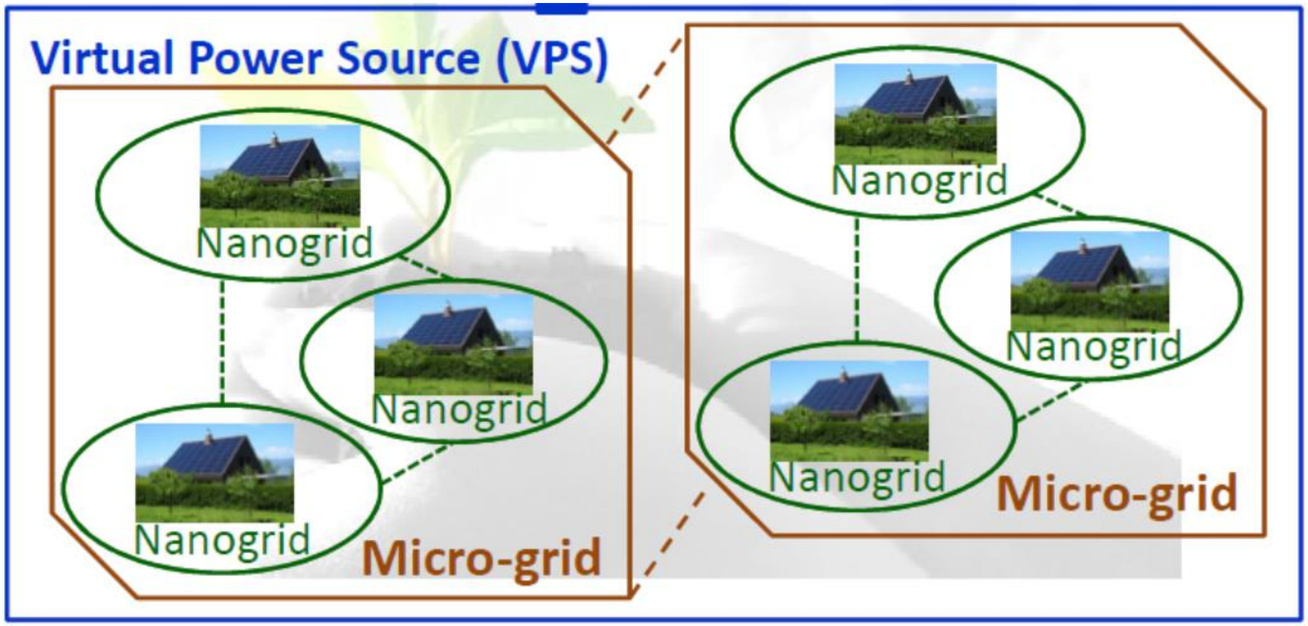
From **no electricity** to **distributed power** – skip traditional grid;
Similar to **no phone** to **mobile phone** – skip landline system

Micro-grid Integration



What is a Micro grid?

- A Microgrid is created by connecting a local group of small power generators using advanced sensors, communications, and control technologies. Microgrids can be powered by distributed generators, batteries, and/or renewable resources like solar panels.
- A microgrid is essentially a local energy grid with independent control capability, which means it can disconnect or "island" from the traditional main grid and operate autonomously by using local energy generation in case of a power outage.



The Microgrid Solution

- In many ways, Microgrids are smaller versions of the traditional power grid. They consist of power generation, distribution, and controls such as voltage regulation and switch gears just like current electrical grids do.
- However, Microgrids differ in that they provide a closer proximity between power generation and power users, resulting in efficiency increases and transmission losses reduction.
- Some Microgrids stand on their own, apart from any larger grid, often in remote rural areas. These off-grid Microgrids are a relatively cheap and quick way to secure some access to power for people who now lack it, often more quickly than large, centralized grids can be extended.

Types of Microgrids

- **There are several types of microgrids, which are defined based on how they function.**
- **Community Microgrid:** Integrated into utility networks and serves critical facilities in a town or city, often backed by government funding. Its primary purpose is to ensure power to services that people can't live without for an extended period of time.
- **Remote Microgrid:** Often found on islands or in isolated areas of the world which lack a central utility grid. It operates independently and relies solely on its own generators to keep the power flowing.
- **Customer/Campus Microgrid:** Is fully interconnected with a local utility grid, but can also maintain some level of service in isolation from the grid (like during a utility outage). Typical examples serve university and corporate campuses, prisons, and military bases.
- **Nanogrid:** Comprised of small network units that can operate independently. A nanogrid can be defined as a single building or a single energy domain.

Benefits of Microgrids

- There are several benefits of Microgrids, including their backup capabilities in case of emergencies. These include: lower energy costs, increase power reliability.
- Can connect to local resources that are too small or unreliable for traditional grid use, thus improving local energy delivery.
- Allow communities to be more energy-independent.
- Environmental friendly and can integrate with renewable energy sources, including:
  - Solar power
  - Wind power
  - Geothermal power
  - Waste-to-energy

New Distribution Technologies on the Horizon

- To address the challenges of an aging infrastructure, outdated and conventional designs, the increased use of distributed resources, new loads from electric vehicles and other devices, and increased demand for higher levels of quality and reliability, advanced technologies will be needed.

Technologies for Tomorrow's Distribution Grid

- Tomorrow's distribution system will use
  - high-bandwidth communications to all substations,
  - a proliferation of intelligent electronic devices (IEDs) that provide adaptable control and protection systems, complete distribution system monitoring that is integrated with larger asset management systems, and fully integrated intelligence to mitigate power quality events and improve reliability and system performance.

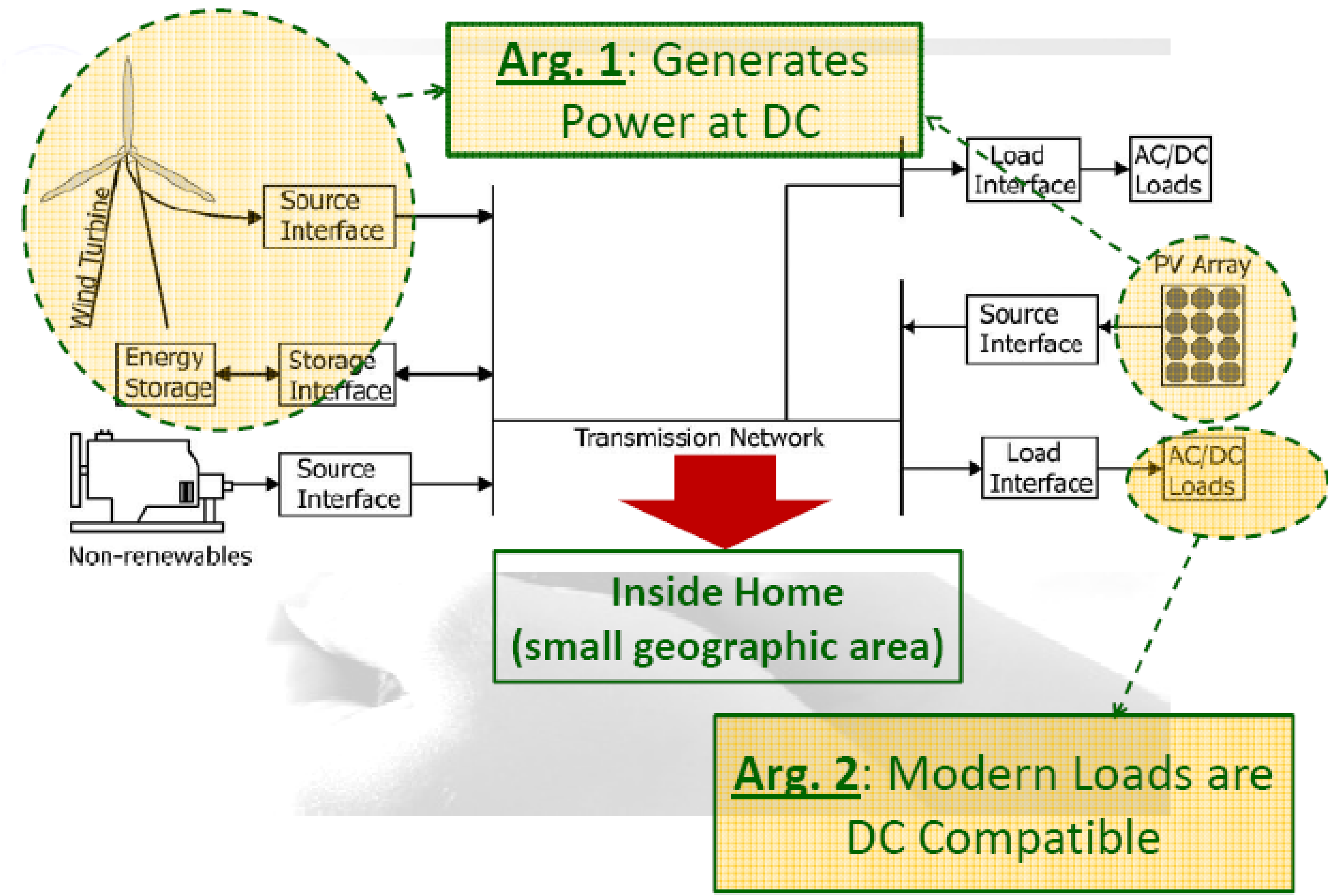
Category of micro grids

- **Based on the nature of electricity, the Microgrids can be categorized as DC-based and AC-based Microgrids.** The DC-based microgrids have some advantages and are given below.
  - **DC-based DGs such as photovoltaic cells and fuel cells can inject power directly to the DC Microgrid.**
  - **Asynchronous AC sources can be connected to the DC-grid by AC/DC converters without considering voltage phases.**
  - **DC Microgrid has the features of reducing the losses caused by the reactive power and overcoming the limitation of the power flow upto certain extent.**
  - **The grid can supply power to the power electronics equipments directly. Hence, stand-by losses caused by the AC/DC conversion can be eliminated.**

MAIN COMPONENTS OF MICROGRID

- **The main components of Microgrid are**
  - **mini-hydro, solar cell, wind energy, fuel cell and energy storage system.**
  - **Microgrid can operate in two modes: one is grid-connected and the other is stand-alone mode**
  - **Generation and loads in a Microgrid are usually interconnected at low voltage.**
  - **Small Microgrid covers 30 - 50 km radius;**
  - **The small Microgrid can produce power of 5 - 10 MW to serve the customers;**
  - **It is free from huge transmission losses and also free from dependencies on long-distance transmission lines.**

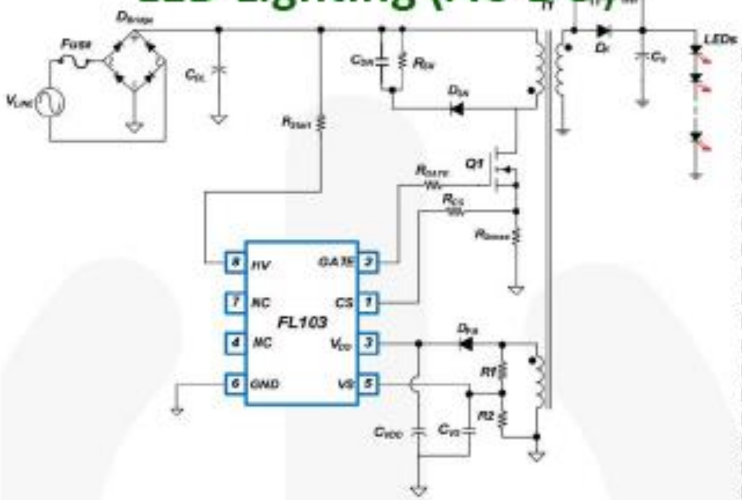
Basic Architecture: Why DC?

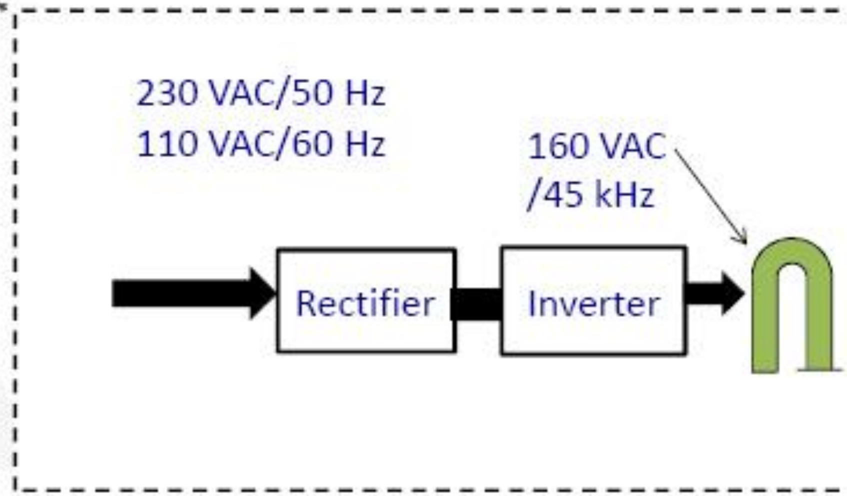


Arg. 2: Modern Domestic Loads (Lightings)

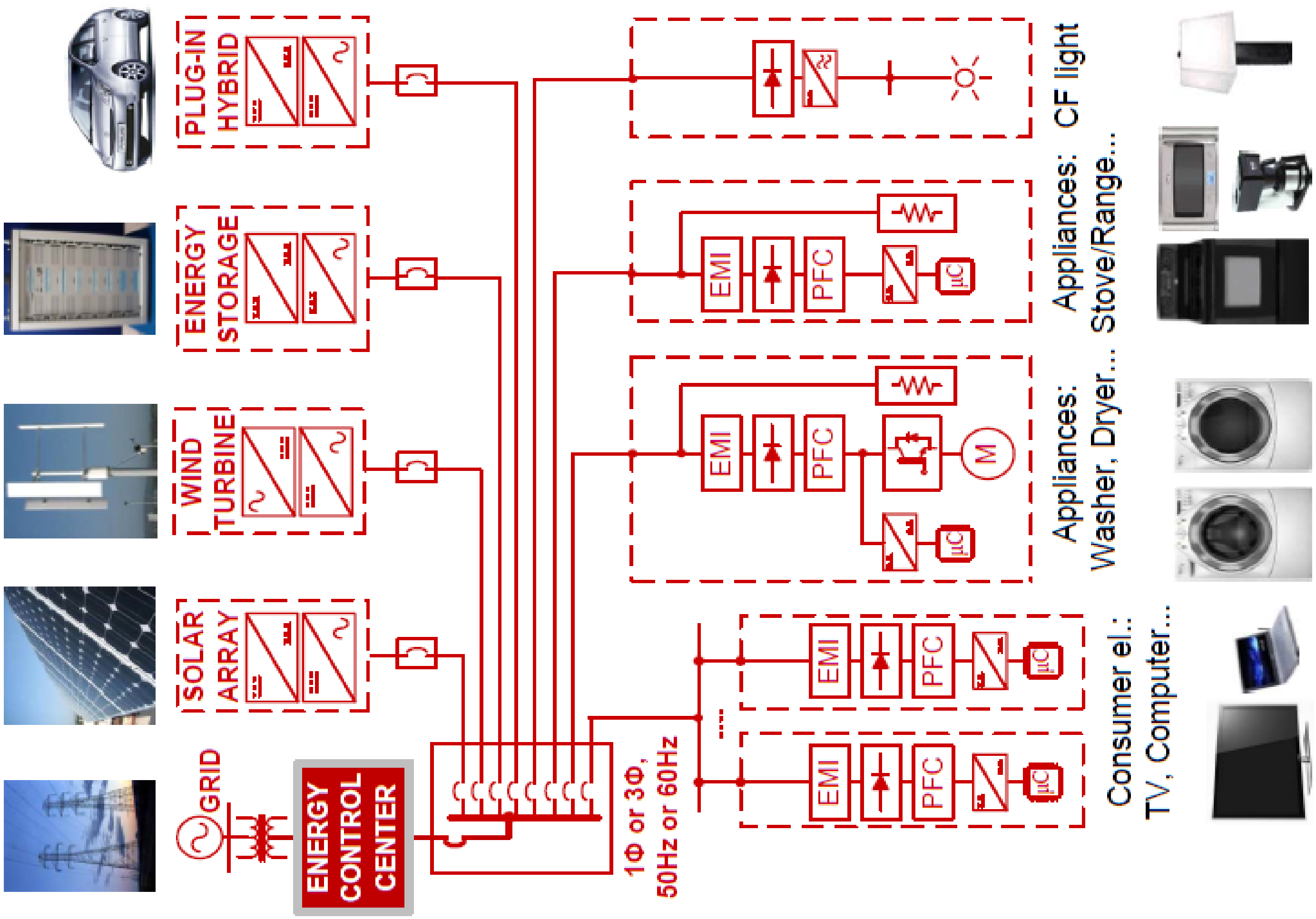
LED Lighting (AC-DC)

CFL Lighting (AC-DC-AC)

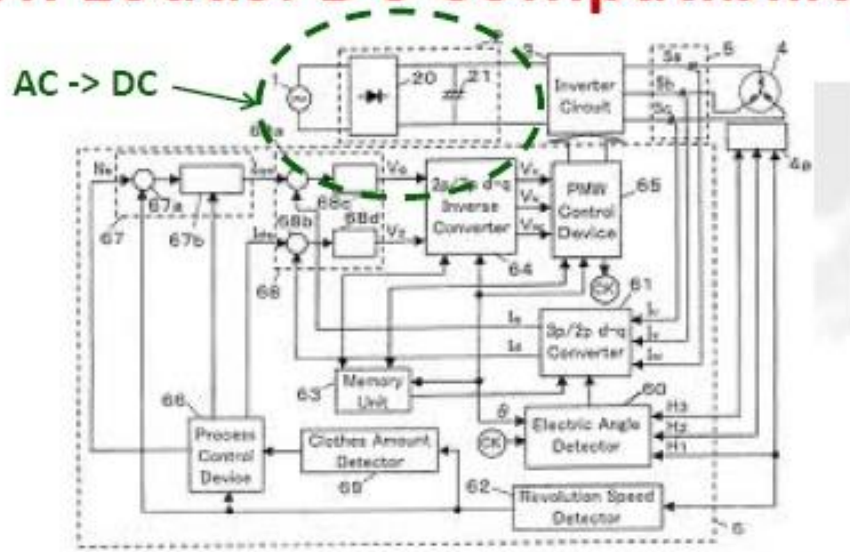




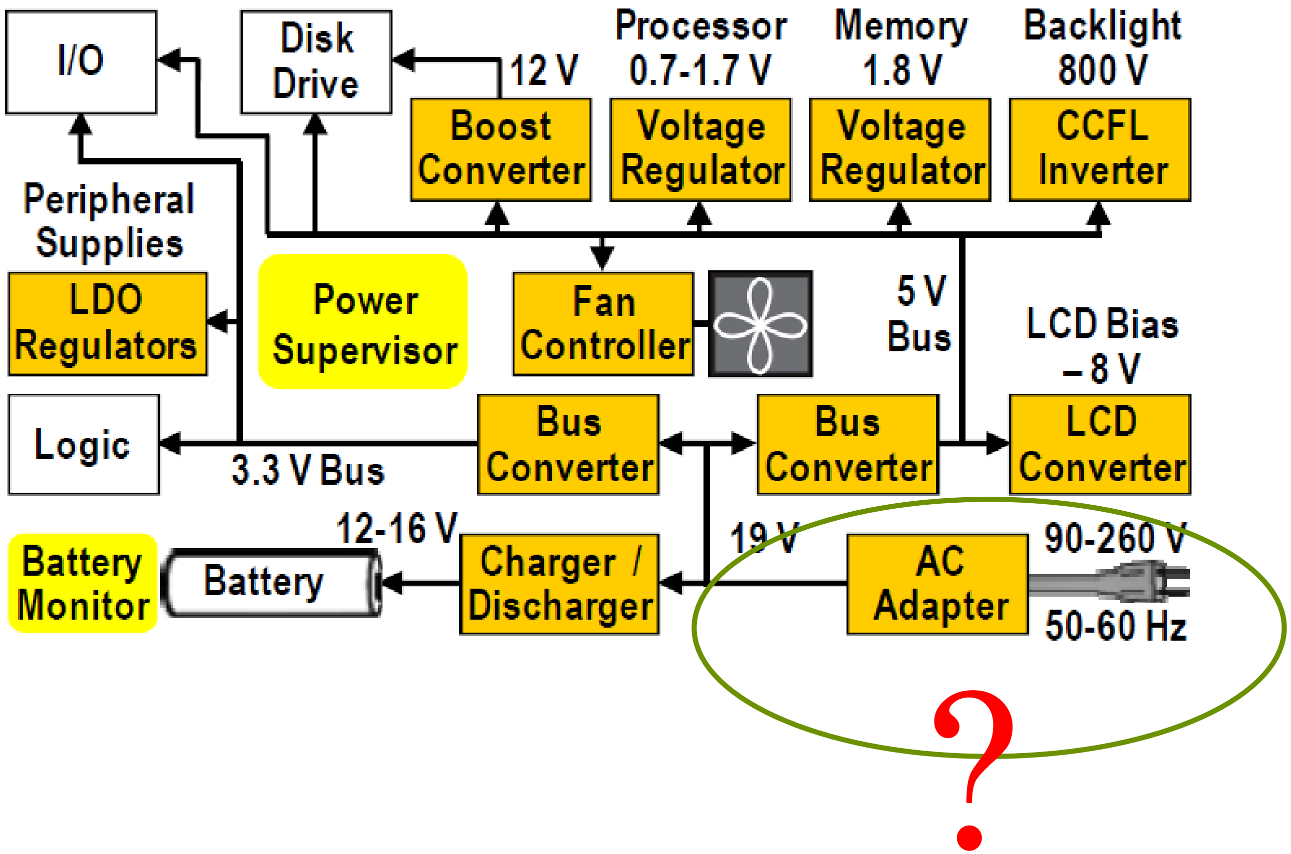
VISION OF "SMART" NANOGRID IN RESIDENTIAL HOME



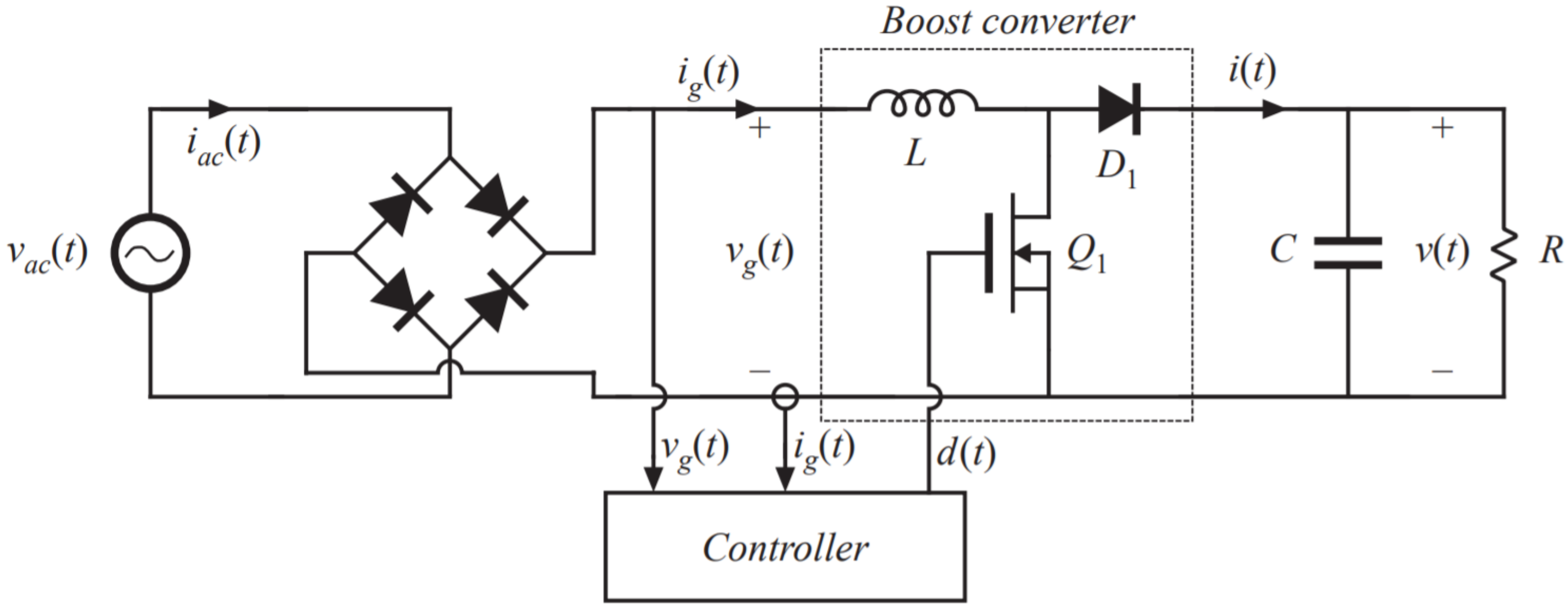
Arg. 2: Modern Loads: DC Compatibility

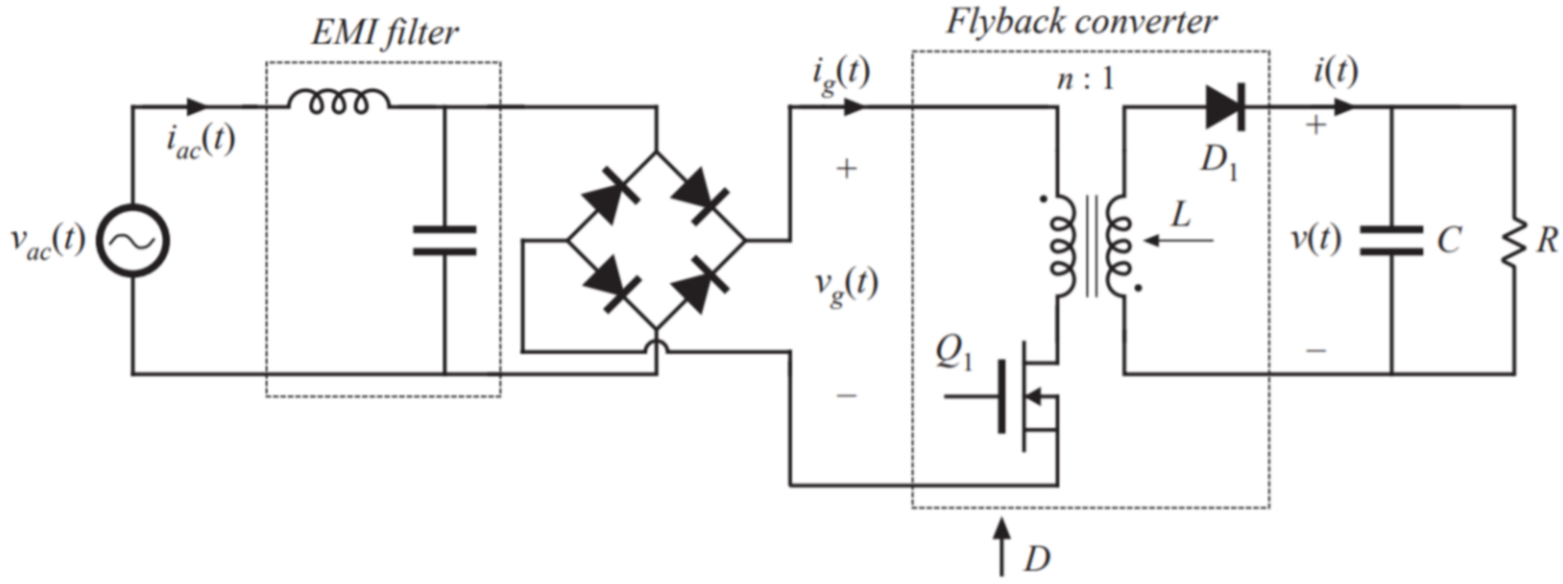


Notebook PC power Management system



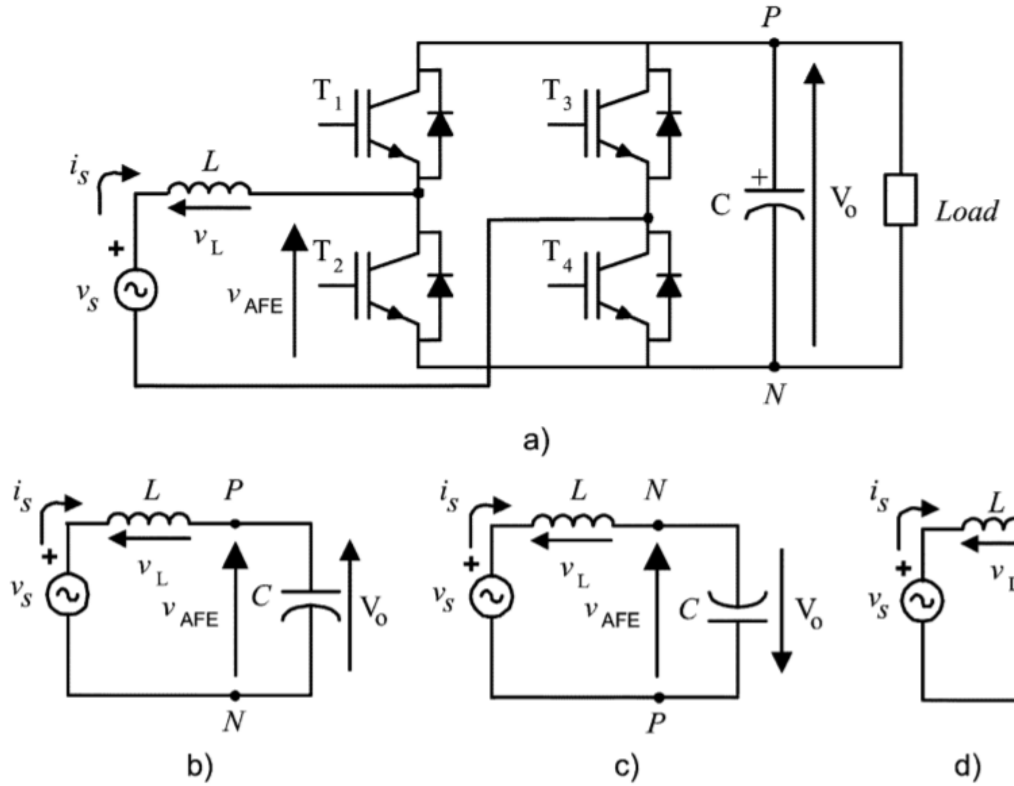
PWM rectifier (unidirectional power flow)

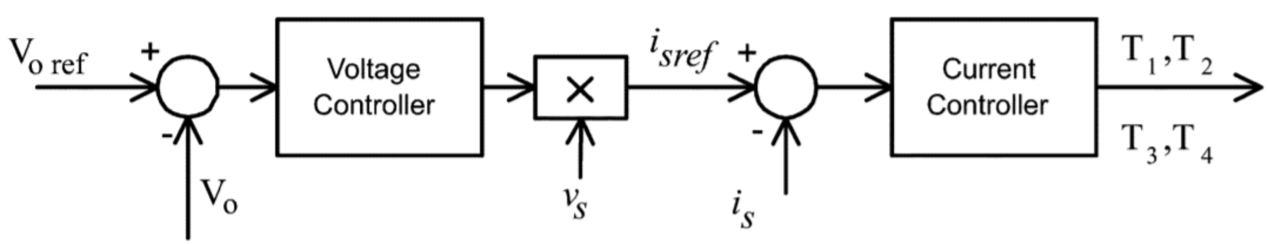


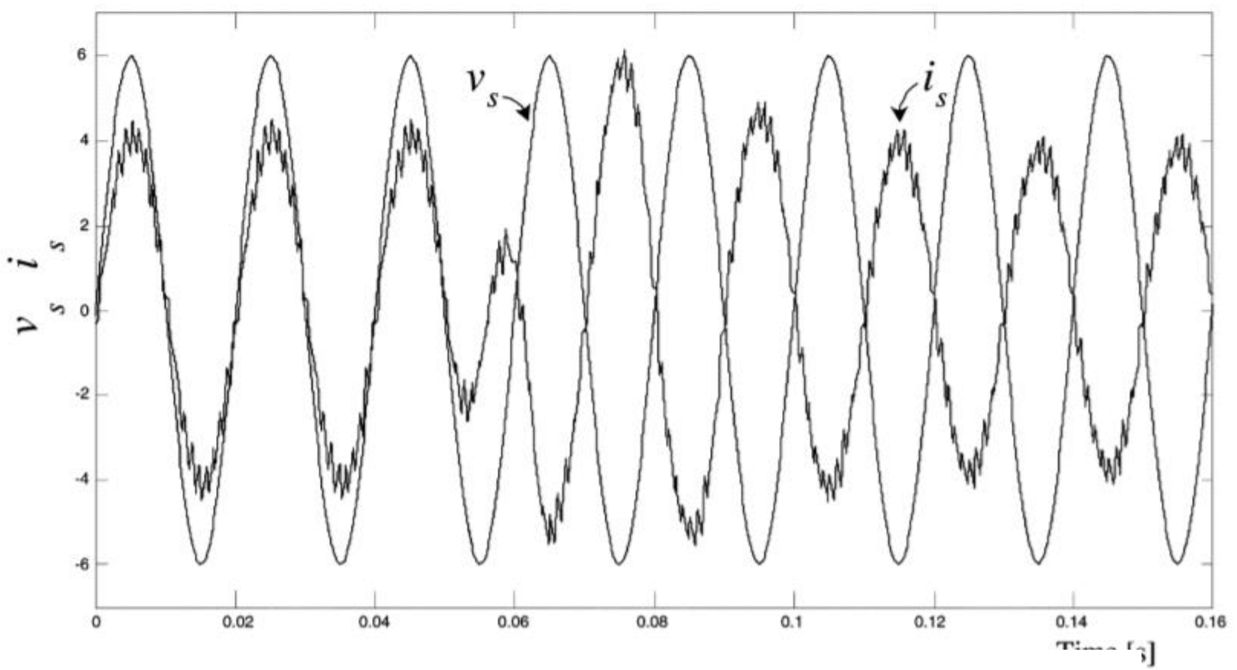


PWM Regenerative Rectifiers

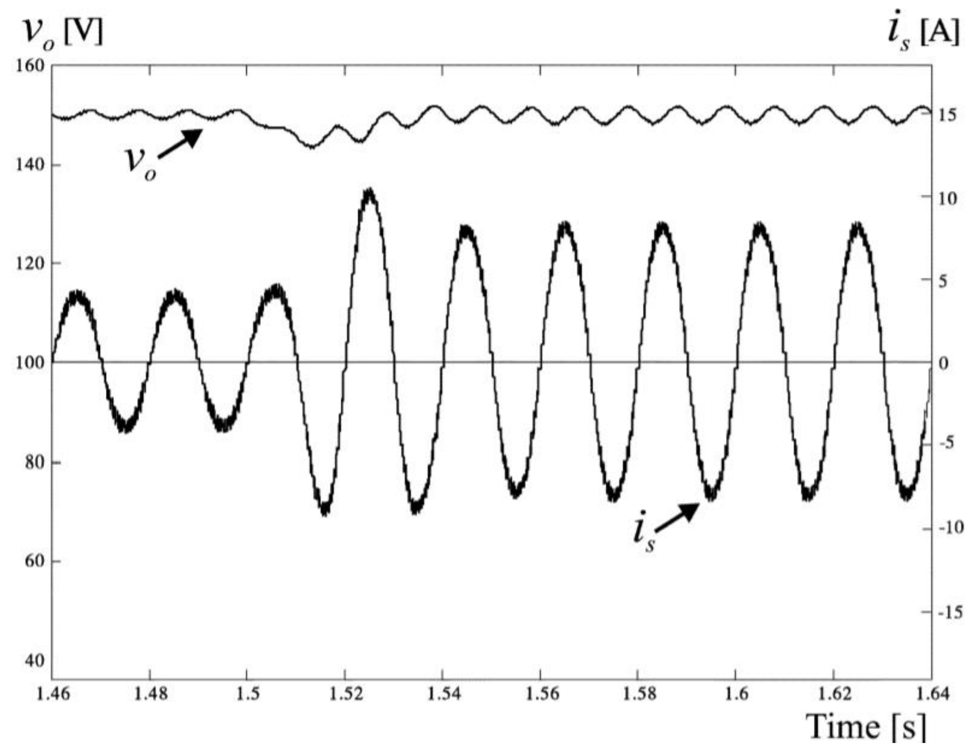
Single-Phase PWM VSRs





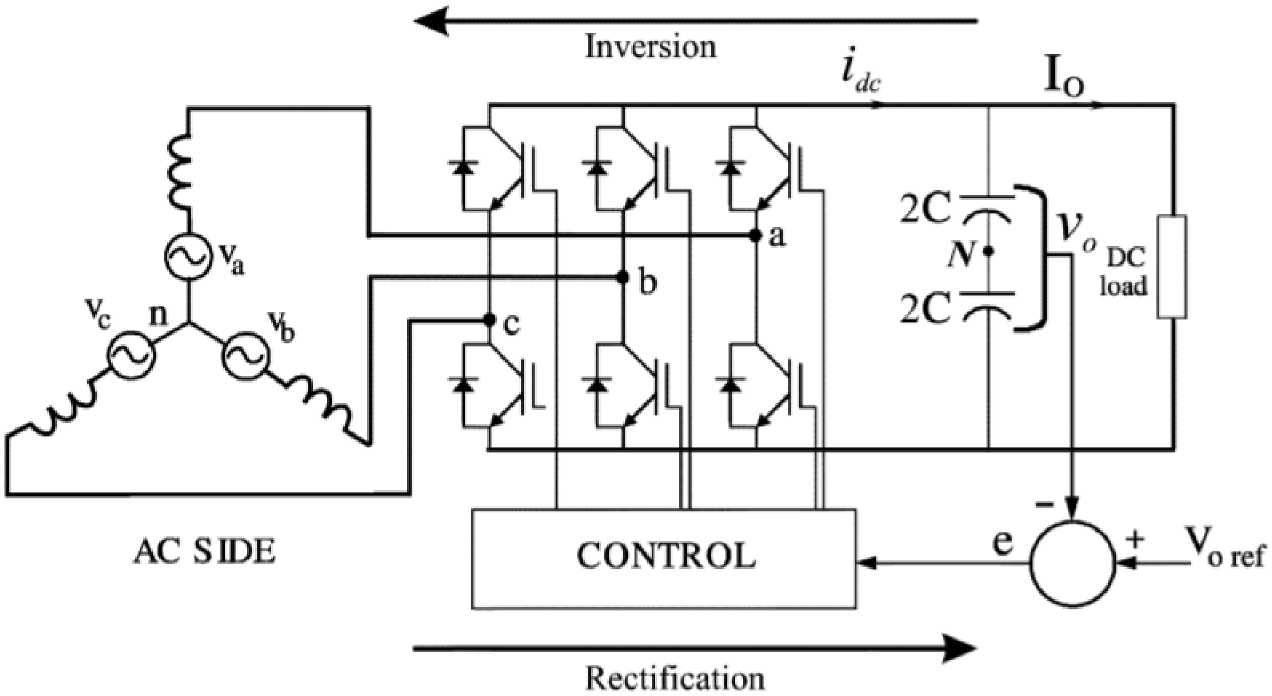


v_s
i_s
$v_s\ i_s$
Time [s]

