THE UNIVERSITY OF ZAMBIA

SERVICE AND EXCELLENCE

EEE 5451 Power Electronics

Lecture 1: Introduction

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1.1 Course Description

- This course is designed to provide final-year electrical engineering students with an in-depth understanding of advanced concepts and applications in power electronics.

- Through a combination of theoretical lectures, practical demonstrations, and hands-on projects, students will gain the knowledge and skills necessary to analyze, design, and implement power electronic systems for modern electrical engineering applications.

- Topics covered will include power semiconductor devices, converter topologies, control techniques, and emerging trends in power electronics.

1.2 Course Outline

1. Introduction to Power Electronics
- ❖ Overview of power electronic systems
- ❖ Importance and applications in modern electrical engineering
- ❖ Review of basic principles of electricity and magnetism

2. Power Semiconductor Devices
- ❖ Characteristics and operation of diodes and thyristors
- ❖ Bipolar Junction Transistors (BJTs) and Insulated Gate Bipolar Transistors (IGBTs)
- ❖ MOSFETs and their applications in power electronics

3. Converter Topologies
- ❖ Single-phase and three-phase AC-DC converters
- ❖ DC-DC converters: Buck, Boost, Buck-Boost, and Cuk converters
- ❖ DC-AC inverters: Voltage source inverters (VSI) and Current source inverters (CSI)

4. Control Techniques in Power Electronics
- ❖ Pulse Width Modulation (PWM) techniques
- ❖ Voltage and current control strategies
- ❖ Closed-loop control and feedback mechanisms

5. Advanced Topics in Power Electronics

- ❖ Multilevel converters
- ❖ Resonant converters
- ❖ Soft-switching techniques
- ❖ Applications in renewable energy systems and electric vehicles

6. Specific Applications

- ❖ Converter harmonic calculations and filter technologies.
- ❖ Motor drive applications
- ❖ Residential, industrial and utility applications

7. Simulation and Design Projects

- ❖ Use of simulation tools (such as MATLAB/Simulink or PLECS) for power electronics design
- ❖ Design and implementation of power electronic circuits
- ❖ Analysis of performance and efficiency

Recommended Books:

1. "Power Electronics: Converters, Applications, and Design" by Ned Mohan, Tore M. Undeland, and William P. Robbins. (Latest)
2. "Fundamentals of Power Electronics" by Robert W. Erickson and Dragan Maksimović. (Latest)

- **Time Allocation:** 4 hour lectures + 3 hours laboratory/tutorial per week.

Assessment:

Assignments	5 %	(8 in total)
Laboratory	15 %	(6 in total)
Test	20 %	(Closed-book)
Examination	60 %	(Closed-book)

1.3 EEE 5451 Labs

- With the aid of numerous experiments and animations, the UniTrain-I multimedia course gives the student insight into the latest important issues relating to power engineering.

- The fundamentals of DC, AC and three-phase technology as well as processes in distribution networks are some of the subjects dealt with in the various Labs.

- Typical processes that occur in the generation and distribution of electrical power receive particular close attention and are reproduced in the experiments using safe extra-low voltages.

