Emerging Trends and Challenges in Electric Power Systems

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Objective

- Introduction to Indian power systems and emerging trends.

Evolution of Modern Power Systems

Prior to 1800	Scientists like William Gilbert, C. A. de Coulomb, Luigi Galvani, Benjamin Franklin, Alessandro Volta etc. worked on electric and magnetic field principles.
Between 1800 and 1810	Commercial gas companies were formed - first in Europe and then in North America. Around the same time with the research efforts of scientists like Sir Humphrey Davy, Andre Ampere, George Ohm and Karl Gauss the exciting possibilities of the use of electrical energy started to dawn upon the scientific community.
Between 1821 and 1831	In England, Michael Faraday worked on his induction principle between 1821 and 1831. Faraday subsequently used his induction principle to build a machine to generate voltage. Around the same time American engineer Joseph Henry also worked independently on the induction principle and applied his work on electromagnets and telegraphs.

Evolution of Modern Power Systems

Between 1840 and 1870	Engineers like Charles Wheatstone, Alfred Varley, Siemens brothers Werner and Carl etc. built primitive generators using the induction principle. It was also observed around the same time that when current carrying carbon electrodes were drawn apart, brilliant electric arcs were formed. The commercialization of arc lighting took place in the decade of 1870s. The arc lamps were used in lighthouses and streets and rarely indoor due to high intensity of these lights. Gas was still used for domestic lighting.
1879	From early 1800 it was noted that a current carrying conductor could be heated to the point of incandescent. Therefore the idea of using this principle was very tempting and attracted attention. However the incandescent materials burnt very quickly to be of any use. To prevent them from burning they were fitted inside either vacuum globes or globes filled with inert gas. In October 1879 Thomas Alva Edison lighted a glass bulb with a carbonized cotton thread filament in a vacuum enclosed space. *This was the first electric bulb that* glowed for 44 hours before burning out.

Evolution of Modern Power Systems

Late 1870s	**Commercial use of electricity**
1882	**First Electric power system (Gen., cable, fuse, load) by Thomas Edison at Pearl Street Station in NY.** - **DC system, 59 customers, 1.5 km in radius** - **110 V load, underground cable, incandescent Lamps**
1884 **1886** **1889**	**Motors were developed by Frank Sprague** **Limitation of DC become apparent** **- High losses and voltage drop.** **- Transformation of voltage required.** **Transformers and AC distribution (150 lamps) developed by William Stanley of Westinghouse** **First ac transmission system in USA between Willamette Falls and Portland, Oregon.** **- 1- phase, 4000 V, over 21 km**

Evolution of Modern Power Systems (Contd.)

1888	N. Tesla developed poly-phase systems and had patents of gen., motors, transformers, trans. Lines. Westinghouse bought it.
1890s	Controversy on whether industry should standardize AC or DC. Edison advocated DC and Westinghouse AC. - Voltage increase, simpler & cheaper gen. and motors
1893	First 3-phase line, 2300 V, 12 km in California. ac was chosen at Niagara Falls (30 km)

	Early Voltage (Highest)
1922	165 kV
1923	220 kV
1935	287 kV
1953	330 kV
1965	500 kV
1966	735 kV
1969	765 kV
19902	1100 kV
000s	1200 kV
	Standards are 115, 138, 161, 230 kV – HV 345, 400, 500 kV - EHV 765, 1100 1200 kV - UHV **The motivation for these voltage changes is to minimize transmission line cost for a given power level.**
	Earlier Frequencies were 25, 50, 60, 125 and 133 Hz; USA - 60 Hz and some countries - 50 Hz

	HVDC Transmission System
1950s	Mercury arc valve
1954	First HVDC transmission between Sweden and Got land island by cable

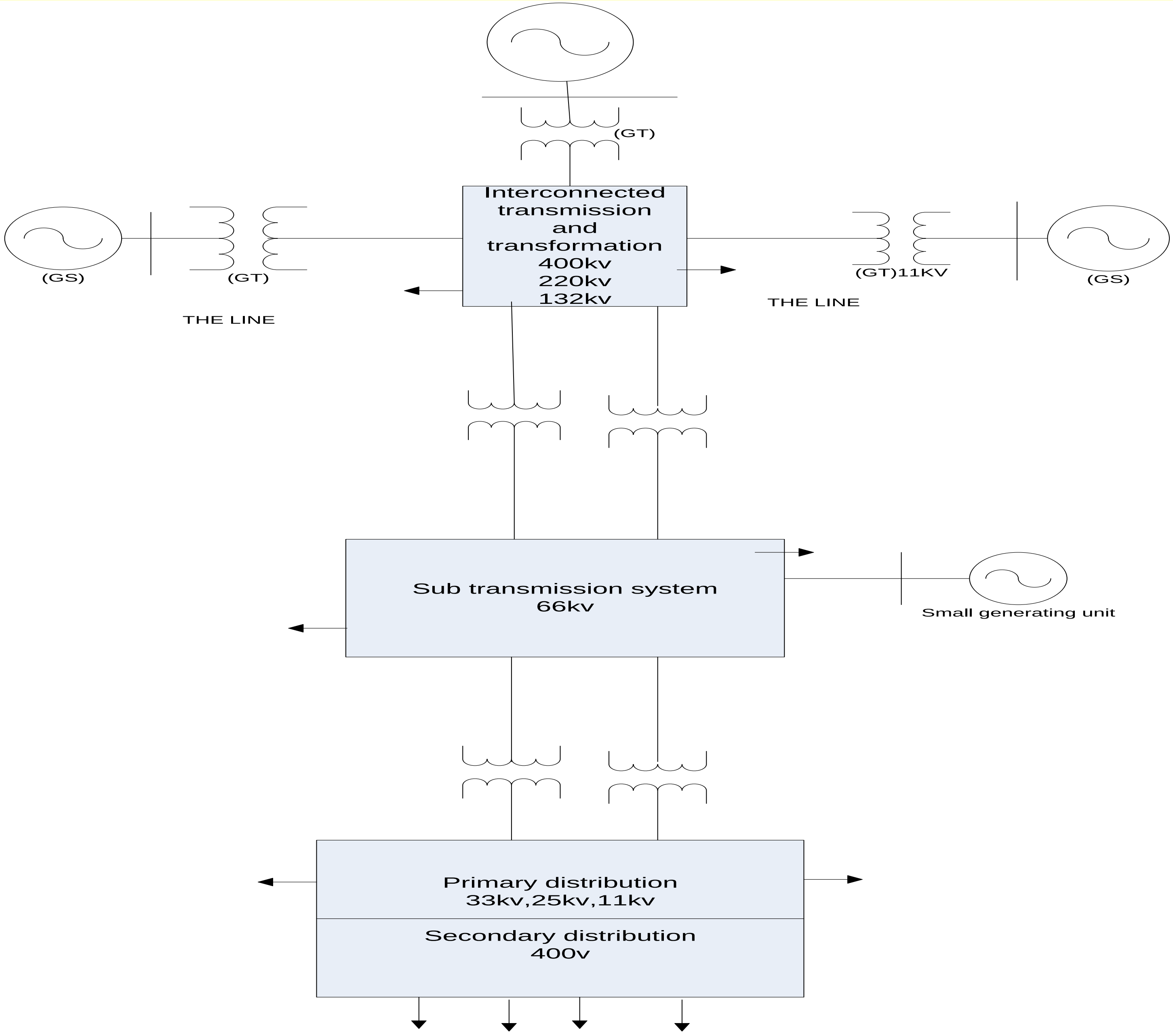
Limitations of HVAC Transmission

1. Reactive Power Loss
2. Stability
3. Current Carrying Capacity
4. Ferranti Effect
5. No smooth control of power flow

Recent Trends in Technologies

- Power electronics application to power systems
  - Good signal processing techniques for design & control
  - Increased rating of semiconductor devices
- Development in materials: machines, conductors, insulators, cooling
- Superconducting Electric Machines/Transmission Lines
- Development of cheap digital signal processing controllers
- Small asynchronous generation
- Design of systems using CAD and validation through FEM.
- New applications from electric vehicles.
- Awareness for renewable energy
- Micro-grid, DC and AC
- *Smart Grids*
  - Maintaining Security, Reliability and Resilience of Large Interconnected System
  - Maintaining Quality of Supply and IT Enabled Services in Distribution Sector
- Regulatory Changes in the Electricity Sector

Structure of Power System in India



Introduction

- **The world needs energy innovation**
  - **<u>Problem</u> : Security of supply, climate change and sustainability**
  - **<u>Solution</u> : Transitions to clean, reliable and affordable energy**
  - **<u>Methods</u> : Renewable energy, energy savings and clean use of fossil fuels**
- **Wind power/Solar power**
  - **Proved as a potential source for generation of electricity**
  - **Minimal environmental impact**
  - **Fastest-growing source and expected to remain in future**
- **Modern wind/solar farms**
  - **Can capture several MWs of power (7 MW largest wind turbine)**
  - **Can supplement the base power**

Installed Generation Capacity

Installed Power Generation Capacity (Jan. 2014)
229 GW Total
156-Thermal power
40-Hydro
4.8-Nuclear
30-Renewable

Renewable Energy Sources (Jan. 2014)
30 GW
20-Wind
7.6-Small-hydro (< 25 MW)
1.3- *Biomass Power & Gasification* nuclear
2.5- Baggasse cogeneration
2.2-Solar power

National Solar Mission

Announced by Minister of New and Renewable Energy on 23rd November, 2009

S. No .	Application segment	Target for Phase I (2010-13)	Target for Phase 2 (2013-17)	Target for Phase 3 (2017-22)
1.	Solar collectors	7 million sq meters	15 million sq meters	20 million sq meters
2.	Off grid solar applications	200 MW	1000 MW	2000 MW
3.	Utility grid power, including roof top	1,000-2000 MW	4000-10,000 MW	20000 MW

http://mnre.gov.in/pdf/mission-document-JNNSM.pdf

Key Drivers

Towards Sustainability in Electric Energy

Renewable Purchase Obligation (RPO)

-Solar & non-solar
-Issued by States (SERC & CERC)
-Obligated by power utilities

*RPO is the minimum amount of renewable energy to be purchased by the States in order to meet the mandatory electric energy requirement.

With high penetration of RES

❑ Conventional power plants

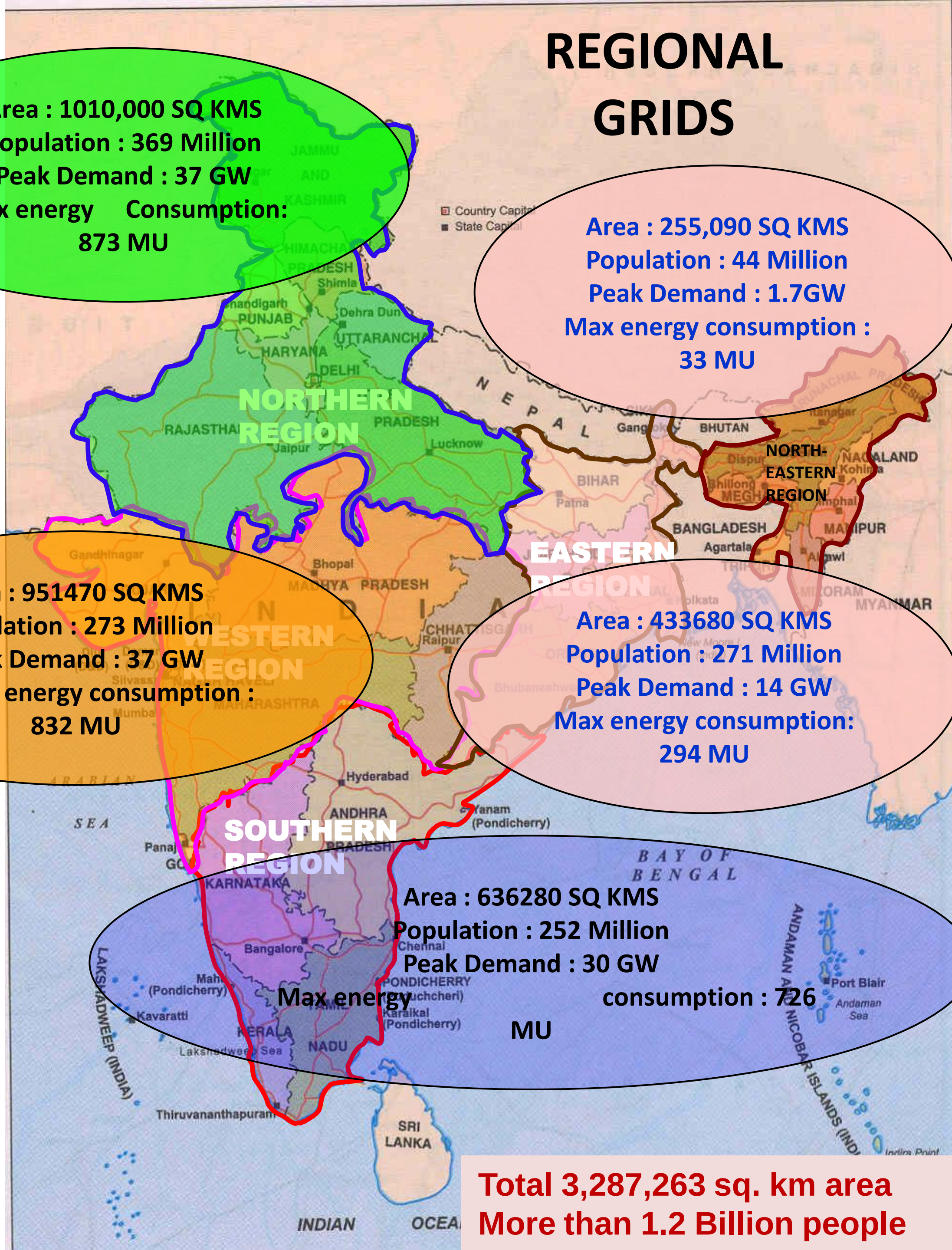
- ✓ Large synchronous machines
- ✓ Provides primary & secondary control
- ✓ Meet the specific grid connection requirements (GCR)

❑ With increased penetration of wind/solar power

- ✓ Mostly converter interfaced *small* asynchronous generators/ generations,
- ✓ Poses new challenges in maintaining reliability and stability of electricity supply,
- ✓ Advanced GCR are required to be developed for efficient, stable and secure operation of grid ,
- ✓ Loss of generation cannot be tolerable,
- ✓ Need to perform suitable studies to analyze the interaction of wind/solar power with existing grid,
- ✓ Need to develop several solutions to improve and mitigate negative consequences on the existing grid, if any.