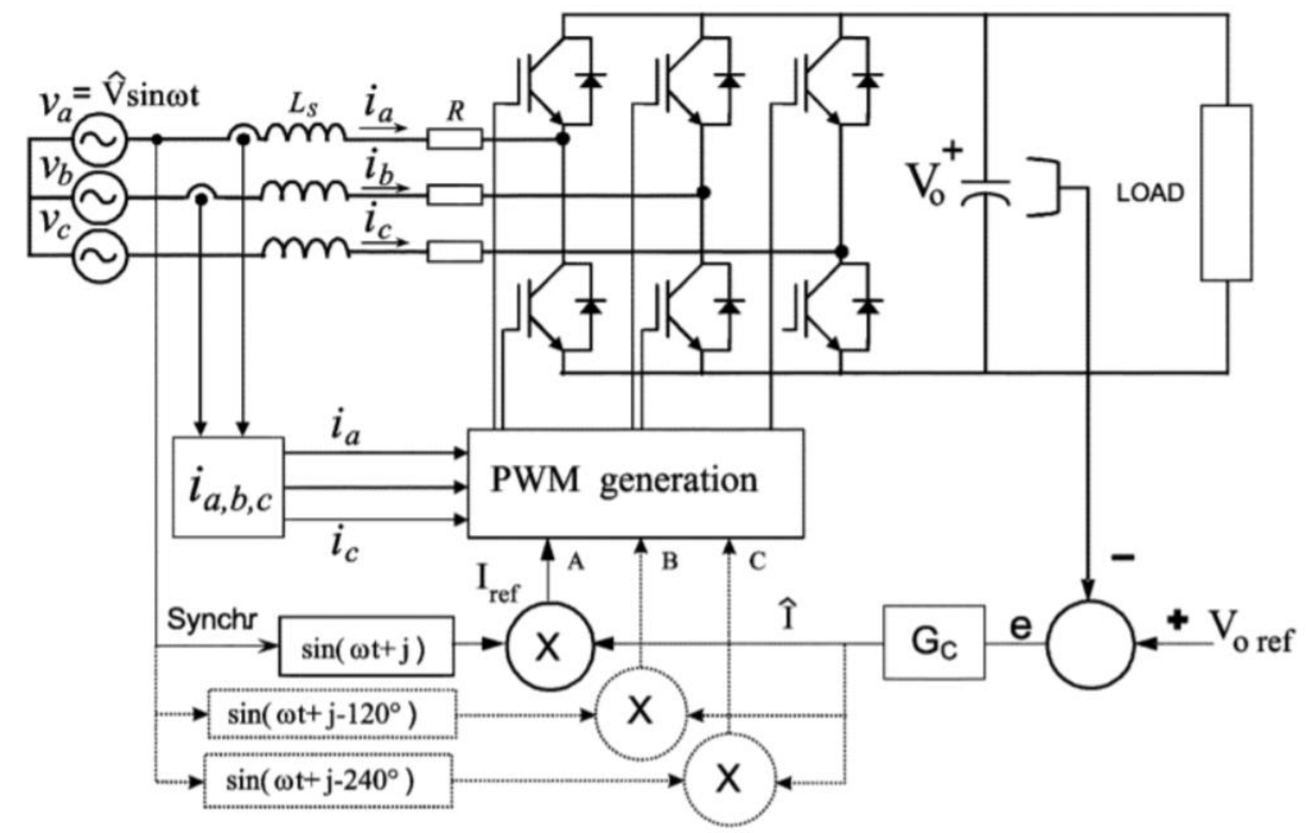


v_o [V]
i_s [A]
v_o
i_s
Time [s]

Three-Phase VSRs



Voltage-source current-controlled PWM rectifier



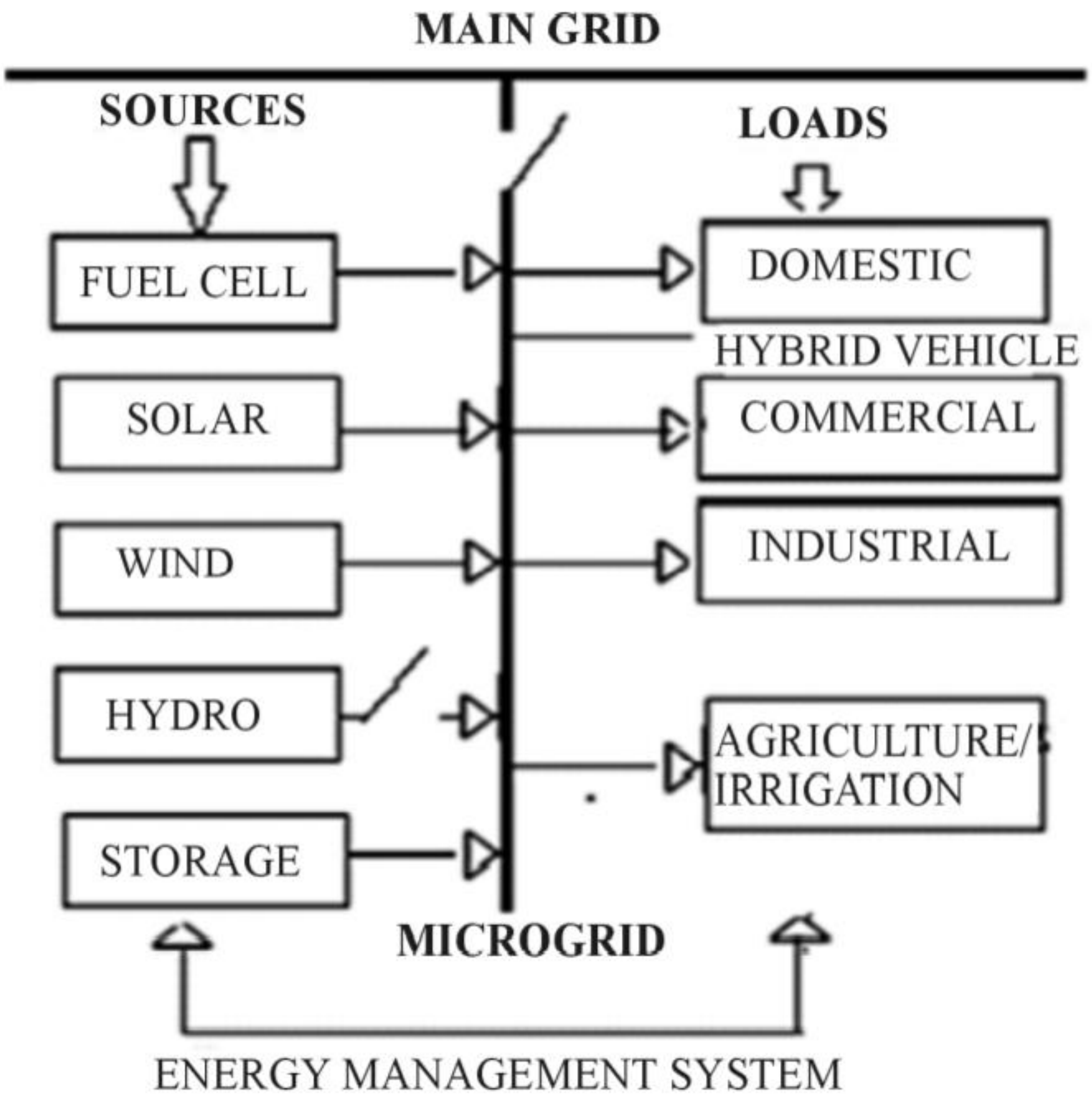
The Need of DC Local Grid

- Direct Current (DC) electricity locally generated by renewable energy sources such as solar panels, windmills used with a minimum conversion (DC to AC or AC to DC) and minimum transmission can reduce energy losses by as much as 30% or more energy. That is typically lost in AC generation, transmission, and distribution infrastructures.
- Unlike 20th century technologies, the cost of generating local power generated from solar PV and wind systems is decreasing daily, with the substitution of DC for AC power further reducing that cost.
- Since 2008, solar PV panel prices have fallen well over 70 percent cost of wind turbines decreasing by 40 percent during that same percent.
- The cost of centralized AC power generation has increased. Wind and solar generated power is cheaper than coal-fired power plants when considering the social costs of carbon foot prints.
- Some utilities are now using more PV as it has become more cost effective with the natural gas.

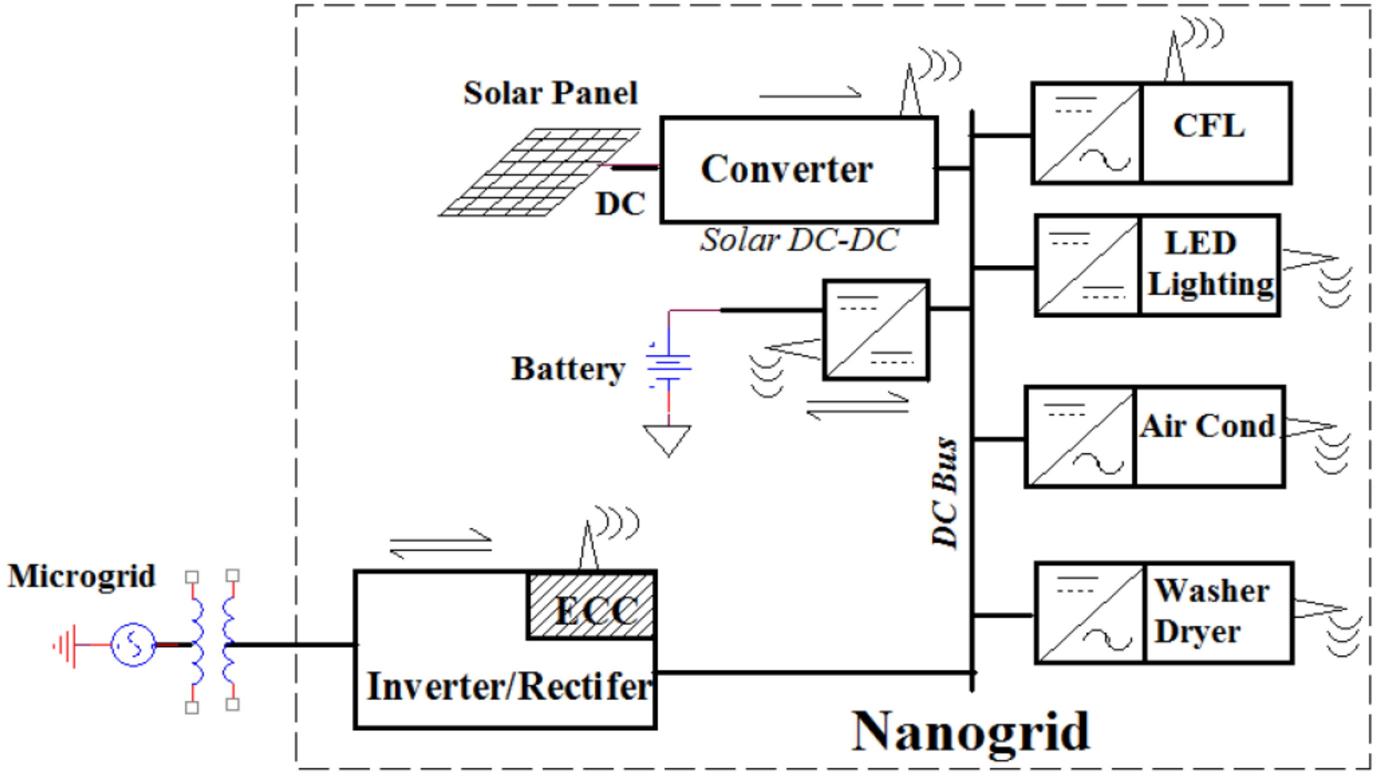
- Batteries, capacitors and fuel cells can be used to store DC electricity. The use of AC in place of DC increases the cost of storage device, as with batteries in which AC based storage systems increase their cost to as much as 50%
- The battery-based hybrid and electrical vehicles and solid-state based LED lighting are transforming the transportation and lighting industries, both of which are powered by direct current
- Energy-efficient appliances use adjustable speed motor drives in which a rectifier converters the AC from the grid into an internal DC bus voltage.

DC NANOGRID BRINGS MANY ADVANTAGES,

- Starting with **fewer power converters**, **higher overall system efficiency**, and **easier interface of renewable energy sources** to a dc system.
- There are **no frequency stability** and **reactive power issues, and no skin effect and ac losses**.
- **What is more, the consumer electronics, electronic ballasts, LED lighting, and variable speed motor drives can be more conveniently powered by dc.**
- **The future home dc nanogrid is envisioned to have two dc voltage levels: a high-voltage (380 V) dc bus powering HVAC, kitchen loads, and other major home appliances, and a multitude of low-voltage (48 V) dc buses powering small table top appliances, computer and entertainment systems, and LED lighting.**


MAIN GRID
SOURCES
LOADS
FUEL CELL
SOLAR
WIND
HYDRO
STORAGE
DOMESTIC
HYBRID VEHICLE
COMMERCIAL
INDUSTRIAL
AGRICULTURE/
IRRIGATION
MICROGRID
ENERGY MANAGEMENT SYSTEM

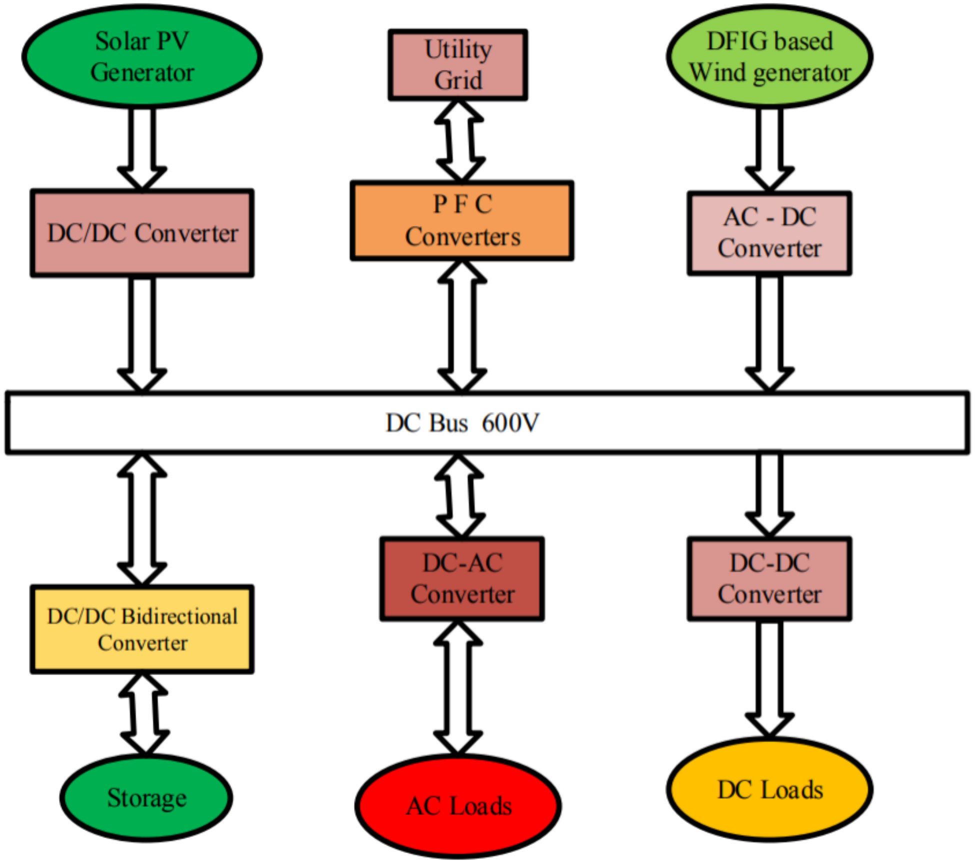
NANO-GRID: URBAN HOME



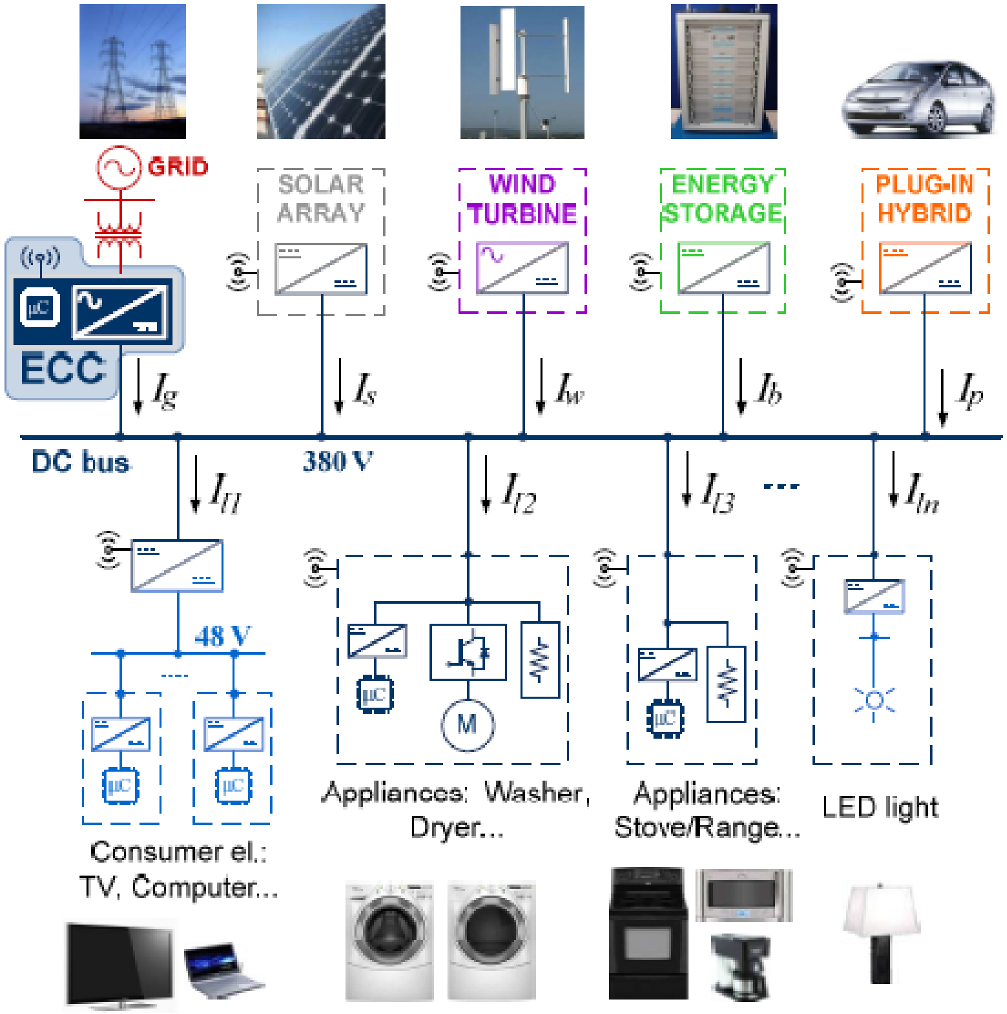
1. Dedicated converter for each job: Can it be Improved
2. All converters communicate with Energy Control Center (ECC)
3. Power electronics intensive with no need of protective gears

DC-BASED MICROGRID ARCHITECTURE AND CONVERTER STRUCTURE

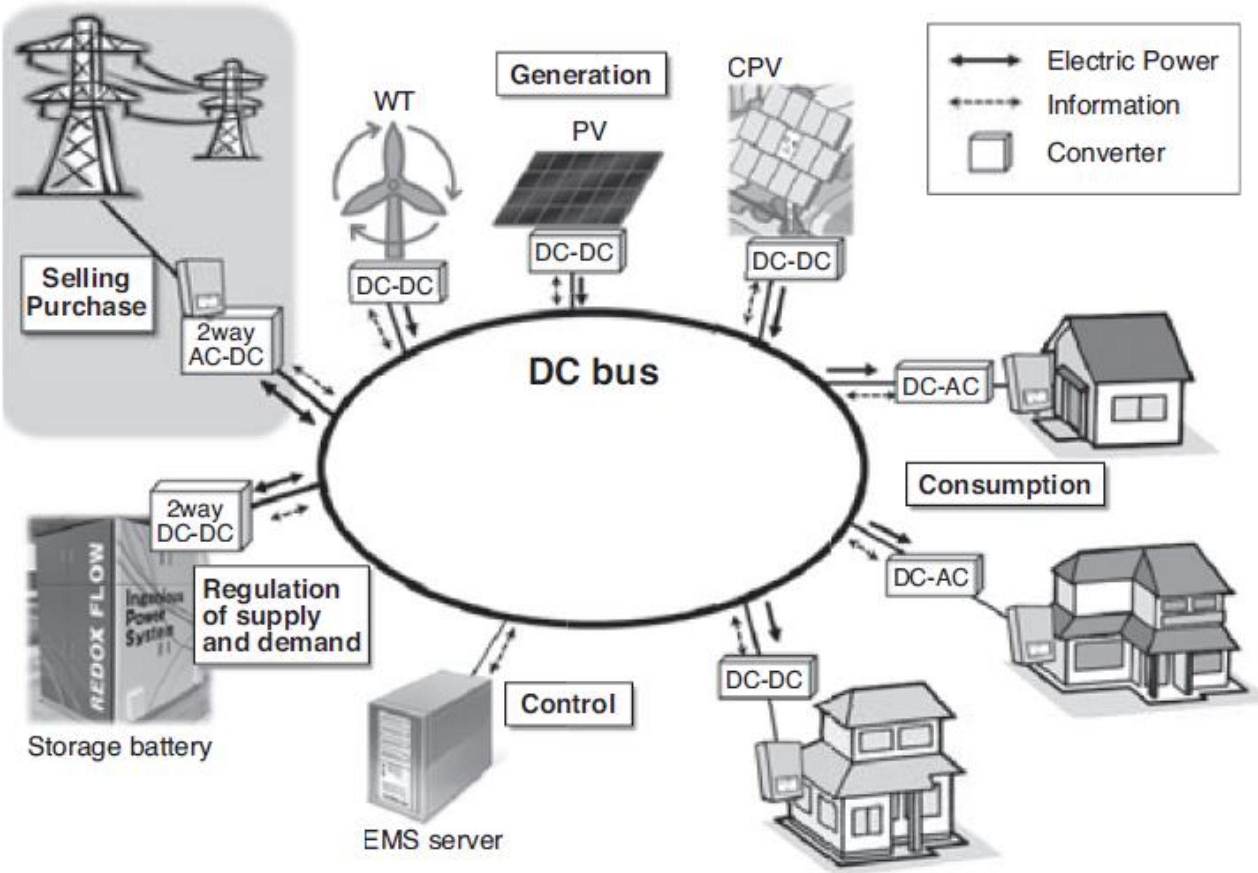
- One Isolated DC/DC boost converter
- Two PFC converters
- The DC bus is connected to different types of loads,
- which may require power in the form of DC or AC and can be achieved by using DC/DC buck or DC/AC converters



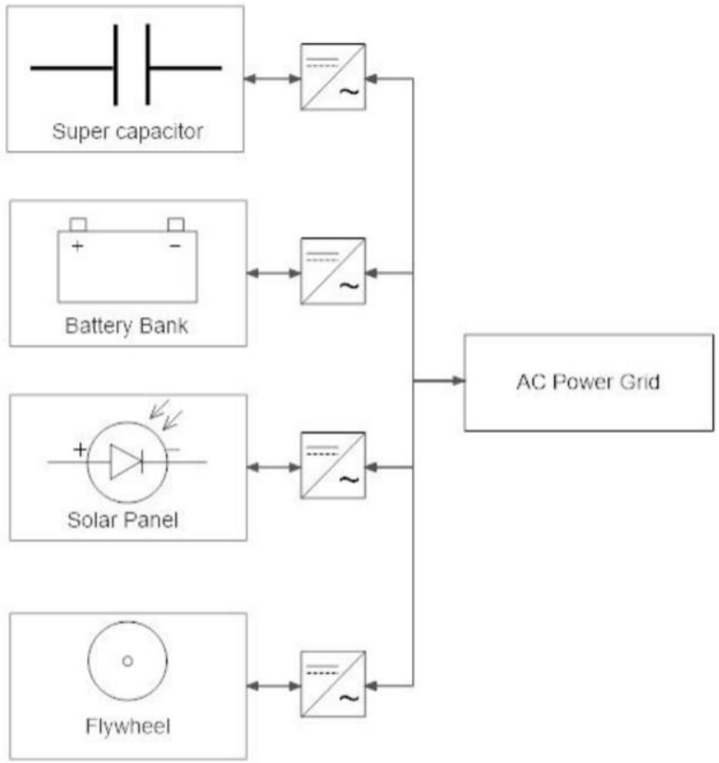
DC-BASED MICROGRID IN A FUTURE HOME.



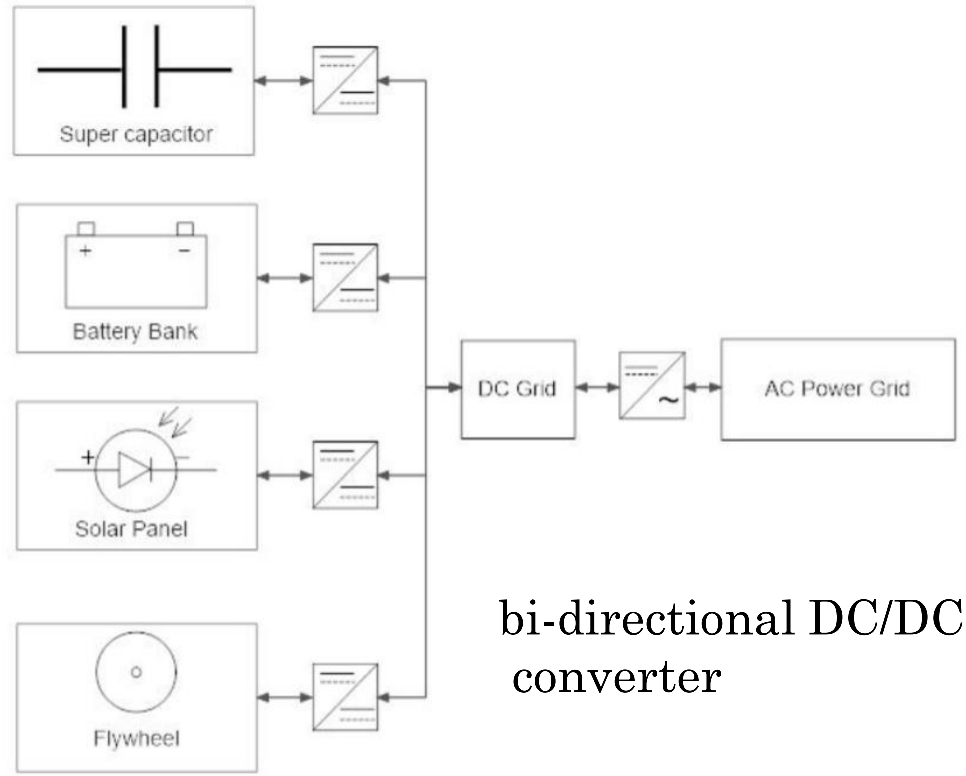
Distributed Generations (DGs) & DC micro grid system