1.4 Basics of electrical engineering

DC technology

AC technology

Three-phase technology

Magnetism/electromagnetism

Measurements with the multimeter

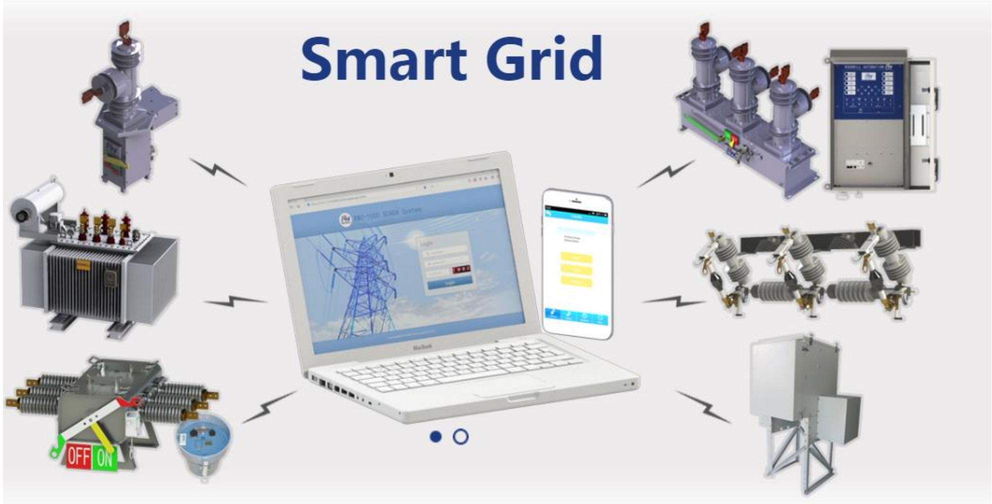
1.5 Background

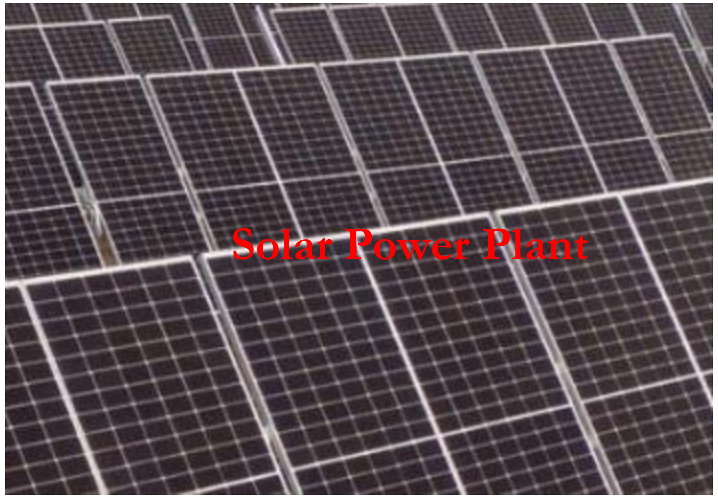
- **Power electronics** is a branch of electrical engineering that deals with the control and conversion of electrical power using electronic devices such as diodes, transistors, and thyristors.

- It involves the design, analysis, and implementation of circuits and systems for efficiently controlling and converting electrical energy between different forms, such as AC to DC, DC to AC, DC to DC, and AC to AC.