❑ Intermittency (reliability, stability etc.) and High Cost

REGIONAL GRIDS



Northern Region
Area : 1010,000 SQ KMS
Population : 369 Million
Peak Demand : 37 GW
Max energy Consumption: 873 MU

North-Eastern Region
Area : 255,090 SQ KMS
Population : 44 Million
Peak Demand : 1.7GW
Max energy consumption : 33 MU

Western Region
Area : 951470 SQ KMS
Population : 273 Million
Peak Demand : 37 GW
Max energy consumption : 832 MU

Eastern Region
Area : 433680 SQ KMS
Population : 271 Million
Peak Demand : 14 GW
Max energy consumption: 294 MU

Southern Region
Area : 636280 SQ KMS
Population : 252 Million
Peak Demand : 30 GW
Max energy consumption : 726 MU

ALL INDIA INSTALLED CAPACITY

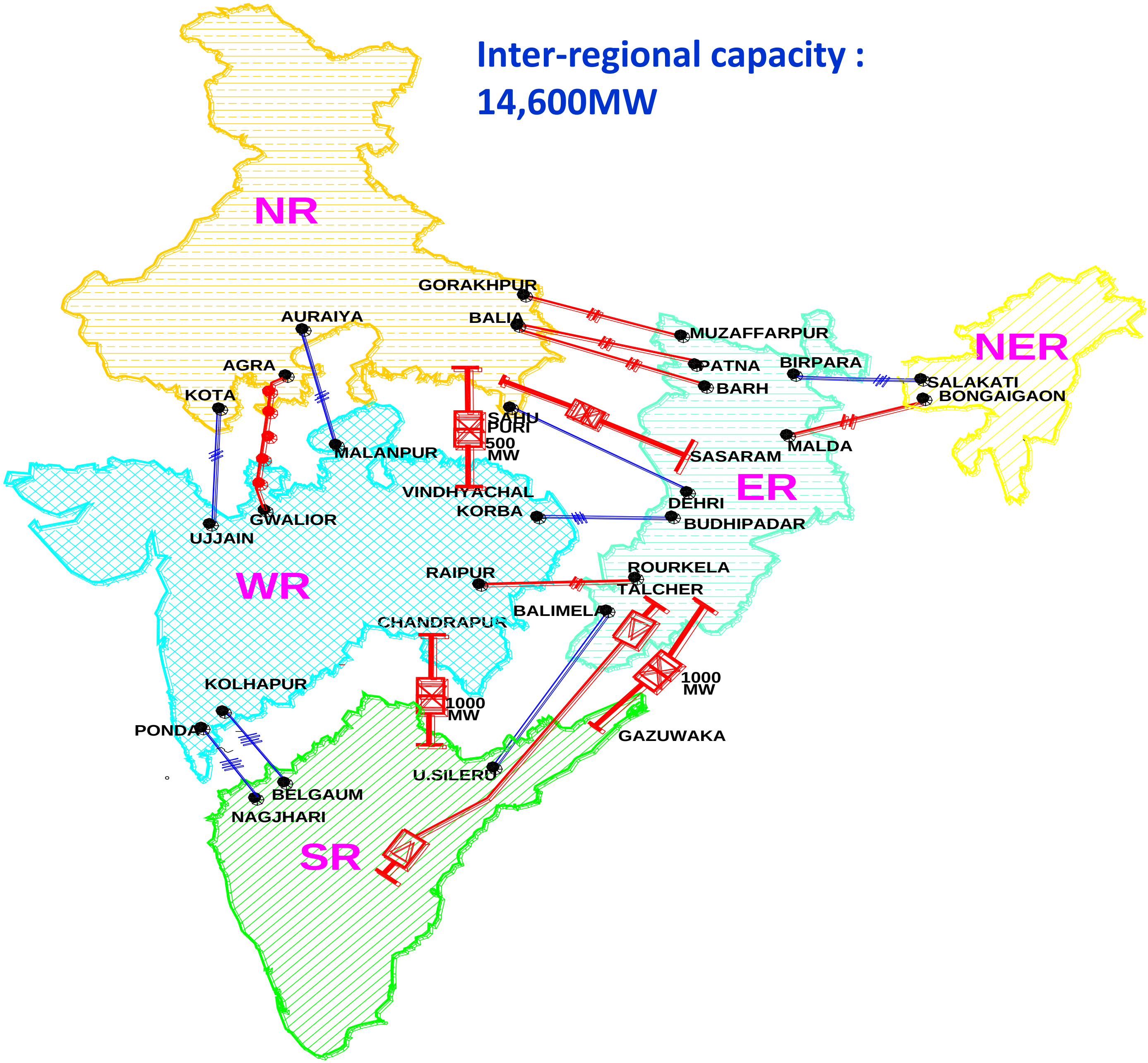
NORTH	:-	53.9 GW
EAST	:-	26.3 GW
SOUTH	:-	52.7 GW
WEST	:-	64.4 GW
NORTH-EAST	:-	2.4 GW
TOTAL	:-	**200 GW**

Total 3,287,263 sq. km area
More than 1.2 Billion people

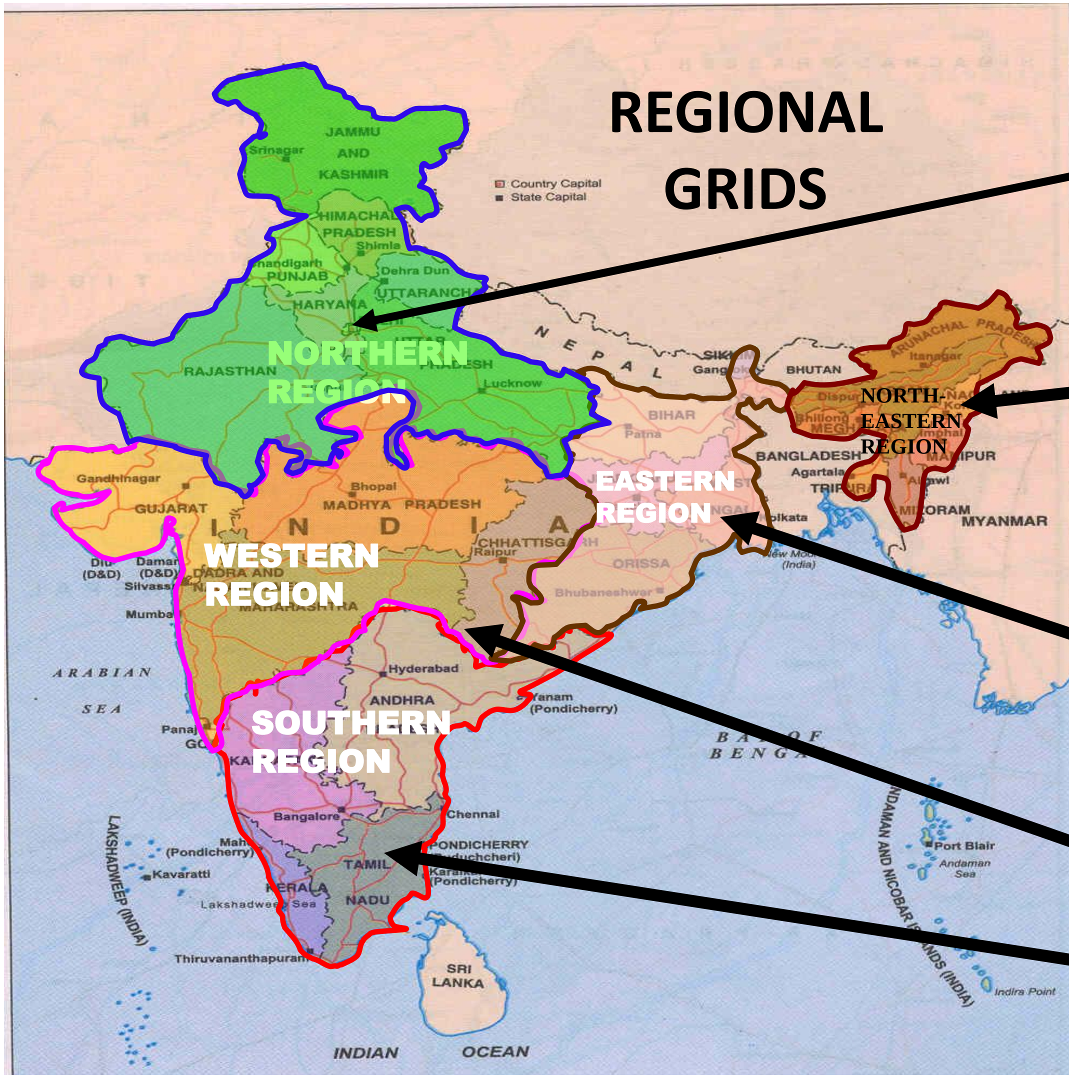
As on 31st March 2012

Inter-regional links – At present

Inter-regional capacity :
14,600MW



Peculiarities of Regional Grids in India



Deficit Region

Snow fed – run-of -the -river hydro

Highly weather sensitive load

Adverse weather conditions: Fog & Dust Storm

Very low load

High hydro potential

Evacuation problems

Low load

High coal reserves

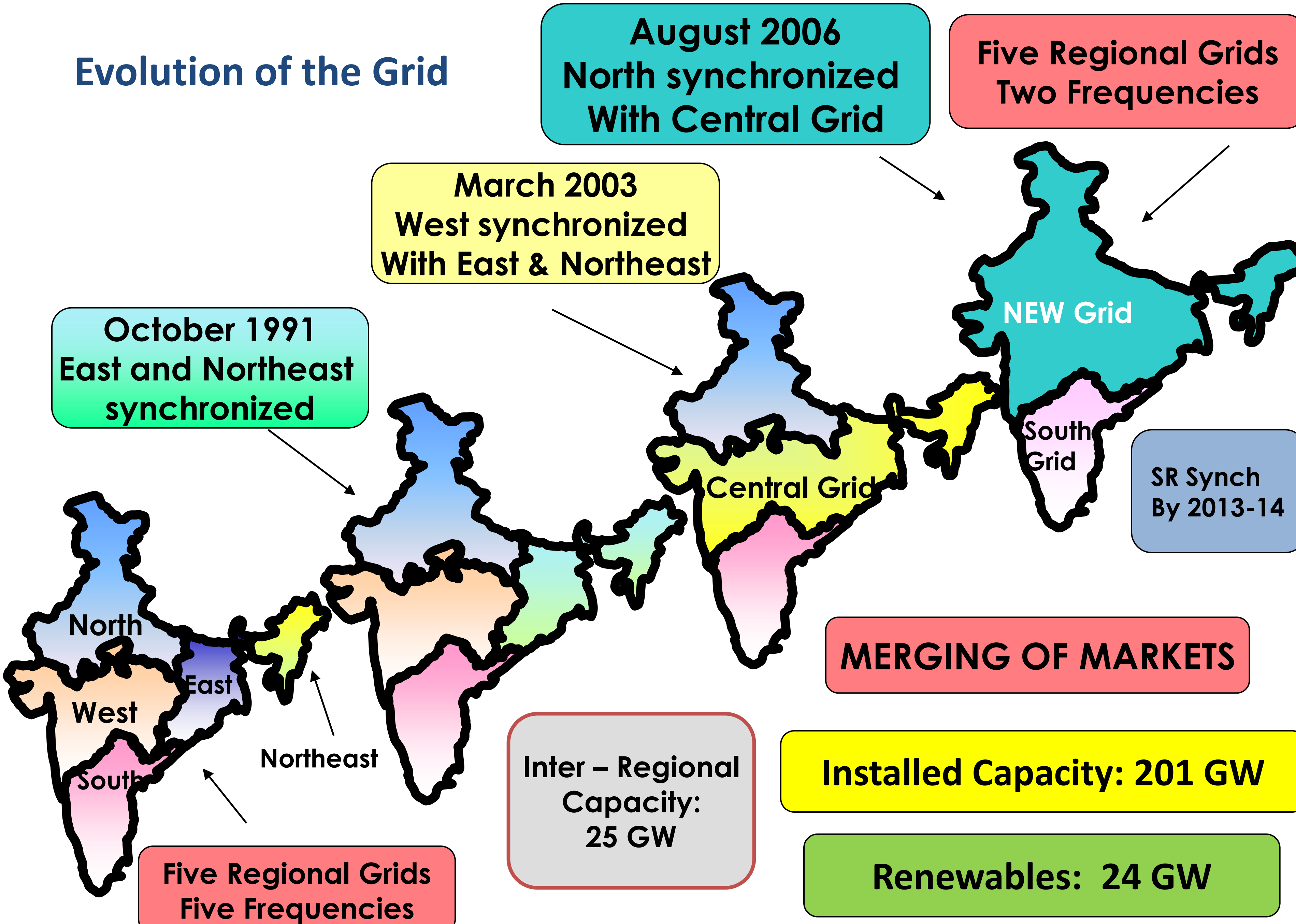
Pit head base load plants

Industrial load and agricultural load

High load (40% agricultural load)