BIDIRECTIONAL DC/DC CONVERTER



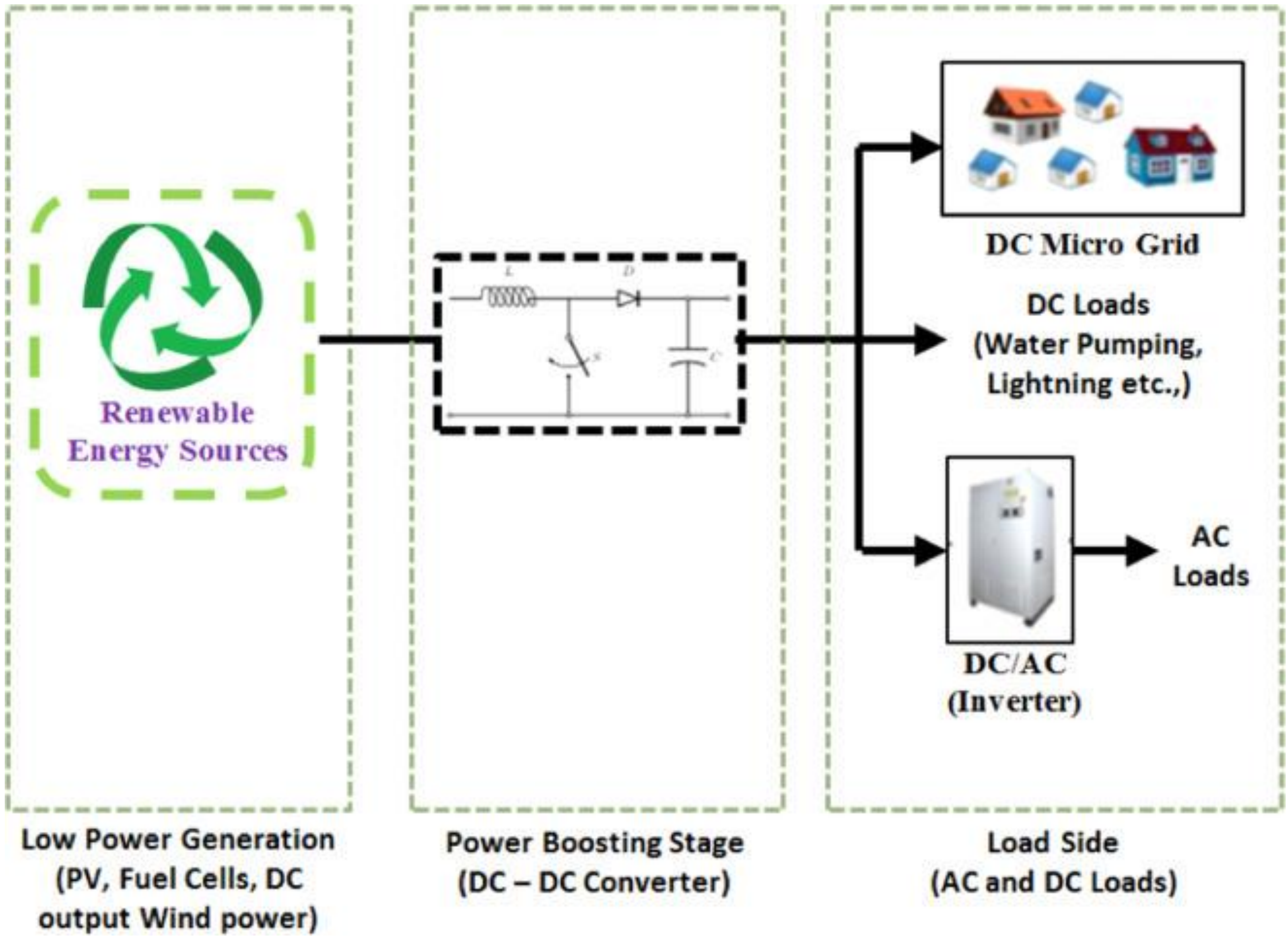
Traditional topology



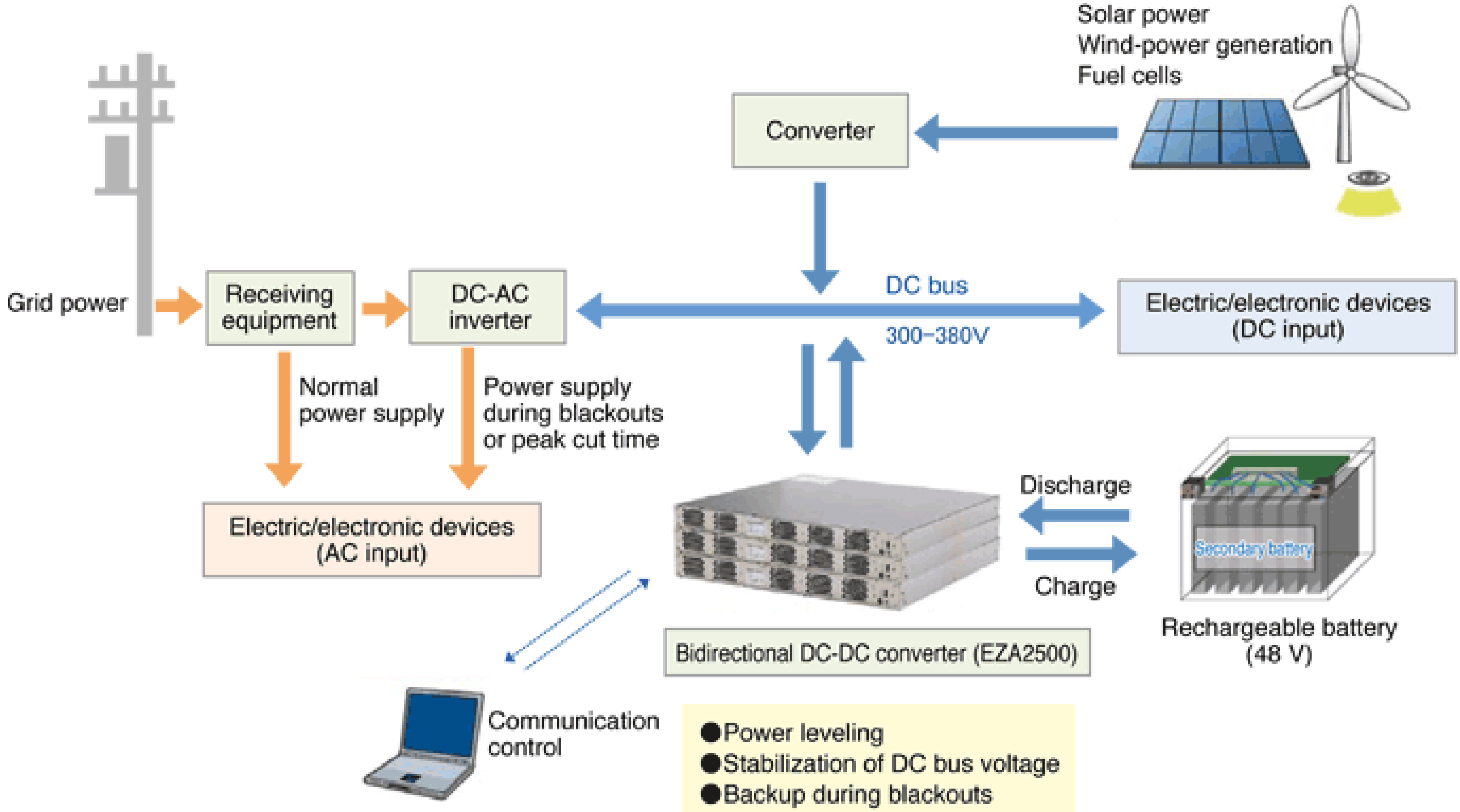
bi-directional DC/DC converter

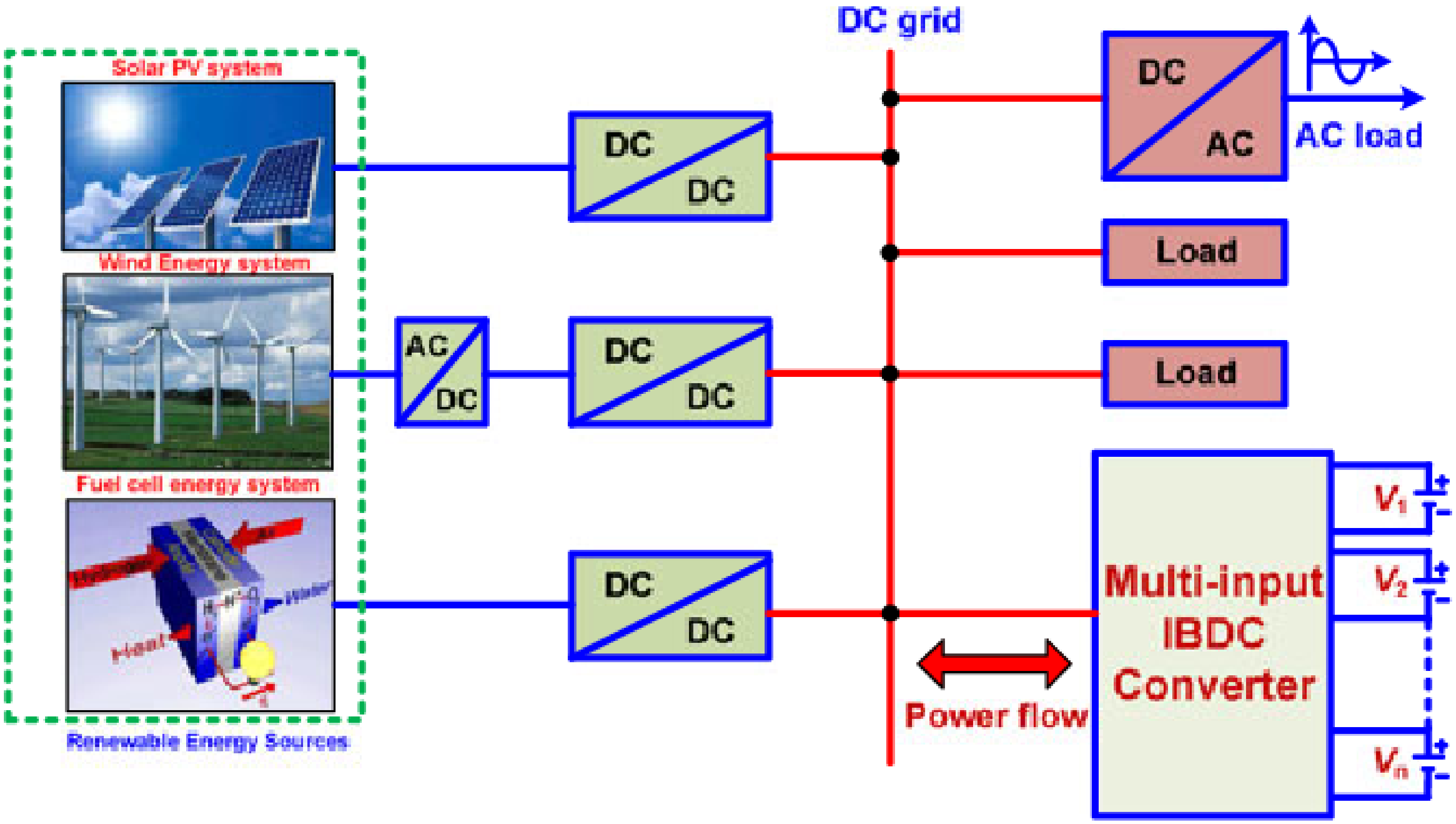
New topology

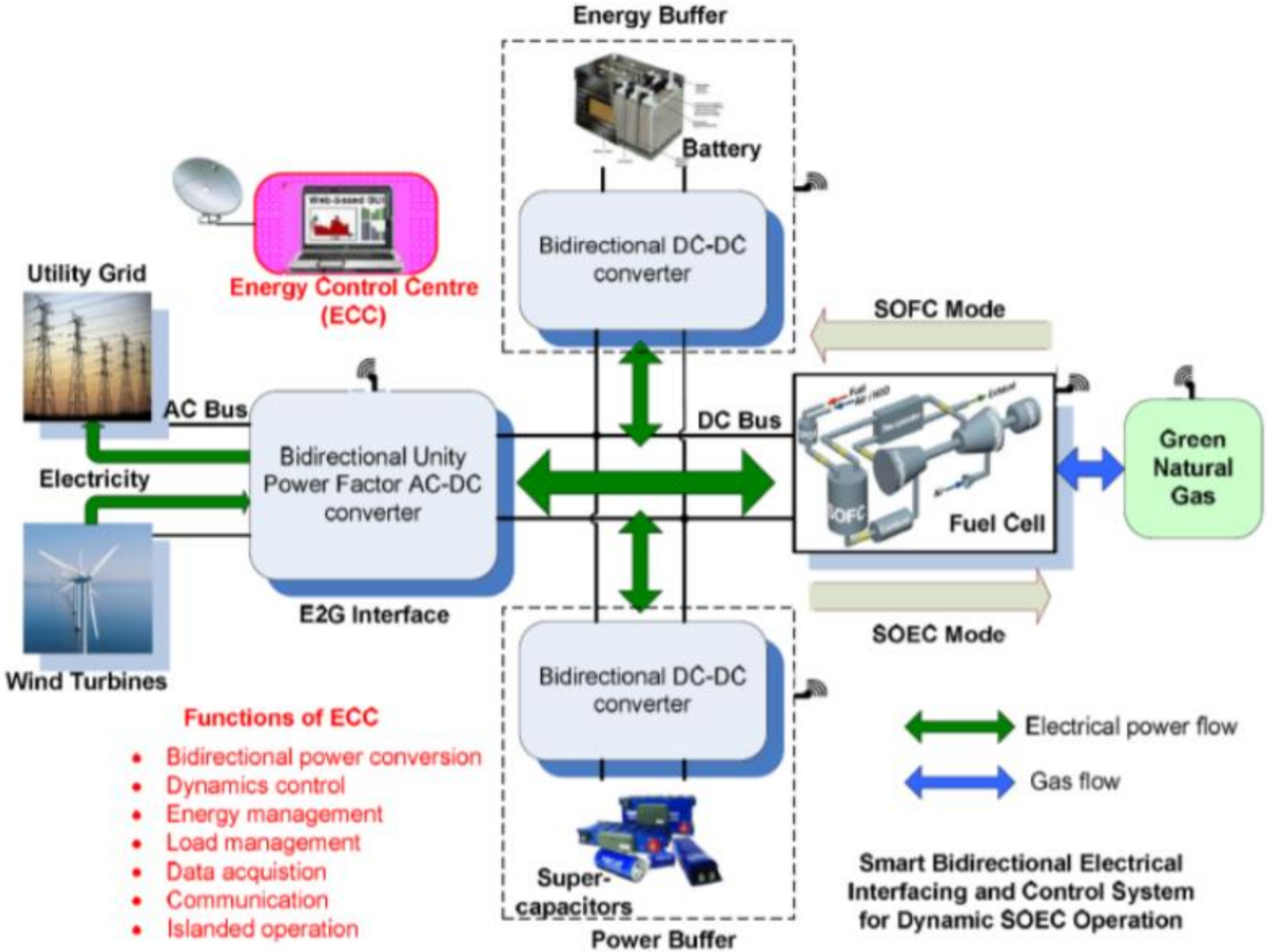
NEW TOPOLOGY



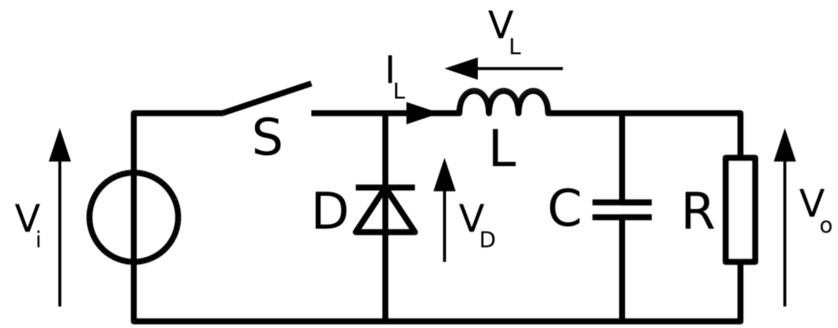
☐ Application example of a bidirectional DC-DC power converter:
a small to medium-sized energy storage system (for industrial/commercial use)



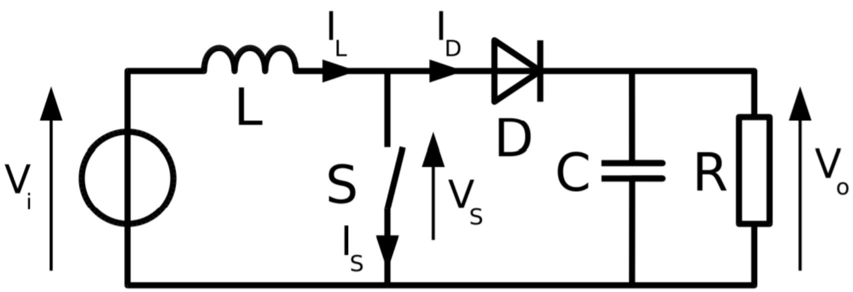

DC grid
Solar PV system
Wind Energy system
Fuel cell energy system
Renewable Energy Sources
DC
DC
AC
DC
DC
DC
DC
DC
DC
AC
AC load
Load
Load
Multi-input IBDC Converter
Power flow
V_1
V_2
V_n


Energy Buffer
Battery
Bidirectional DC-DC converter
Utility Grid
Energy Control Centre (ECC)
SOFC Mode
AC Bus
DC Bus
Electricity
Bidirectional Unity Power Factor AC-DC converter
Fuel Cell
Green Natural Gas
E2G Interface
SOEC Mode
Wind Turbines
Bidirectional DC-DC converter
Functions of ECC
• Bidirectional power conversion
• Dynamics control
• Energy management
• Load management
• Data acquistion
• Communication
• Islanded operation
Electrical power flow
Gas flow
Super-capacitors
Power Buffer
Smart Bidirectional Electrical Interfacing and Control System for Dynamic SOEC Operation

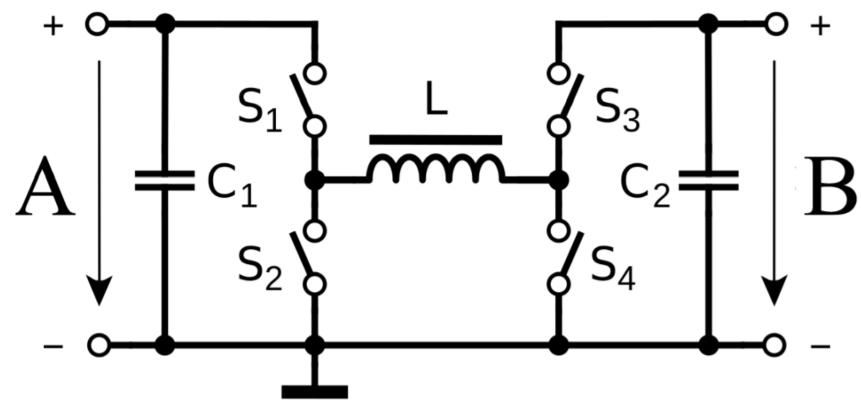
Four quadrant bi-directional converter



Buck converter

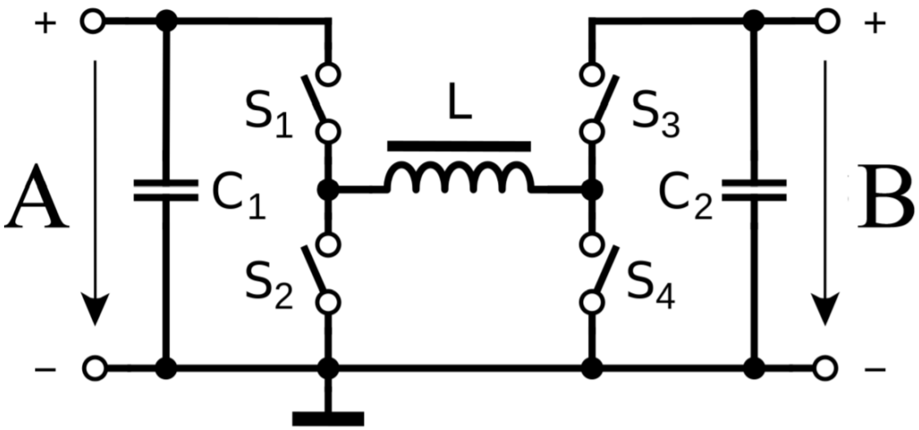


Boost converter

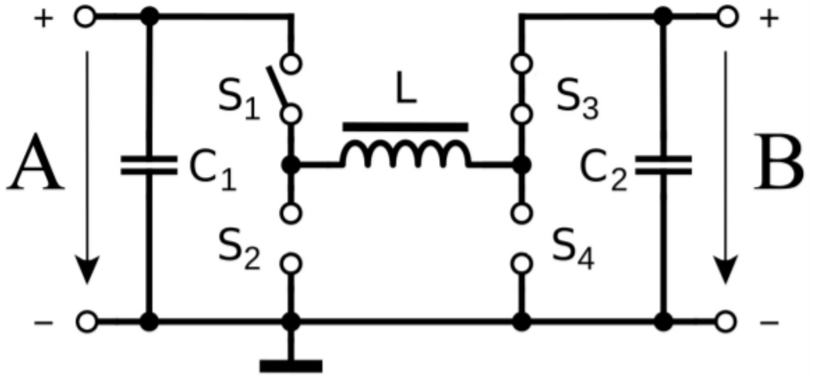


Four quadrant bi-directional converter

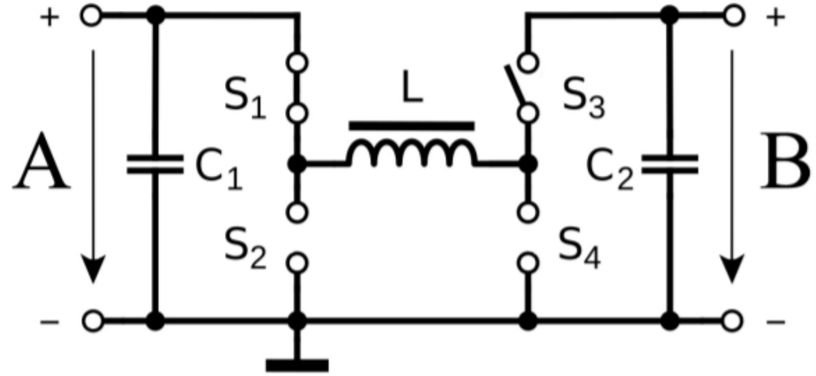
Operation of bi-directional converter



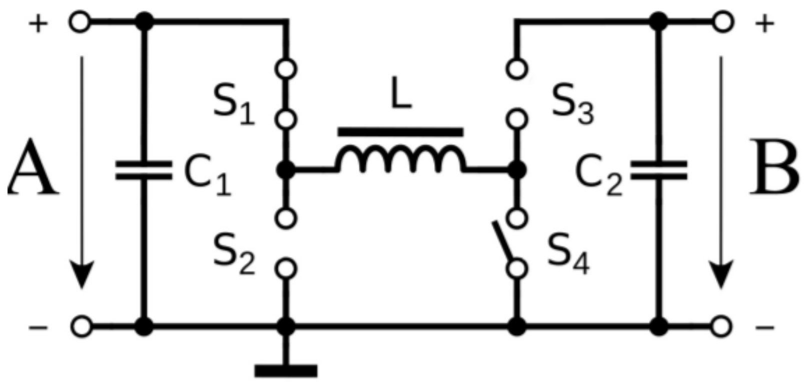
Direction	Mode	S_1	S_2	S_3	S_4
A to B	Buck	Switching	OFF	OFF	OFF
A to B	Boost	ON	OFF	OFF	Switching
B to A	Buck	OFF	OFF	Switching	OFF
B to A	Boost	OFF	Switching	ON	OFF



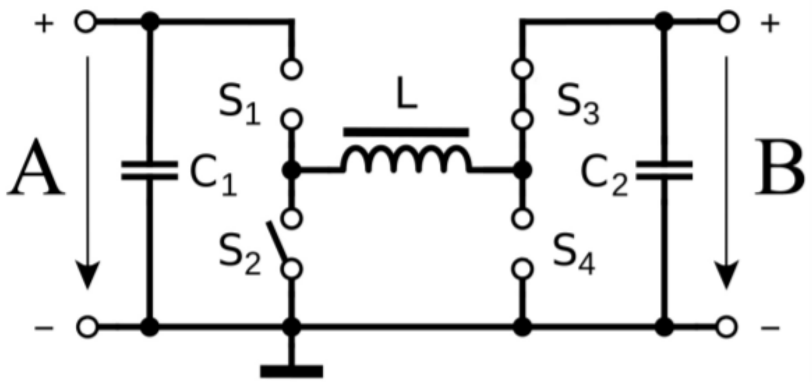
B to A - Buck



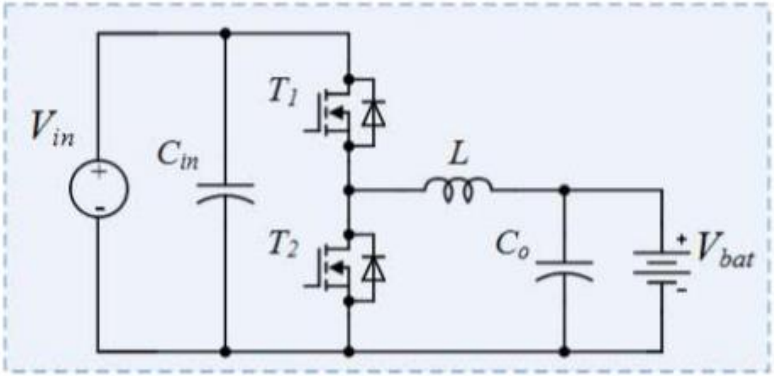
B to A - Buck



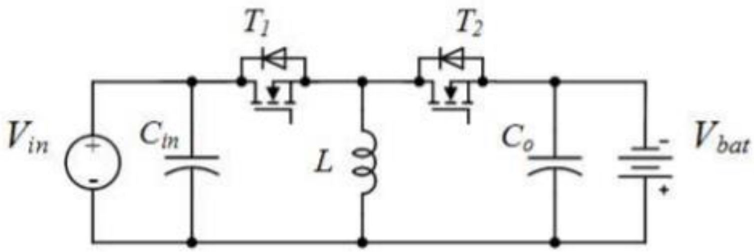
B to A - Boost



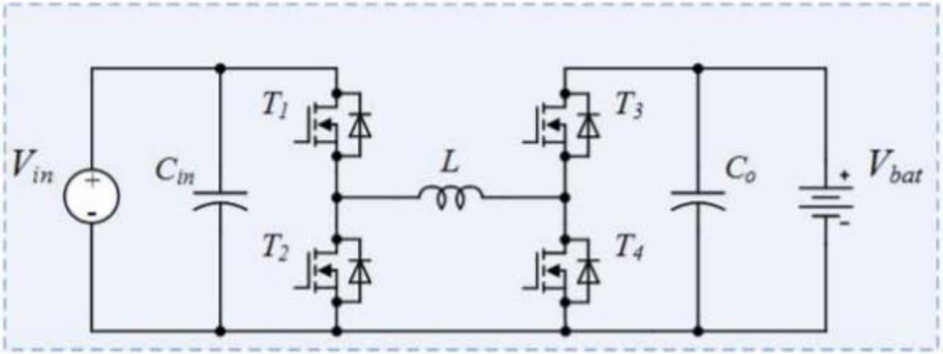
B to A - Boost



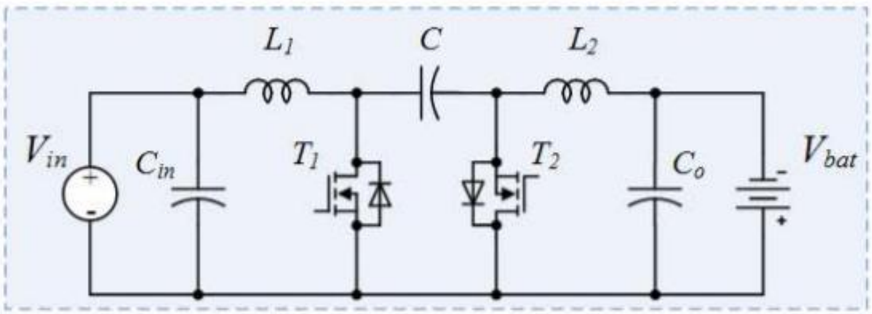
Synchronous buck or boost

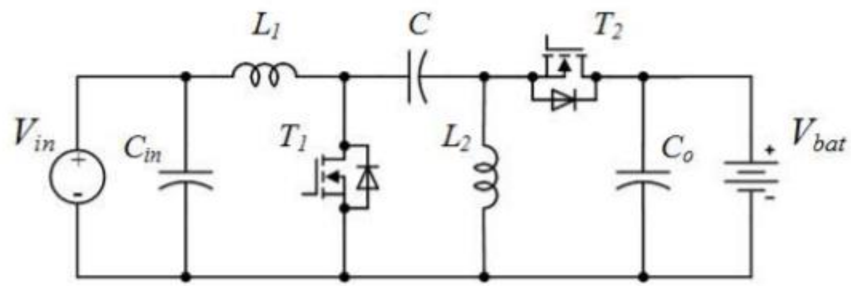


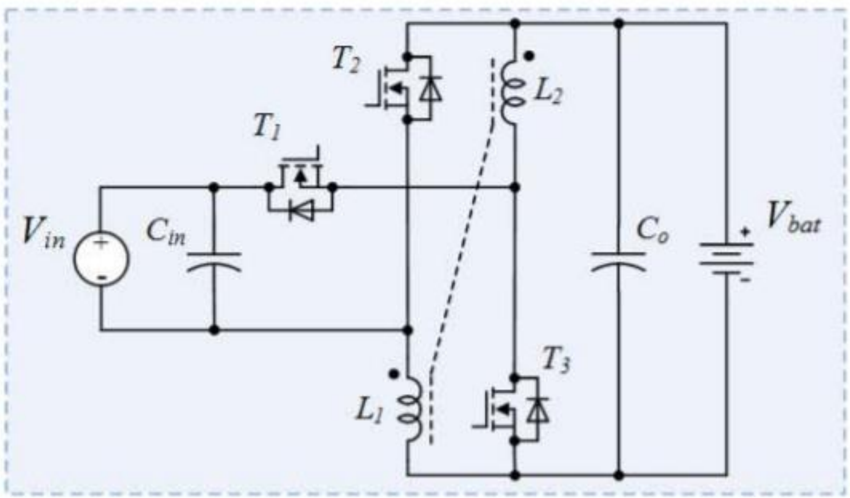
Synchronous Buck-boost



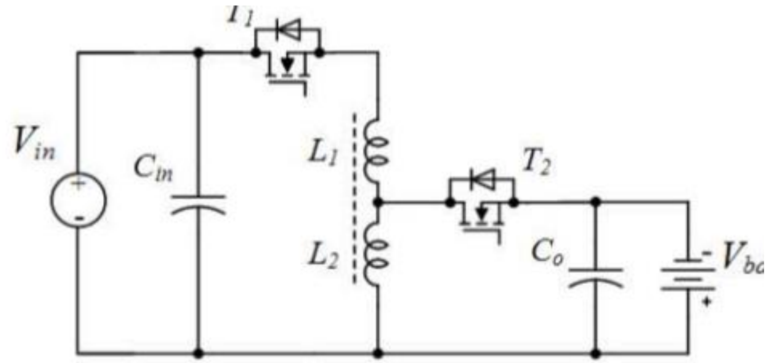
But it has several drawbacks: increasing the number of power switches and, as a consequence, a more complex control system and control algorithms and higher turn-on losses caused by reverse recovery problem of transistors body diodes.

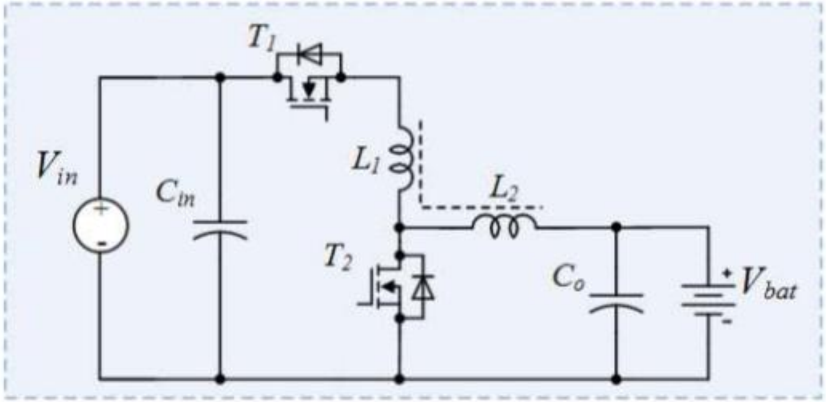


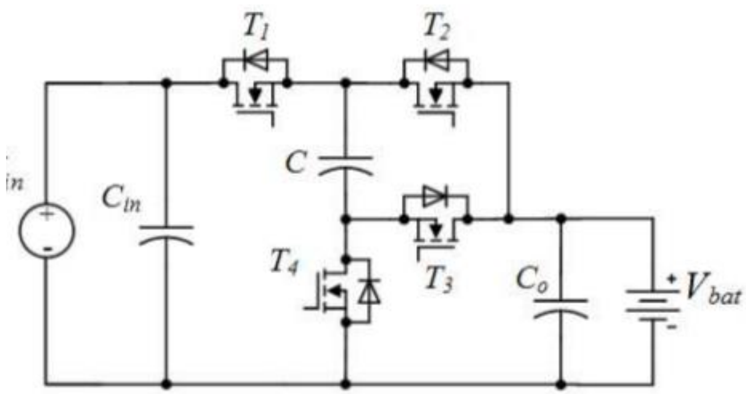


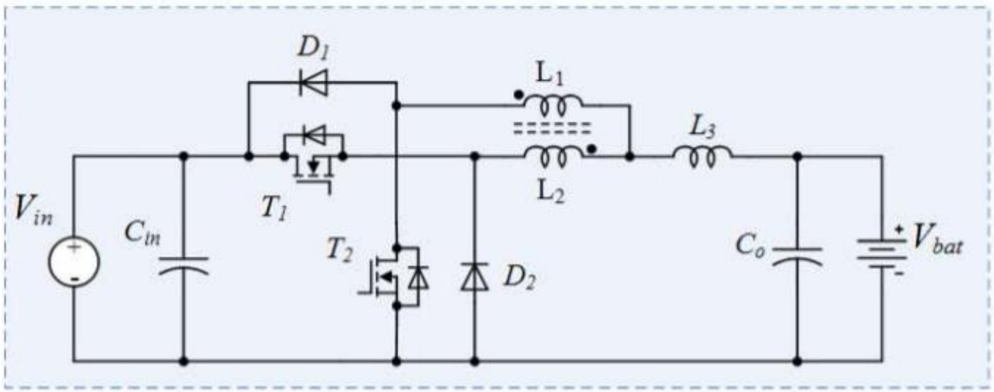


Low ripple in the input and the output currents, therefore, the bidirectional Cuk converter is a proper choice for applications like battery equalization, ultracapacitor-battery interface circuits, and bidirectional converter to manage the power flow and maintain energy storage device`s health.





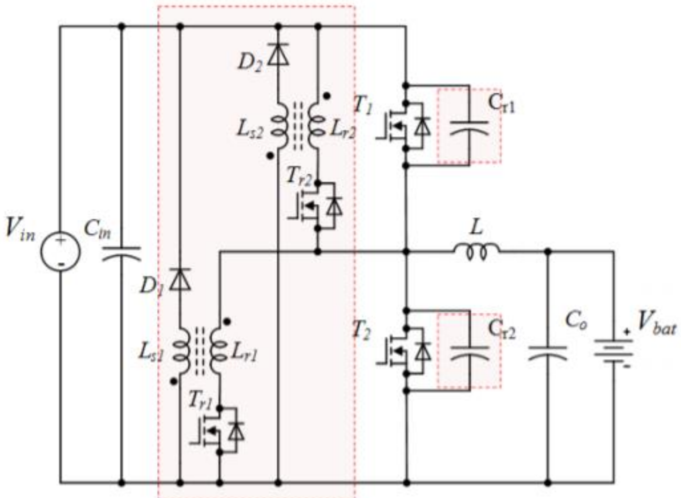


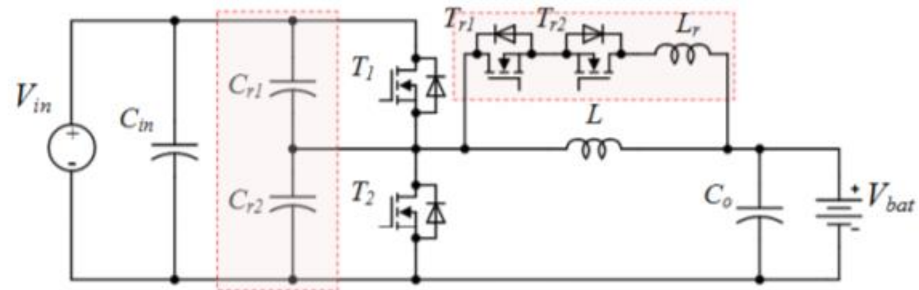


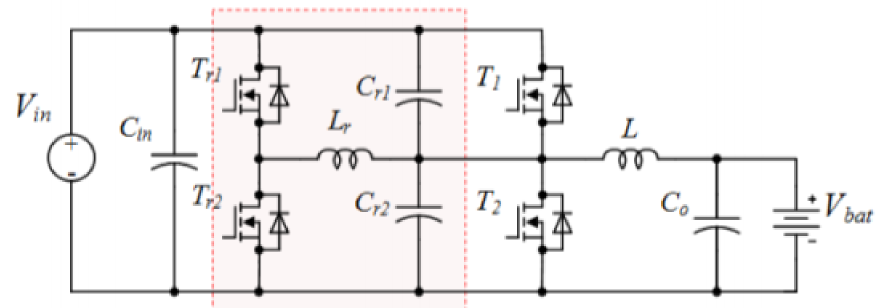
Mostly used when it is required to realize the dc-dc converter by Integrated Circuit (IC) technology.