- **Power electronics** is crucial in various applications, including power supplies, renewable energy systems, electric vehicles, industrial motor drives, and more..

1.5.1 Overview of Power Electronic Systems





Trolley Assist Technology

1.6 Trolley Assist Technology

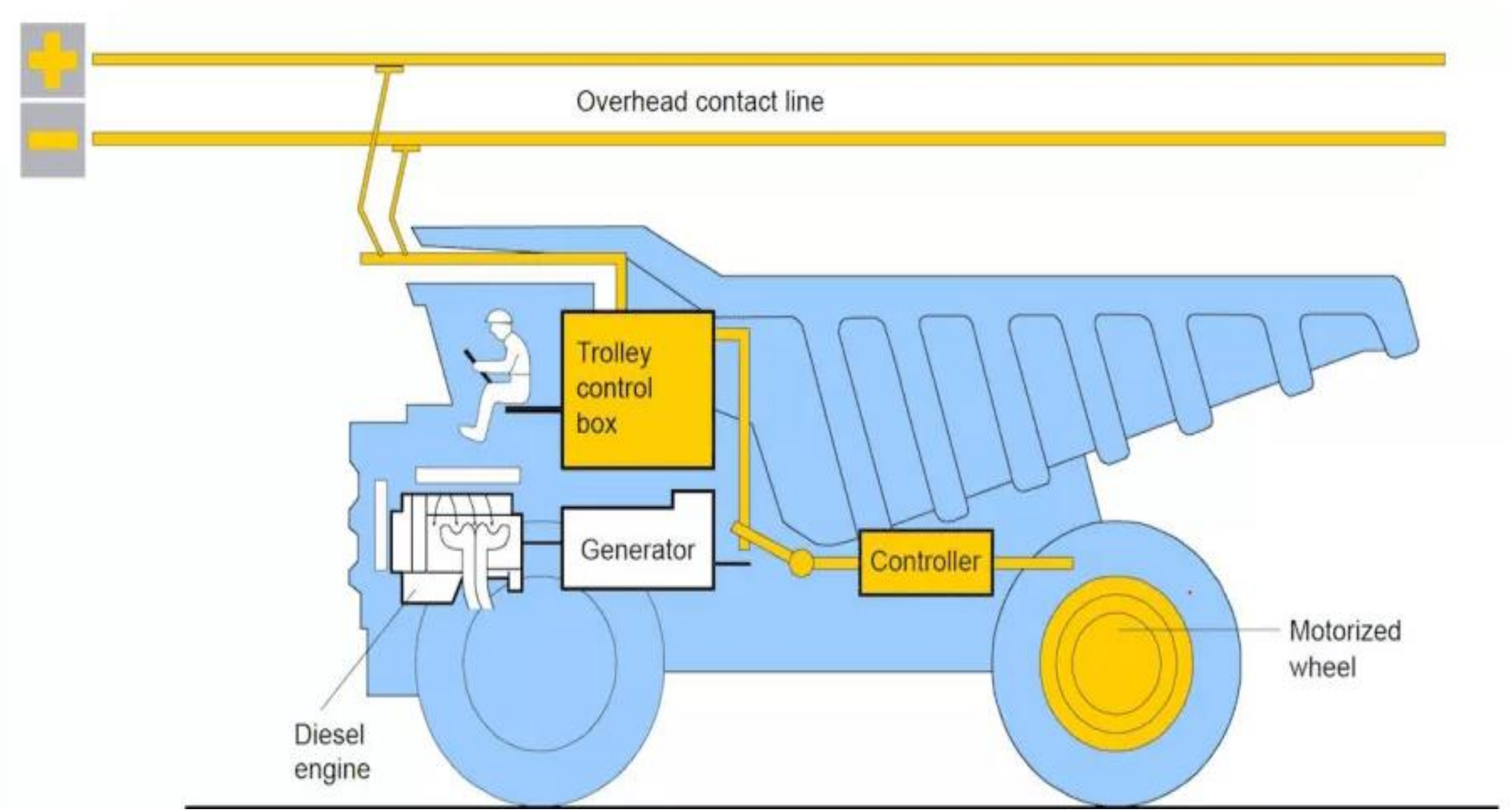
- The future of electrification is spreading throughout the world, as a major player in technological advancement, mining has looked at electrification in enhancing mining production. To haul loads of earth, mines utilize large dump trucks operated using a diesel engine coupled to an alternator.