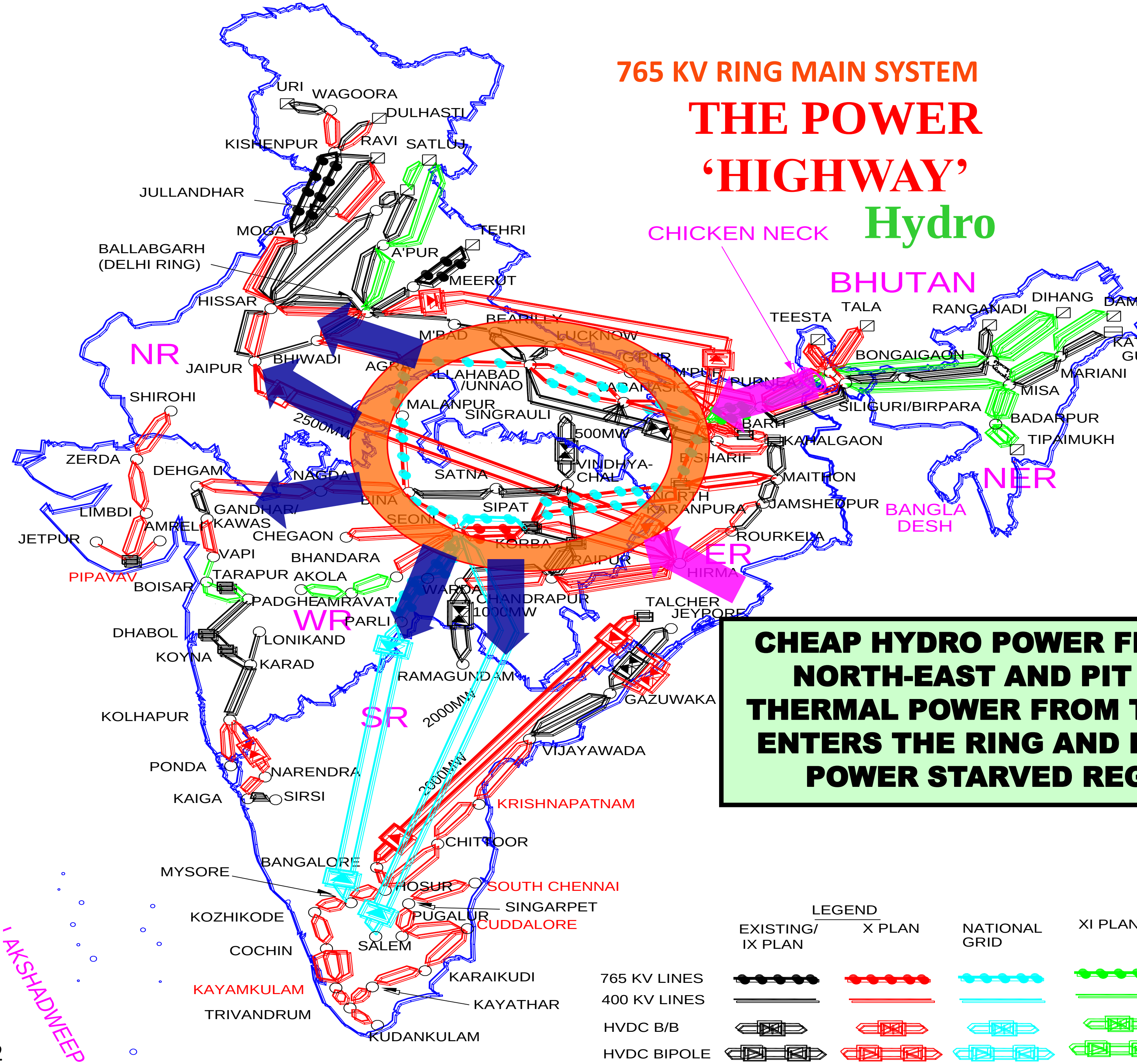
Monsoon dependent hydro

Evolution of the Grid



765 KV RING MAIN SYSTEM

THE POWER 'HIGHWAY'



CHEAP HYDRO POWER FROM THE NORTH-EAST AND PIT HEAD THERMAL POWER FROM THE EAST ENTERS THE RING AND EXITS TO POWER STARVED REGIONS

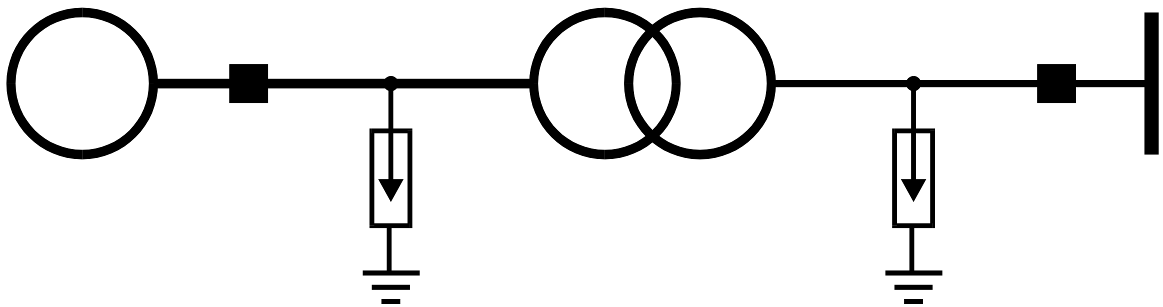
New Transmission Technologies

- **High Voltage Overhead Transmission**
  - Voltage up to 1200 kV
  - High EM radiation and noise
  - High corona loss
  - More ROW clearance
- **Gas Insulated Cables/Transmission lines**
- **HVDC-Light**
- **Flexible AC Transmission Systems (FACTS)**

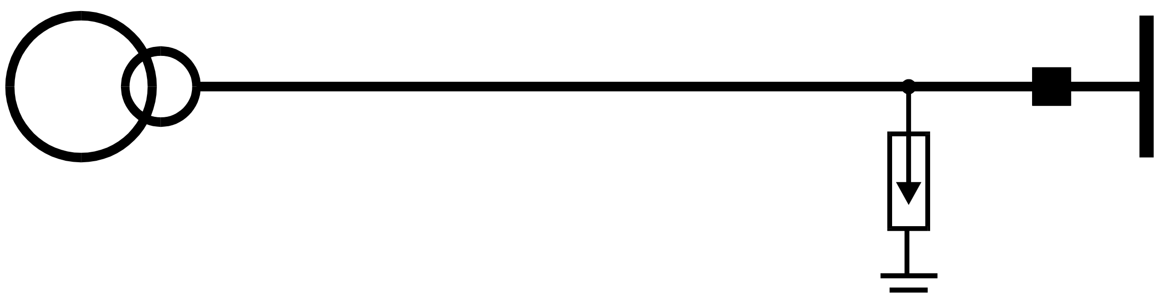
- **Developments in Generation side**
  - Powerformer Energy System
  - Distributed/Renewable Generations
    - Wind Power
    - Fuel Cells
    - Solar
    - Biomass etc.
  - Combined Cycle Power Plants
  - DC Distribution System
  - Smart grid

Powerformer Energy System

Conventional



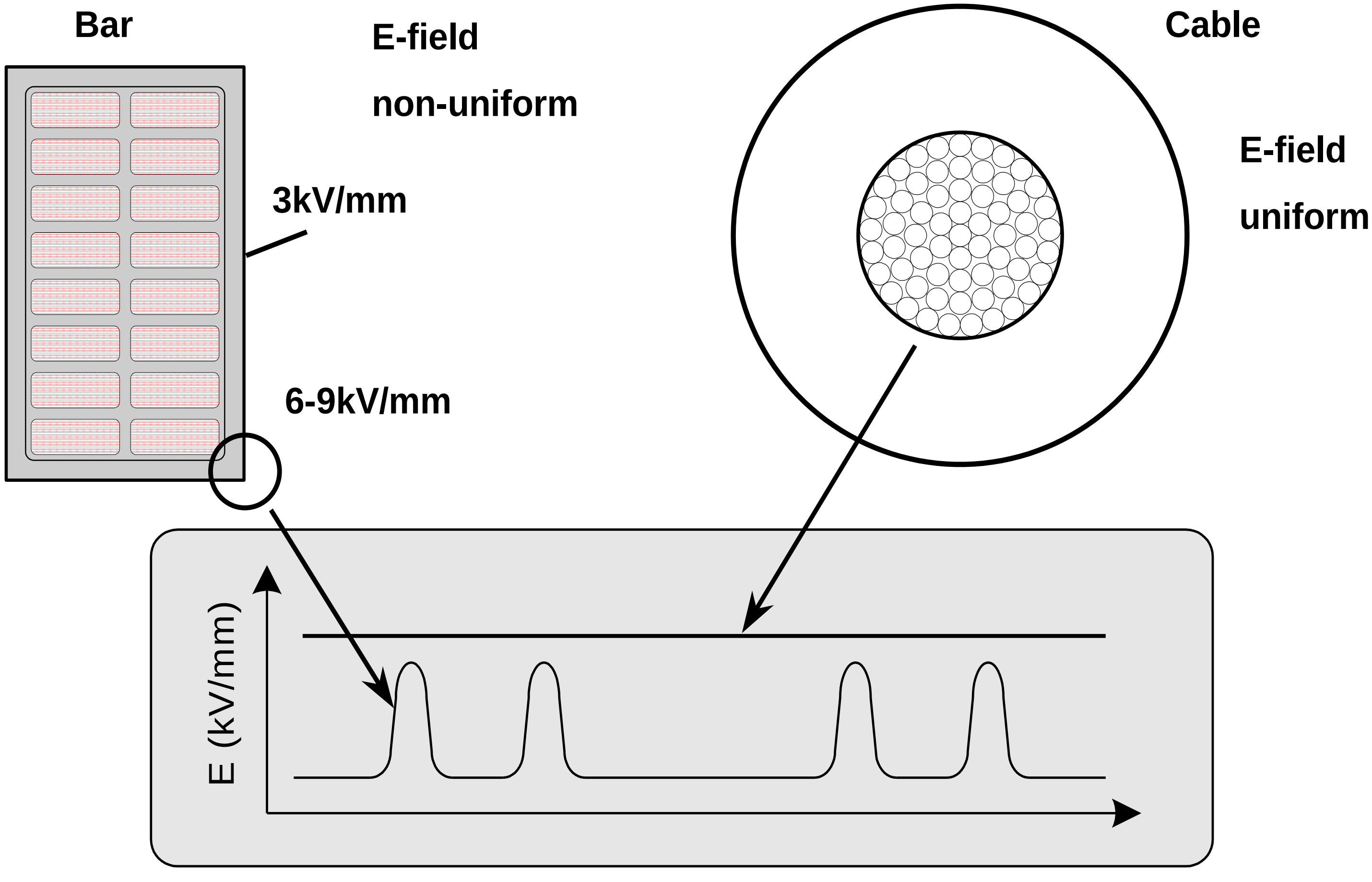
Powerformer™



Powerformer^{TM} Benefits

- Higher performance (availability, overload)
- Environmental improvement
- Lower weight
- Less total space requirement
- Lower cost for Civil Works
- Less maintenance
- Reduced losses
- Lower investment
- Lower LCC

Electrical Field Distribution



DG "Wins" Not Because It is Efficient, But Because It Avoids T&D Costs

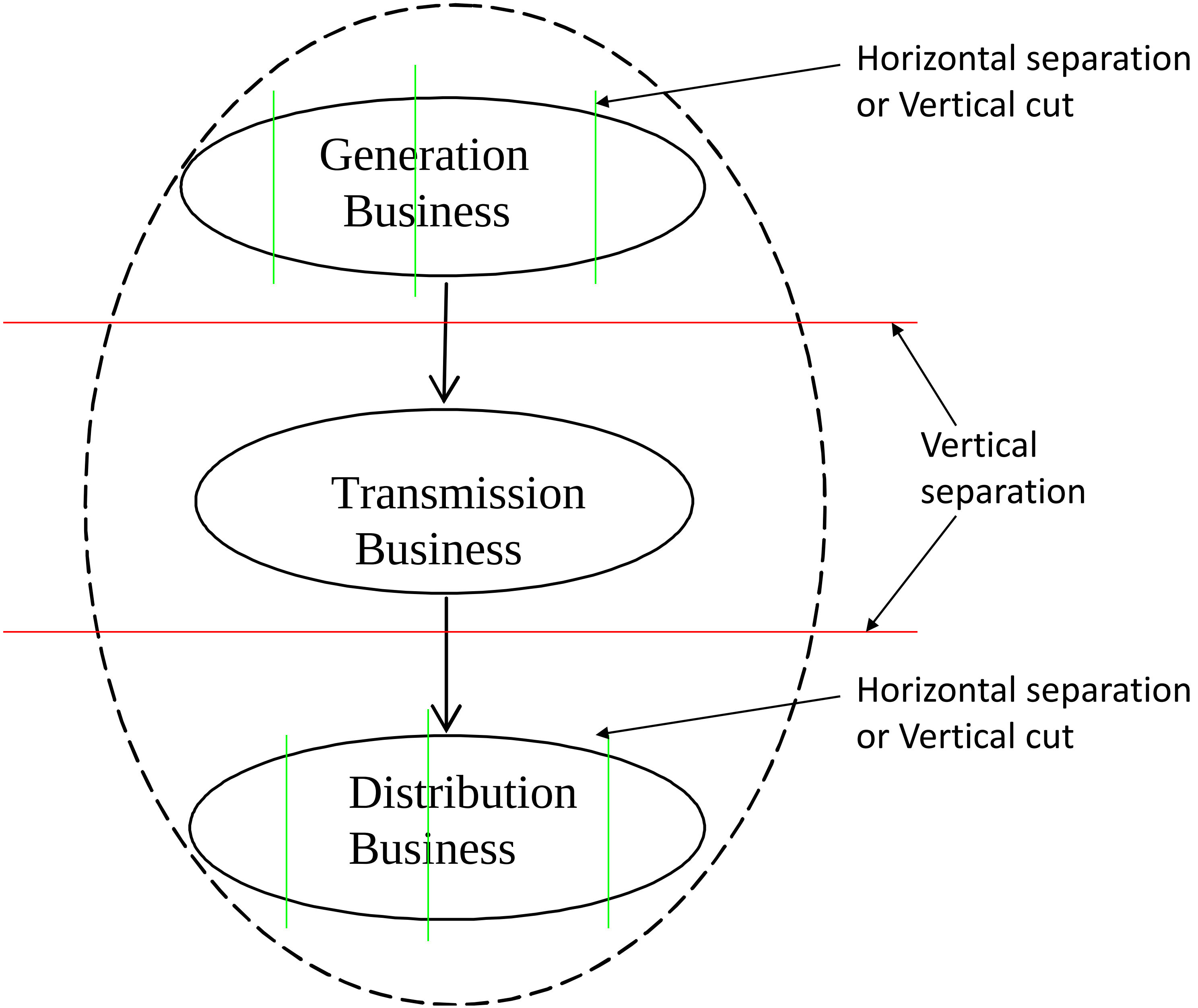
Proximity is often more important than efficiency

- Why use DG units, if they are not most efficient or the lowest cost?
  - The reason is that **they are closer to the customer**. They only have to be more economical than the central station generation and its associated T&D system. A **T&D** system represents **a significant cost** in **initial capital** and **continuing O&M**.
  - By avoiding T&D costs and those reliability problems, DG can provide **better service at lower cost**, at least in some cases. For example, in situations where an existing distribution system is near capacity, so that it must be reinforced in order to serve new or additional electrical demand, the capital cost/kW for T&D expansion alone can exceed that for DG units.