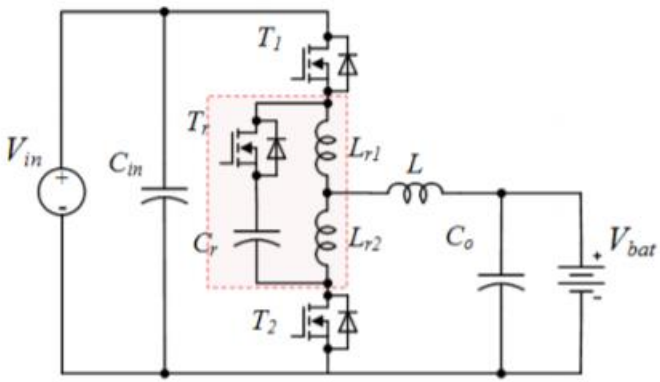
As no magnetic devices are required in those converters, possibilities of IC fabrication are promising

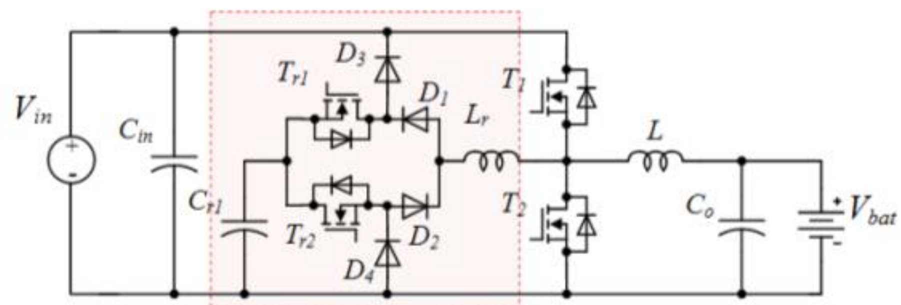
SOFT-SWITCHING TECHNIQUES FOR NON-ISOLATED BDCs



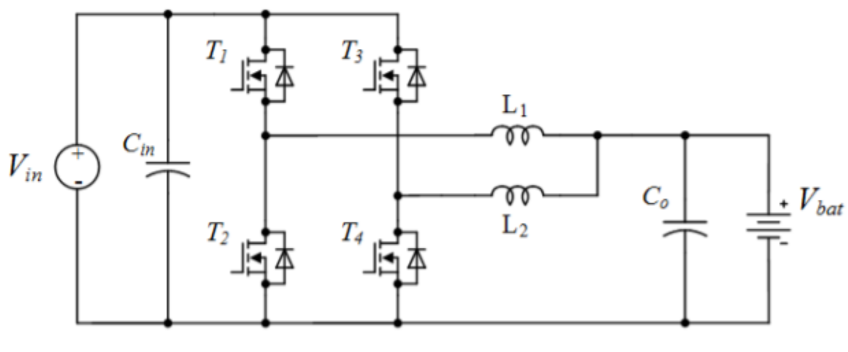




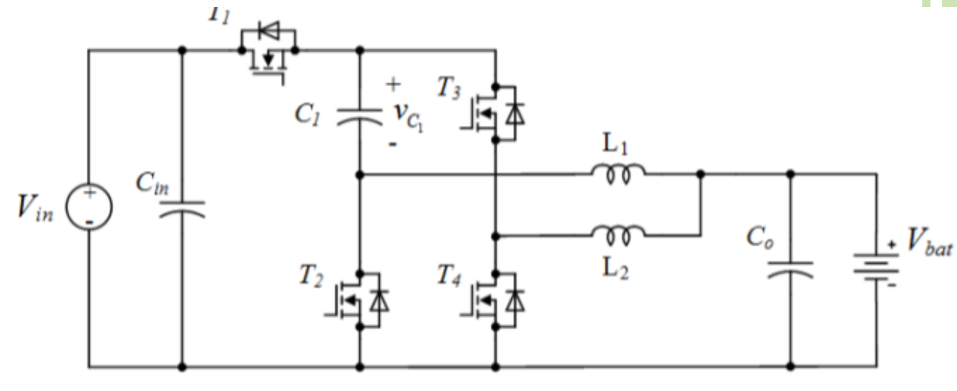




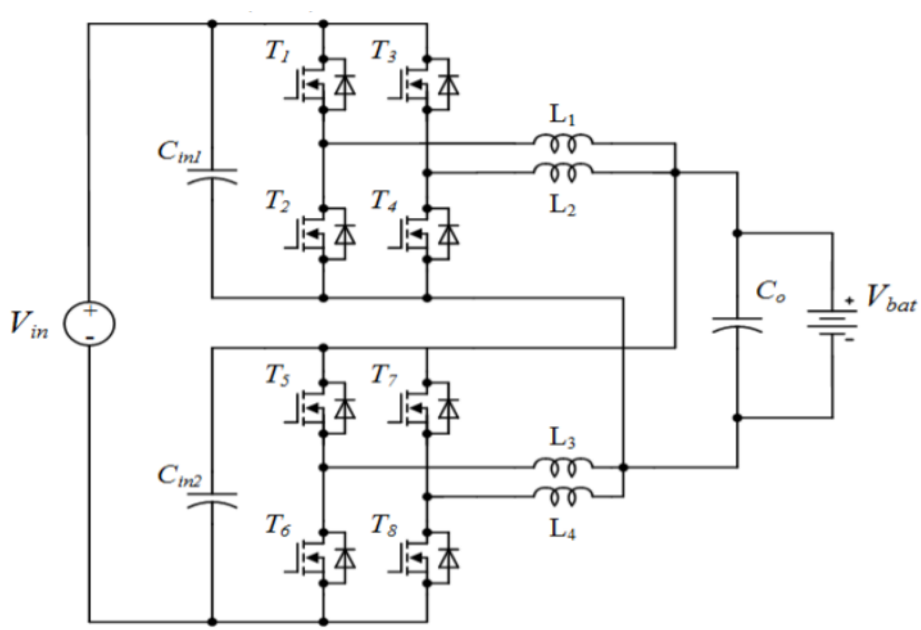
INTERLEAVED CONVERTERS



(a)



(b)



NANO GRID FOR URBAN HOUSE: A LIST OF DC VOLTAGE HOUSEHOLD APPLIANCES

- Group-1: Appliances that are operated using AC to DC power adapters and do not use batteries.

- Group-2: AC to DC power adapters but they are only as a means of charging a battery (cordless appliances).

- Group-3 : household appliances that are sold for the leisure industry and have been manufactured or modified to work directly off a DC voltage power supply, such as a car battery or solar panel system.

Choice of rating of voltage of DC grid

- Most DC appliances are working on 12 or 24 V DC
- Energy efficient strategy to upgrade the output voltages of local sources to such a high voltage (380 V DC)
- Another popular voltage standard is 48V DC, it will be safer than 380 volt.
- Using 48 V DC will decrease loss to one fourth of that of 24 V DC

ARG-2 Modern LOADS are DC Compatible at Homes

- As home-appliances are moving towards being DC-powered.

AC fan	72W	BLDC fan	30W
at speed 1	60W		9W
CFL tube	36W	LED tube	15W
low intensity	na		4W

- All Electronics devices work on low-voltage DC
  - TV (LED/LCD), laptops, Cell-phones, speaker-phones, tablets, speakers
  - AC to DC conversion has losses from 15% to 50% in each device
  - Use of DC-powered and energy-efficient devices reduce the Consumption by 50%

Nano grid Rural home: (But what will 10% DC Power do?)

- Assume uninterrupted but limited Power: 100 Watts DC
  - Can support 3 lights + 2 fans + cell-phone charging
  - Or 3 lights + 1 fan + TV (24" LED/LCD) + cell-phone charging
    - can be installed incrementally

- 100W per home is such a small amount that it can be supplied even in adverse power situation

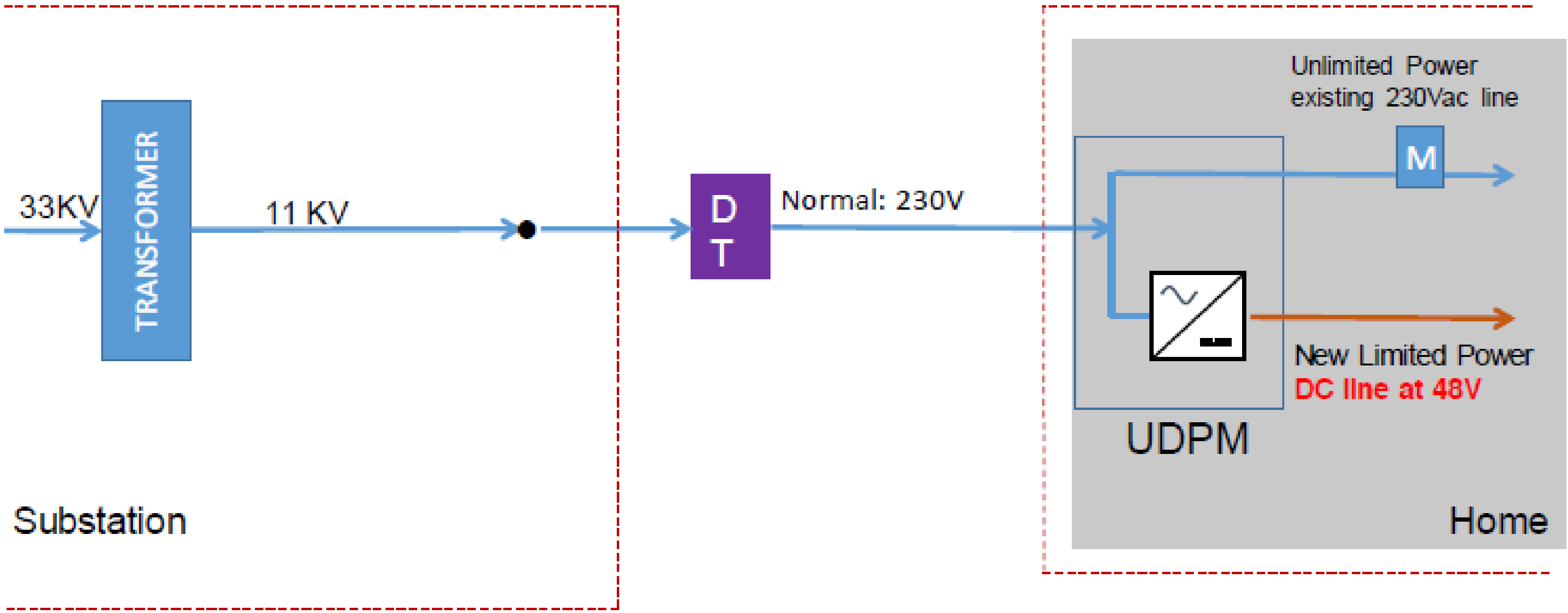
- What if one wants more?
  - Add Solar PV
  - If needed, add a battery to have a Solar DC system
  - 500W Solar DC can support 5 fans, 8 lights, 2 TVs, multiple cell-phone / tablet chargers and a laptop charger

Comparison of power consumption of appliances in small home for AC & DC

Appliances	DC				AC			
	Wattage (W)	Per unit cost (Rs)	No.s	Total cost (Rs)*	Wattage (W)	Per unit cost (Rs)	No.s	Total cost (Rs)*
Fan	24	4	3	5.18	67	5	3	18.09
Bulb	5	4	3	1.08	40	5	3	10.8
Tubelight	18	4	3	3.88	36	5	3	9.72
TV	30	4	1	2.16	40	5	1	3.6
Phone	5	4	1	0.36	7	5	1	0.63
Cooler	24/48	4	1	3.45	170	5	1	15.3
Total			224 W	14.6			646W	57.6

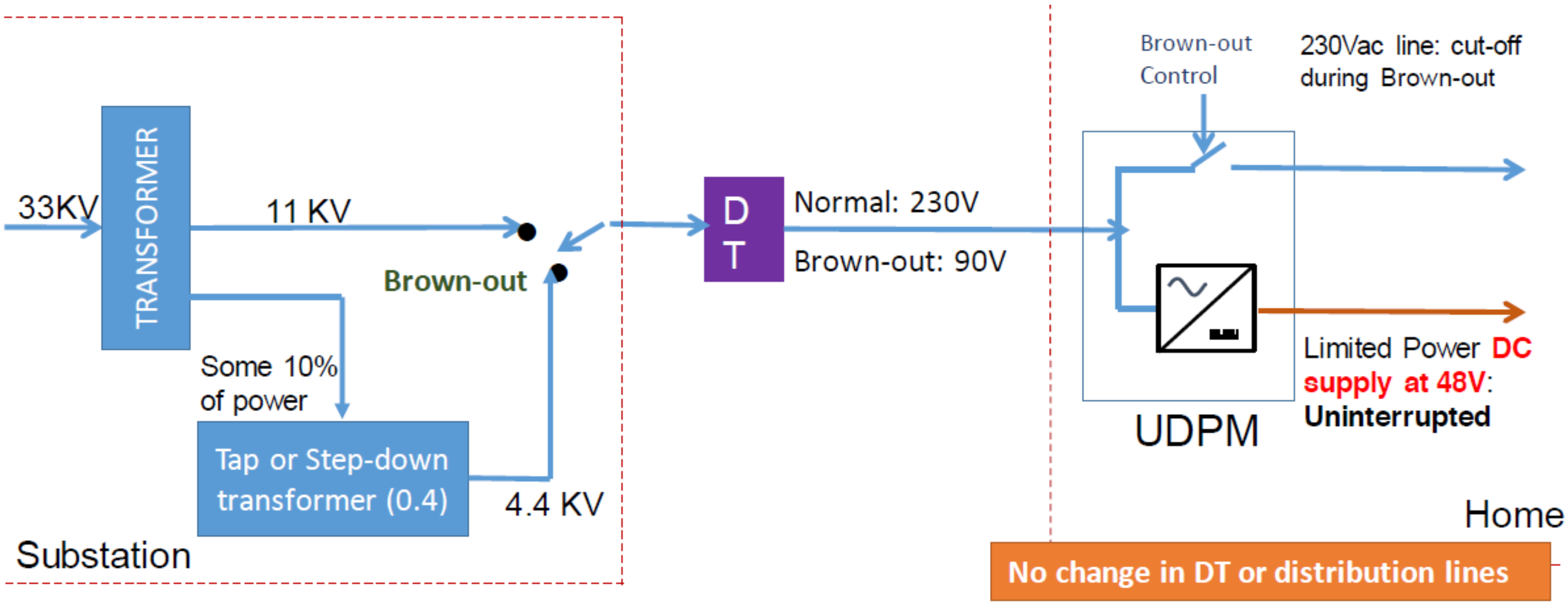
*means appliances operates on an average of 18 hours/day

UDC (Uninterrupted DC)
A power distribution innovation



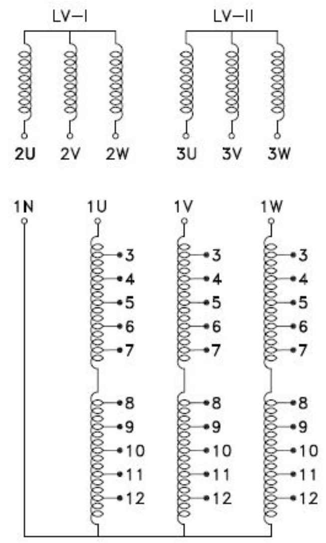
- Substation charges feeders with 11kV Distribution Line
  - Distribution transformer steps down voltage to 230V in each of the three phases
- UDPM at home allows using present AC line and a limited power DC line
  - UDPM has built-in DC meter; AC meter remains as it is

LOAD SHEDDING: 90% POWER CUT – BROWN-OUT



- Brown-out: continue feeding 10% power to Distribution Line
  - Substation feeds 11kV in normal and with 4.4kV in brown-out condition (only 10%) on DL
  - Distribution transformer steps down voltage to 230V in normal / 90V in brown-out condition
- UDPM detects AC voltage drop to 90V: cuts off AC line but continues feeding 48V DC
- 10% BO Power small enough to be made available even during worst power-shortage

OFF CIRCUIT TAP CHANGE DESIGN CONCEPTUAL [BY : V.R.V]



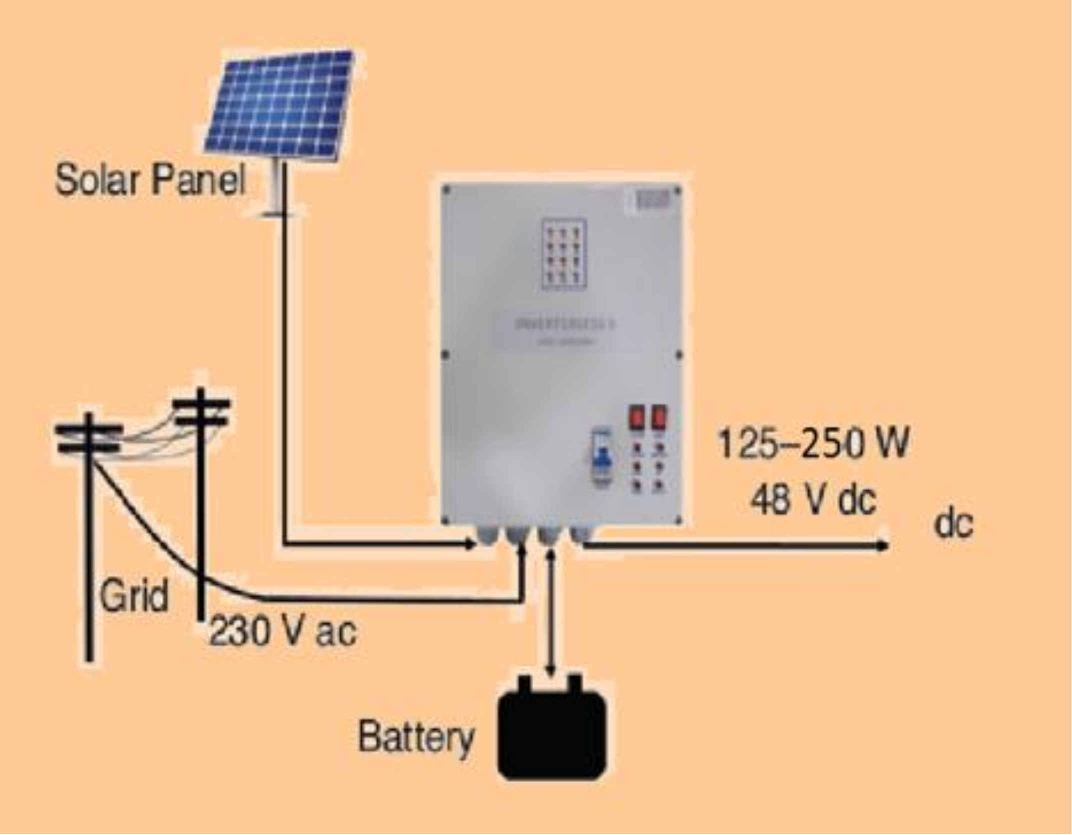
TAP CIRCUIT DIAGRAM
DESIGNED BY : V.R.V

OFF CIRCUIT TAP CHANGER			
TAP POSITION	CONNECT	TAP VARIATION	HV VOLTS
1	7 – 8	+10.0%	36300
2	8 – 6	+7.5%	35475
3	6 – 9	+5.0%	34650
4	9 – 5	+2.5%	33825
5	5 – 10	0	33000
6	10 – 4	–2.5%	32175
7	4 – 11	–5.0%	31350
8	11 – 3	–7.5%	30525
9	3 – 12	–10.0%	29700

TRANSFORMER RATING : 2000KVA
VOLTAGE RATIO : 33 / 0.400 – 0.400KV
TYPE : OIL TYPE TRANSFORMER FOR PV INVERTER DUTY [SOLAR PV PLANT APPLICATION]
TAP CIRCUIT : OFF CIRCUIT TAP CHANGE +10% TO –10% @ 2.5% STEPS

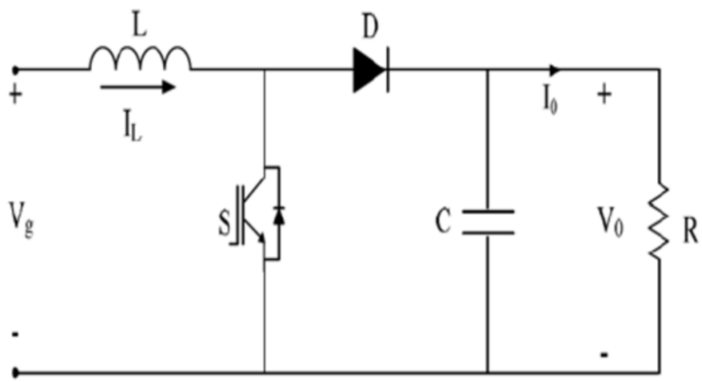
THE ABOVE DESIGN IS DESIGNED & IMPLEMENTED BY US FOR THE SOLAR PV PLANT LOCATED AT TAMILNADU.

Power Converter Interface for Uninterrupted DC Supply in Nano grid Applications

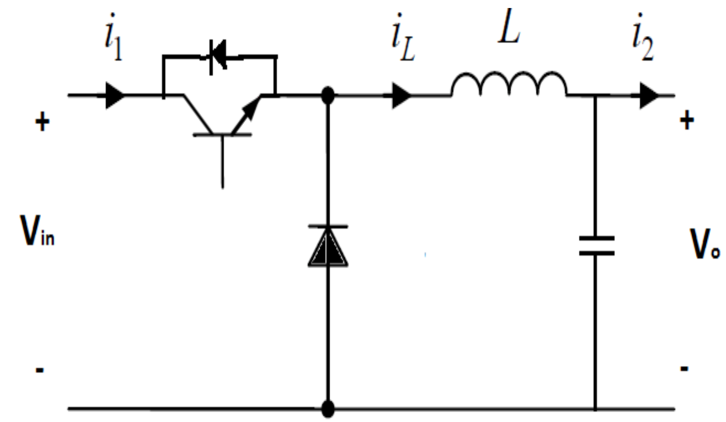


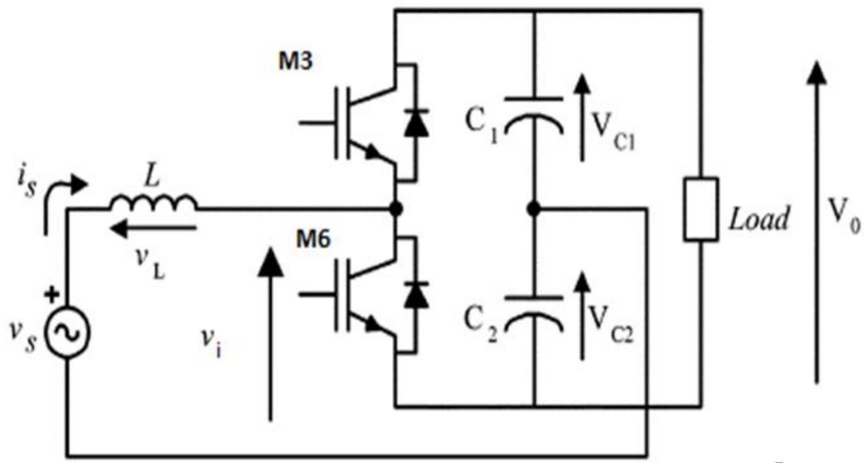
Bidirectional Converter Topology

Boost Converter



Buck Converter

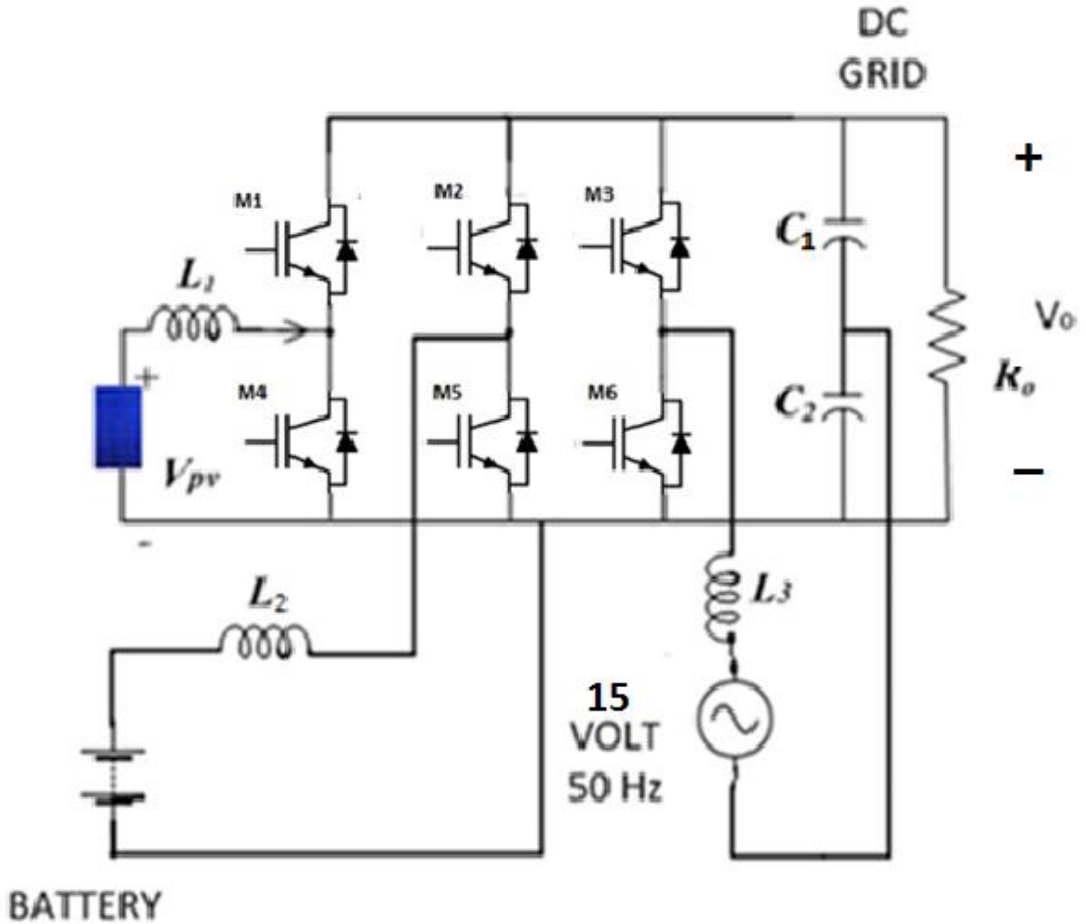




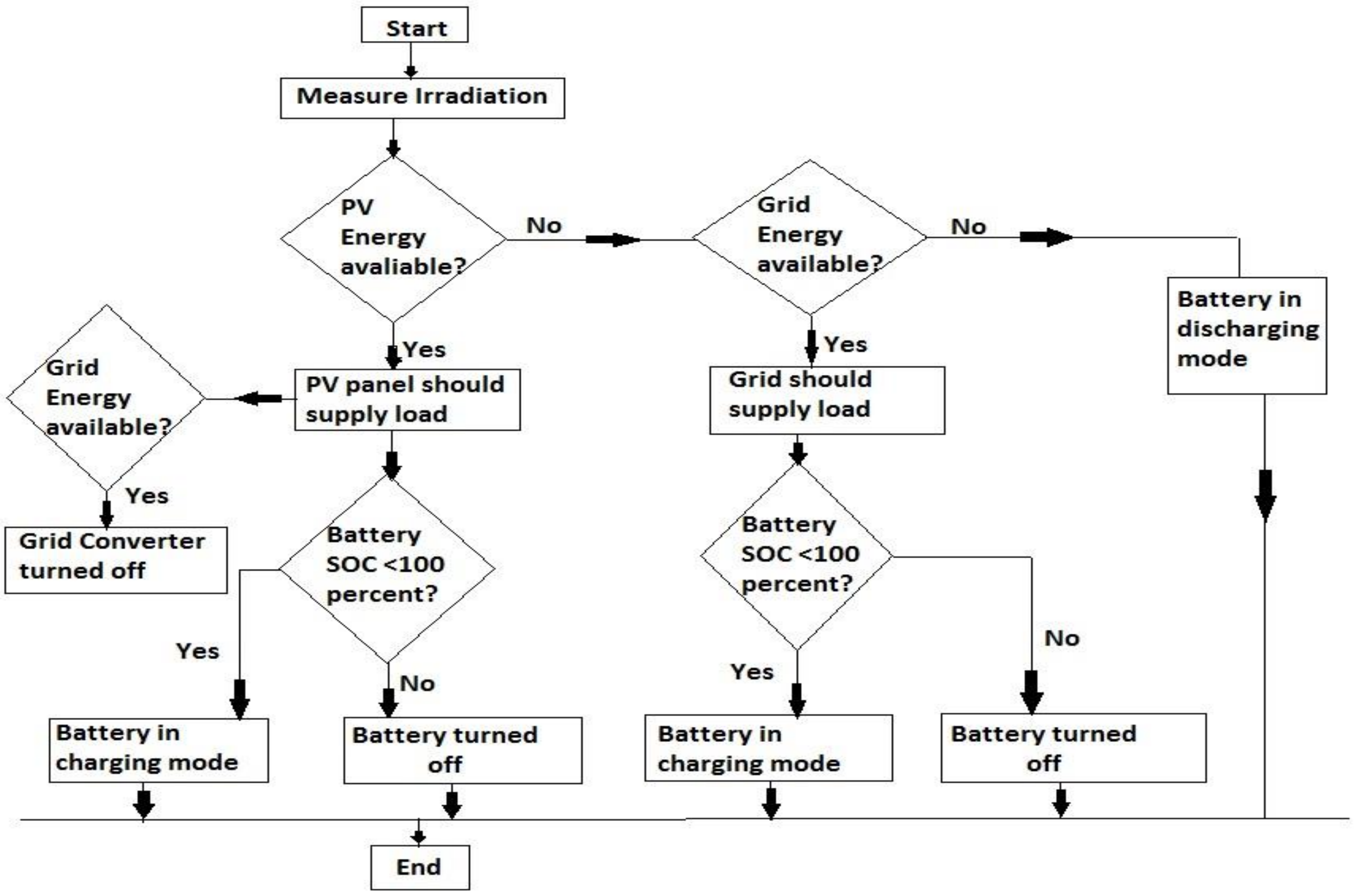
Voltage Doubler Circuit

System Description

Uninterrupted DC Power (UDC)

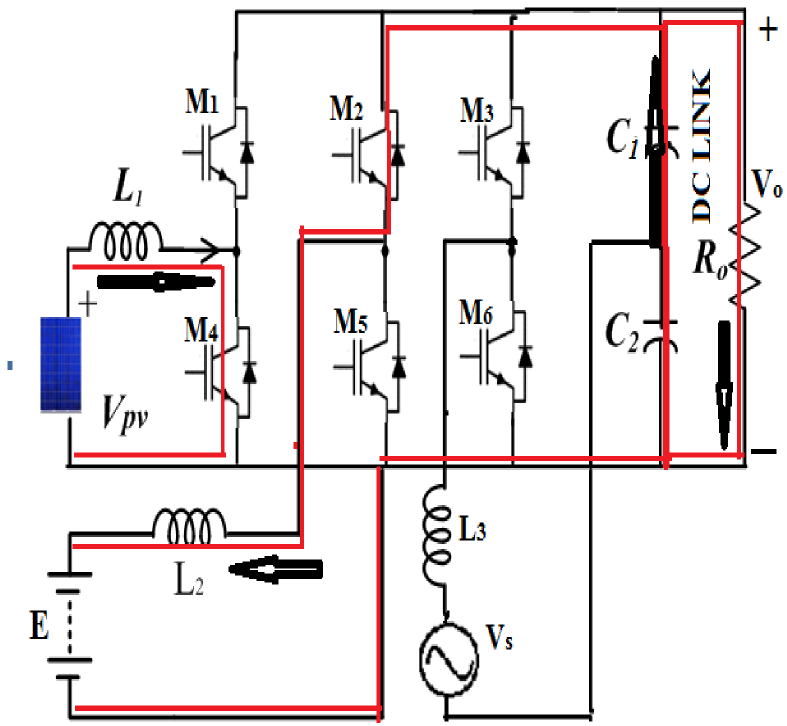


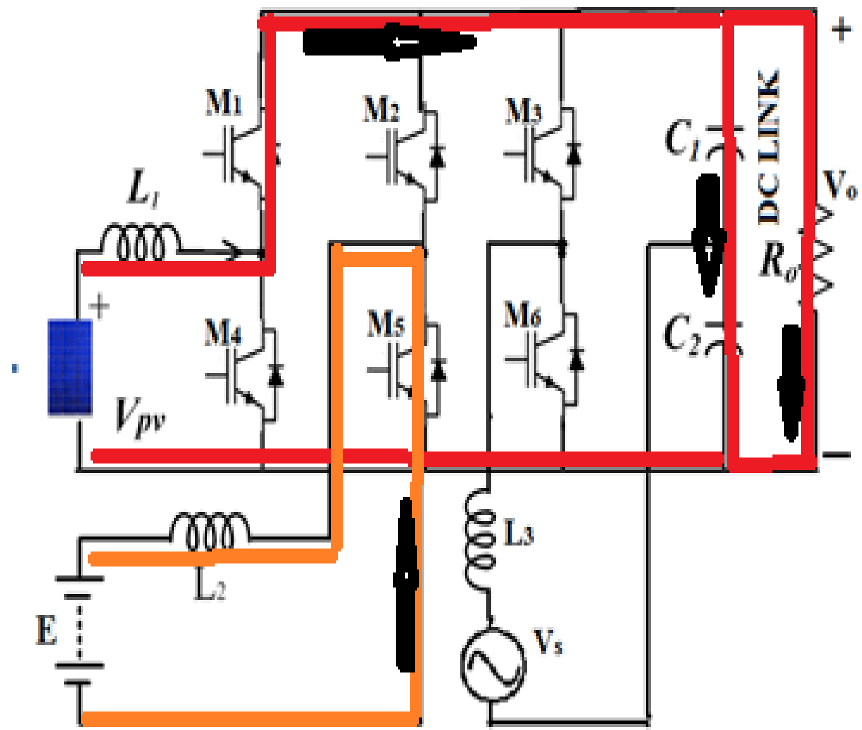
Energy Management System



Converter Interface

Mode 1

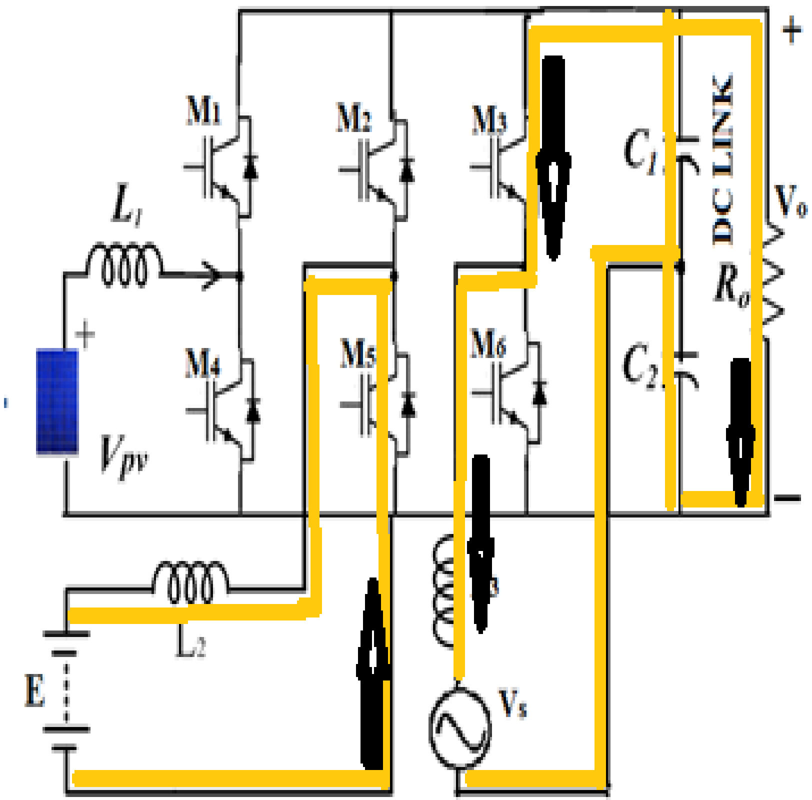


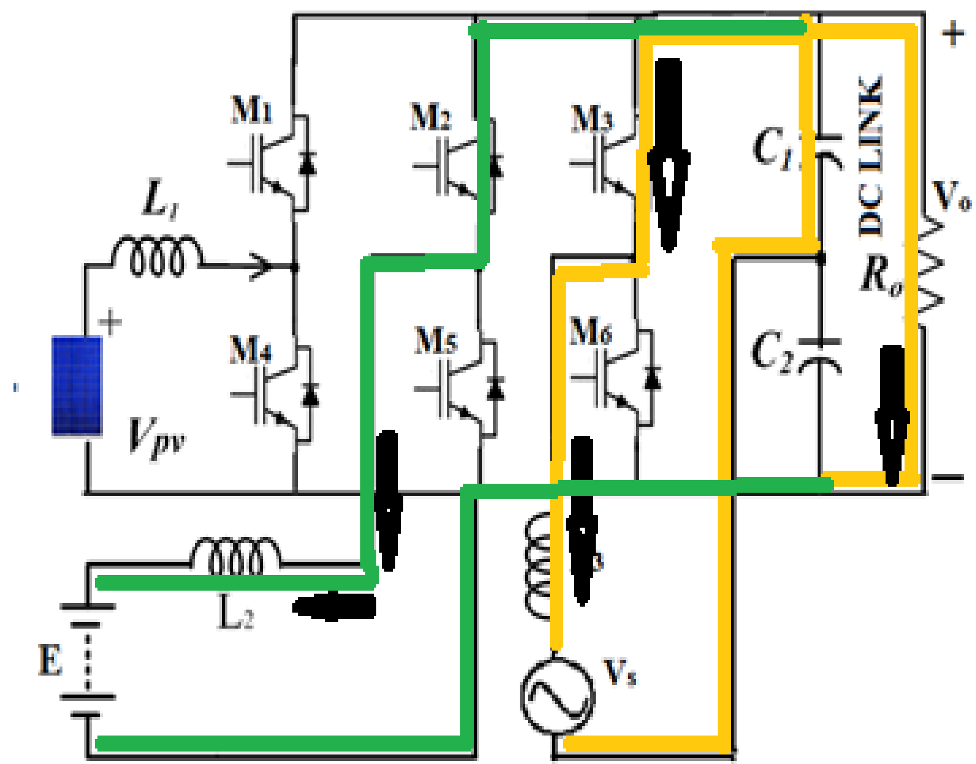


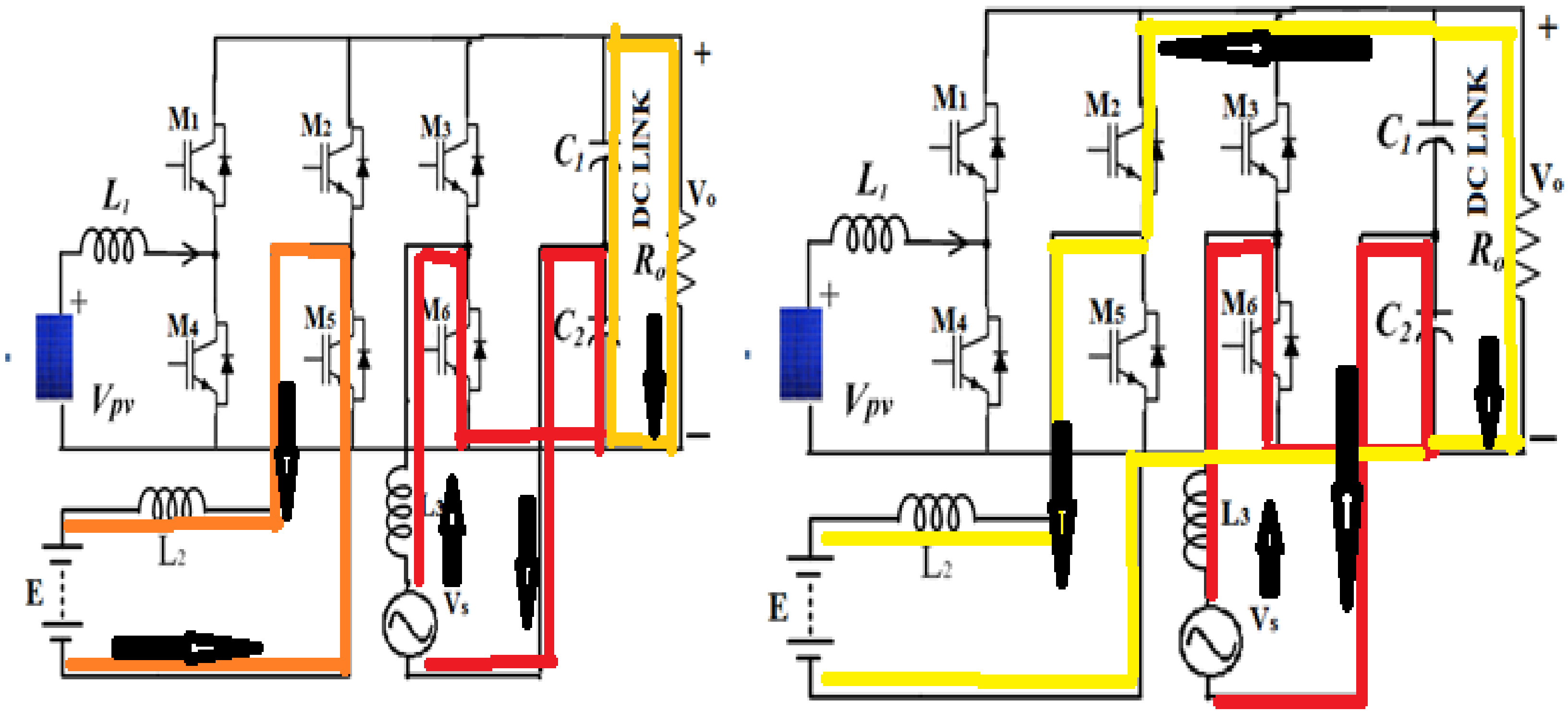
Mode 2

If PV energy is available and Grid is available and Battery Status is Full then PV module supplies power to load and battery will be in idle mode i.e. no charging & discharging & Grid remains off.