- To increase the productivity of diesel-electric dump trucks, there is a consideration of utilizing DC power from an overhead line to power large mining dump trucks eliminating the diesel engine power thus supplying power to the inverter circuit directly. To take advantage of this development, a technology known as Trolley Assist was inverted.

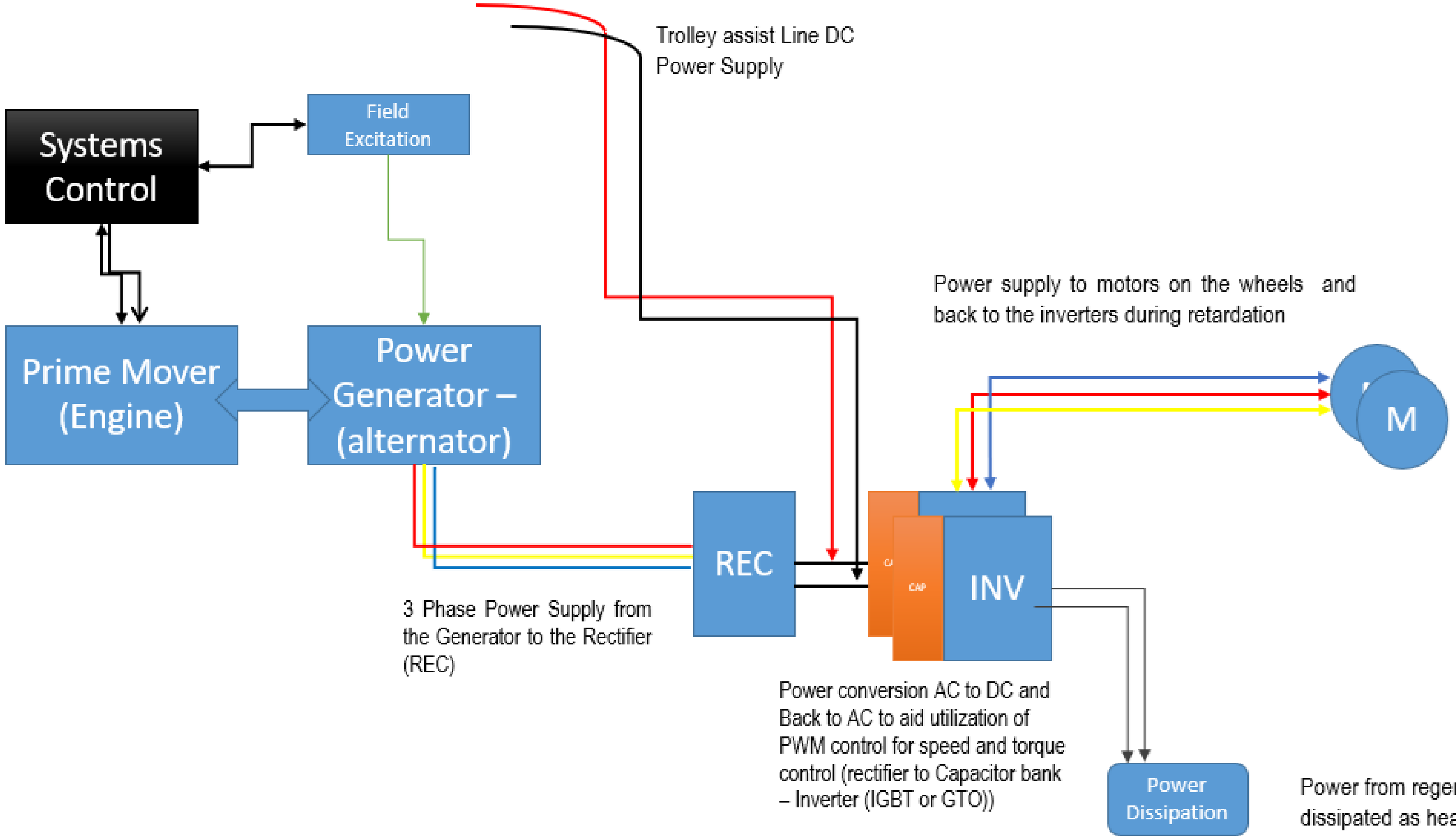
- Diesel- electric haul trucks utilize Trolley Assist. This is a system in which haul trucks in open pit mines are propelled by electric energy along a designated haul road segment usually an incline.