- Power System Restructuring (Privatization or Deregulation)
  - But not only Privatization

- **Deregulation is also known as**

  - Competitive power market
  - Re-regulated market
  - Open Power Market
  - Vertically unbundled power system
  - Open access


Horizontal separation or Vertical cut
Generation Business
Vertical separation
Transmission Business
Horizontal separation or Vertical cut
Distribution Business

- **Why Restructuring of Electric Supply Industries?**
  - Better experience of other restructured market such as communication, banking, oil and gas, airlines, etc.
  - Competition among energy suppliers and wide choice for electric customers.
- **Why was the electric utility industry regulated?**
  - Regulation originally reduced risk, as it was perceived by both business and government.
  - Several important benefits:
    - It legitimized the electric utility business.

- **Forces behind the Restructuring are**
  - High tariffs and over staffing
  - Global economic crisis
  - Regulatory failure
  - Political and ideological changes
  - Managerial inefficiency
  - Lack of public resources for the future development
  - Technological advancement
  - Rise of environmentalism
  - Pressure of Financial institutions
  - Rise in public awareness
  - Some more …….

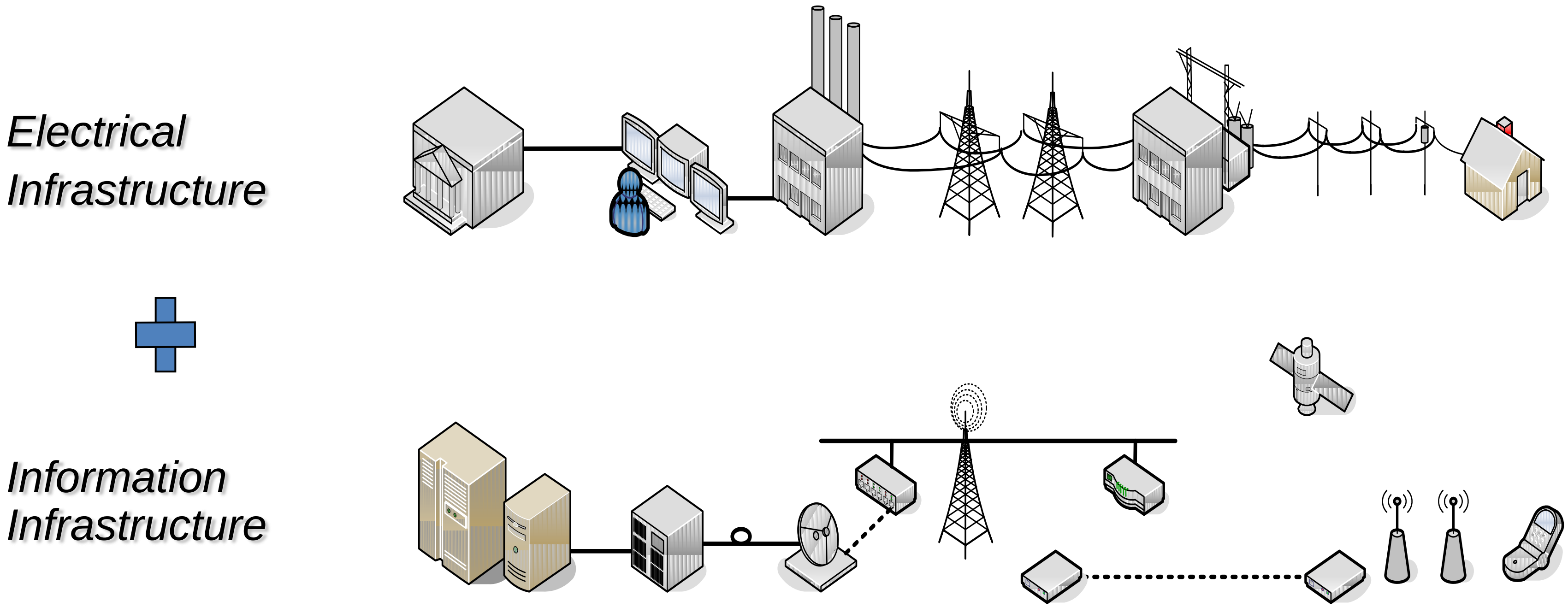
Intelligent Grid - WAMS

Leader not a follower

- What is Smart Grid?
- Is the present grid not smart?
- Why Smart Grid?
- Smart or Intelligent ???

Merging Two Technologies

The integration of two infrastructures… securely…



Source: EPRI® Intelligrid at http://intelligrid.epri.com

Some of the Recent Concerns

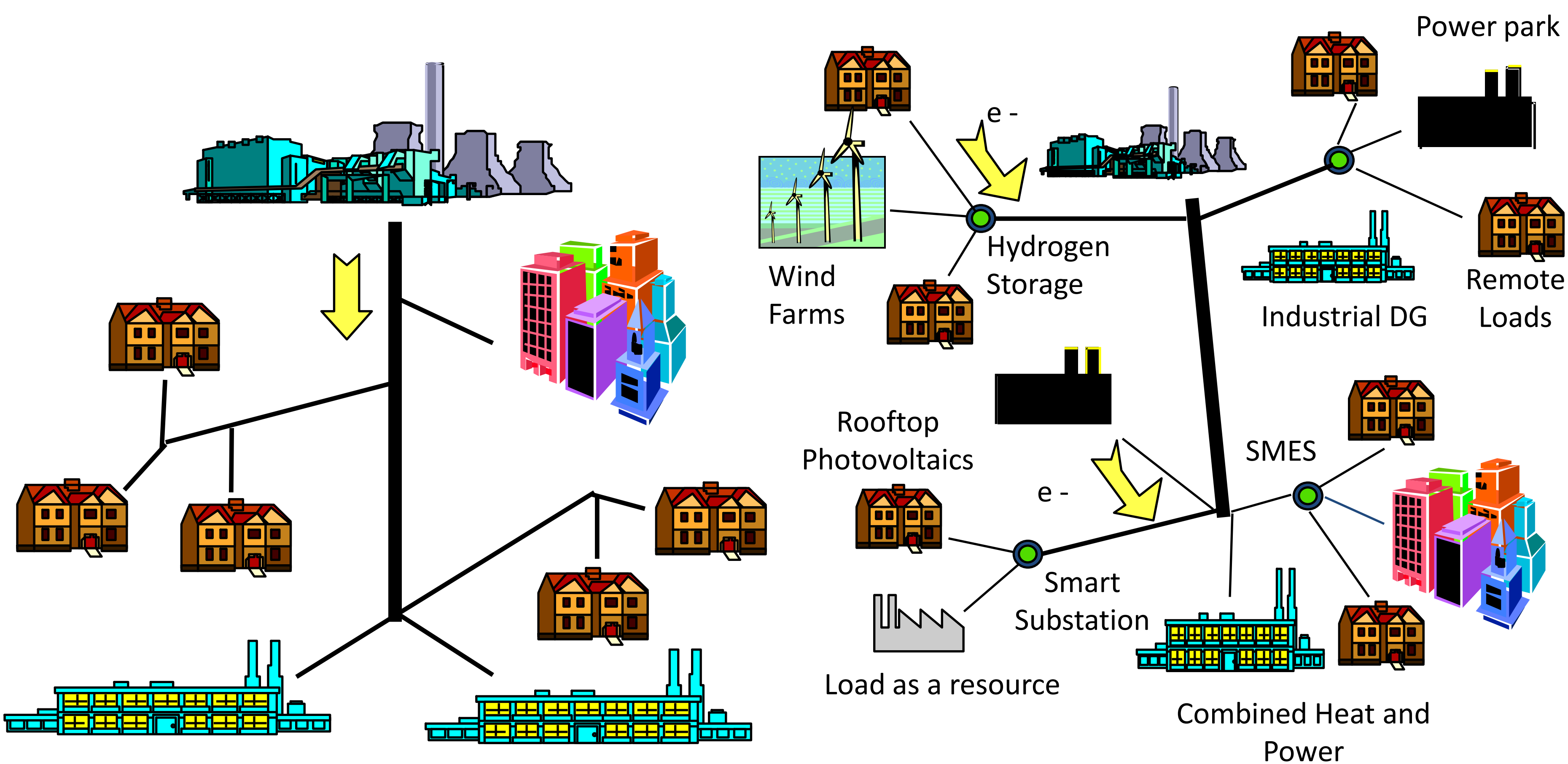
- Limited expansion of transmission network as compared to the generation addition.
  - Most of the generation, T&D systems have become old.
- Efficiency: Increased transmission and distribution losses.
- Lack of dynamic data for health monitoring and control.
- Reliability & Security: Increased concern towards vulnerability and resilience of the system under natural and man made disasters.
- Growing *environmental* concerns including the global warming.
- *Poor power quality*, limited customer focus and their participation in energy Management.
- Meeting the ever increasing electricity demand.
- Affordability:

Present and Future Power System

Present Power System
- Heavily Relying on Fossil Fuels
- Generation follows load
- Limited ICT use

Future Power System
- More use of RES, clean coal, nuclear power
- Load follows Generation
- More ICT & Smart meter use

Today's Electricity … *Tomorrow's Choices …*



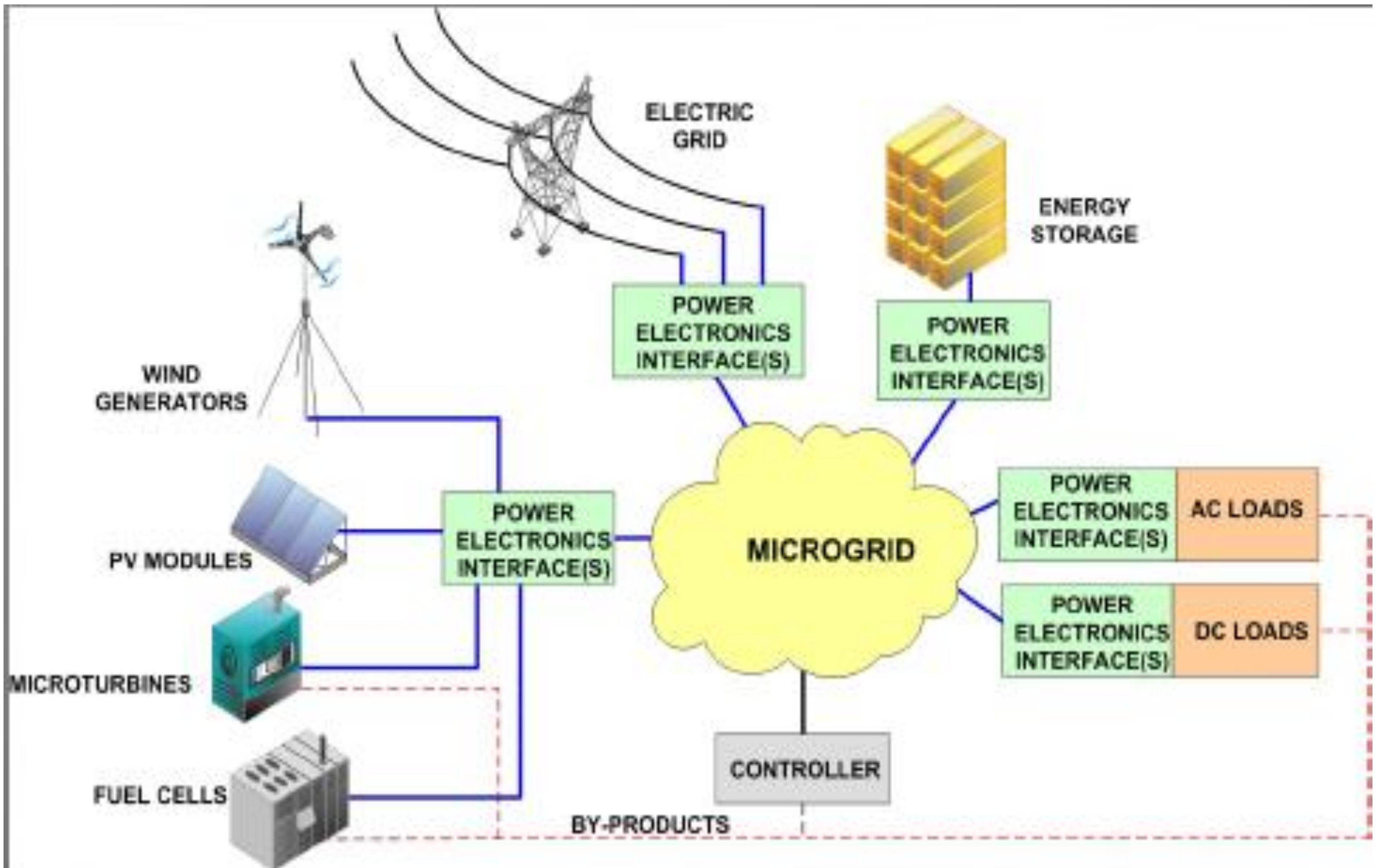
What a Smart Grid would look like?

Green, Environment friendly

Source: European Technology Platform SmartGrids

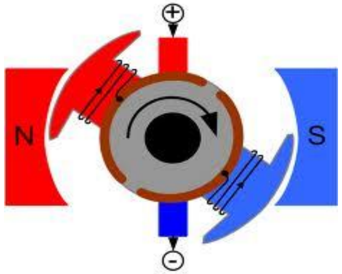
Micro Grid (DC or AC ?)

- Micro-grids are independently controlled (small) electric networks, powered by local units (distributed generation).