Mode 3



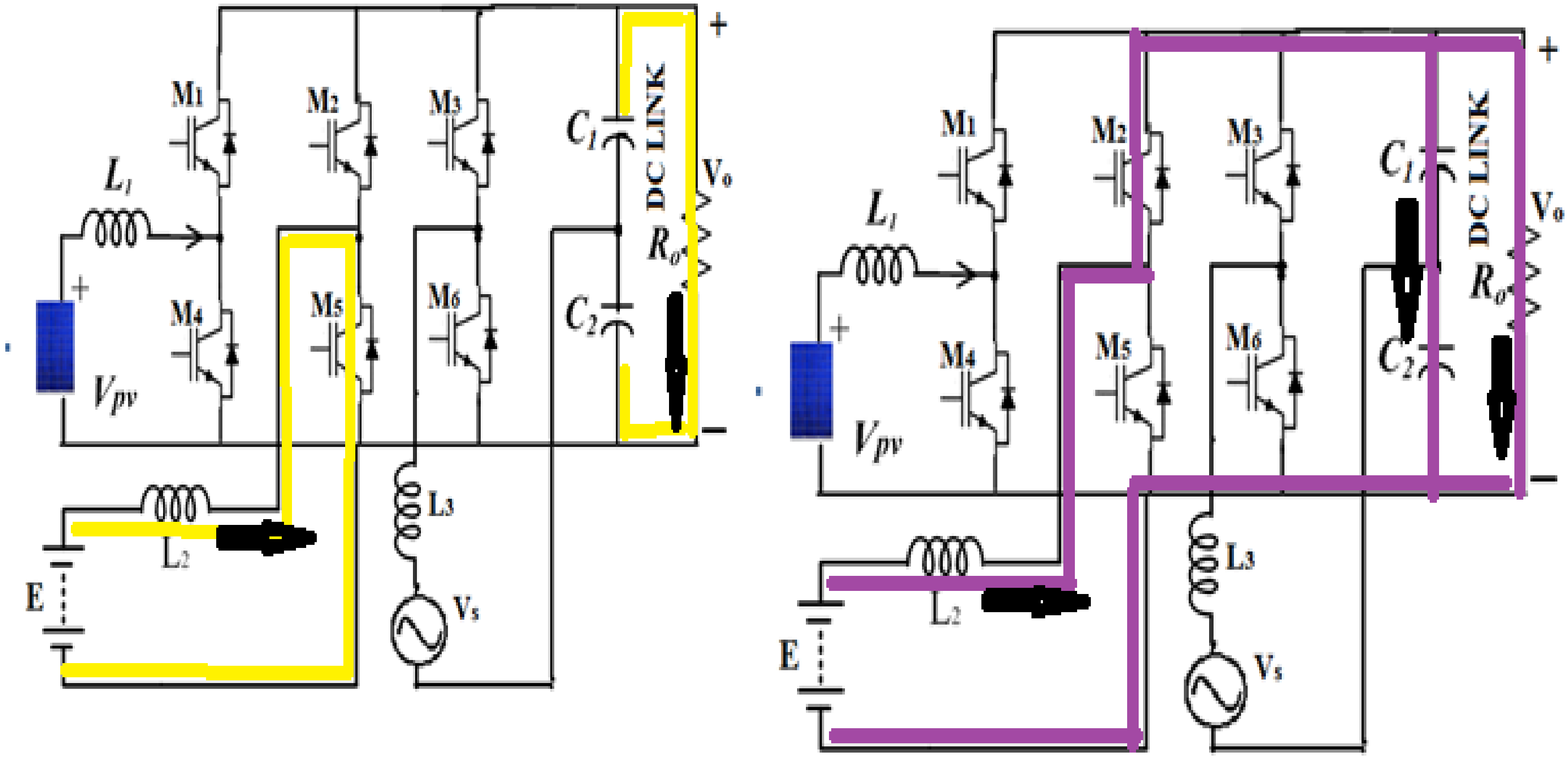




Mode 4

If PV energy is not available and Grid is available Battery Status is Full battery will be turned off Grid supplies power to load

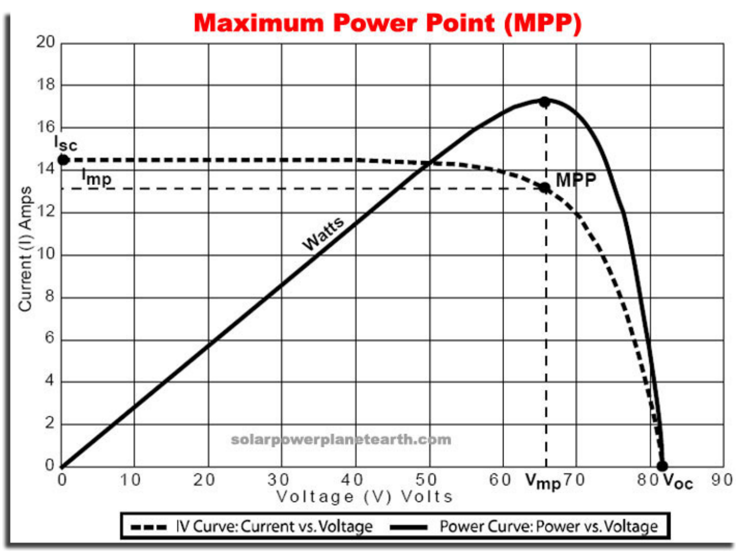
Mode 5

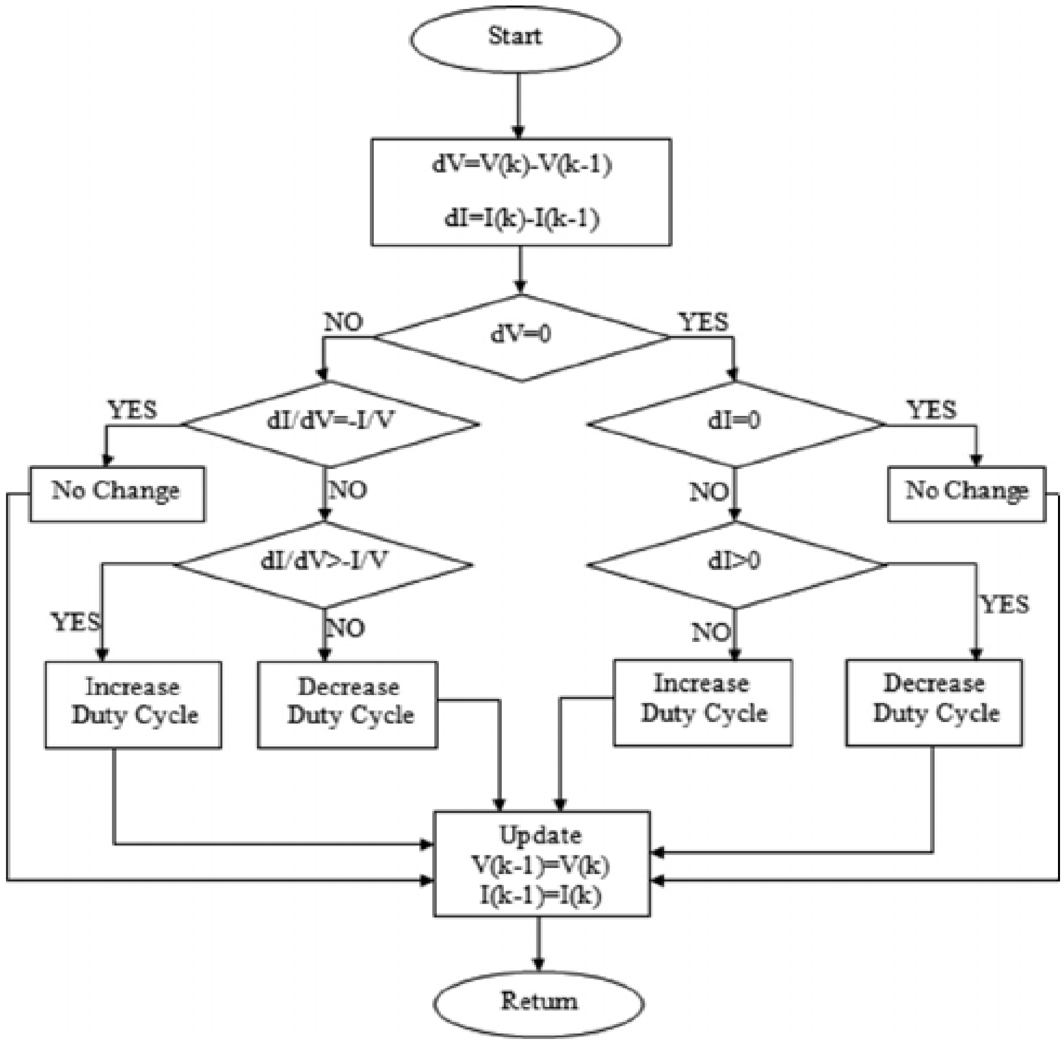


Closed Loop Control Techniques

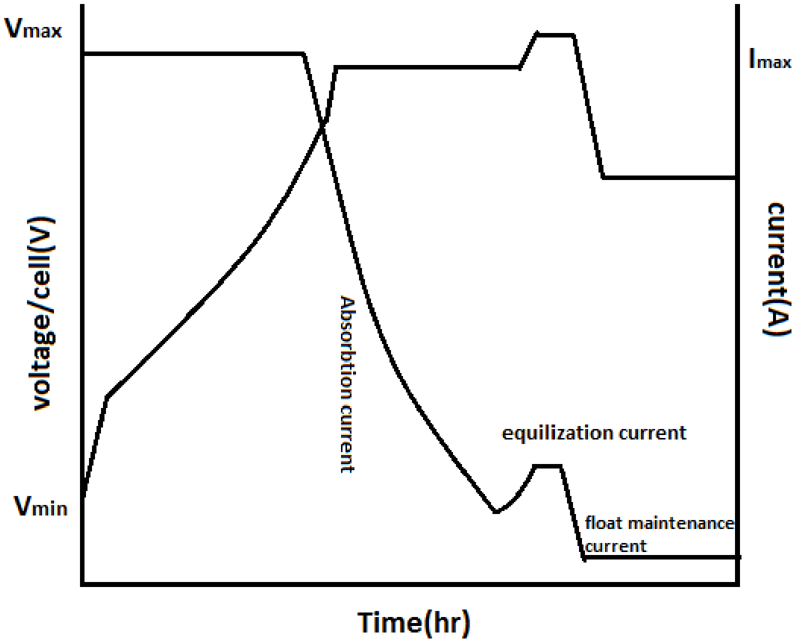
PV Panel closed loop control technique

Incremental Conductance Technique





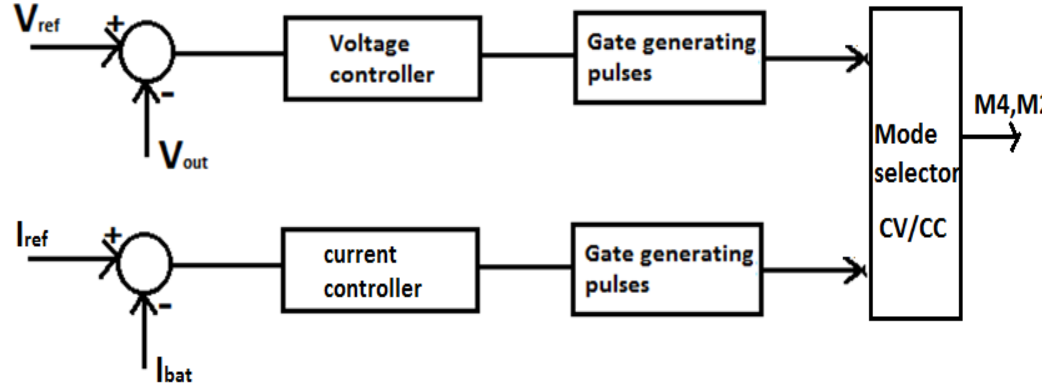
Battery closed loop control technique



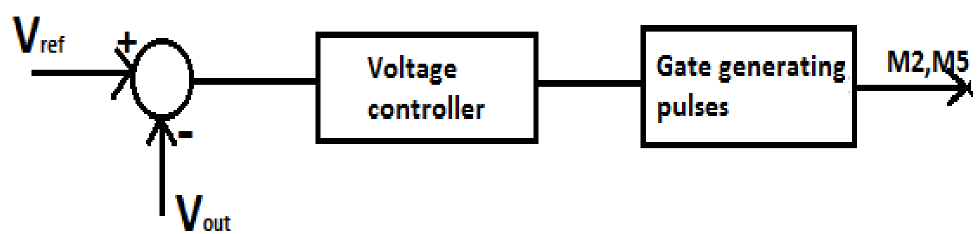
Battery Charging Methods

- Constant current
- Constant voltage

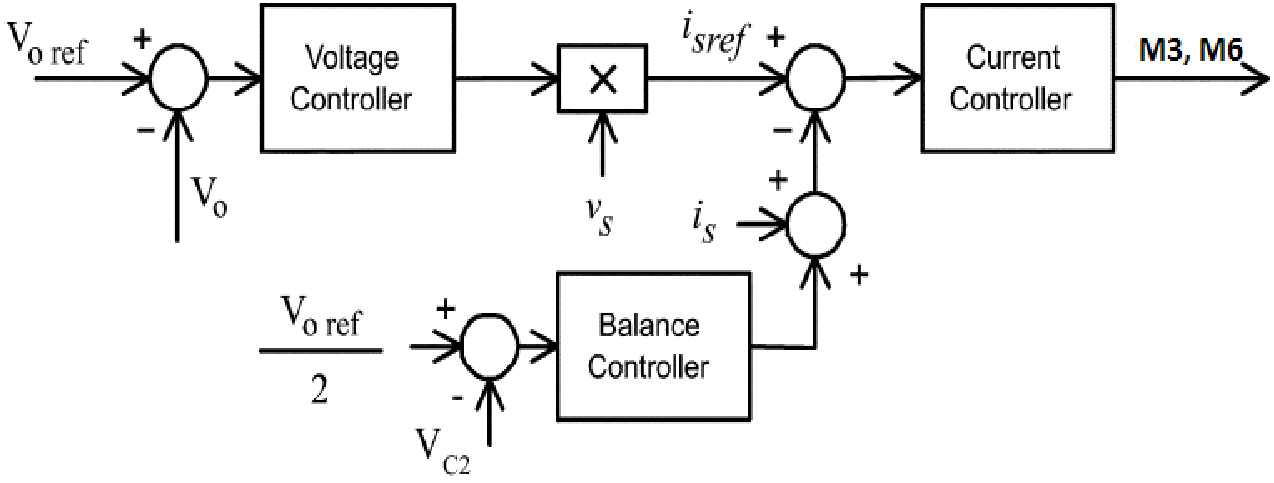
Closed loop current & voltage charging of battery

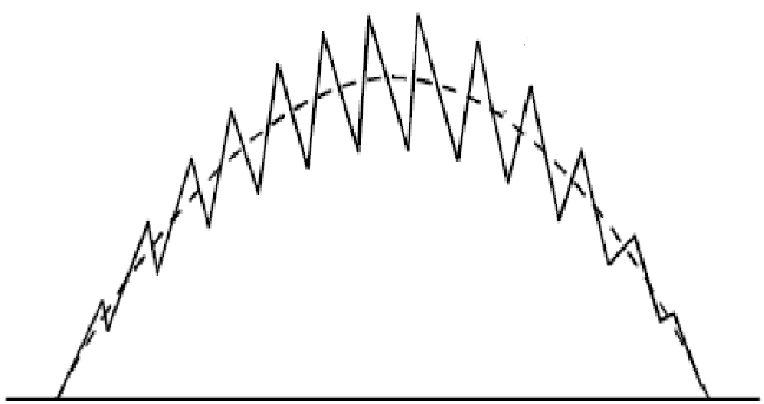


Constant voltage discharging for boost converter by battery



Voltage Doubler closed loop control technique



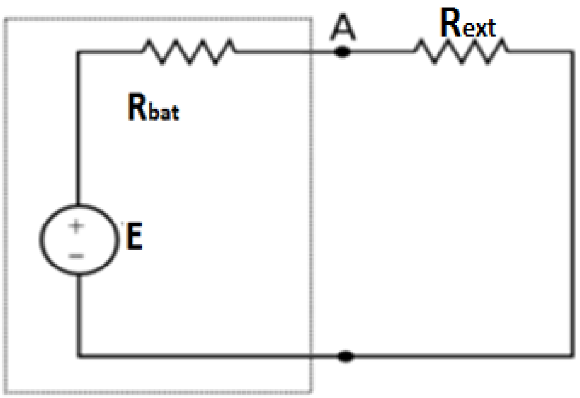


Design of Solar PV Array

- The PV Array is designed for a 250 W power capacity
- one solar module consists of 36 cells in series. Each cell has an open circuit voltage of 0.5 V to 0.6 V and short circuit current (*Isc*) of 4 A.
- Thus one module has open circuit voltage (*Voc*) of 18-21V and short circuit current of 4A.
- Maximum power occurs generally *Pmax* = (85% of *Voc* * 85 % of *Isc*) thus *Imppm* is 3.4A and *Vmppm* is 17.85 V of each module.
- Number of series connected modules = output voltage/*Vmppm* = 1
- Number of parallel connected modules = output current/*Imppm* = 15/3.4 = 5

Specification of battery requirement in the system

$$V = E - I_{bat} R$$



For 200 Watt load battery discharge current is 25 A

V=12-25*.2=7 volt. It has to boost to 48 volt so duty ratio comes 88%.

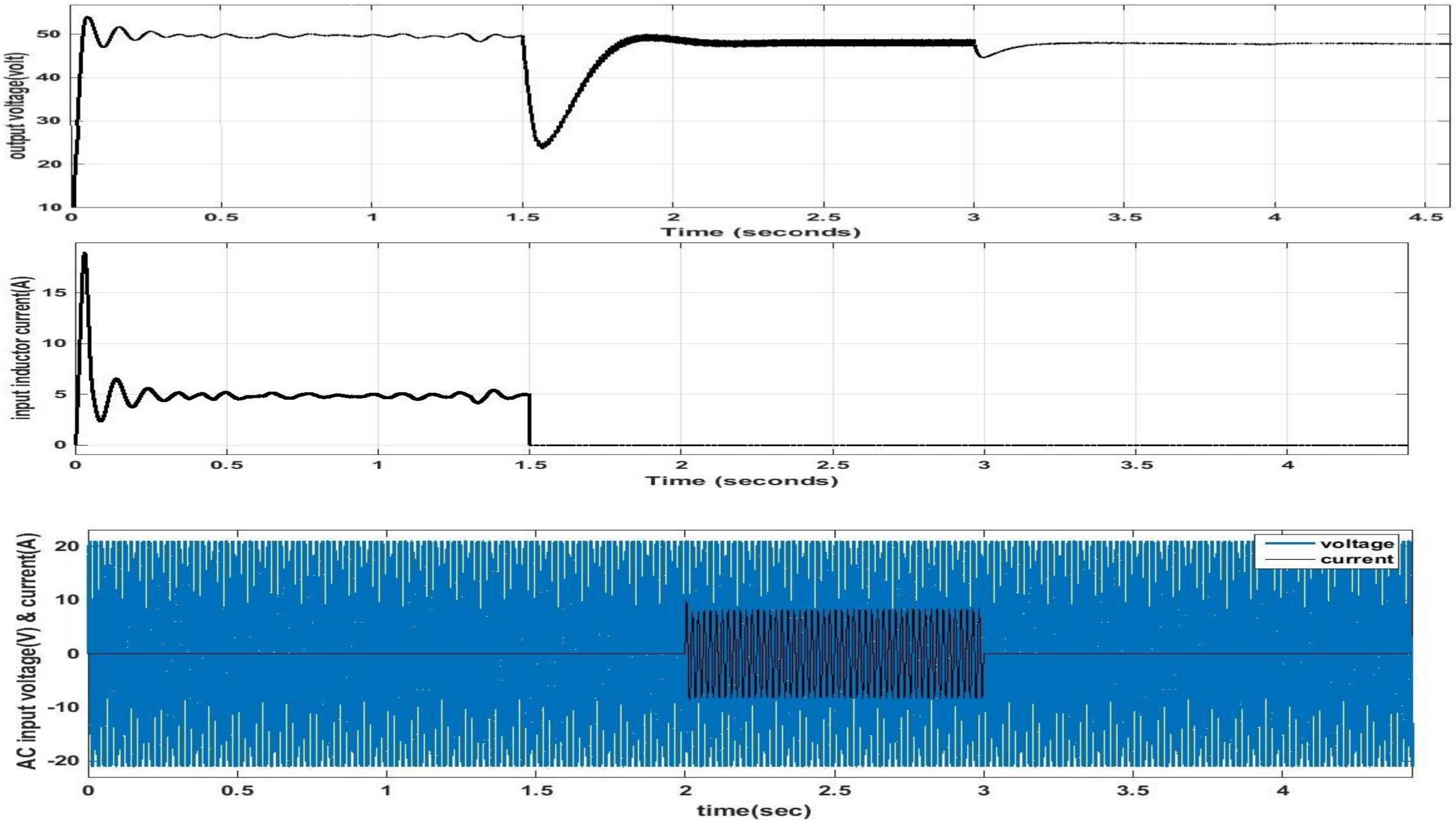
Current required 25 A to supply 200 Watt load. Now the battery power required P=7*25=175 Watt. If there is 2 hours load shedding then power required P=175*2=350 Watt-hr. The rating of battery in A-hr is 50 A-hr

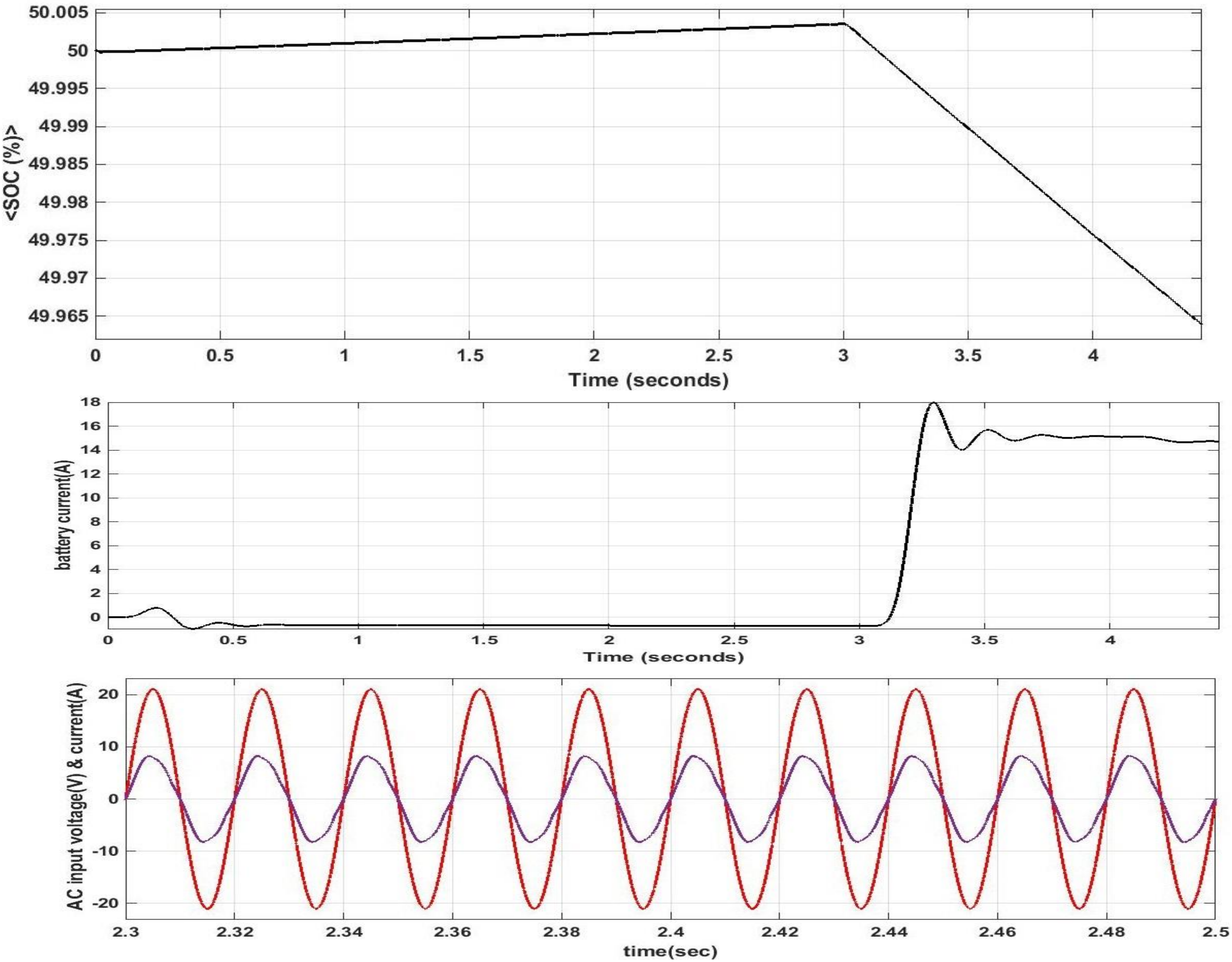
Specification of parameters used in simulation

SL No.	Parameters	Specification
1	Inductance L_1	3 mH
2	Inductance L_2	1 mH
3	Capacitance C_1, C_2	7 mF
4	Inductance L_3	16mH
5	Solar panel V_{oc}, I_{sc}	21 V, 4 A
6	Solar Array	5 modules in parallel
8	Switching frequency	20 KHz
9	Battery capacity	42 Ah
10	Battery full charged voltage	13 V
11	Battery nominal charged voltage	12 V
12	Solar panel Vmp	18V
13	Solar panel current Imp	3A

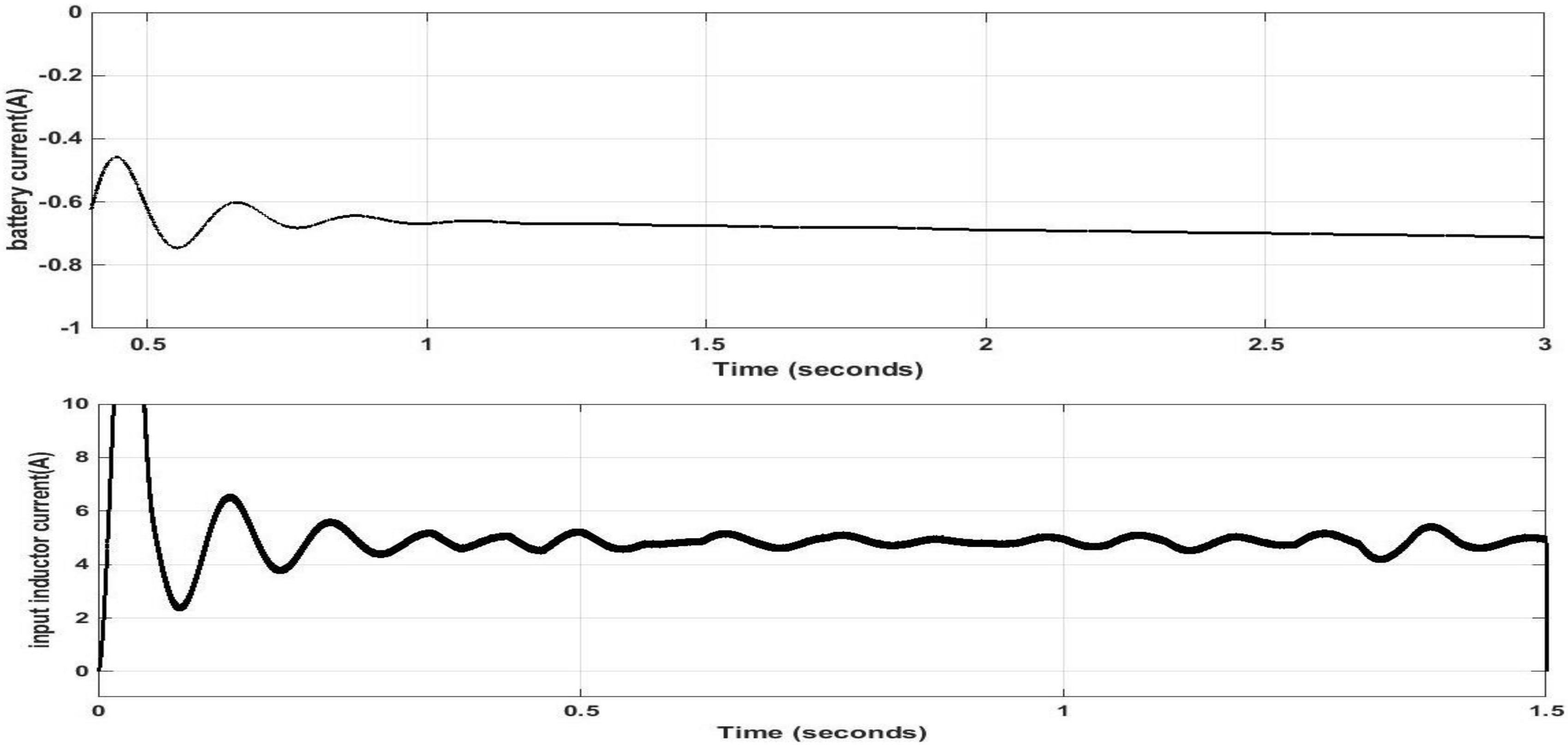
Simulation Results and Discussion

Analysis done on 77 Watt load & 1.5 Amp battery current charging





<SOC (%)>
Time (seconds)
battery current(A)
Time (seconds)
AC input voltage(V) & current(A)
time(sec)



The input current is 4.5 amp. Solar voltage is 22 volt so power supplied is 22*4.5=99 watt. Output load is 30 ohm so, power supplied is 1.6*48=77 watt

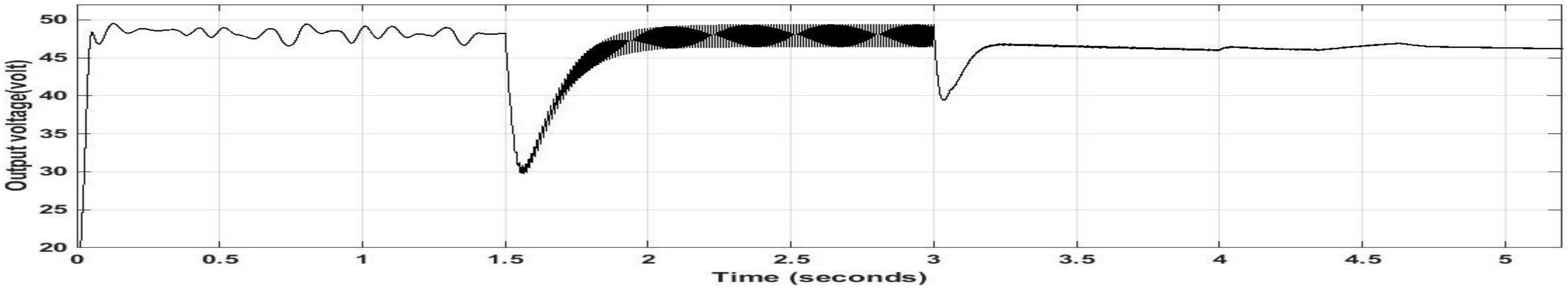
Power supplied to battery is 12*1.5= 18 watt Efficiency = 95.5%

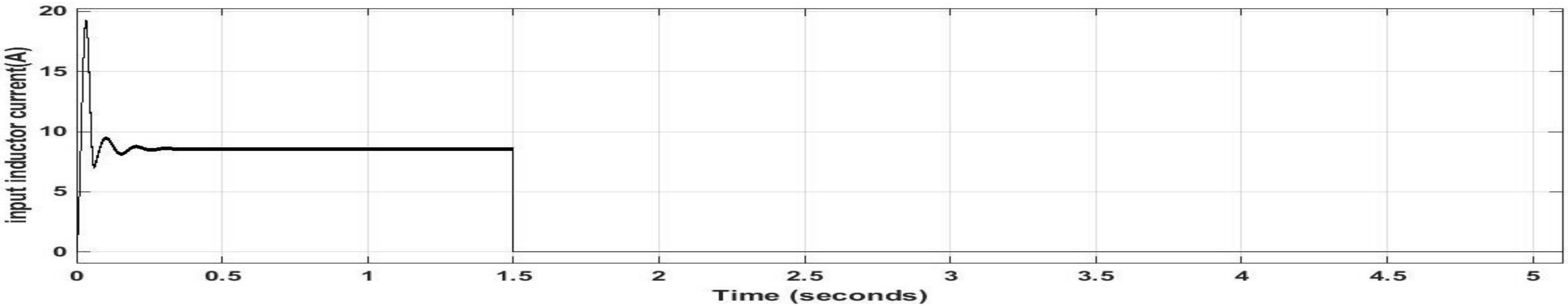
For AC part input current is 6.4 Amp & input voltage is 15 volt.