- Diesel –Electric Haul Trucks have a capability to load up to 320 tonnes (320,000 Kg) of mining material.

1.6.1 Design of Machine - Illustration



1.6.2 Power Flow - Machine



Systems Control

Field Excitation

Prime Mover (Engine)

Power Generator – (alternator)

REC

CAP

INV

M

Power Dissipation

Trolley assist Line DC Power Supply

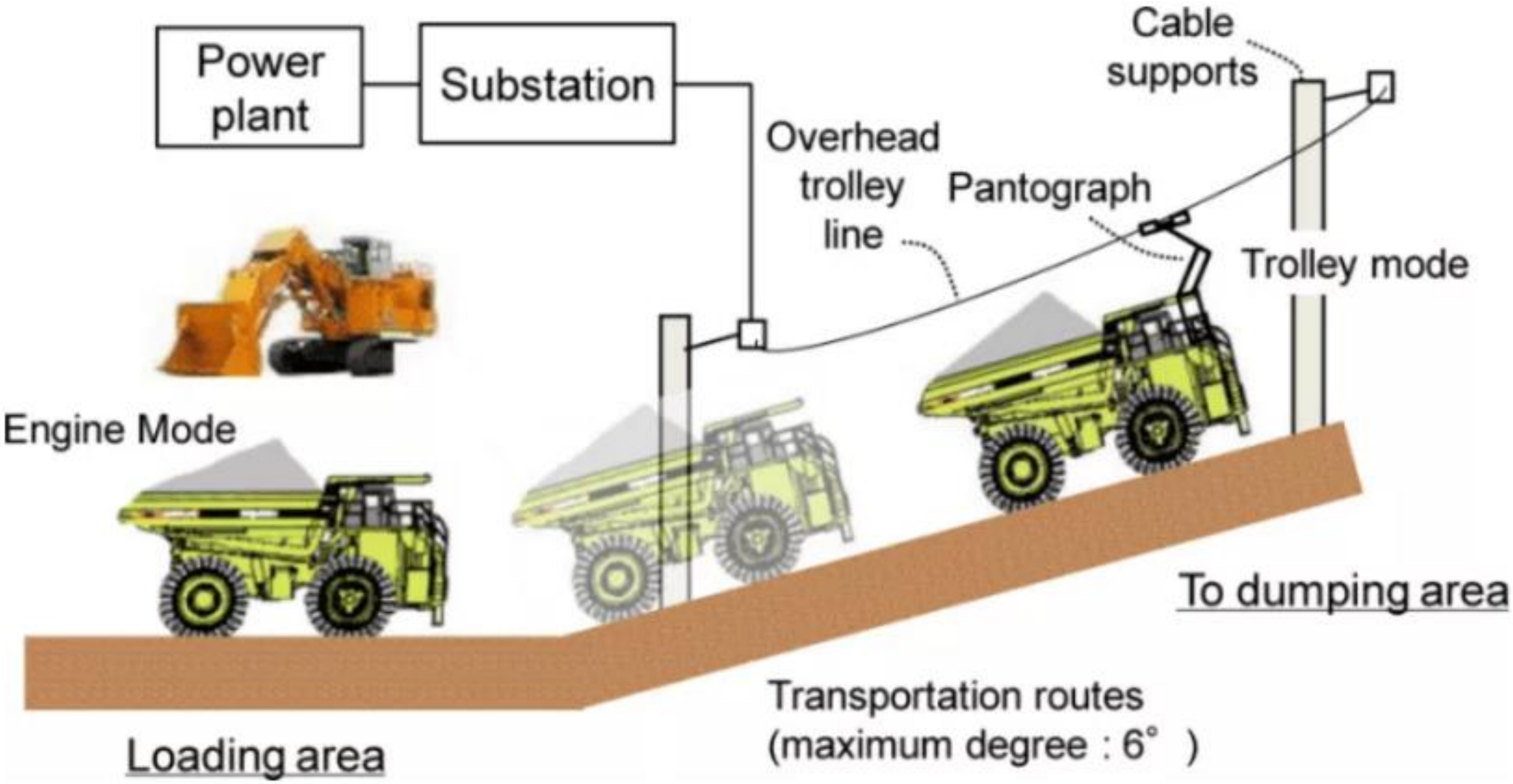
Power supply to motors on the wheels and back to the inverters during retardation

3 Phase Power Supply from the Generator to the Rectifier (REC)

Power conversion AC to DC and Back to AC to aid utilization of PWM control for speed and torque control (rectifier to Capacitor bank – Inverter (IGBT or GTO))

Power from regenerative braking is dissipated as heat energy in the Diesel-electric arrangement

1.6.3 Power Flow: Substation to Machine



- When Trolley mode is selected the diesel engine RPM increases to maximum but power supply to the rectifier from the alternator is cut. Power is now supplied via trolley to the DC link between the Rectifier and the inverter. Under trolley the engine is running, but not utilized until the trolley mode end is selected.

1.6.4 Pros and Cons

Travel uphill nearly 2X faster

Extend engine life

Reduce CO2 emissions

Burn 70% less fuel

Improved fleet productivity with shorter mine cycle times and maintenance schedules

Setting the foundation for building towards zero-emissions future

High Operation Cost

Labor Intensive

Mine Haul Roads require constant maintenance

Extra investment due to the Installation of Trolley line Systems.

1.6.5 Where is this Technology Currently?

Manufacturer & Make	Mine & location	Type of surface mines
Komatsu 830E-5	Copper Mountain, Canada	Open-pit copper
Komatsu 830E-5	Aitik mine, Sweden	Open-pit copper
Hitachi EH3500ACII	Lumwana mine, Zambia	Open-pit copper
Hitachi EH4500-II		
Komatsu 850E-5		
Hitachi EH3500ACII	Kansanshi mine, Zambia	Open-pit copper and gold
Hitachi EH3500ACIII		
Komatsu 730E	Rossing mine, Namibia	Open-pit uranium
Komatsu 850E-5	Kevitsa mine, Finland	Open-pit copper and nickel
Liebherr T 284	Sentinel mine, Zambia	Open-pit copper
Liebherr T 284	Cobre mine, Panama	Open-pit copper
BELAZ 75306	Solntsevsky mine, Russia	Underground coal
Liebherr T 236	VA Erzberg mine, Austria	Open-pit iron ore
Komatsu 930E-5	Penasquito mine, Mexico	Open-pit gold

1.7 Electric Utilities

- ✓ High-voltage DC (HVDC) transmission lines have come into service through the advent of power electronics.

- ✓ These have an advantage over AC lines in that they are free from capacitive effects and phase shifts that can cause regulation problems and impair system stability on faults.