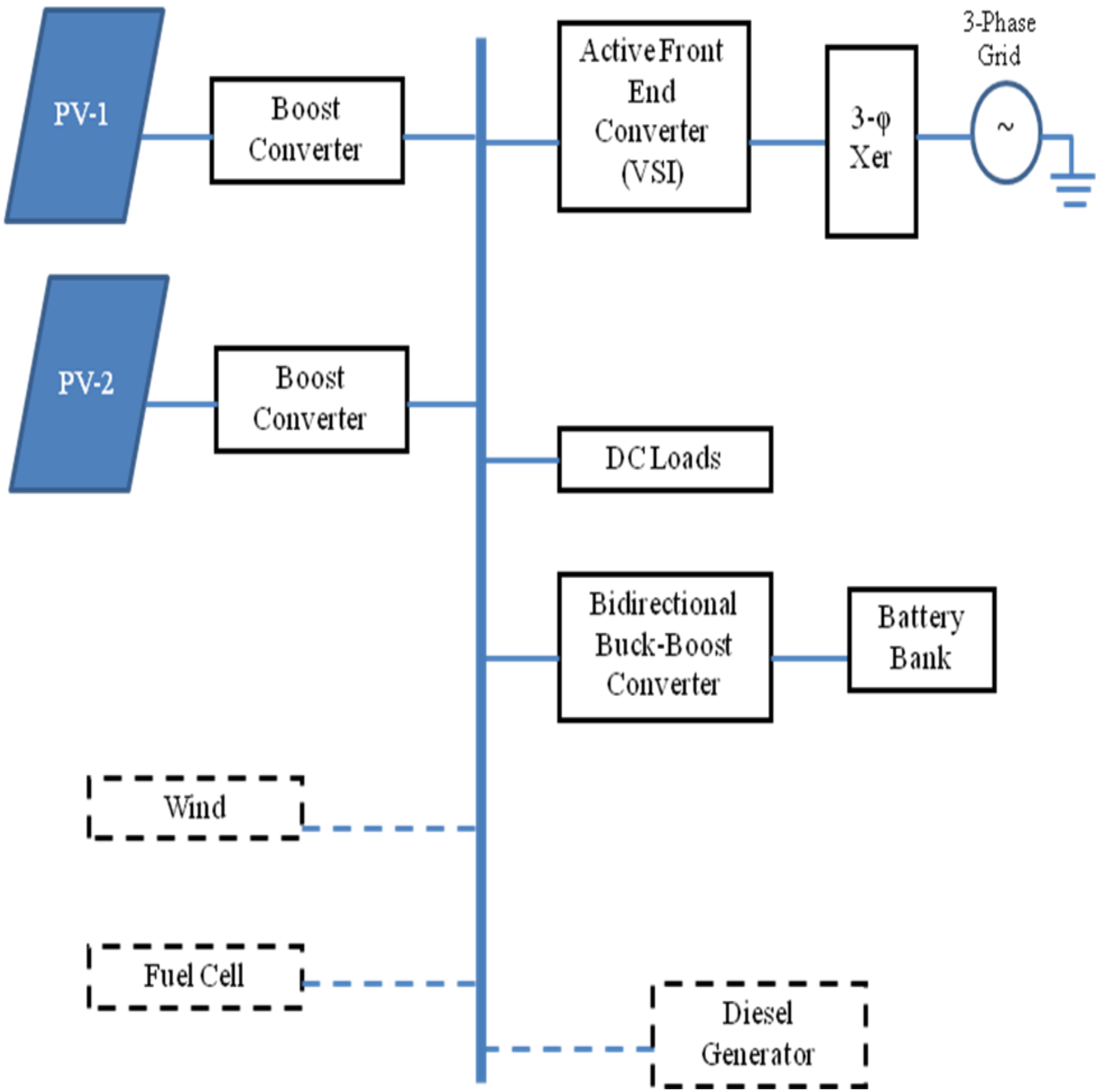
Why continue to use AC appliances?

- Lighting
  - LEDs, 10 to 100 times more efficient as compared to tungsten bulb, use only DC power
  - CFL is neutral to AC or DC power



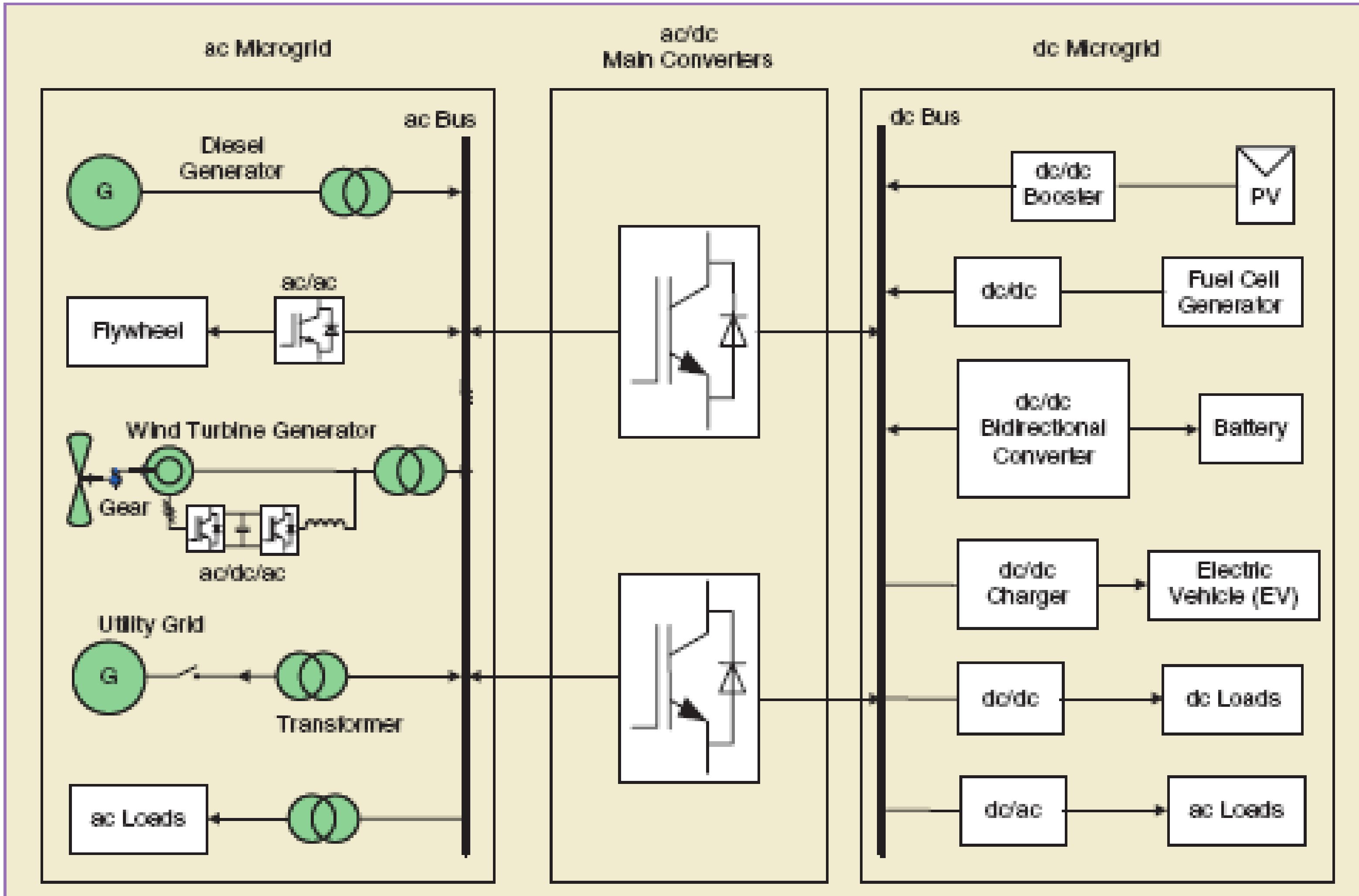
- Motor: a small DC motor can be 2.5 tomes more energy efficient as compared to a AC motor
  - Historically brush replacement needed – but not anymore
  - A fan is primarily a motor – a dc fan also allows better speed control
  - A refrigerator is essentially a motor
  - An air-conditioner is primarily a motor
  - A washing-machine / grinder is a motor
- Electronics: all electronics (mobiles/TV/Computers) use low voltage DC
  - Need a ac/dc power adaptor to charge

- World switched to AC primarily for transmission of power
  - Any ac / dc conversion or vice-versa implies 7 to 15% losses



DC Micro-grid System.

Hybrid AC/DC Microgrid



AC vs. DC Micro Grid

- ❖ Some of the issues with Edison's dc system:
  - ➢ Voltage-transformation complexities
  - ➢ Incompatibility with induction (AC) motors

- ❖ Power electronics help to overcome difficulties
  - ➢ Also introduces other benefits – DC micro-grids

- ❖ DC micro-grids
  - ➢ Help eliminate long AC transmission and distribution paths
  - ➢ Most modern loads are DC – modernized conventional loads too!
  - ➢ No need for frequency and phase control – stability issues?

AC vs. DC Micro Grid

- **Cabling in DC distribution**
  - Greater current carrying capacity with DC system over AC
  - Therefore smaller and cheaper distribution cables for a given power
- **Interconnection into HVDC schemes**
  - Lower reacatance as large transformers & filters AC can be removed at offshore platform
  - Less components provides higher availability and less maintenance
- **DC transformer less, & filter less generation can provide efficiency improvements**

Challenges to DC systems

- **Technology**
  - Lack of DC on-load circuit breakers.
    - Converteam's Foldback Technology provides a solution
  - Can we generate in DC effectively?
- **Standards**
  - Real need for open standards if ideas such as Multi-terminal HVDC schemes, i.e. Supergrid, are to be realised
    - Best achieved at pre-competitive stage
- **Supply chain partnering**
  - To be ready and on time
- **Fantastic opportunities for innovation**
  - Great challenges for Universities and R&D teams

Thank You
and Questions

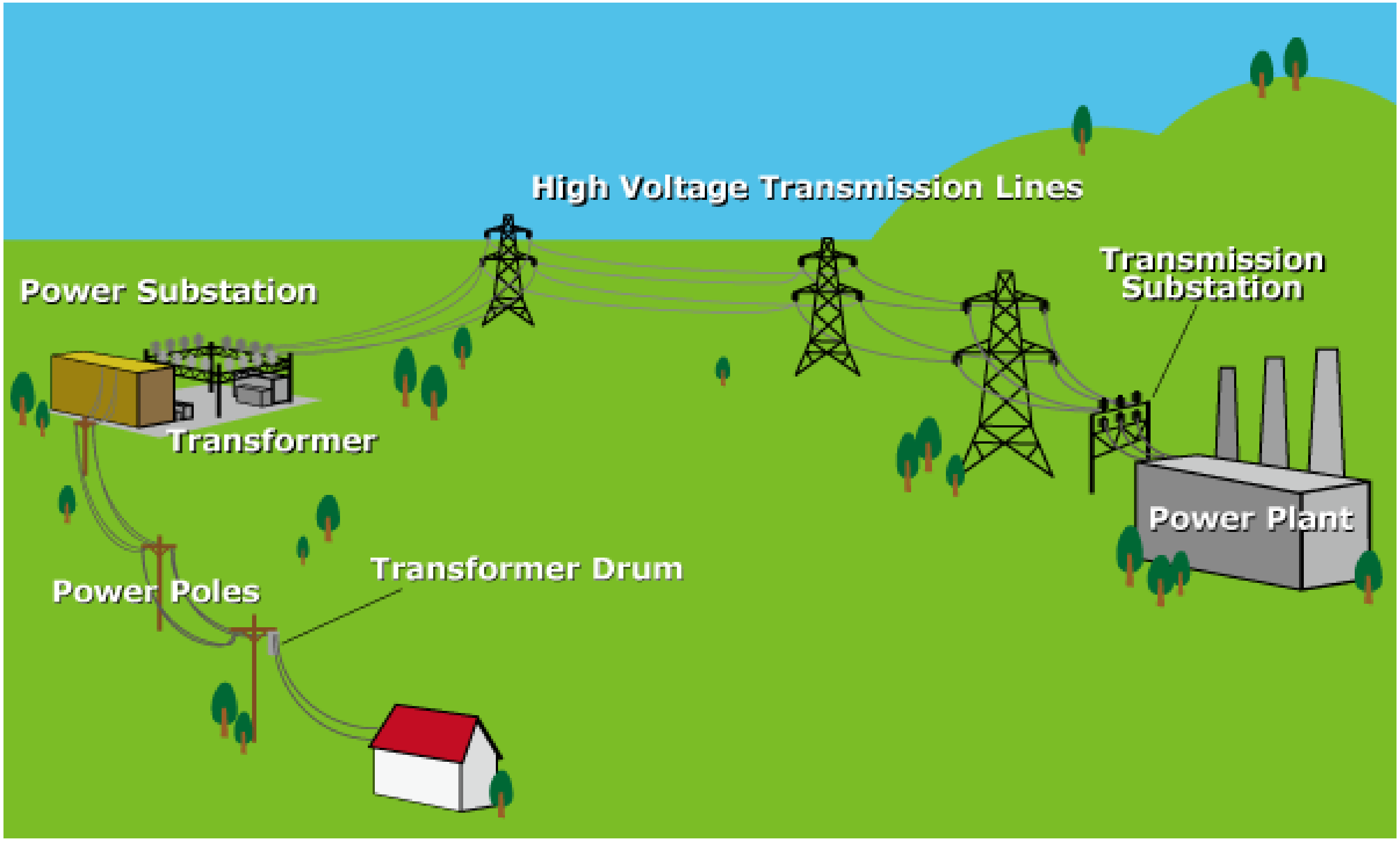
Energy Management System for DC Micro Grid

Presented By : Rajeev Kumar Chauhan

School of Computing & Electrical Engineering

Indian Institute of Technology Mandi, India

Introduction



Introduction

- India is running shortage of 11% peak demand.