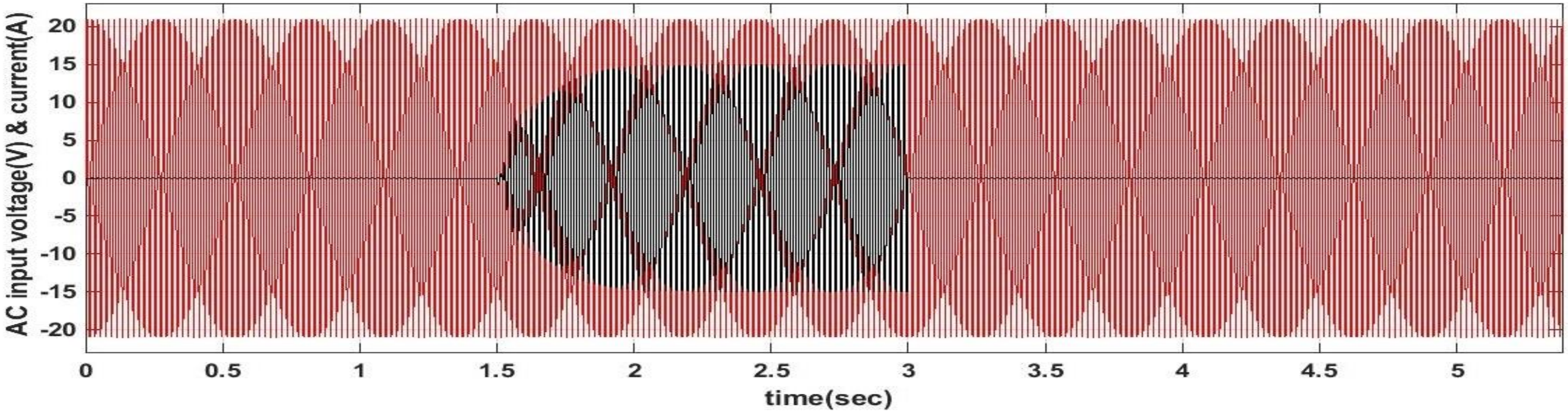
So, input power =15*6.4=95.45 watt.

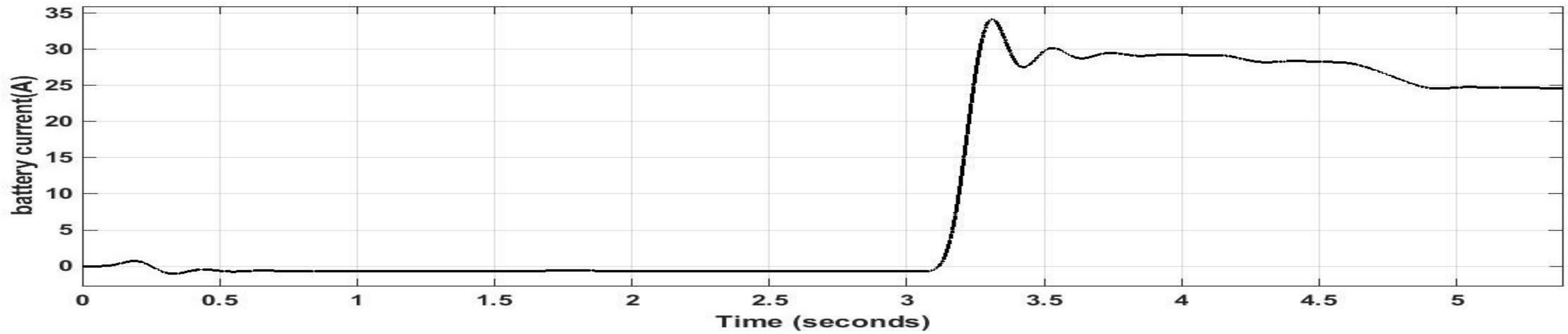
Efficiency is 99.3%

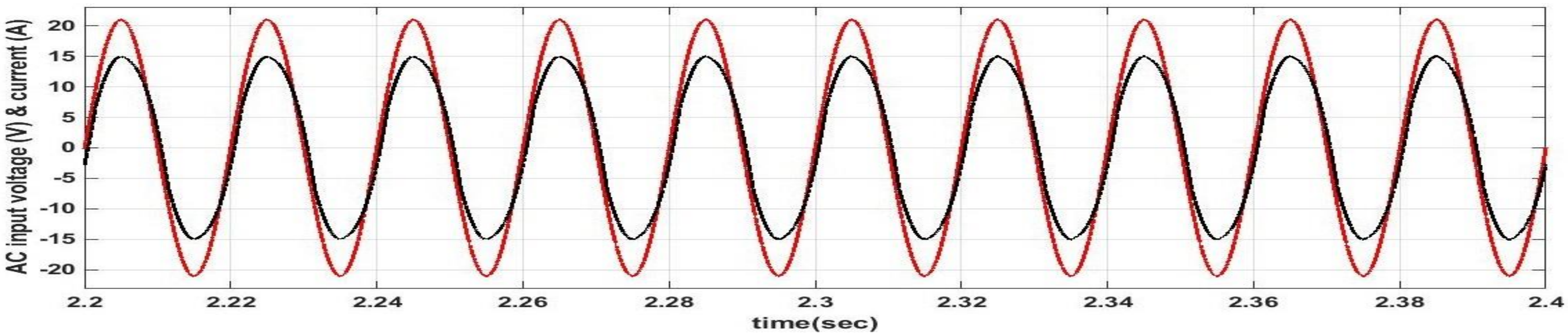
Analysis done on 164 Watt load & 1.5 Amp battery current charging





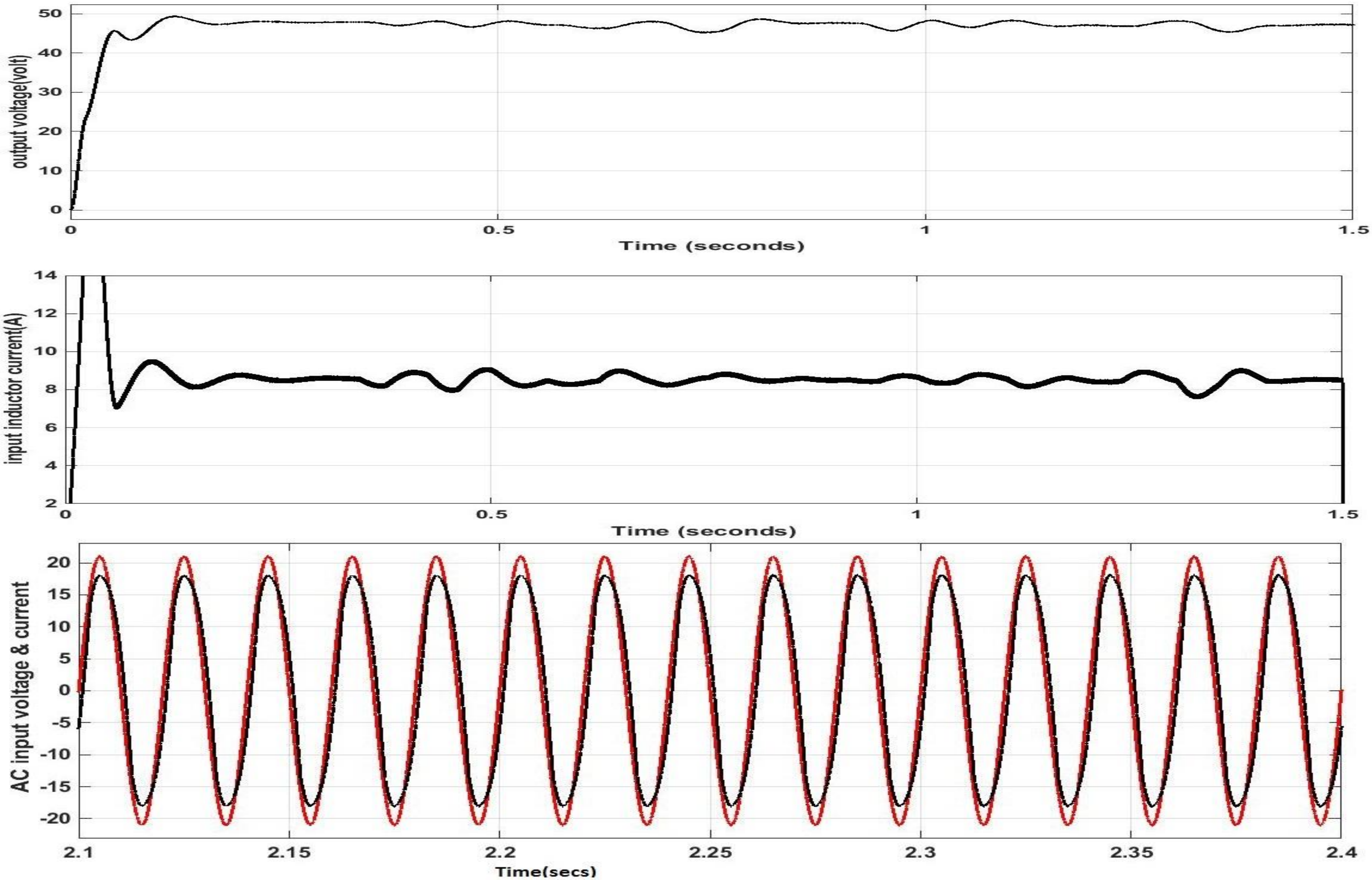


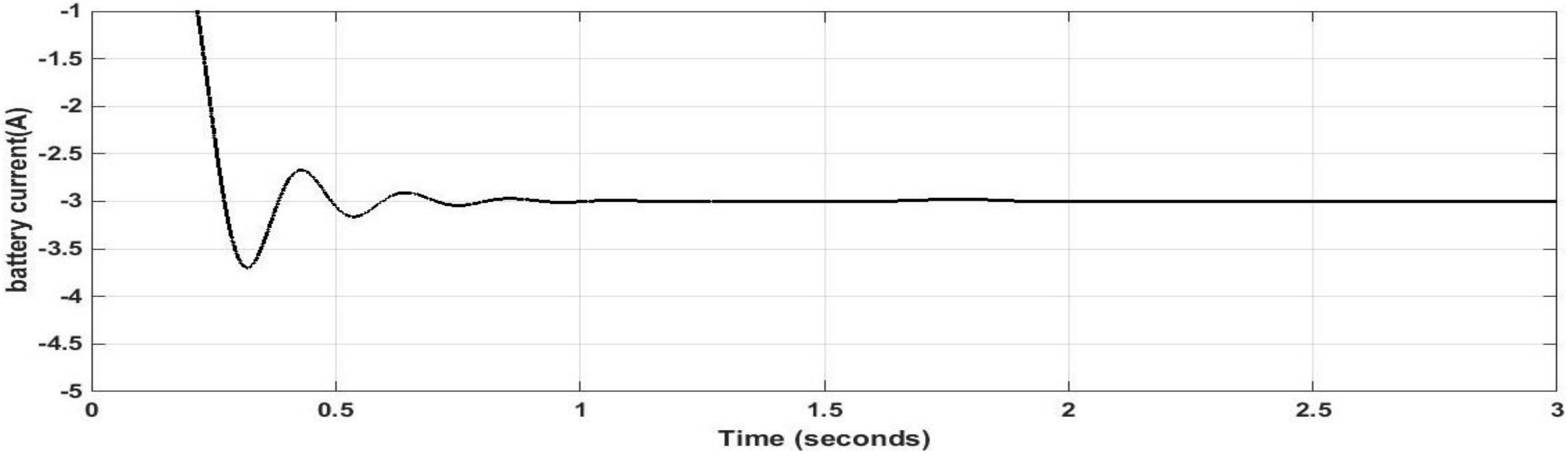




The input current is 8 amp. Solar voltage is 22 volt so power supplied is 22*8.5=187 watt.
Output load is 15 ohm so, power supplied is 3.4*48=164 watt.
Power supplied to battery is 12*1.5= 18 watt.
Total power supplied to load & battery= 164+18=182 watt.
Efficiency = 97.6%
For AC part input current is 12 Amp & input voltage is 15 volt.
So, input power =15*12=180 watt.
Efficiency is 98.3%

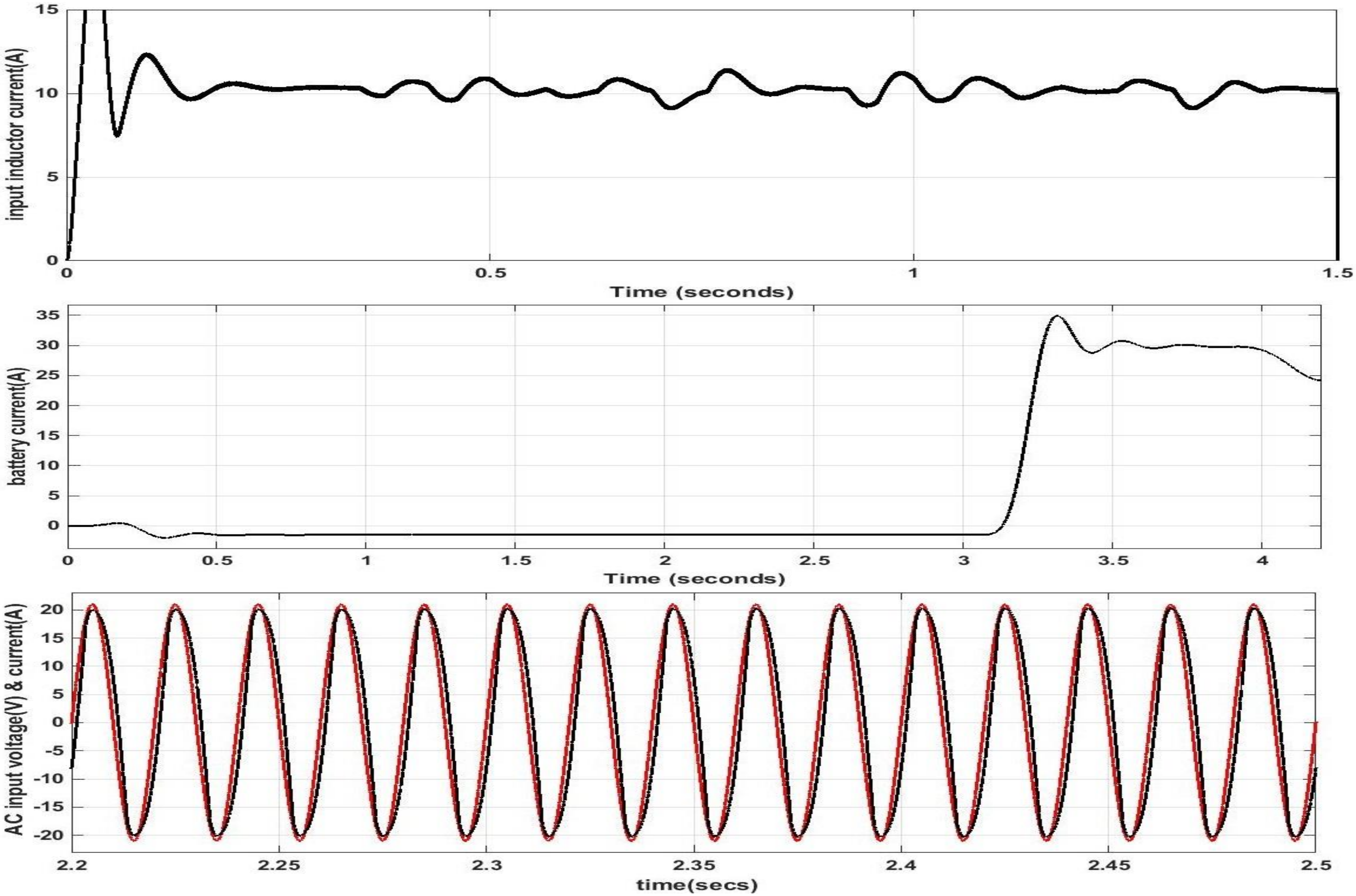
Analysis done on 160 Watt load & 3 Amp battery current charging





The input current is 8 amp. Solar voltage is 22 volt so power supplied is 22*9=198 watt.
Output load is 15 ohm so, power supplied is 3.4*48=160 watt.
Power supplied to battery is 12*3= 36 watt.
Total power supplied to load & battery= 160+36=196 watt.
Efficiency = 98.1%
For AC part input current is 13.3 Amp & input voltage is 15 volt.
So, input power =15*13.3=199 watt.
Efficiency is 98.3%

Analysis done on 200 Watt load & 1.5 Amp battery current charging



The input current is 8 amp. Solar voltage is 22 volt so power supplied is 22*10.2=224 watt.

Output load is 15 ohm so, power supplied is 4.1*48=200 watt.

Power supplied to battery is 11*1.5= 16 watt.

Total power supplied to load & battery= 200+16=216 watt.

Efficiency = 97.1%

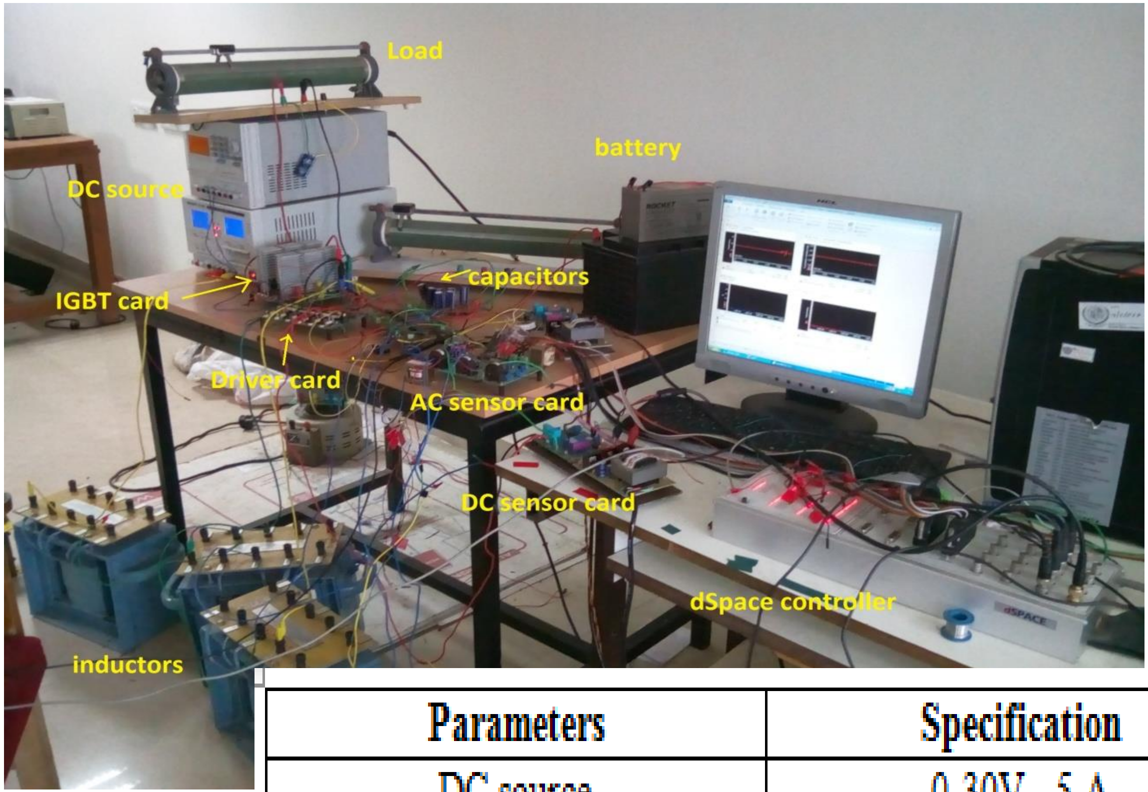
For AC part input current is 13.3 Amp & input voltage is 15 volt.

So, input power =15*14.4=217 watt.

Efficiency is 99.3%

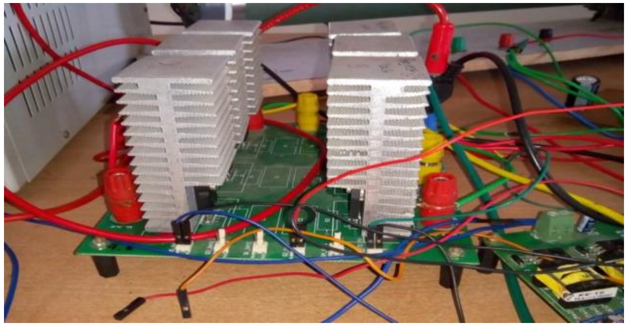
Input current of boost converter(A)	Battery charging current(A)	Load (ohm)	Input AC current(A)	Battery discharge current(A)
4.5	1.5	30	6.4	15
8.5	1.5	14	12	22
9	3	15	13.3	23
10.2	1.5	11	14.4	25

Experimental setup



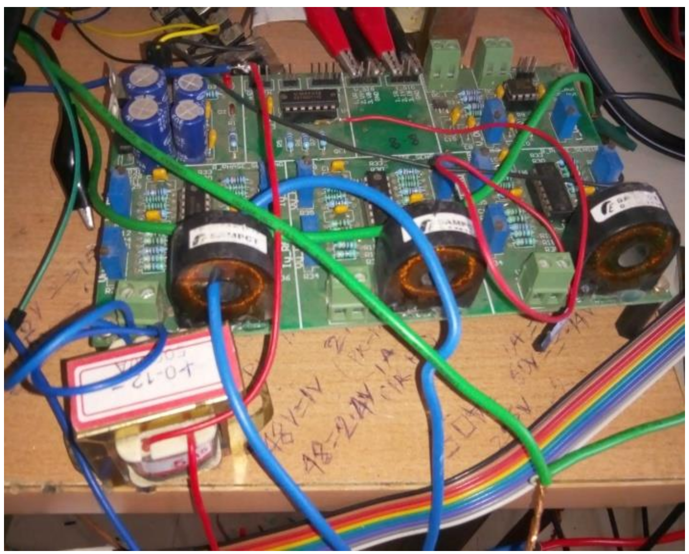
Parameters	Specification	Quantity
DC source	0-30V, 5 A	01
Three-leg inverter	IGBT Based	01
Resistors (Ro)	200 ohm 2.8 amp	01
Inductors (L1, L2,L3)	0.25 mH, 4 mH, 16 mH	03
Capacitors	3.3 mF, 50V	02
Battery	12 Volt, 7Ah	01

Converter Card



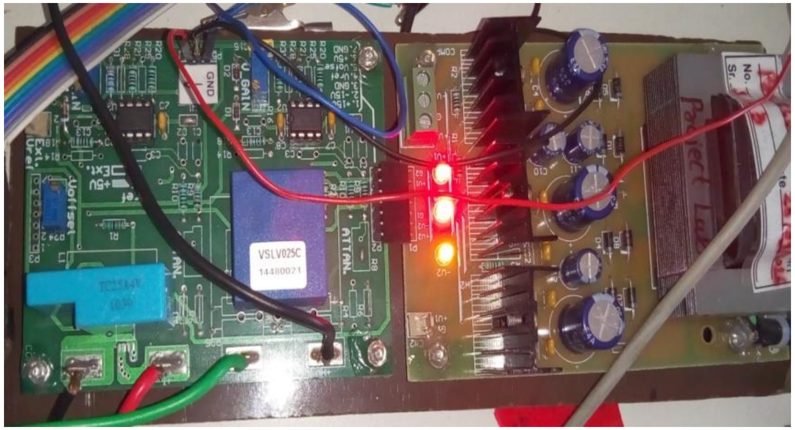
6 IGBTS used G*W30NC120HD*

Voltage & Current Sensor for AC Grid



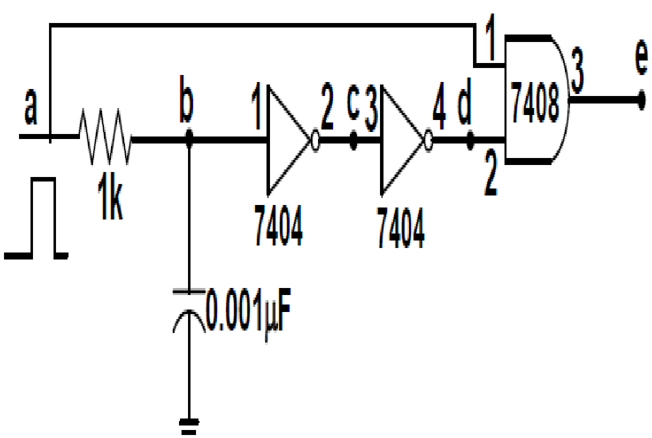
CTs having ratio of 10:1 A now Current sensed by the CT is converted in to voltage by a burden resistor
PT having ratio 230/12 Volt

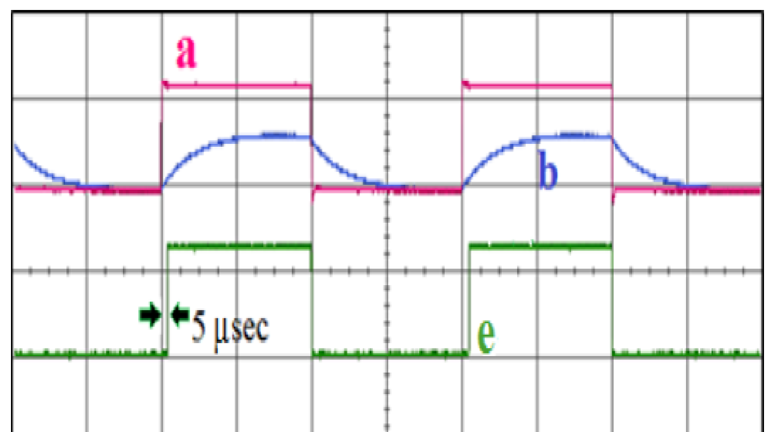
Voltage and Current Sensor for DC Grid



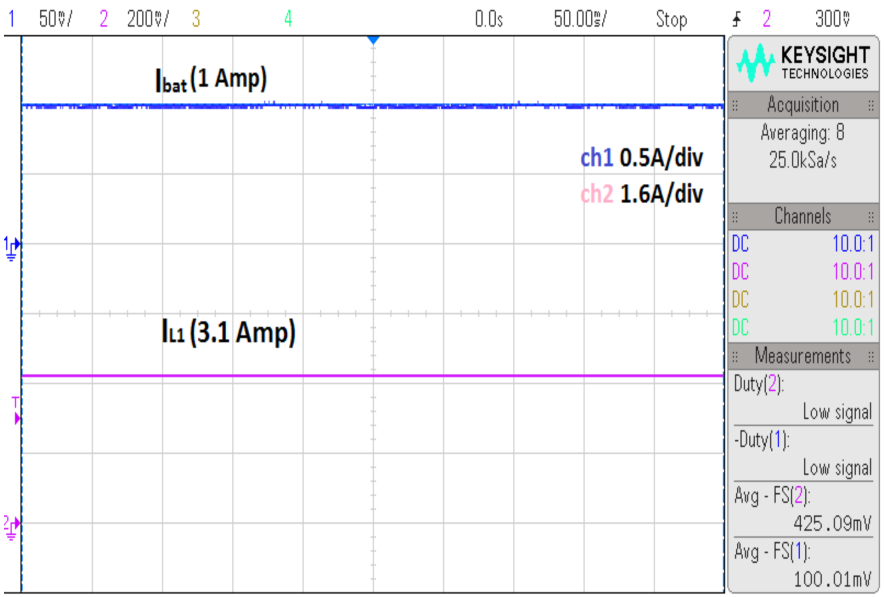
current measuring range 0-25 Amp
Voltage Measuring Range 10~500 volt

Dead Band Circuit

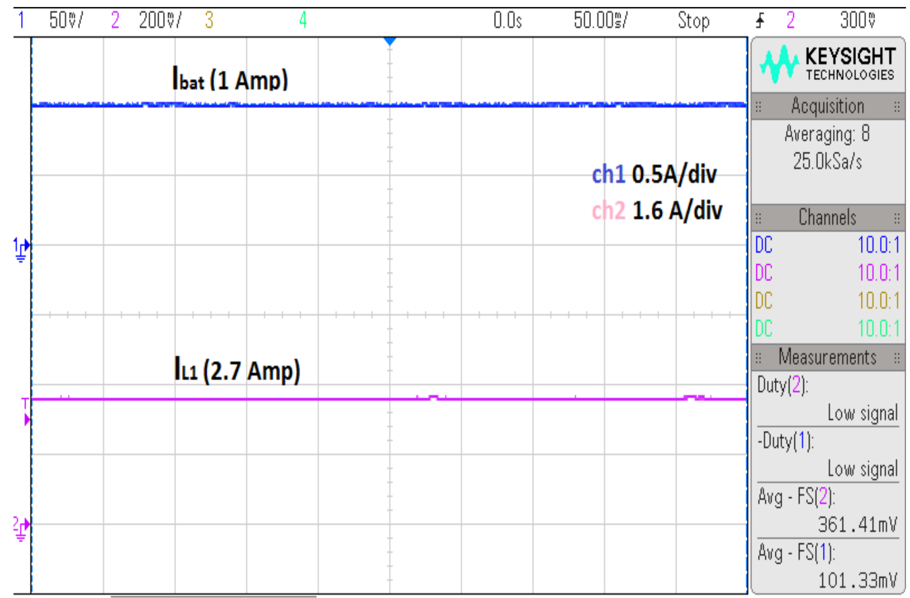




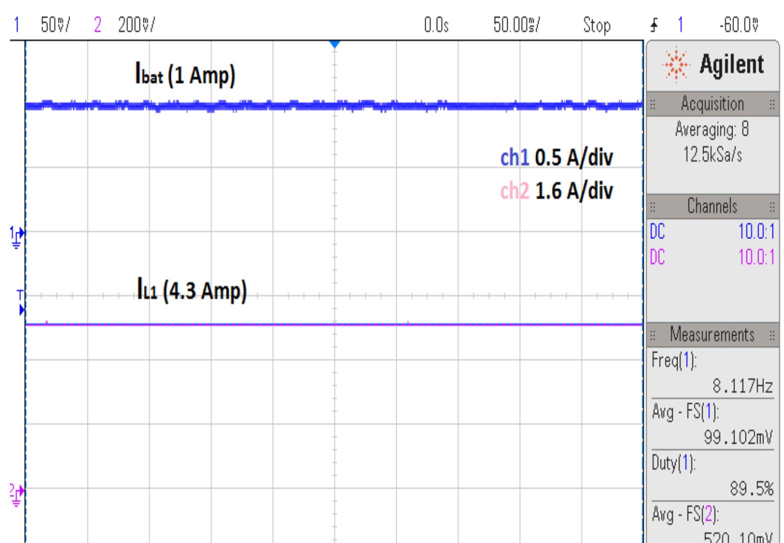
Performance of converter for 1A battery charging with different loads from DC source