- ✓ An early HVDC transmission line ran from BPA sites in Washington to Sylmar, CA, a few miles north of Los Angeles, to supplement the AC Pacific Intertie. It is rated 1200 MW at ±400 kVdc.

- ✓ A significant advance in system stability has come from the development of FACTS converter systems.
- ✓ This acronym for *flexible AC transmission systems* describes power electronics control systems that are able to effect very rapid changes in system voltages and phase angles.
- ✓ Voltages can be maintained through fault swings, and power oscillations can be damped.
- ✓ System stability can be maintained even with increased transmission line loadings.
- ✓ FACTS installations can defer or eliminate the need for additional transmission lines that are difficult to install because of environmental concerns, permitting processes and right-of-way costs.

1.7.1 HVDC Electricity Transmission

- Modern thyristors can switch power on the scale of megawatts.
- Thus, thyristor valves are the heart of high-voltage direct current (HVDC) conversion either to or from alternating current.
- For very high power applications, both electrically triggered (ETT) and light triggered (LTT) thyristors are still the primary choice.
- The valves are arranged in stacks usually suspended from the ceiling of a transmission building called a valve hall as depicted in the figure.

Manitoba Hydro Thyristor Valves

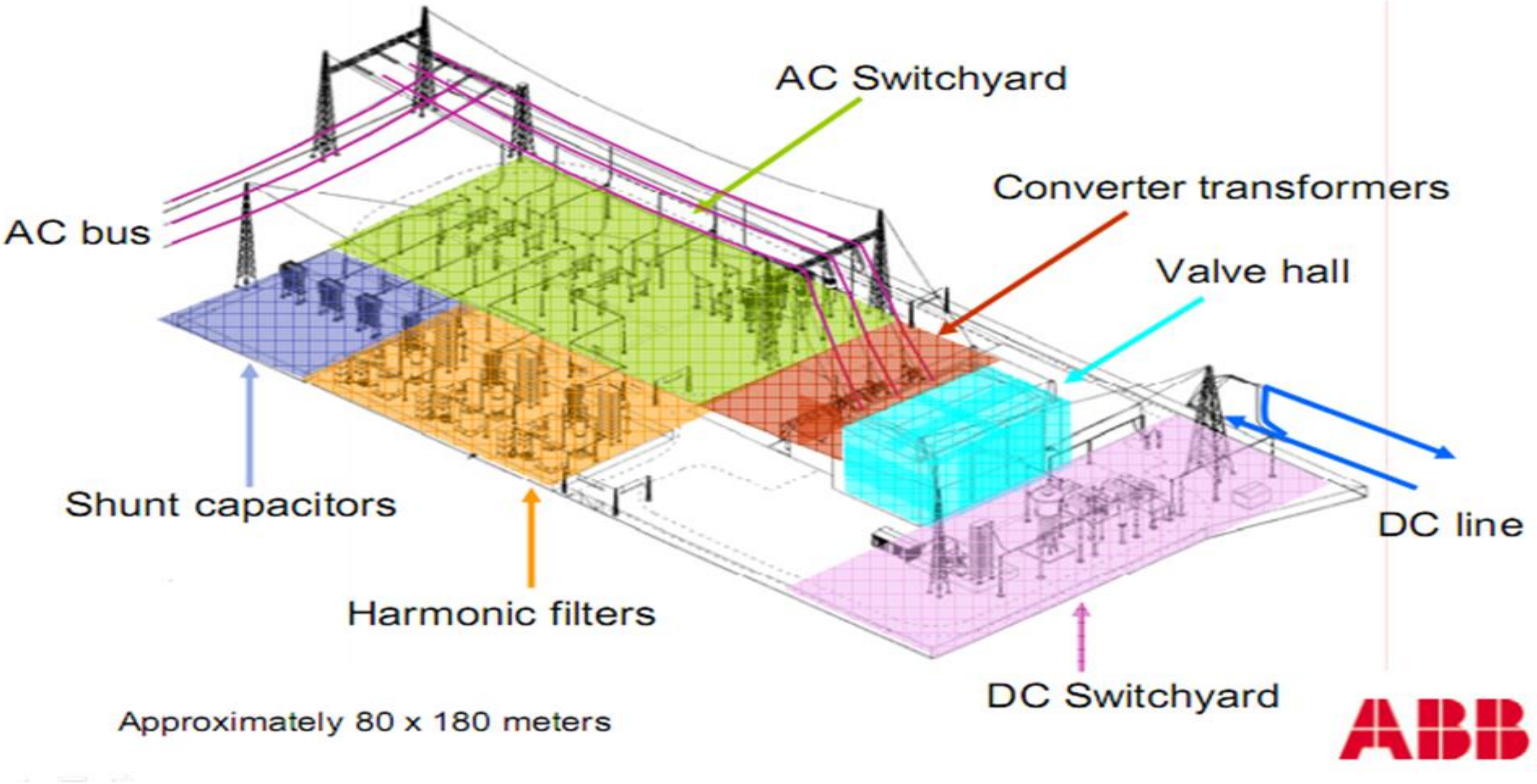
Converter Substation in Southern Manitoba