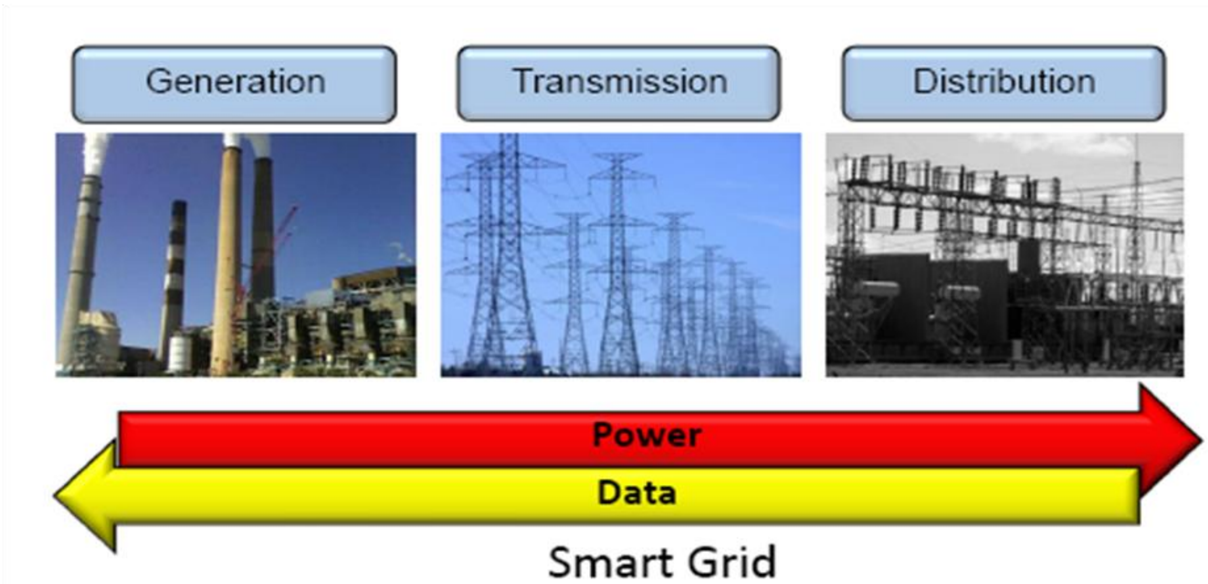
- Power losses in transmission and distribution system are more than 24% [2].

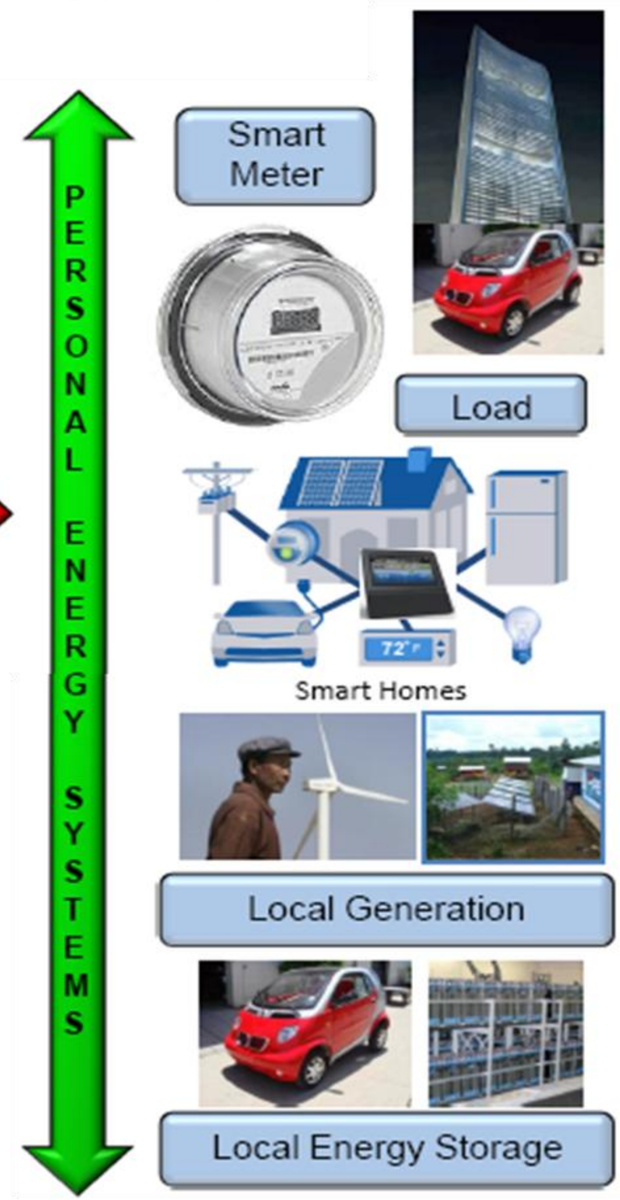
- The energy consumption in commercial and residential is increased by 20% and 40% in developed countries [3].

Introduction Cont…

- **Generation**
  - ✓ Conventional Power Plant
  - ✓ Renewable Energy Source (RES)
- **Line Losses**
  - ✓ Transmission and Distribution System
  - ✓ Conversion Losses
- **Energy Efficient Buildings**
- **Demand Management**

From Grid to Microgrid Energy System





Why Microgrid Energy?

- ✓Improve Reliability & Security
- ✓Increase Availability of Energy from Renewable Energy Sources
- ✓ Creates an Open Horizontal Environment for Energy Innovation and Application

Classification of Grids

- Nano- Grid

  An electrical power system as described in the two universal points of agreement that serves a defined space in one building.

- Micro- Grid

  A micro-grid consists of interconnected distributed energy resources capable of providing sufficient and continuous energy to a significant portion of internal load demand.

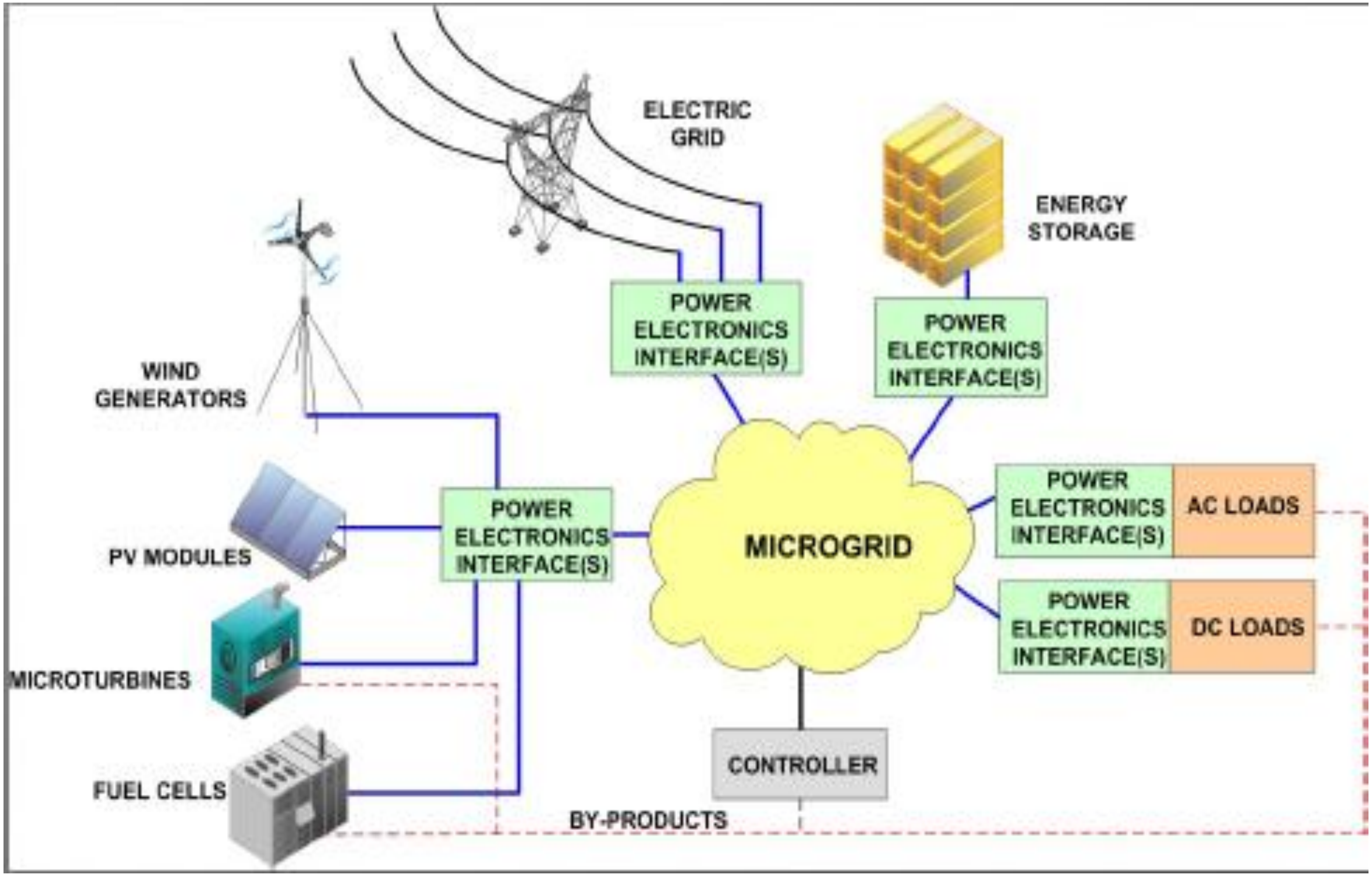
  Or

  An electrical power system as described in the two universal points of agreement that serves one building

- Mini-Grid

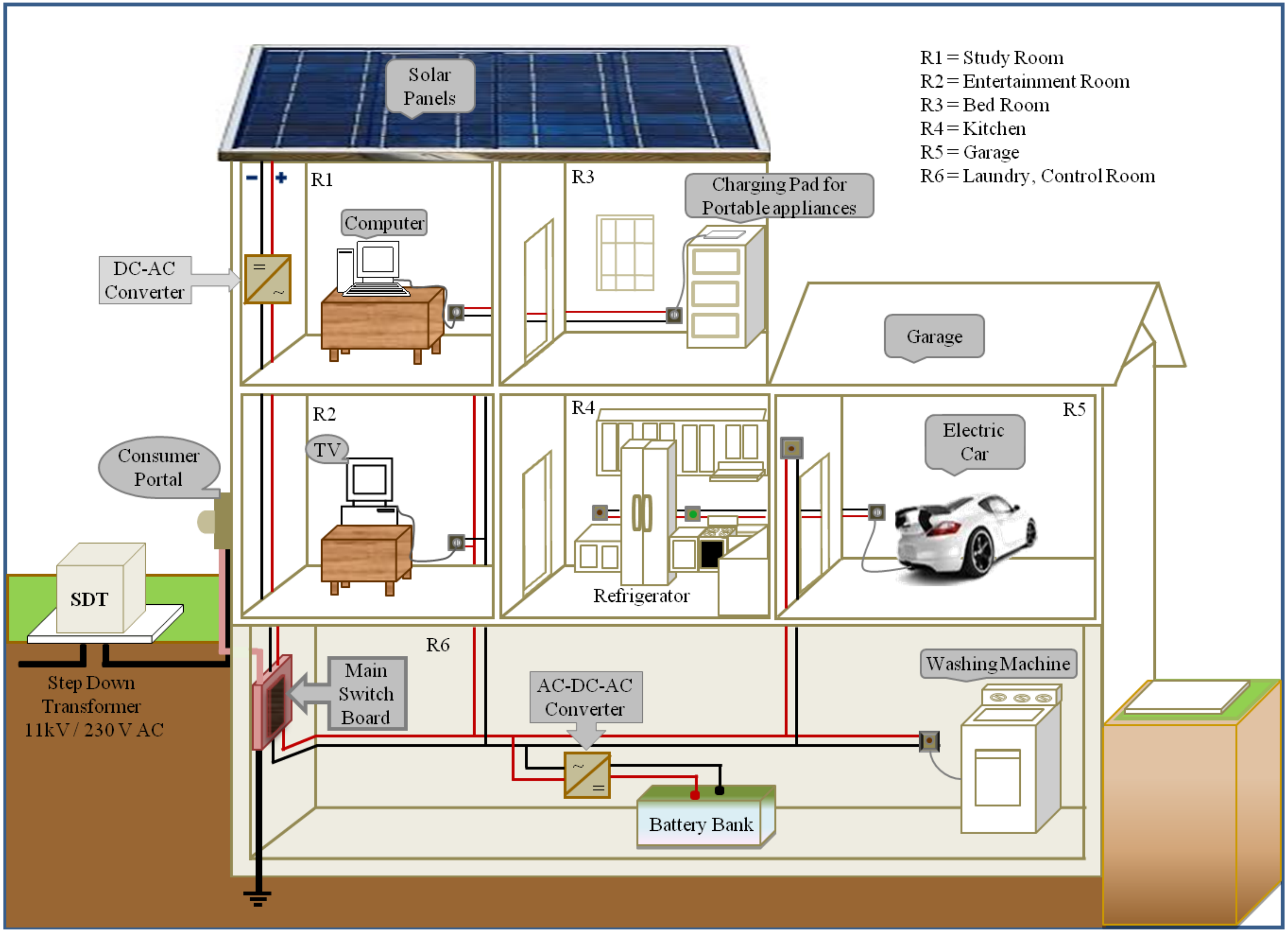
  An electrical power system as described in the two universal points of agreement that serves more than one building.

MicroGrid



ELECTRIC GRID
ENERGY STORAGE
POWER ELECTRONICS INTERFACE(S)
POWER ELECTRONICS INTERFACE(S)
WIND GENERATORS
PV MODULES
POWER ELECTRONICS INTERFACE(S)
MICROGRID
POWER ELECTRONICS INTERFACE(S)
AC LOADS
POWER ELECTRONICS INTERFACE(S)
DC LOADS
MICROTURBINES
FUEL CELLS
CONTROLLER
BY-PRODUCTS

AC Distribution System for Residentail Buildings



Why Continue to Use AC Distribution System?