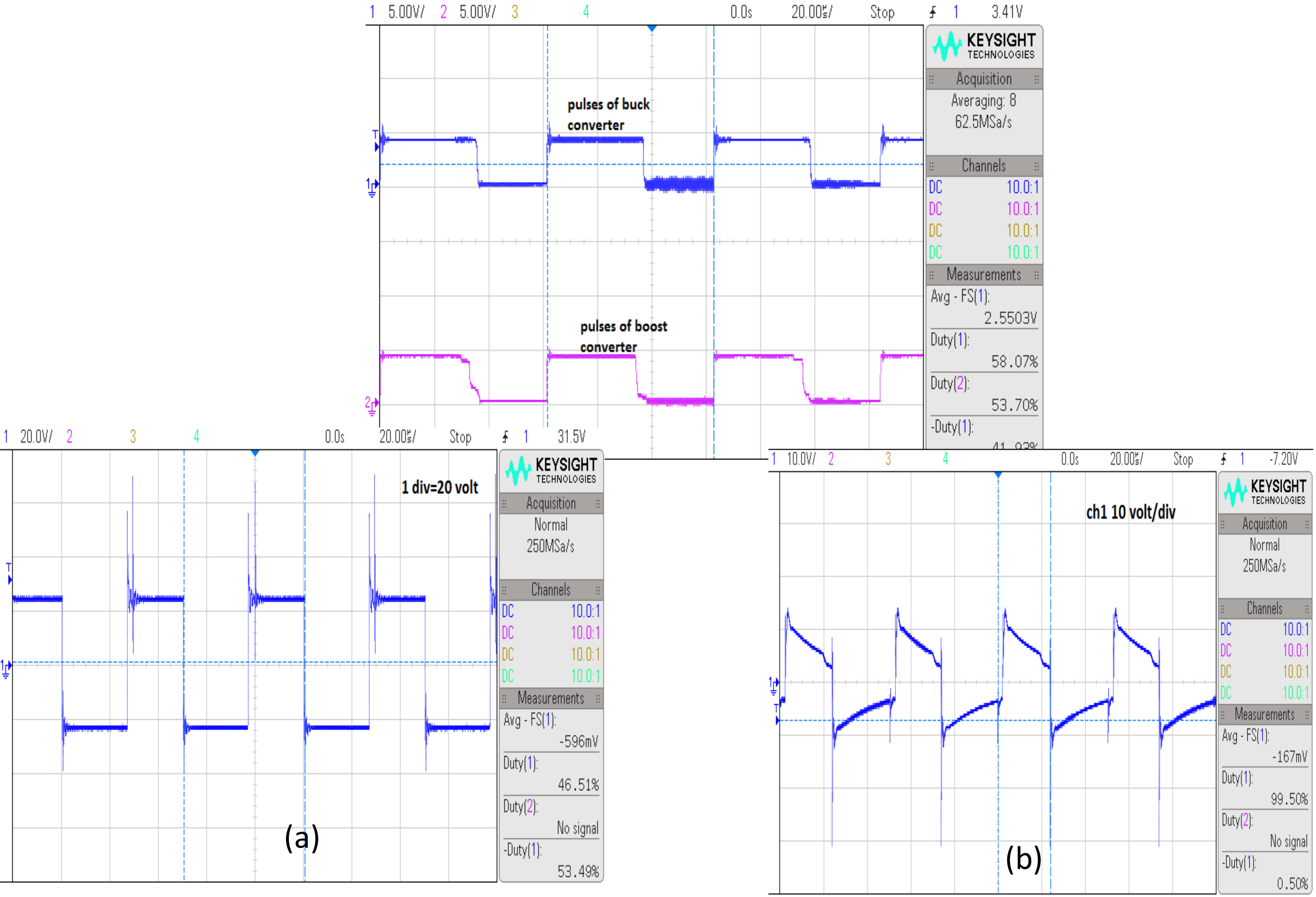
100 Ω



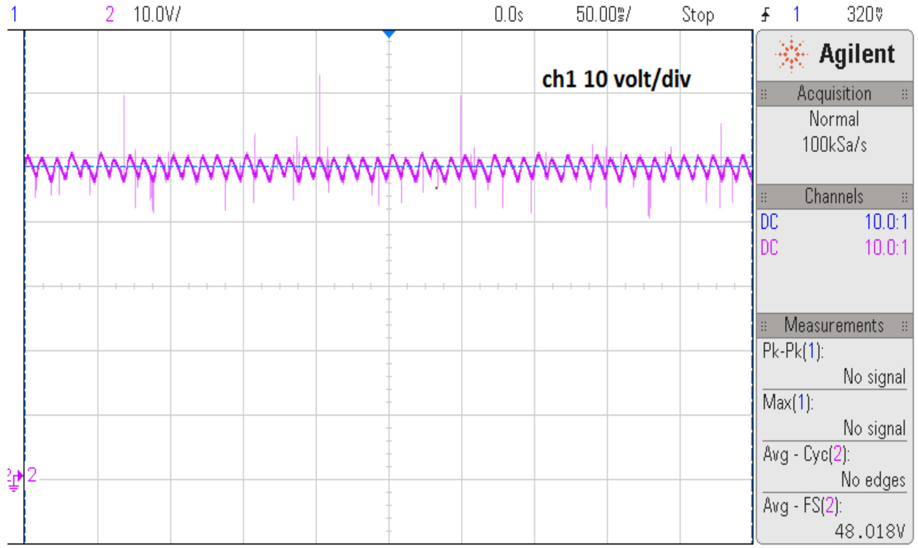
200 Ω



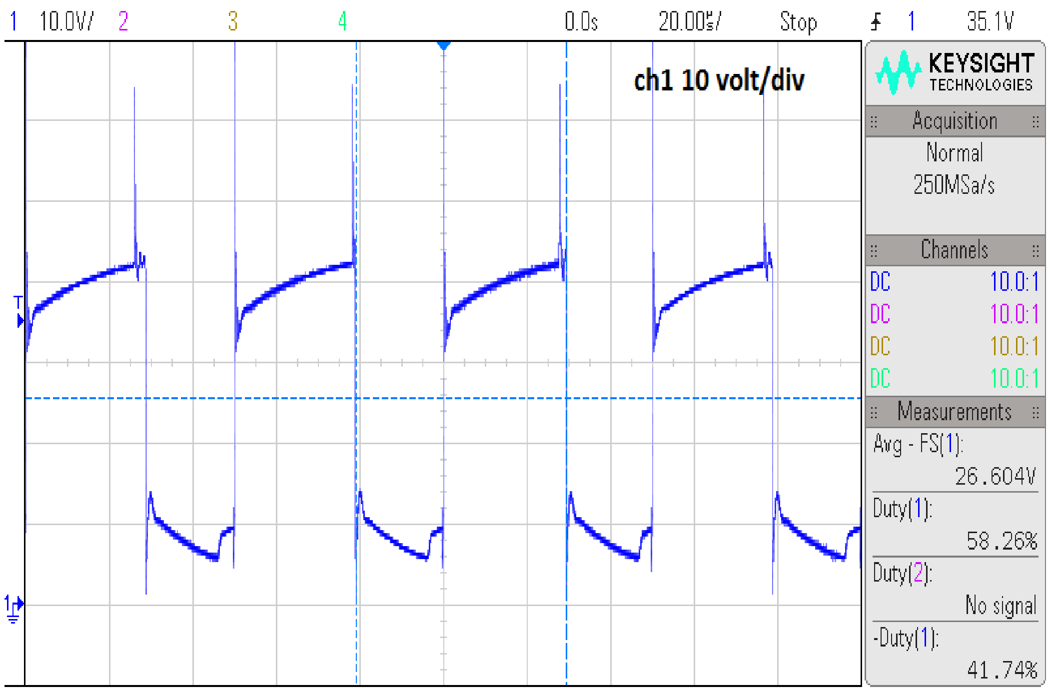
50 Ω



Voltage across inductors (a) L1, (b) L2

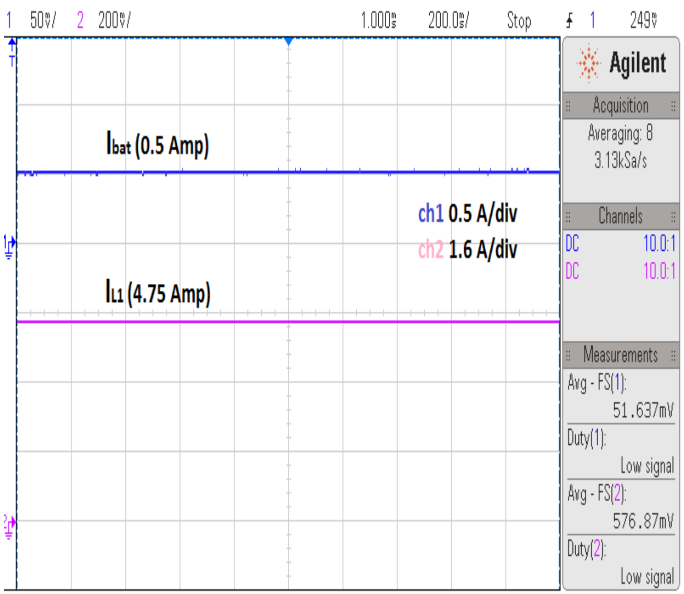


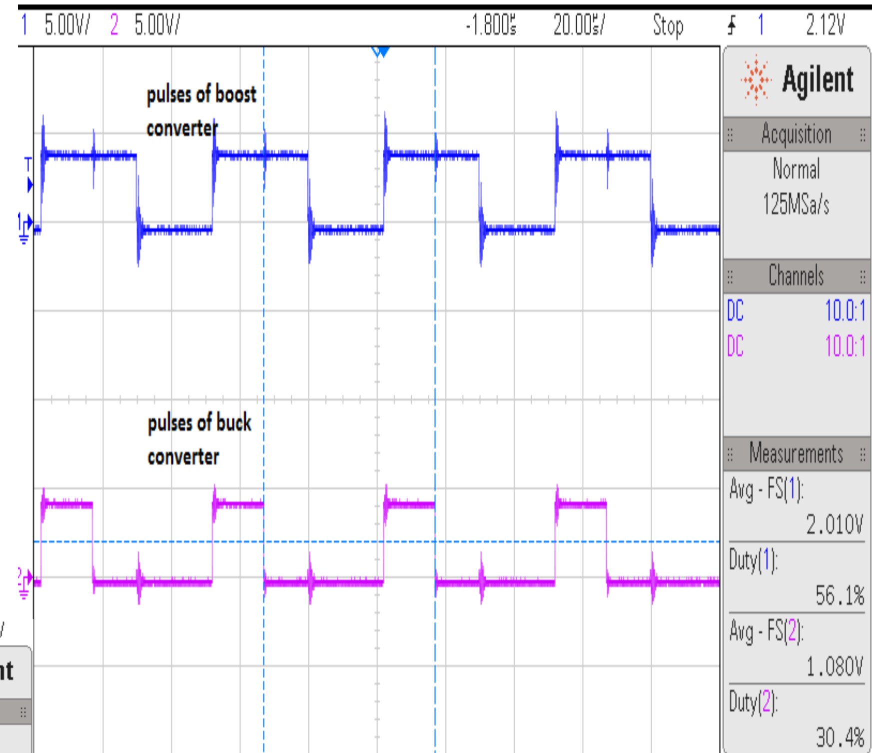
output voltage across load

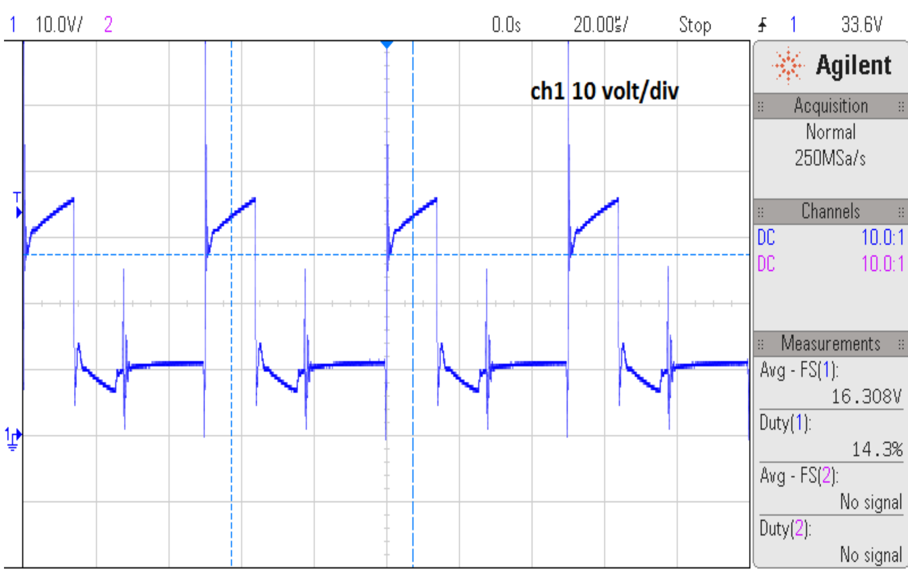


Voltage across battery

Performance of converter for 0.5 A battery charging and 25 ohm load

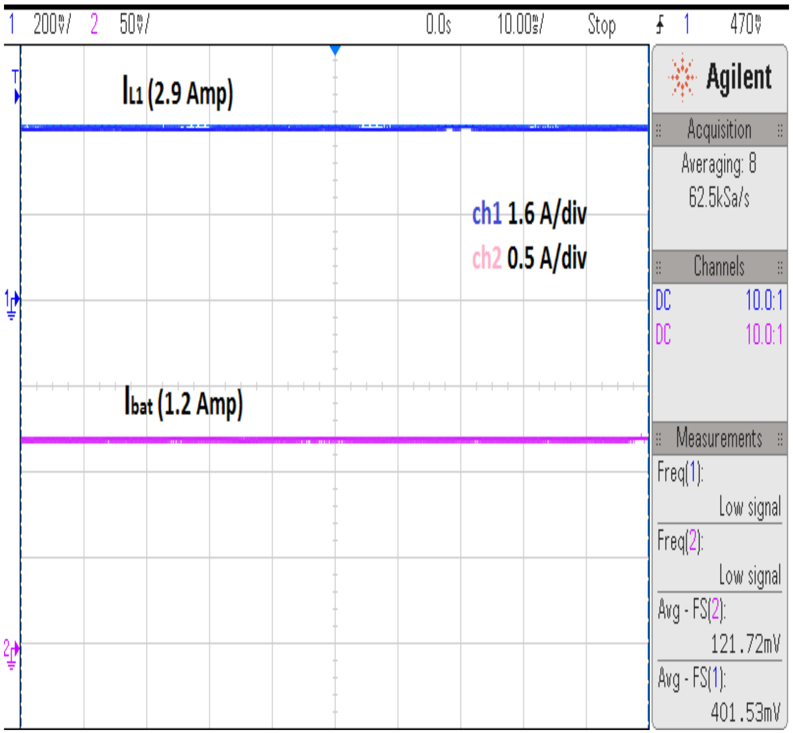


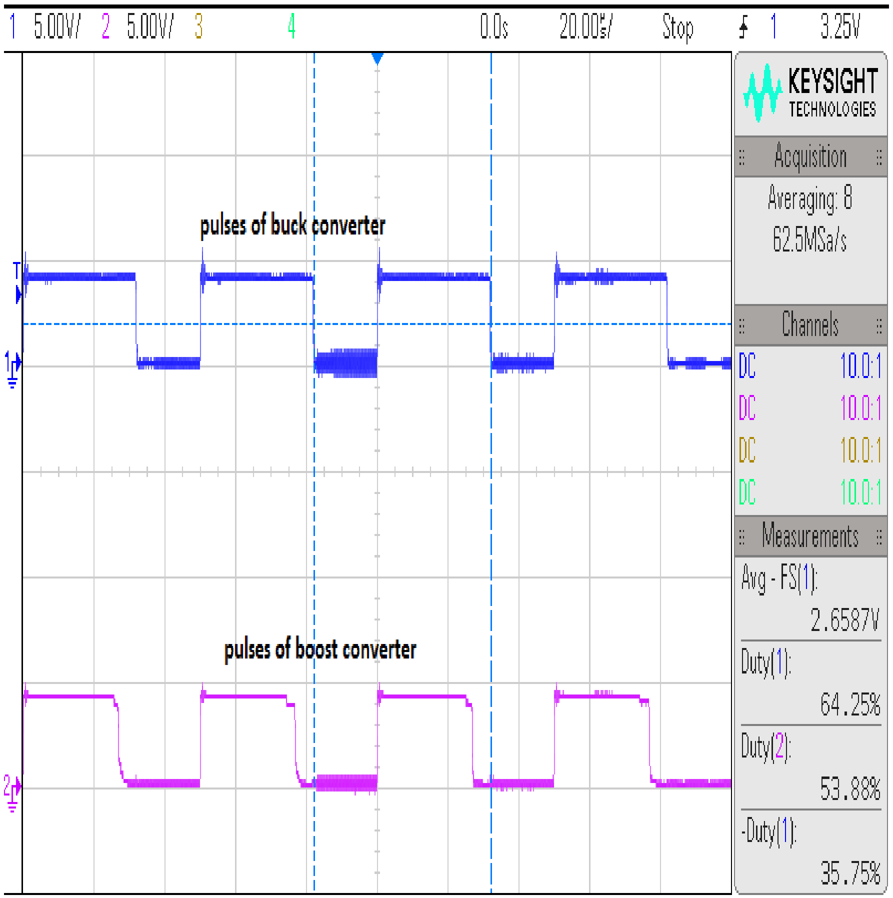




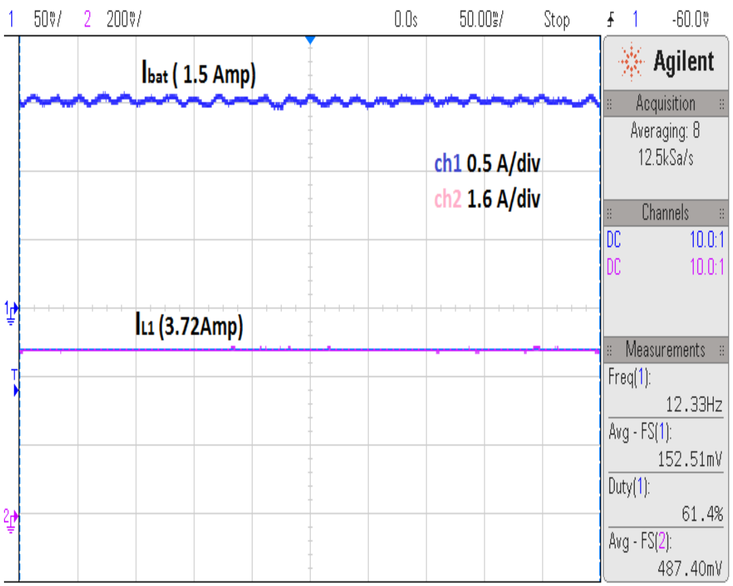
Voltage across battery

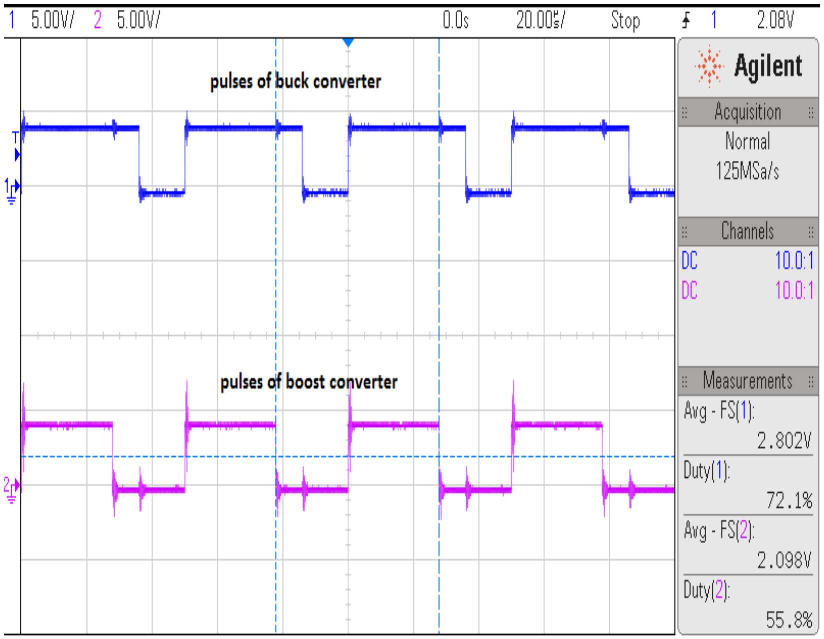
Performance of converter for 1.2 A battery charging and 200 ohm load





Performance of converter for 1.5 A battery charging and 200 ohm load

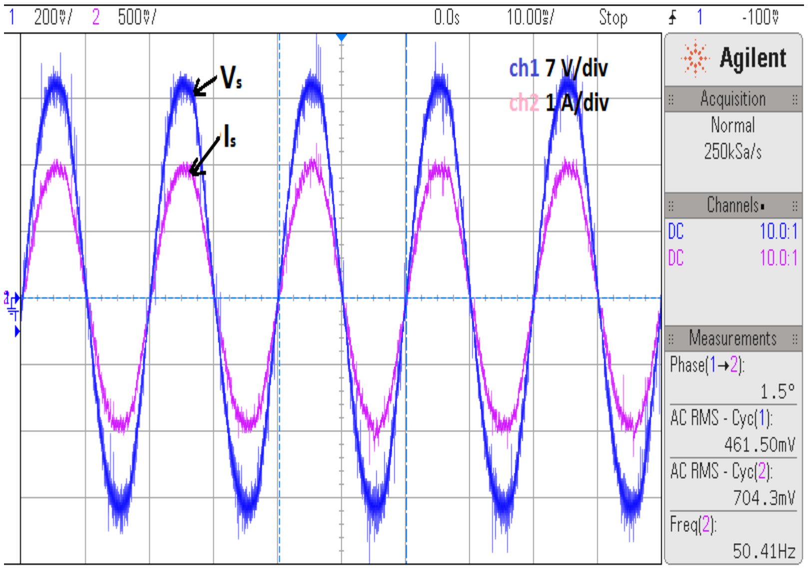




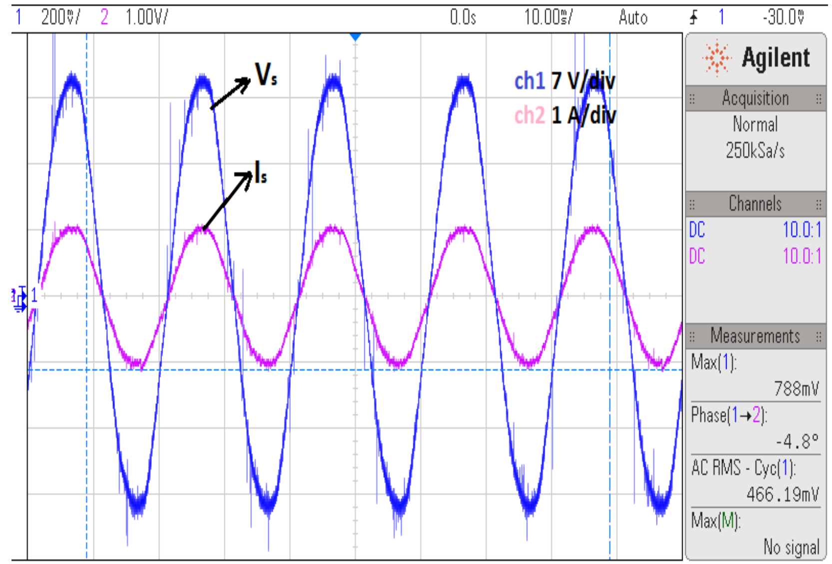
Estimation of different parameters of system

Input current(A)	Battery current(A)	Load current(A)	Load(ohm)
2.7	1	0.24	200
3.1	1	0.5	96
4.3	1	1	48
4.75	0.5	2	25
2.9	1.2	0.24	200
3.5	1.2	0.5	98
3.72	1.5	0.24	200

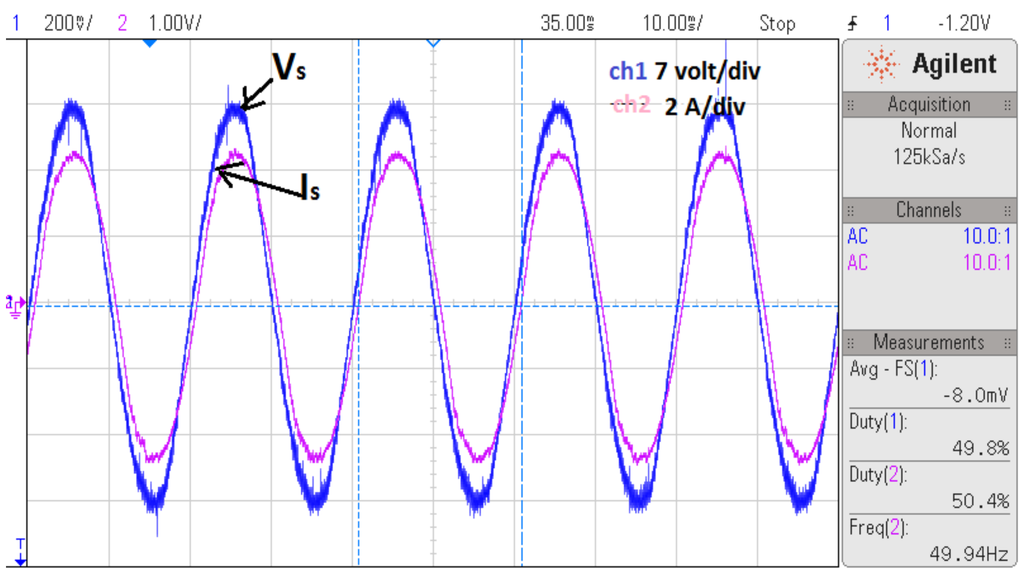
Experimental results of Voltage Doubler from AC source to load



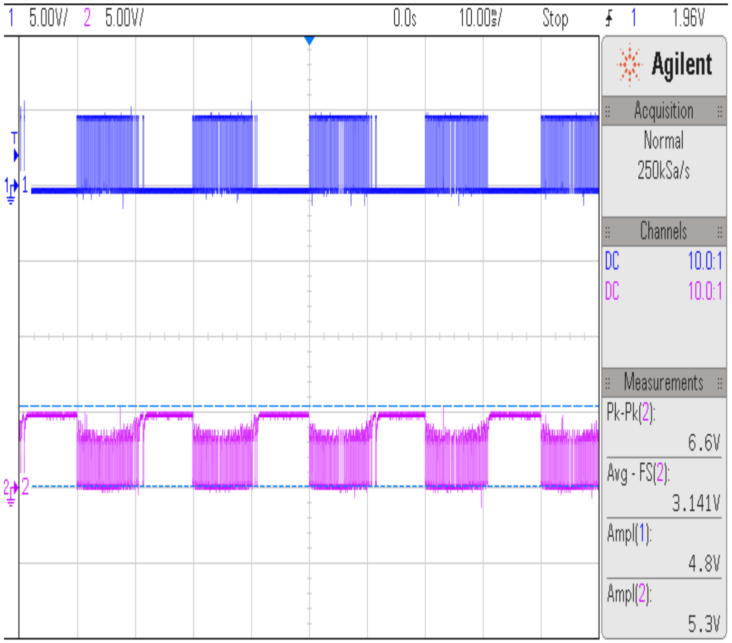
100 ohm



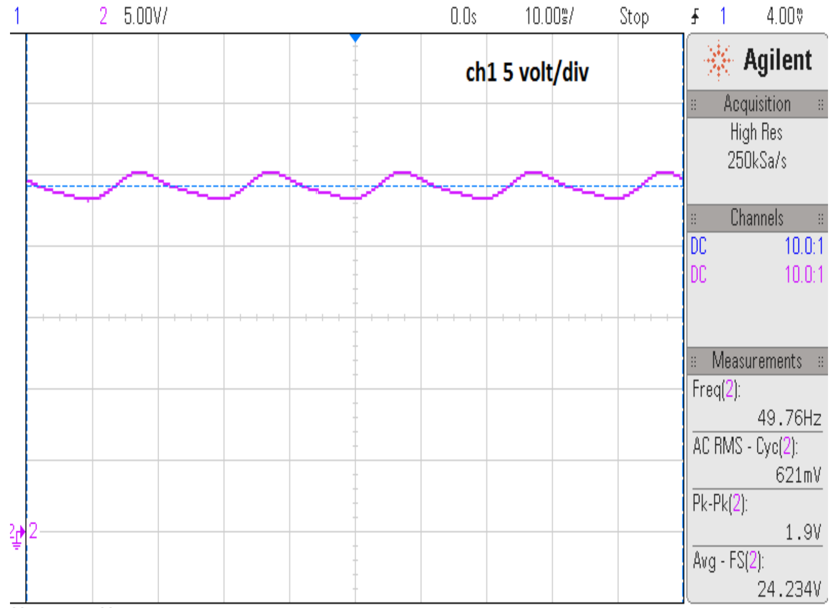
200 ohm



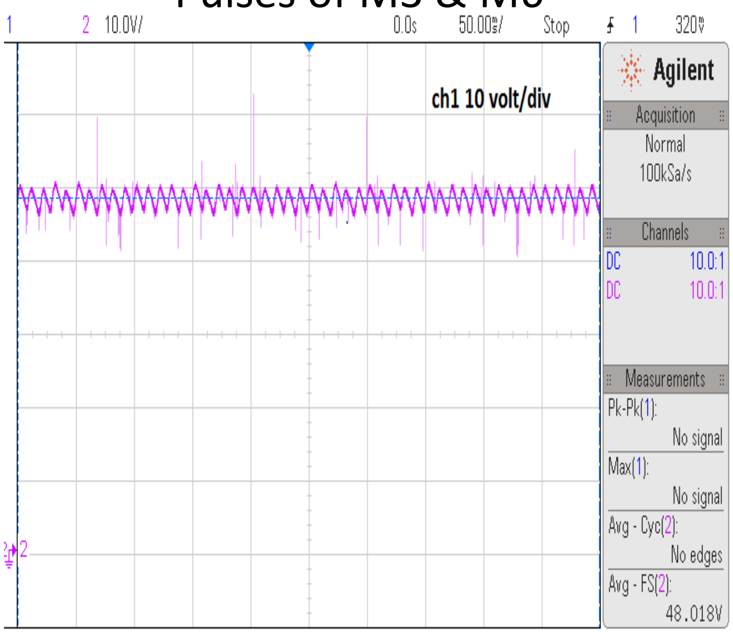
50 ohm



Pulses of M3 & M6



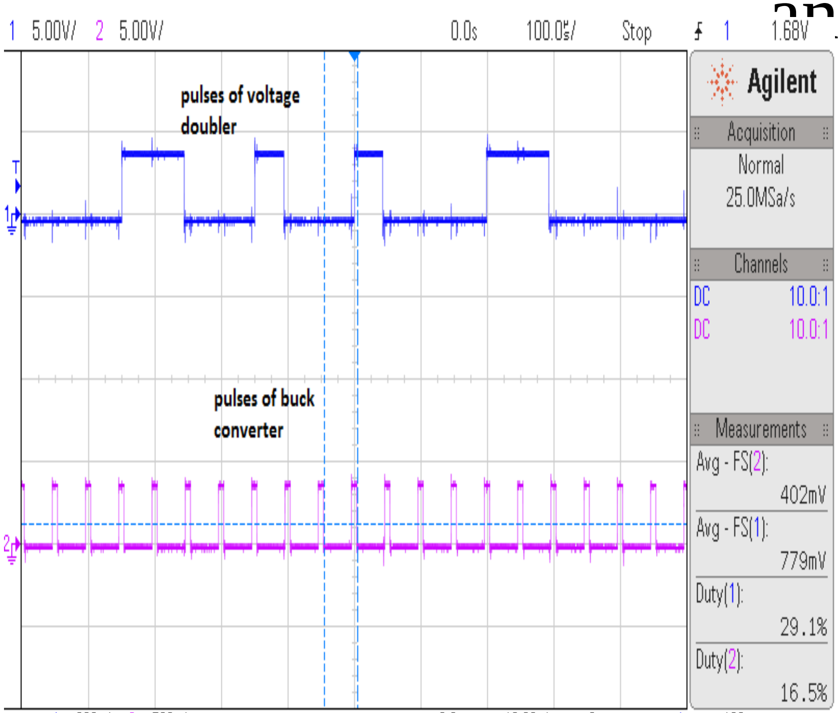
Voltage across each capacitor

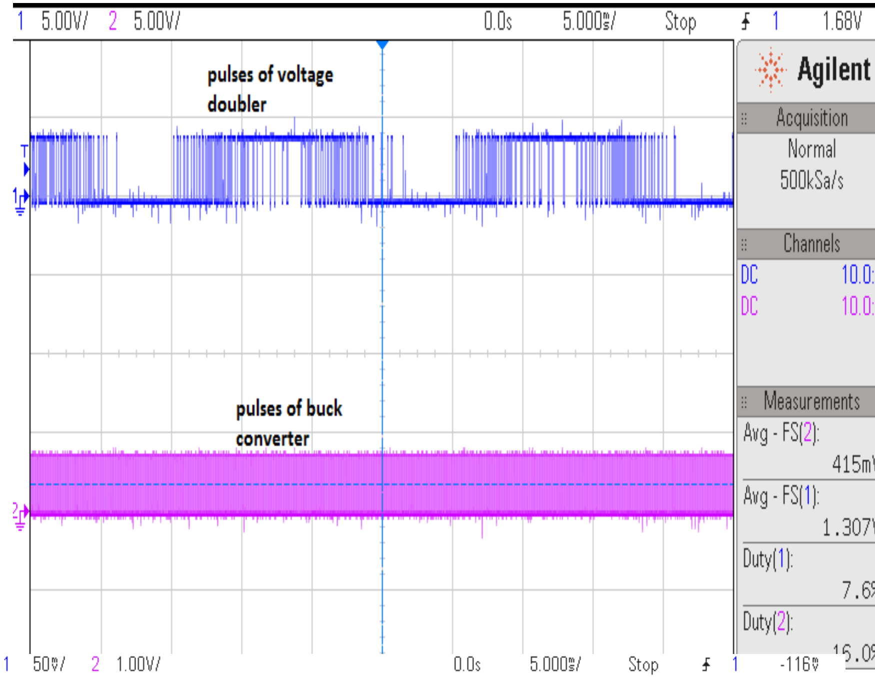


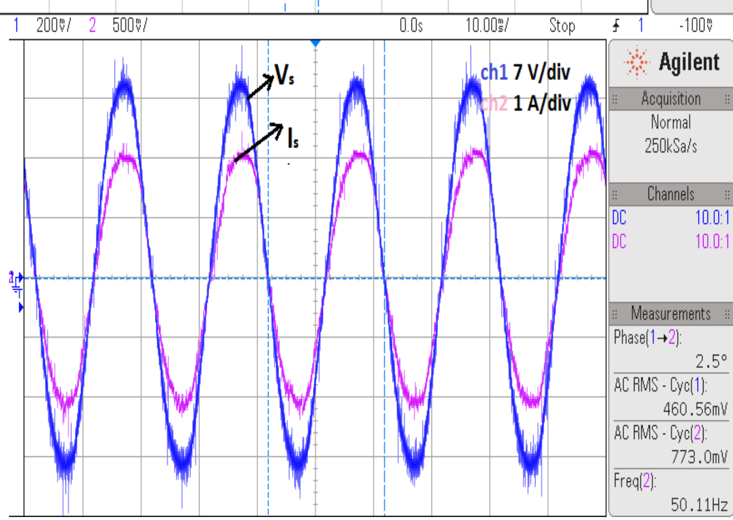
Input current(A)	Load (ohm)	Load current(A)
0.707	200	.24
1.06	150	.32
1.414	96	0.5
3	48	1