DC Energy Sources

❖ **Energy Storage**

- ✓ Battery
- ✓ Electrical Vehicles

❖ **Renewable Energy Sources**

- ✓ Solar Photovoltaic
- ✓ Wind
- ✓ Small Hydro Power Plant

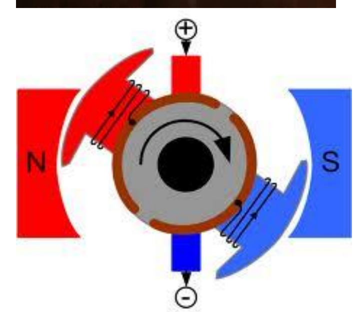
DC Appliances

❖ **Lighting**

- ✓ LEDs, 10 to 100 times more efficient as compared to tungsten bulb, use only DC power
- ✓ CFL is neutral to AC or DC power

❖ **Motor**

- ✓ The micro-grid applications utilizes BLDCs
- ✓ Conventional DC machines need brush replacement – but not anymore



Other Appliances

- Fan is primarily a motor
  - A dc fan also allows better speed control
- Refrigerator is essentially a motor
- Air-Conditioner is primarily a motor
- Washing-Machine / grinder is a motor

- **Electronics**
  - ✓ All electronics (Mobiles/TV/Computers) use low voltage DC
  - ✓ Need a ac/dc power adaptor to charge

Note: These appliances power supplies with small transformers , which have only 60-70% energy efficiency.

Advantage of DC System

- A DC system requires only two conductors as compared to three for AC system.
- A DC system has no inductance as a result the voltage drop in DC system is less than that of AC system for same load and hence a better voltage regulation.
- A DC system has no skin effect so we can utilize entire cross section area of the line conductor.
- A DC system requires less insulation than an AC system because of less potential stress for same working voltage.

Advantage of DC System Cont…

- Absence of capacitance in DC system leads to less power loss because there is no need for charge and discharge of capacitance.

- DC system reduces the amount of resistance in the line.

- Use of non-conventional energy like wind and solar reduce the carbon emission in the atmosphere.

- The Power Quality is not a issue.

Advantages of a DC Bus rather than Conventional AC Bus

- It is easier to enhance the capacity of the system by adding additional DC power generating sources like PV, fuel cell, wind turbine and the integration is much easier than the integration in AC bus.
- System reliability is higher. In AC bus system, if any power generating source like an alternator fails, there is a good chance of circulating current to flow though the alternator and there is a big impact on the system.
- DER ability to inject *fault current contributions and power* into the utility system, a dc approach is an interesting way to prevent such injections.

Advantages of a DC Bus rather than Conventional AC Bus Cont…

- However, in common DC bus, every power-generating source can be isolated using diodes and they are able to share the power independently.
- The dc approach is able to avoid almost all of the key complications of interconnection because they isolate the generation from the grid.
- The blocking diode prevents power injection into the ac system during both steady state and transient system conditions.
- No fault contributions, or reverse power injection from the dc system into the ac power system.
- Ripple management can be accomplished by adding more capacitors in the DC bus.

DC System Parameters

- Single phase system: $V_{dc} = \sqrt{2} \times V_{ac}$ Volt
- Three phase system: $V_{dc} = \frac{3\sqrt{3}}{\pi} V_P$ Volt
- Current $I = \frac{P}{V}$ Ampere
- Power Loss $p = I^2 R$ Watt

DC Voltage	AC Voltage	Reduction in Current Rating	Reduction Power losses
325	230	29.24%	50.07%
325	110	66.15%	88.54%

Where V_{dc} = DC system voltage, V_{ac} = AC System Voltage; I = System Current ;

R = Line resistance; P = Power transfer; V_p = peak value of the phase (line to neutral) input voltages

Total Daily Load (TDL)

- TDL with DC System for Fixed Load: $\Gamma = \frac{k}{v_{dc}} \times \chi$ Ampere hour

- TDL with DC System for Variable Load: $\Gamma = \sum_{\delta=1}^{\Omega} \gamma_{\delta} \chi_{\delta}$ Ampere hour

- TDL with DC System for AC Load: $\Gamma = \frac{\mu \times {v_{ac}}/{v_{dc}}}{\eta_{inv}} \times \chi$ Ampere hour

Γ = Total Daily Load ; $\gamma_1, \gamma_2, \dots \gamma_{\Omega}$ = DC Loads in Ampere

χ = Number of operating hours per day, k = Load rating in kW

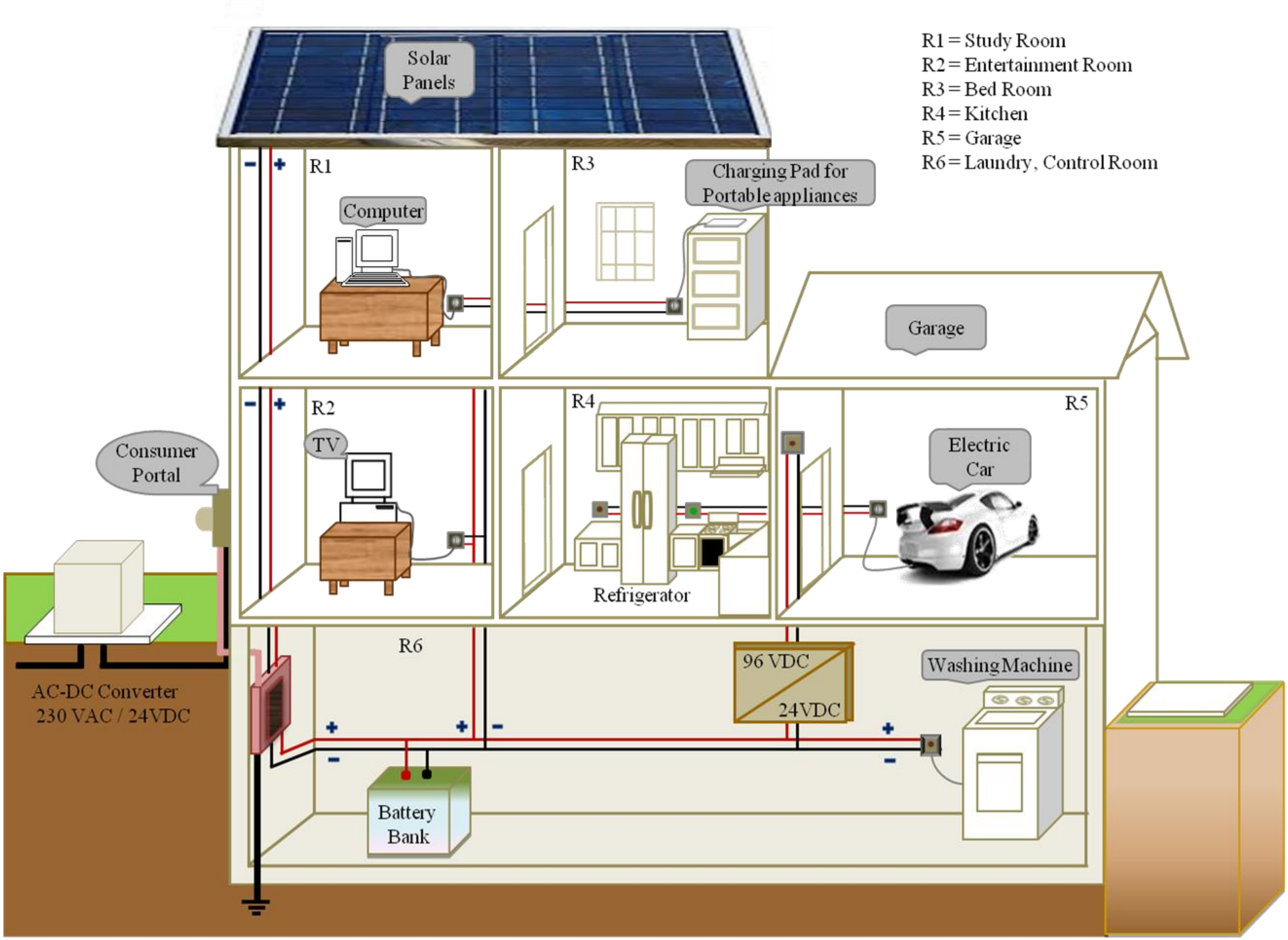
v_{dc} = DC System voltage , v_{ac} = Rated voltage of AC Load, η_{inv} = Inverter efficiency

μ = AC Load in ampere at rated system voltage , Ω = Number of Loads

Total Daily Load for different AC and DC Loads

S.N	Load		Load Power Rating (kW)	Inverter Efficiency	Total Daily Load (Ah)
	AC	DC			
1.	-	24	2.4	-	2400
2.	-	48	2.4	-	1200
3.	120 V	-	2.4	92%	2608.7
4.	220	-	2.4	92%	2608.7
5.	110	-	2.4	95%	2526.32

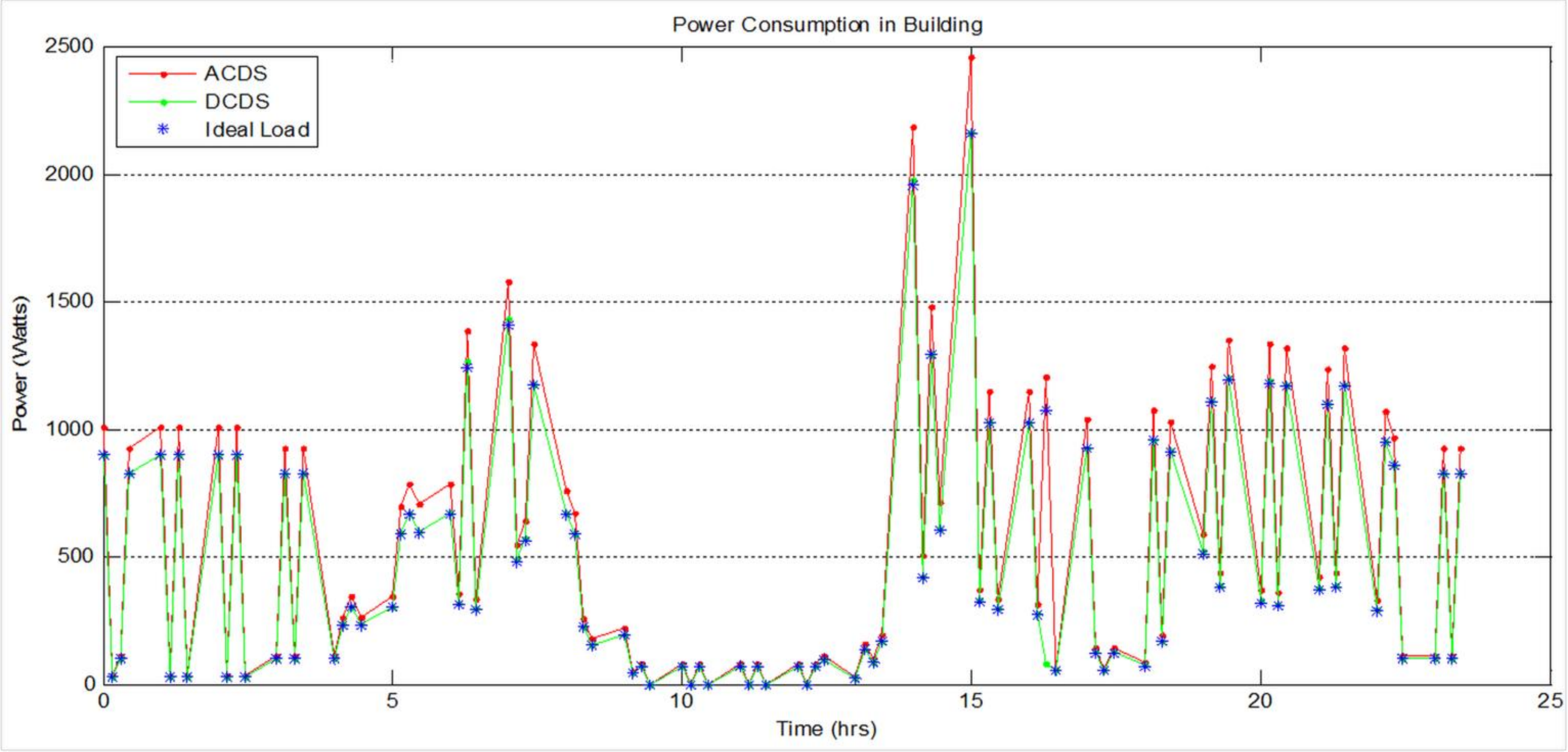
DC Distribution System for Residential Buildings



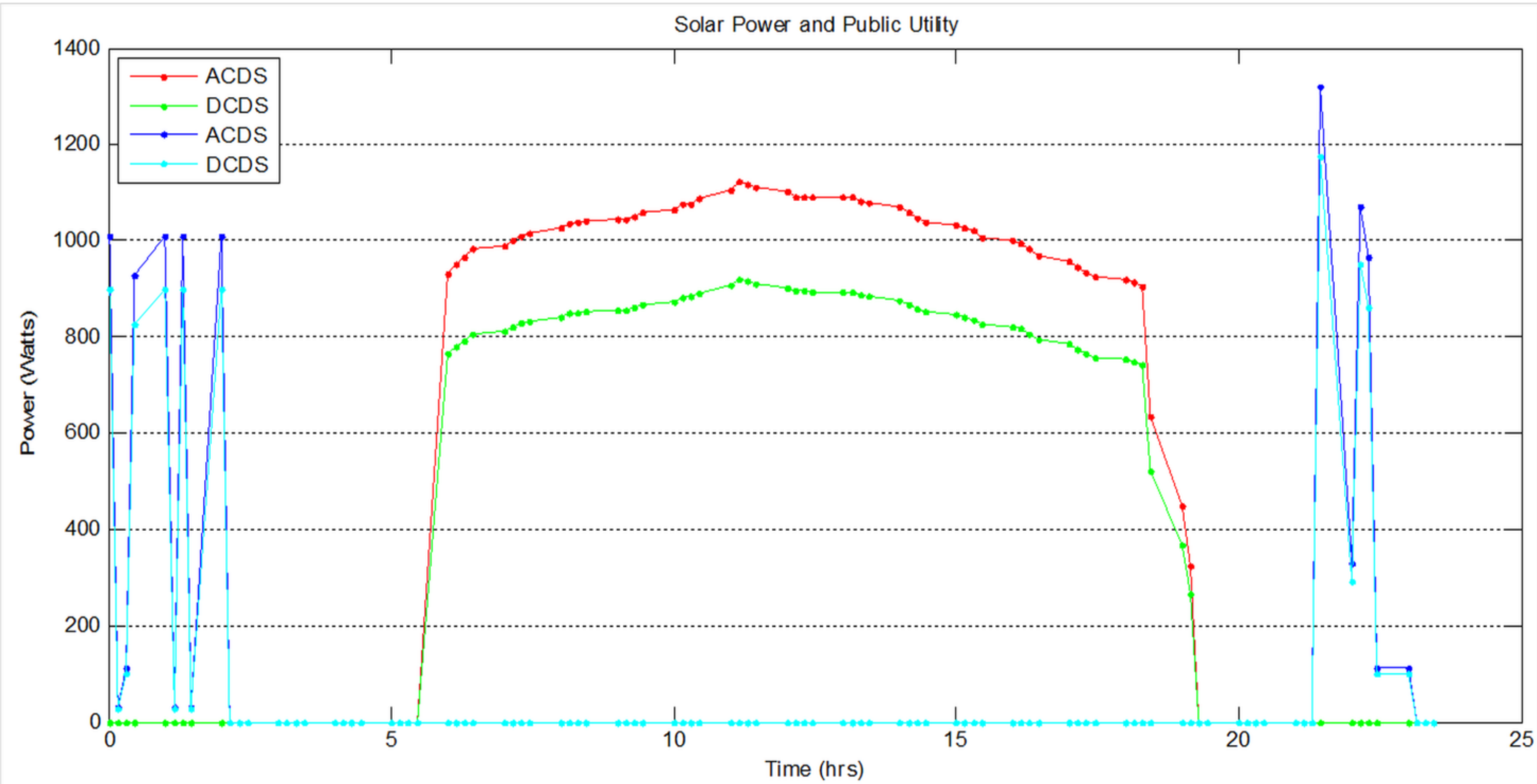
System Specifications

- ✓ **PV Panel ratings**
  - ❖ Voltage :24 Volt DC
  - ❖ Power rating: 1.8kW
- ✓ **Battery Details**
  - ❖ Battery Bank: 4*150=600AH
  - ❖ Voltage Level: 12 Volt
- ✓ **Power ratings of Converters:**
  - ❖ AC-DC :1.5kW
  - ❖ DC-DC : 1.5kW

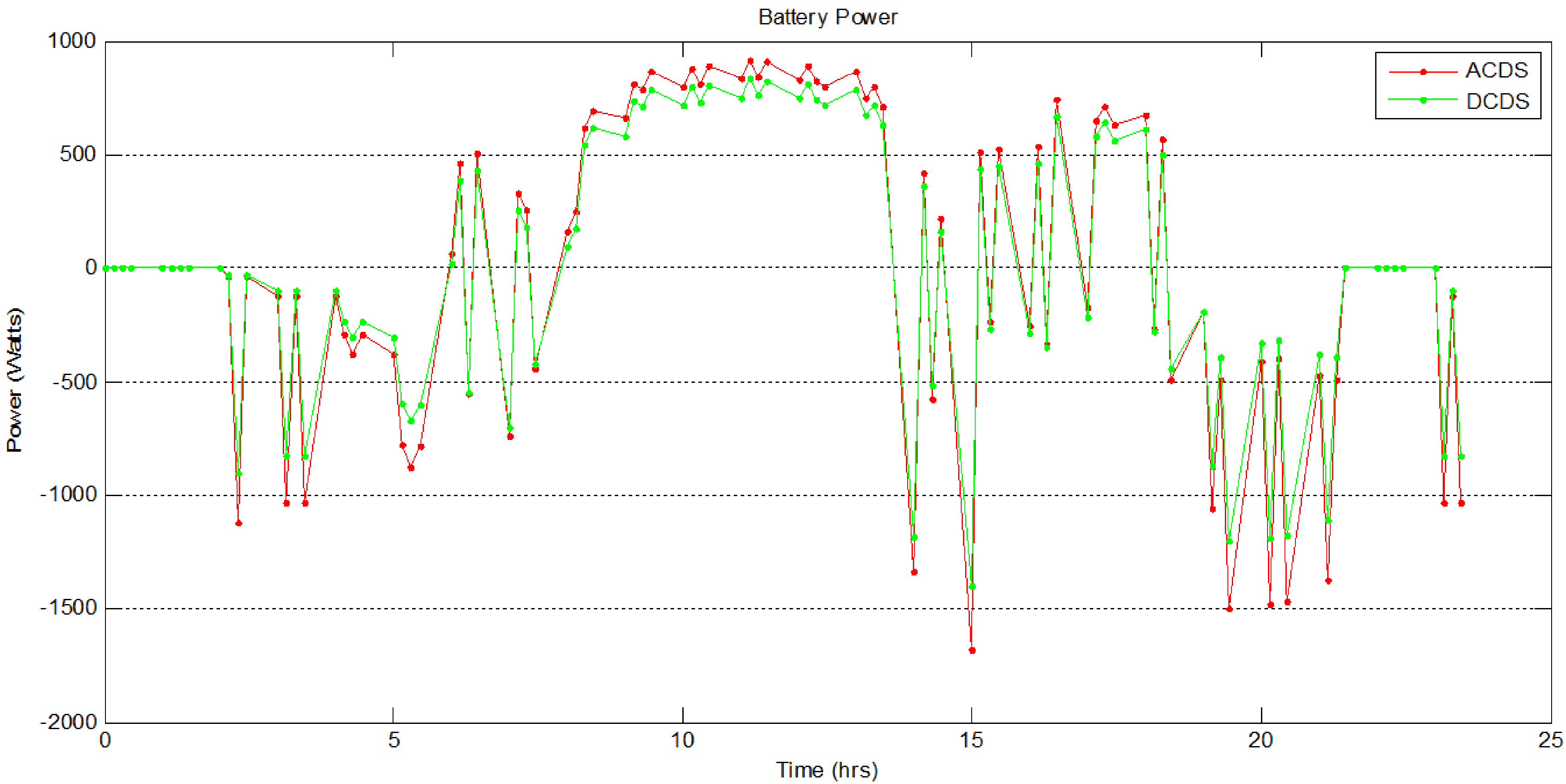
Power Consumption for ACDS and DCDS



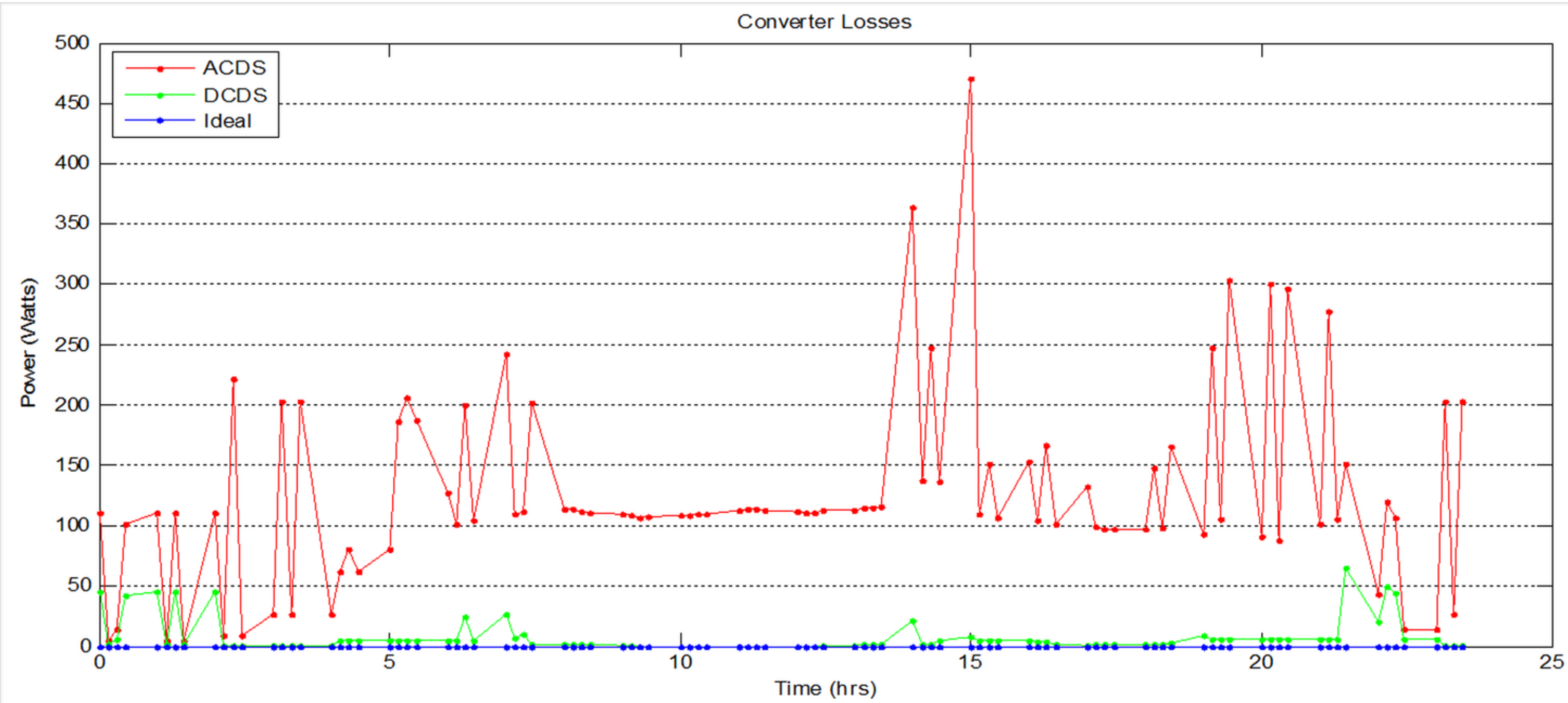
Power Consumption from PV and PU for ACDS and DCDS



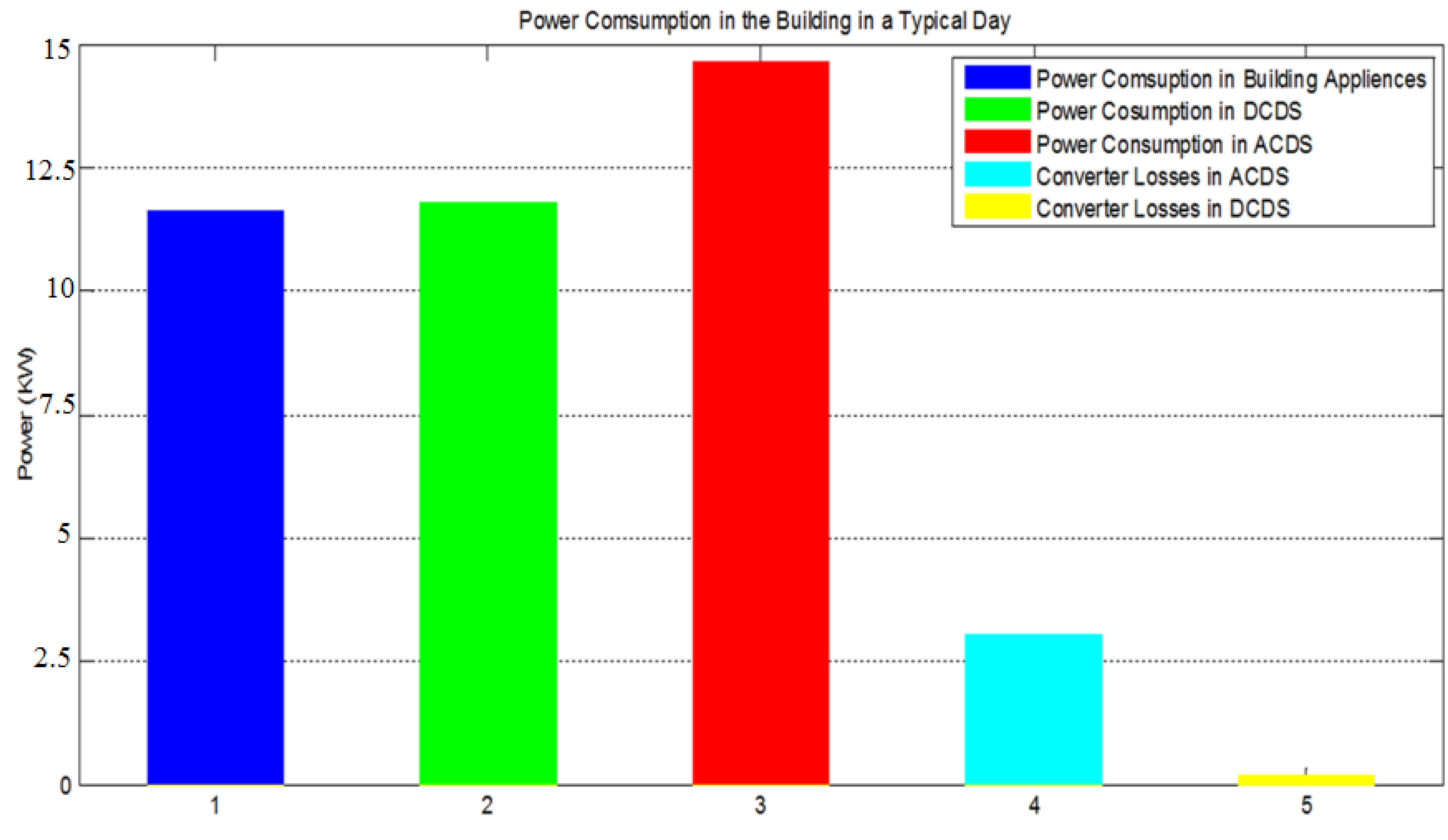
Battery Bank Power Curve for ACDS and DCDS



Converter Losses for ACDS and DCDS



Total Power Consumption and Converter Losses for ACDS and DCDS



Conclusion

- Number of conversion stages becomes less in DCDS over ACDS.
- The power consumption in DCDS is less over ACDS.
- The converter losses in ACDS are approximately 6 times higher than DCDS.
- DCDS required small size of PV panel and Battery Bank than ACDS.

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Thanks!