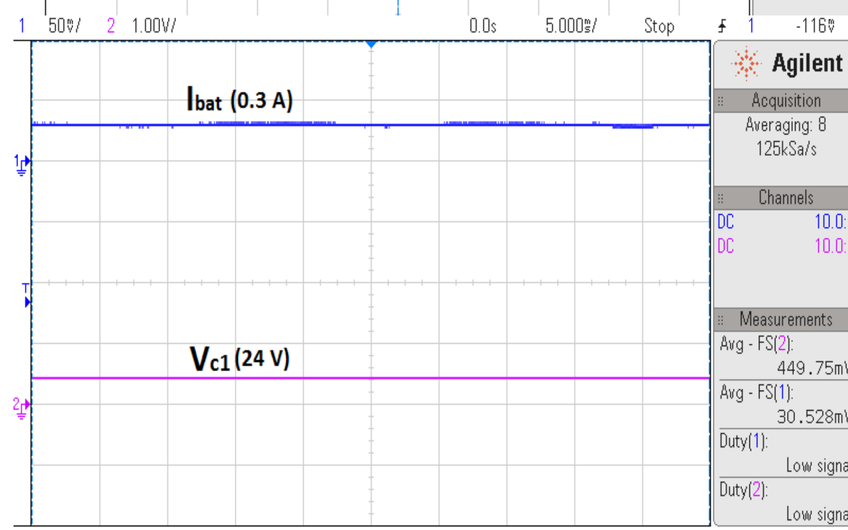
Output voltage of converter

Performance of converter for 0.3 A battery charging and loads

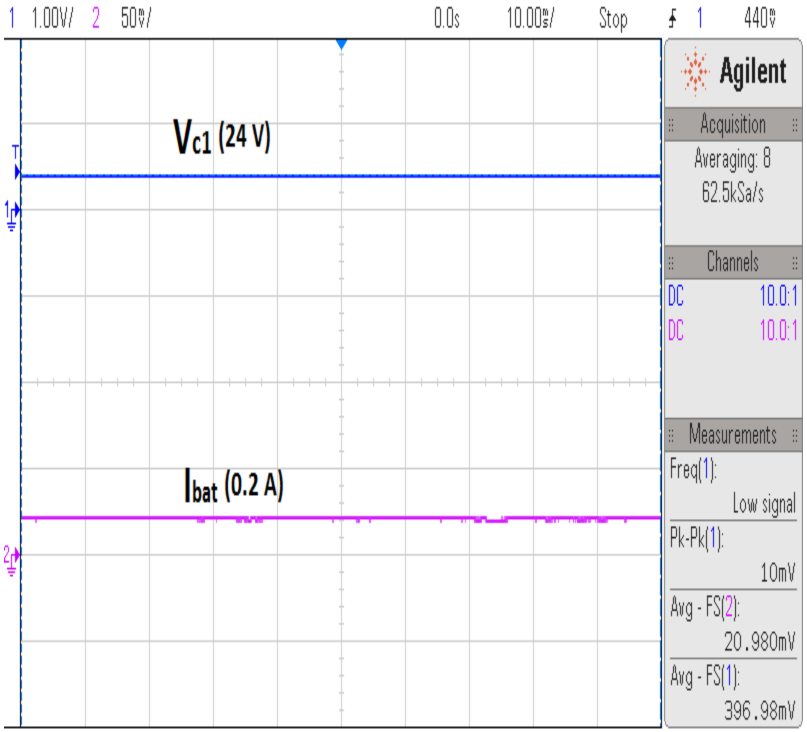


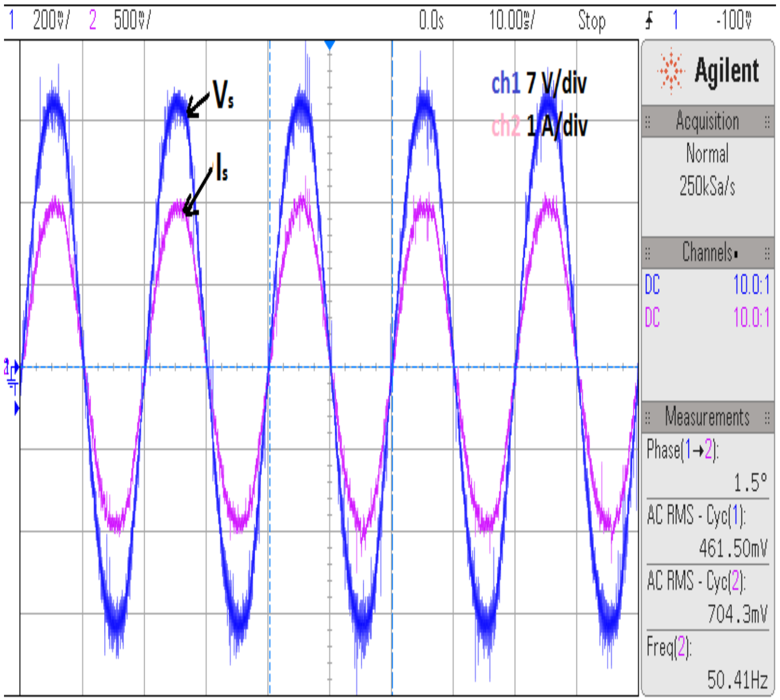






Performance of converter for 0.2 A battery charging and loads





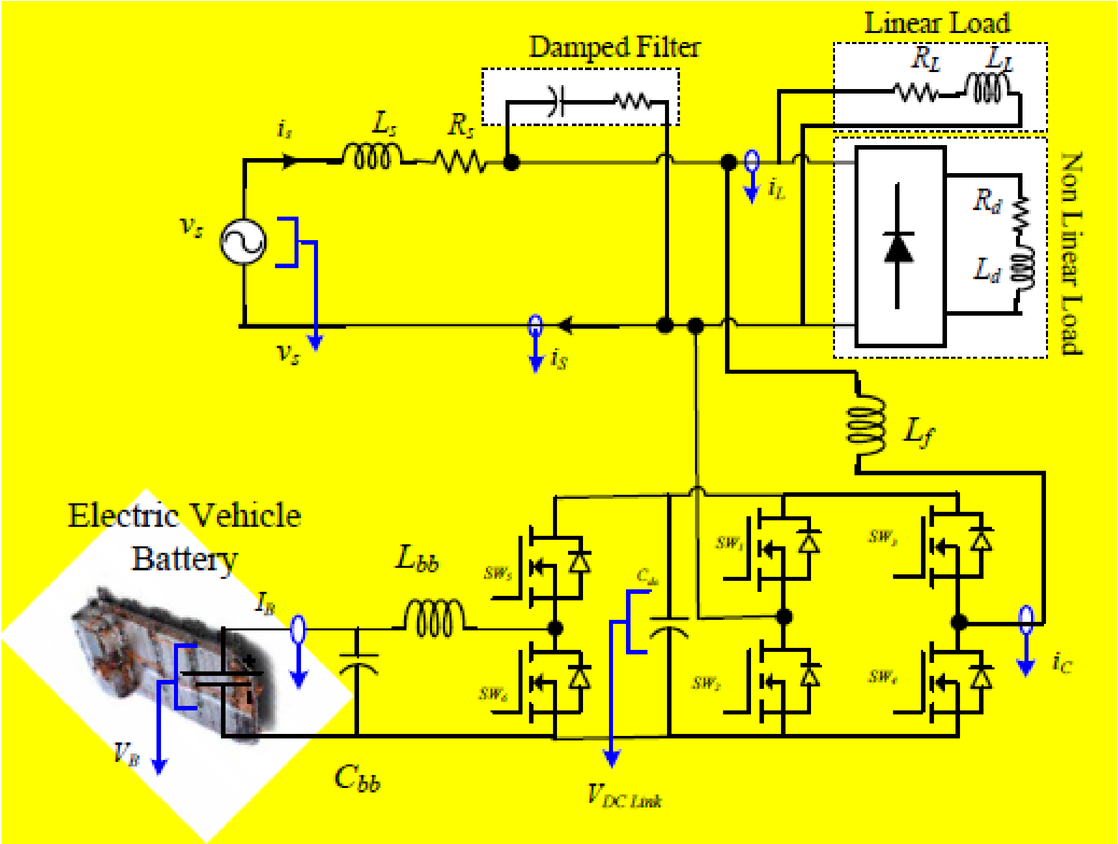
Input current(A)	Battery current(A)	Load current(A)	Load(ohm)
1.414	0.2	0.5	96
1.55	0.3	0.5	96

Bidirectional Converter for Electric Vehicle Battery Charging with Power Quality Features

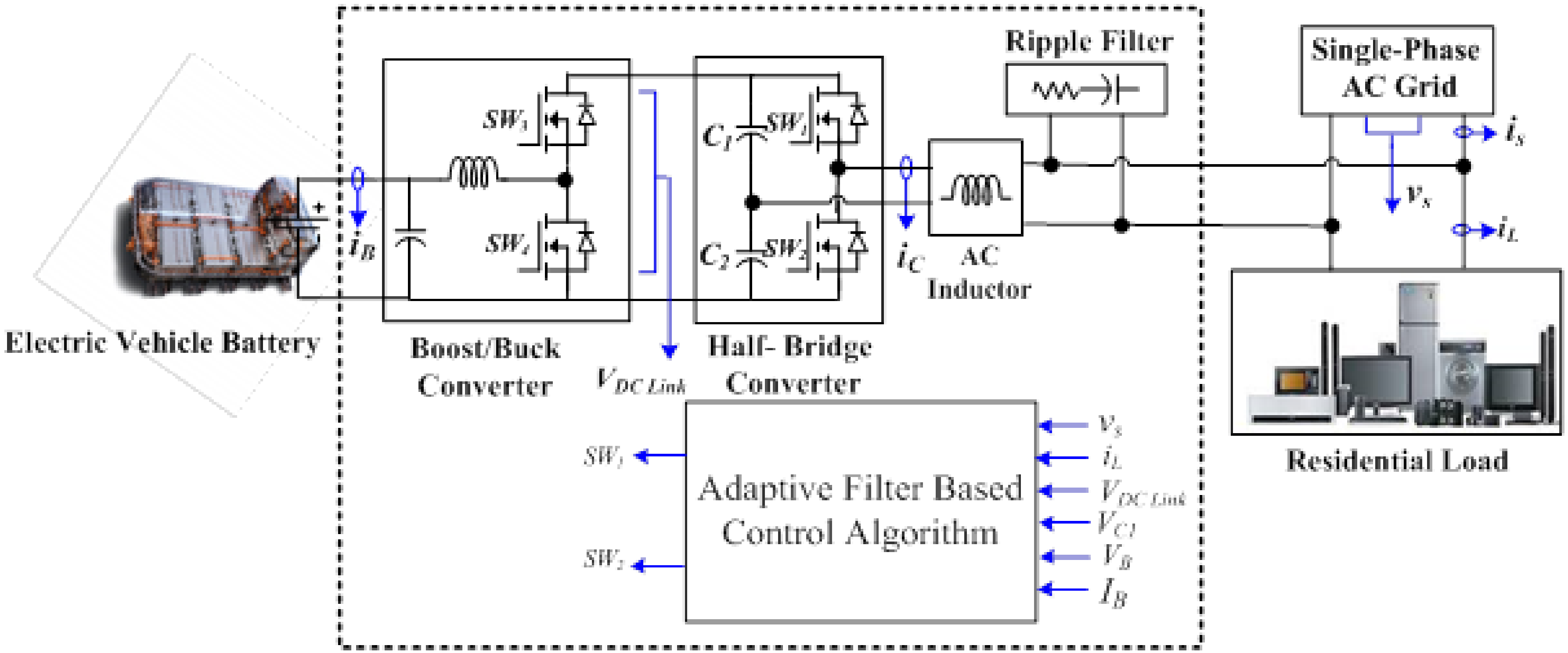
Abstract

- In this work, bidirectional converter for an electric vehicle battery charging with the inherent on board system to mitigate the harmonics and reactive power in a residential installation is discussed.
- It consists of adaptive transverse filter for the detection of fundamental component of the load current.
- The inclusion of additional tasks to an electric vehicle charger for power quality improvement leads to reduction in cost for utility.
- A revenue generating scheme for the vehicle owner for its promotion in the backdrop of environment and climate issues.
- The importance of imposing additional tasks to the onboard power electronic equipment of the vehicle is also discussed with the backdrop of renewable power generation.

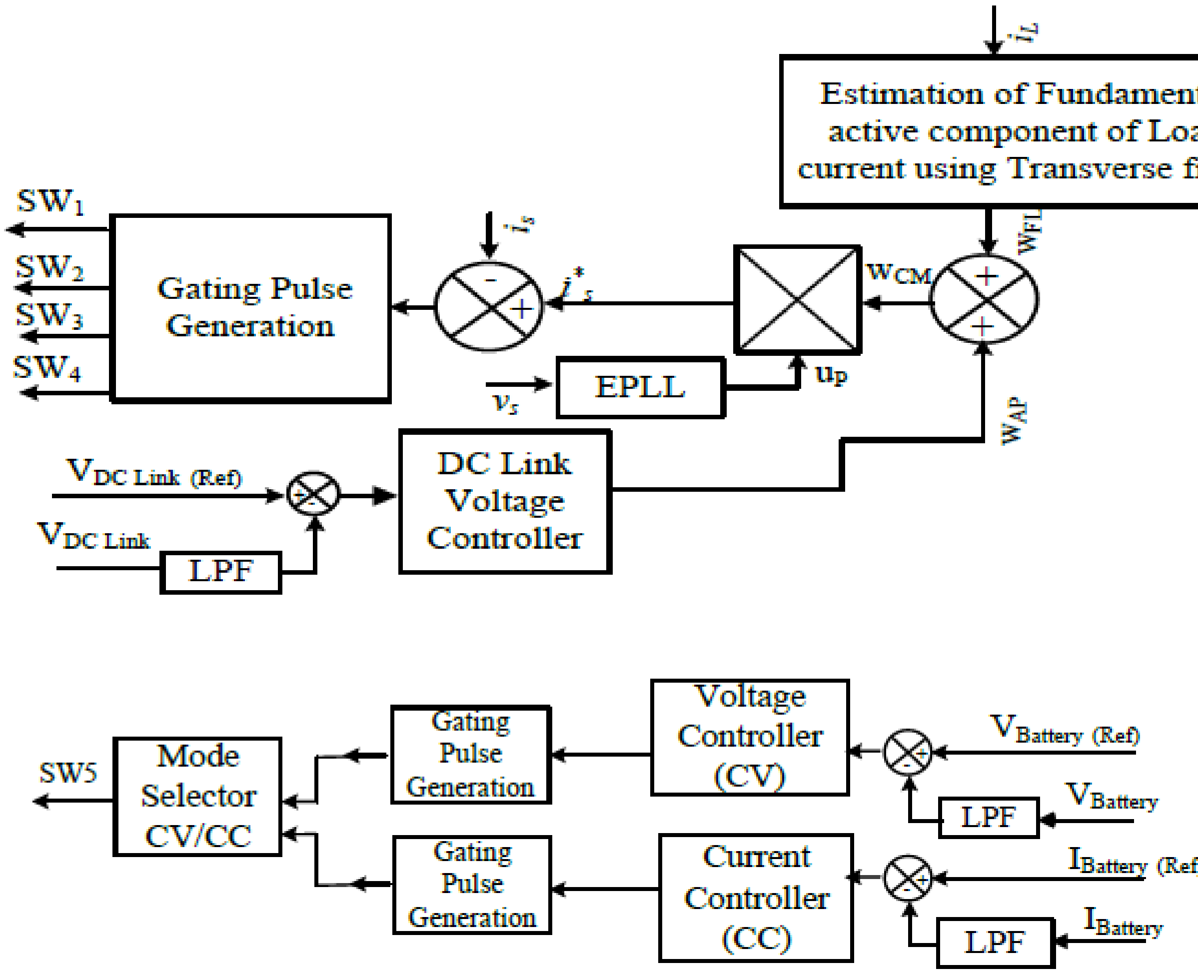
Schematic Diagram of System Configuration-1



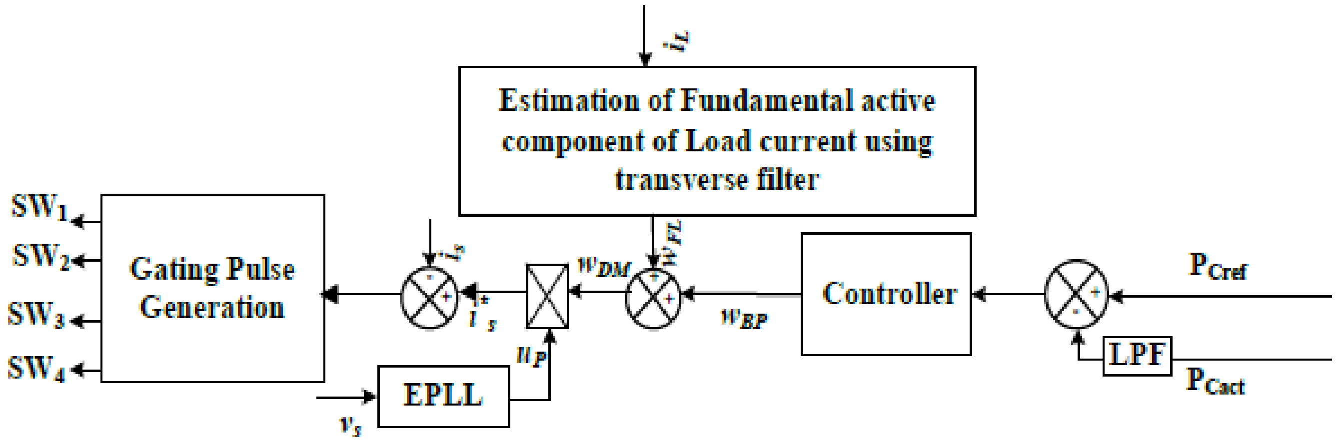
Configuration-2

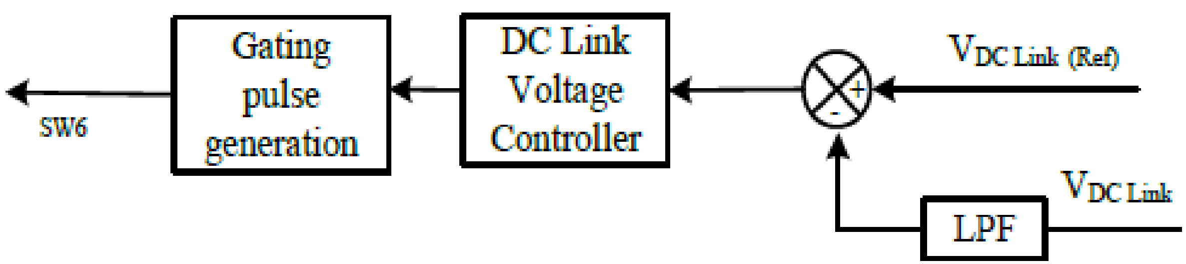


Block diagram of control scheme with proposed transverse filter during battery charging mode (a)for PWM rectifier (b)for Buck converter



Block diagram of control scheme with proposed transverse filter during battery discharging mode(a) for PWM rectifier (b)for Boost converter





PERFORMANCE OF PROPOSED CONVERTER

- **Simulink model of converter, rated for 500 W, 400V/1.25A is developed with the help of SIM Power System toolbox of MATLAB software.**

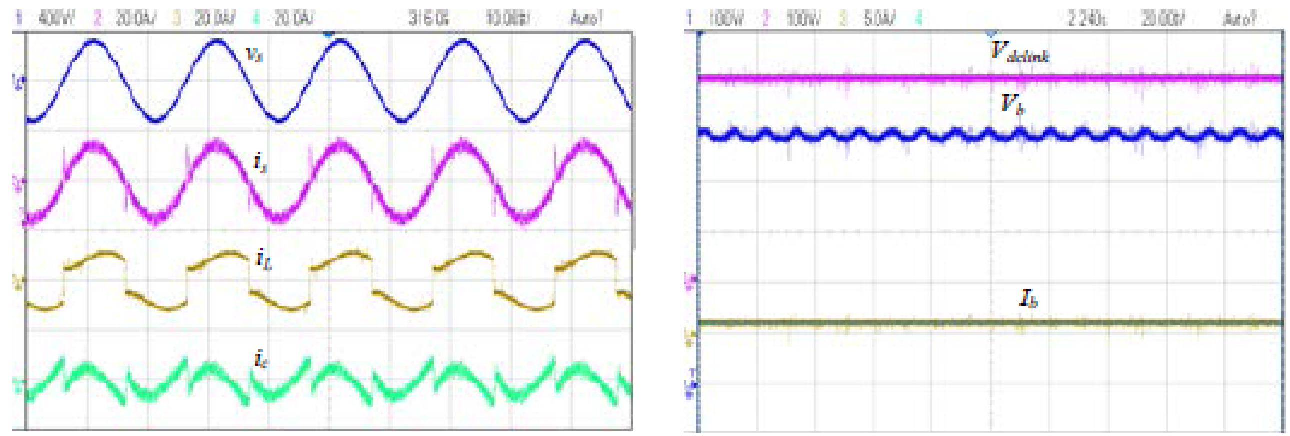
Electric Vehicle Battery Charging together with Power quality feature

Table-1 : Specification of Components in Proposed Converter

Parameter	Specification
Input ac voltage (v_s)	230V, 50Hz
Output	500W, 400V/ 1.25A
Lithium Ion Battery (E)	400V, 12Ah
Interfacing Filter Inductor (L_f)	14.7mH
DC Bus Capacitor (C_{dc})	1.6mF
Damped filter (R_{df}, L_{df})	
Linear Load (P, Q)	550W, 400VAR
Non Linear Load	Single phase Bridge rectifier with R-load of 1450W.
Switching frequency (f_{sw})	5 kHz
Sampling time (T_s)	20 µSec
Adaptation Parameter	0.4

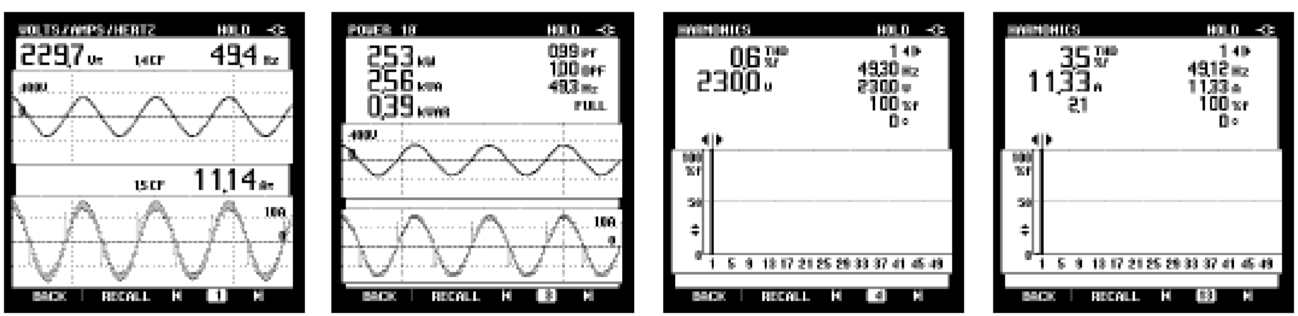
Electric Vehicle Battery Charging together with Power quality feature

- *Constant Curent Charging Mode:* A constant current of 1.25A is supplied to battery at a voltage of 400V, thus power input of 500W is delivered.



(a) Ch. 1 400V/div, II, III 20A/div, Ch. IV 20A/div, Time axis-10ms/div.

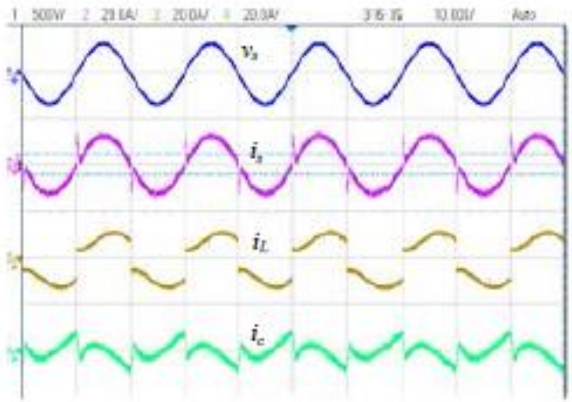
(b) Ch. I, II 100V/div, Ch. III 5A/div, Time axis-20ms/div



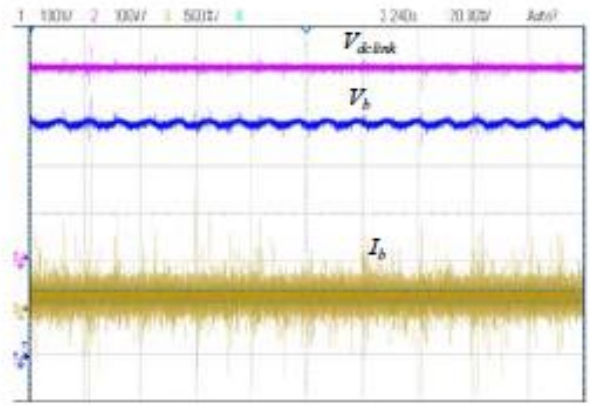
(c) (d) (e) (f)

Fig.9 Steady state waveforms under constant current charging mode (a) v_s, i_s, i_L, and i_C (b) V_{dclink}, V_b and I_b. (c) v_s with i_S (d) input power(P_s,Q_s) (e) THD spectrum of v_S (f)THD spectrum of i_S

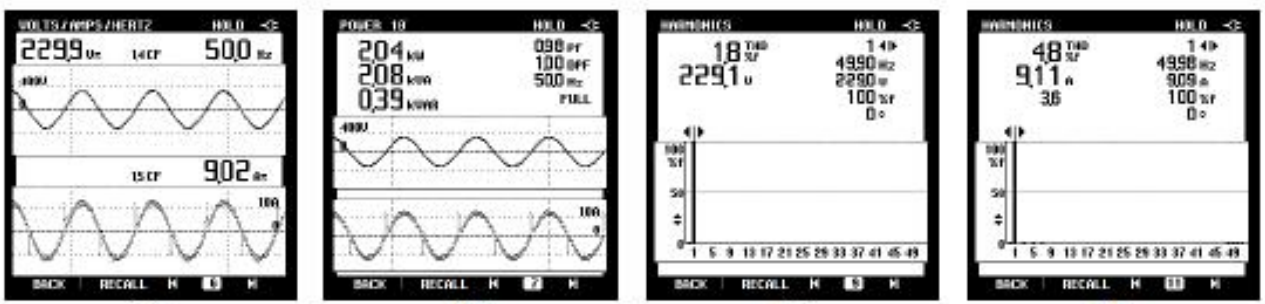
Constant Voltage Charging Mode:



(a) Ch. 1 500V/div, II, III, IV-20A/div, Time axis-10ms/div.



(b) Ch.I, II, 100V/div, Ch.III-500mA/div, Time axis-120ms/div

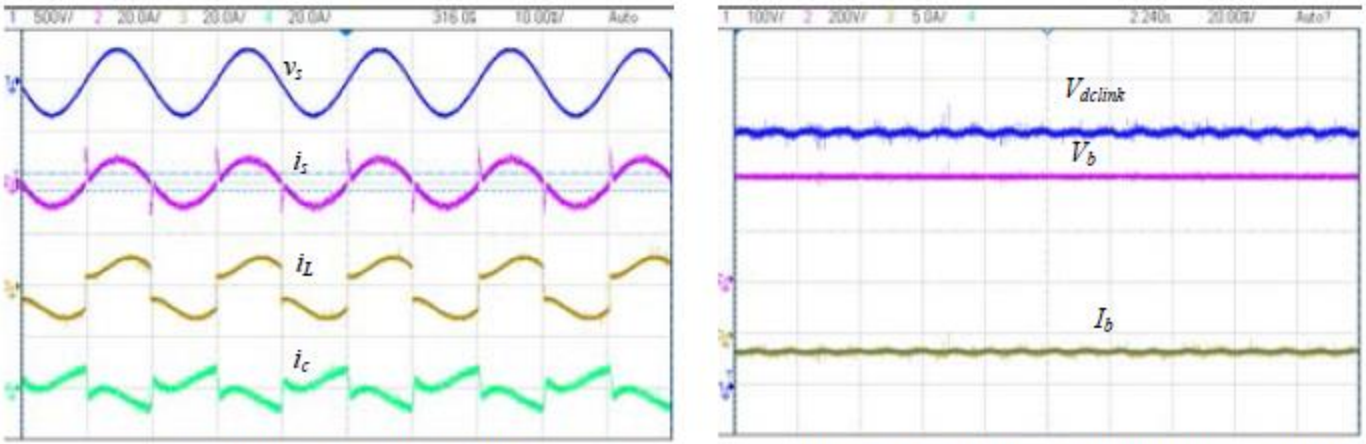


(a) (b) (c) (d)

Fig.10. Steady state voltage and current waveforms under constant voltage charging mode (a) v_s, i_s, i_L, and i_C (b) V_{dclink}, V_b and I_b (c) v_s and i_s (d) input power (P_s,Q_s) (e) THD spectrum of v_s (f)THD spectrum of i_s

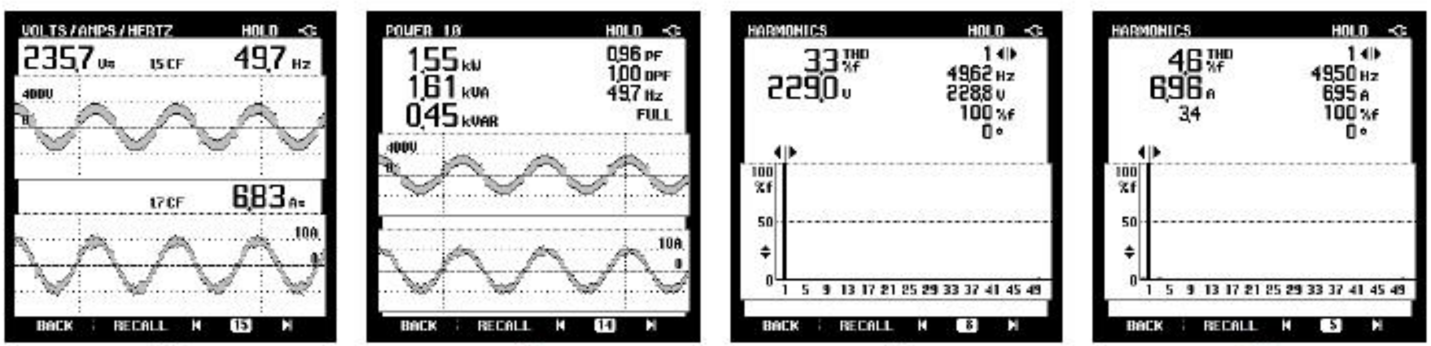
Electric Vehicle Battery as power source, together with Power quality feature

-



(a) Ch. 1 500V/div, II, III, IV 20A/div, Time axis-10ms/div.

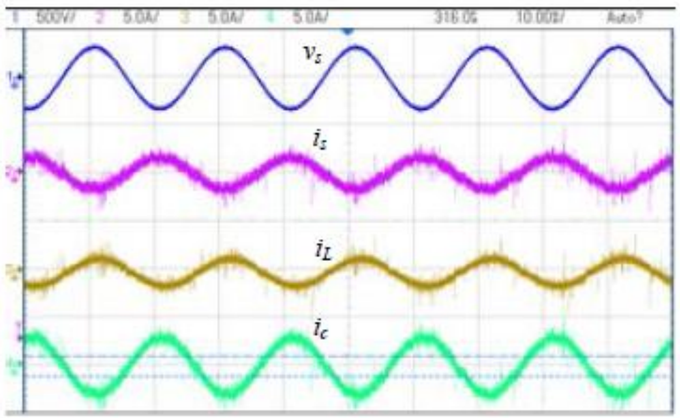
(b) Ch. I 100V/div, Ch.II 200V/divm Ch. III 5A/div, Time axis-20ms/div.



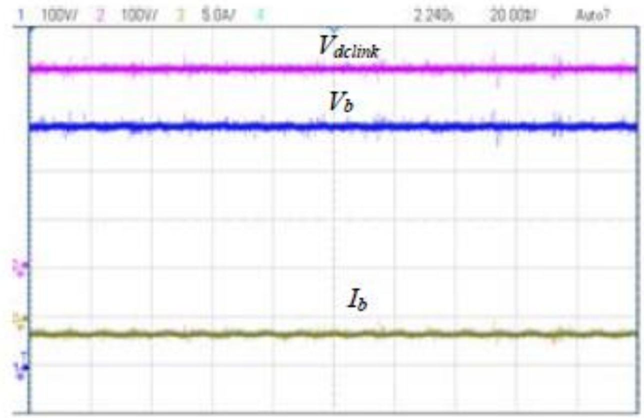
(a) (b) (c) (d)

Fig.11 Steady state voltage and current waveforms under discharging mode, when power supplied by battery is less than total load power (a) v_s, i_L, i_s, i_C (b) V_{dclink}, V_b, I_b (c) v_s and i_s (d) input power (P_s, Q_s) (e) THD spectrum of v_s (f) THD spectrum of i_s

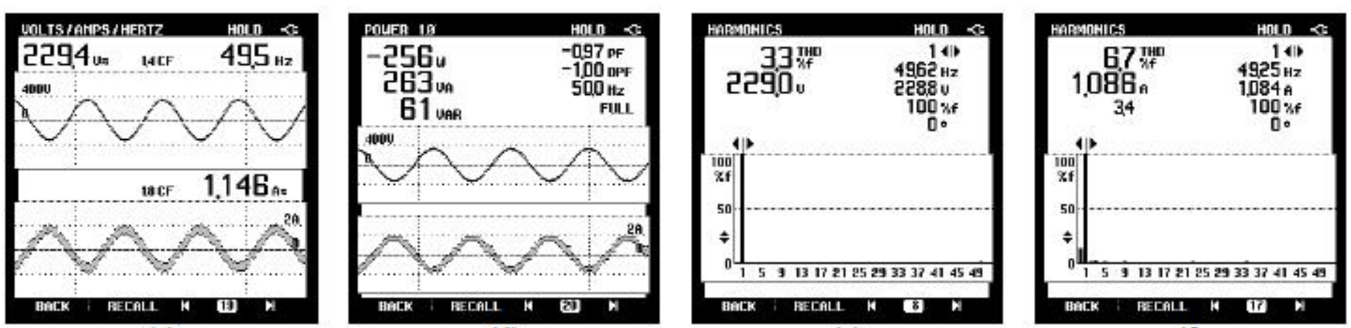
Power Demanded by the Load is less than the Power supplied by the



(a) Ch. 1 500V/div, II, III, IV 5A/div, Time axis-10ms/div.



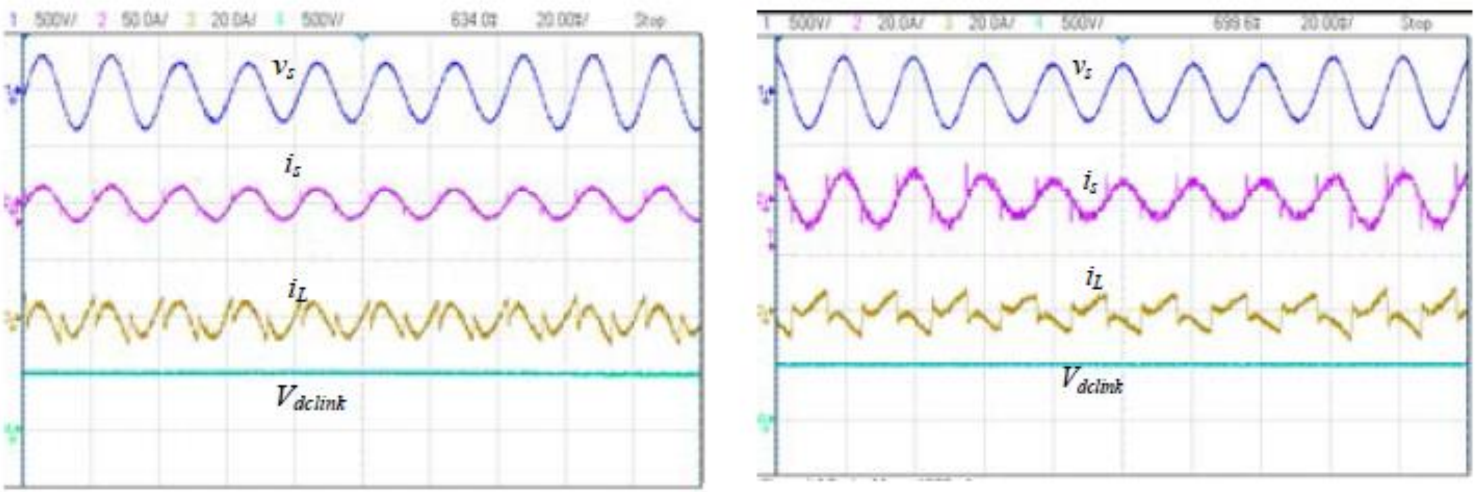
(b) Ch. I,II 100V/div, Ch. III 5A/div, Time axis-20ms/div



(c) (d) (e) (f)

Fig.12 Steady state voltage and current waveforms under discharging mode, when power supplied by battery is greater than total load power (a)v_s,i_s,i_L, i_C (b) V_{dclink}, V_b, I_b (c) v_S and i_S (d) input power (P_s,Q_s) (e) THD spectrum of v_s (f)THD spectrum of i_s.

during source voltage disturbance and when battery power is less than the load power (a) CC Mode of charging (b) discharging mode



(a) Ch. 1 500V/div, II, III 20A/div and 10A/div, Ch. IV 500V/div, Time axis-50ms/div.

(b) Ch. 1 500V/div, II, III 20A/div and 10A/div, Ch. IV 500V/div, Time axis-20ms/div.

Fig.13. Waveform of v_s, i_s, i_C, V_{dclink} during source voltage disturbance and when battery power is less than the load power (a) CC Mode of charging (b) discharging mode

Conclusion

- Future of RES and role of power electronics for Microgrid installation.
- Interfacing Power Converters and its coordinate control to feed power to local users and microgrid.
- The application of an electric vehicle battery and the inherent onboard power electronics for harmonic and reactive power compensation in a residential installation are discussed.
- Under discharging mode two situations are discussed
    - When the EV battery generates less power than the demand in which case utility complements the load and
    - when the EV battery generates more power than the demand in which case the additional power is injected into the utility. The current THD under these modes are found to be 4.6% and 6.7% respectively.

Thank You!