- Thyristors are arranged into a diode bridge circuit and to reduce harmonics are connected in series to form a 12 pulse converter.

- Each thyristor is cooled with deionized water.

- In low and medium power (from a few tens of watts to a few tens of kilowatts) they have virtually been replaced by other devices with superior switching characteristics like MOSFETs or IGBTs.

1.7.2 Monopolar Converter Station, 600 MW, 450 kVDC



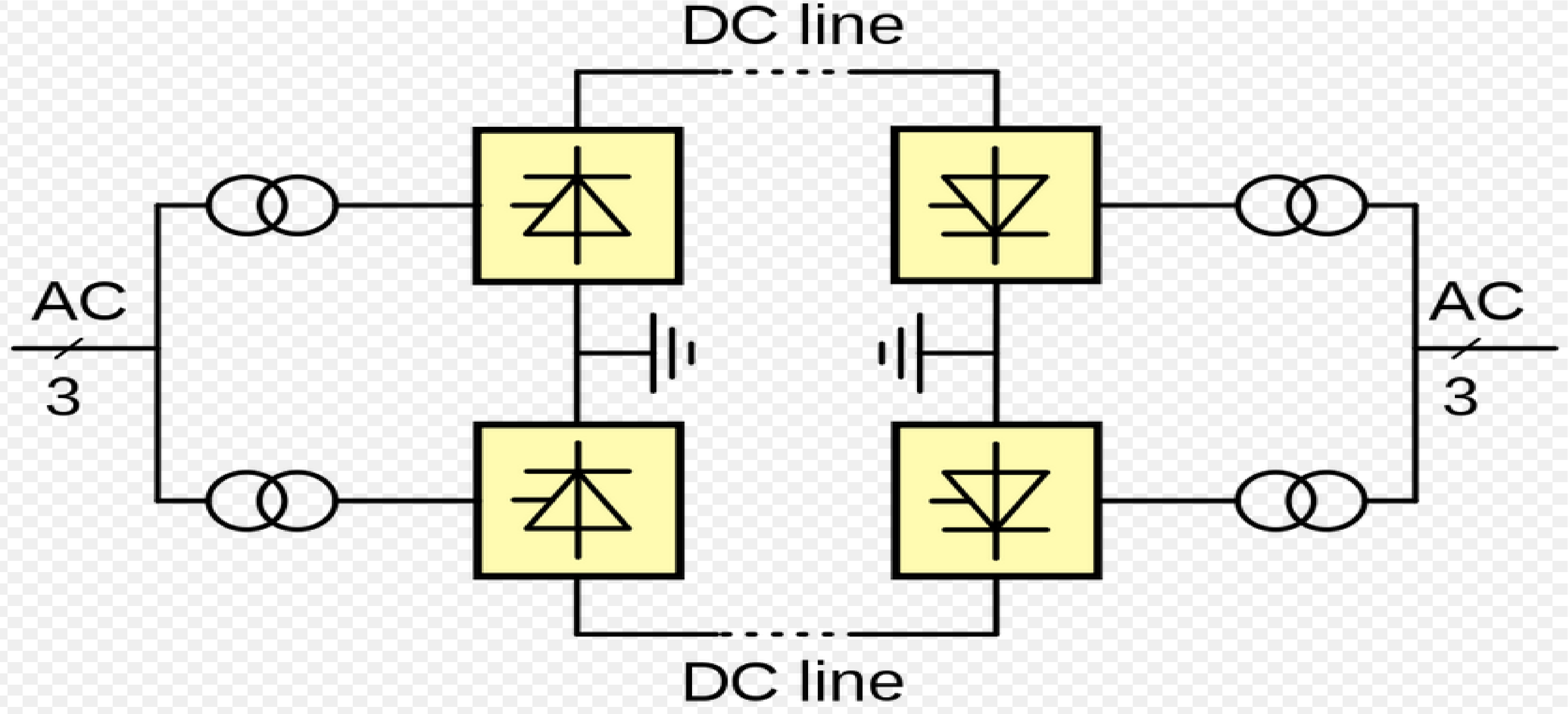
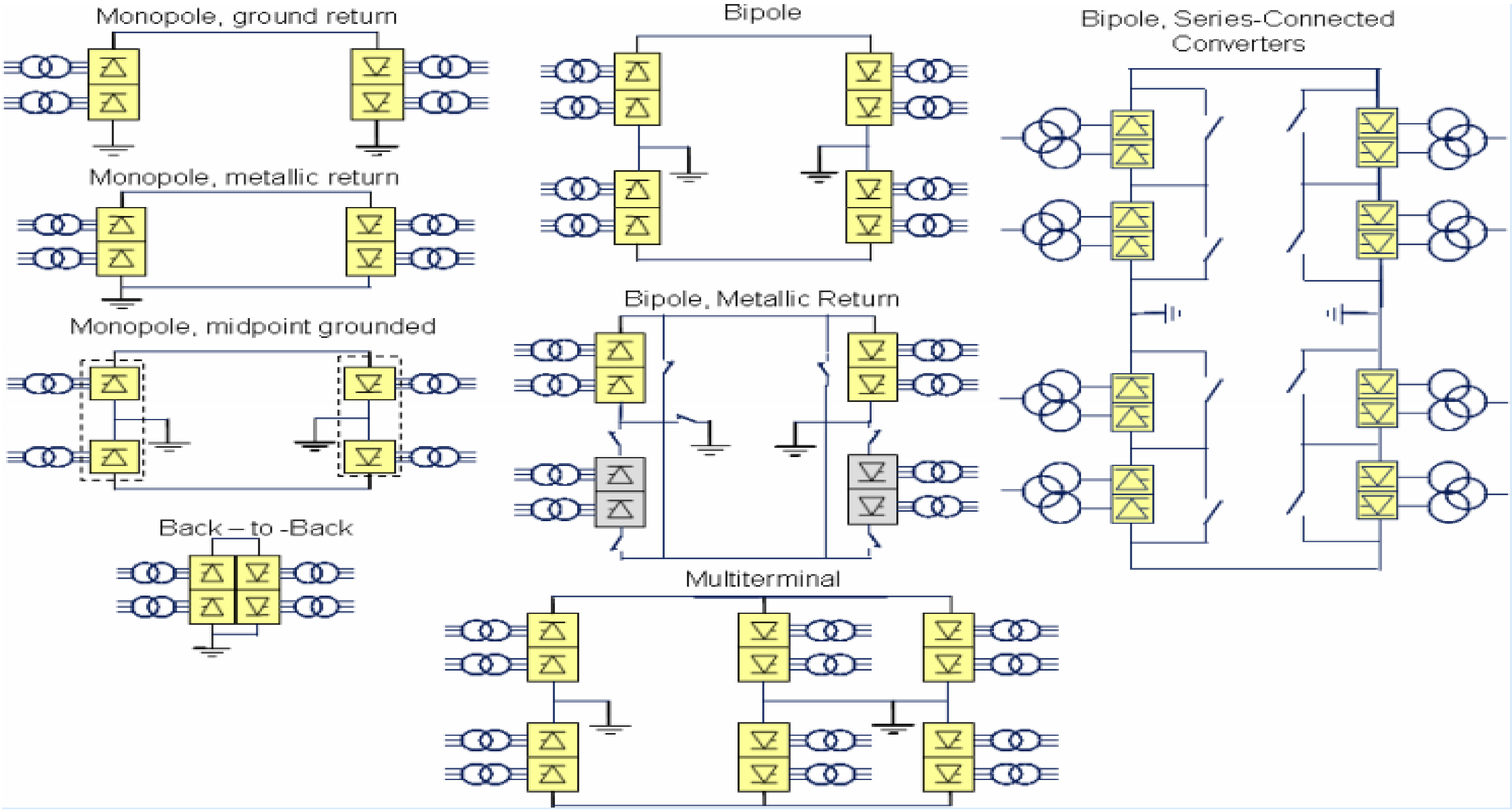
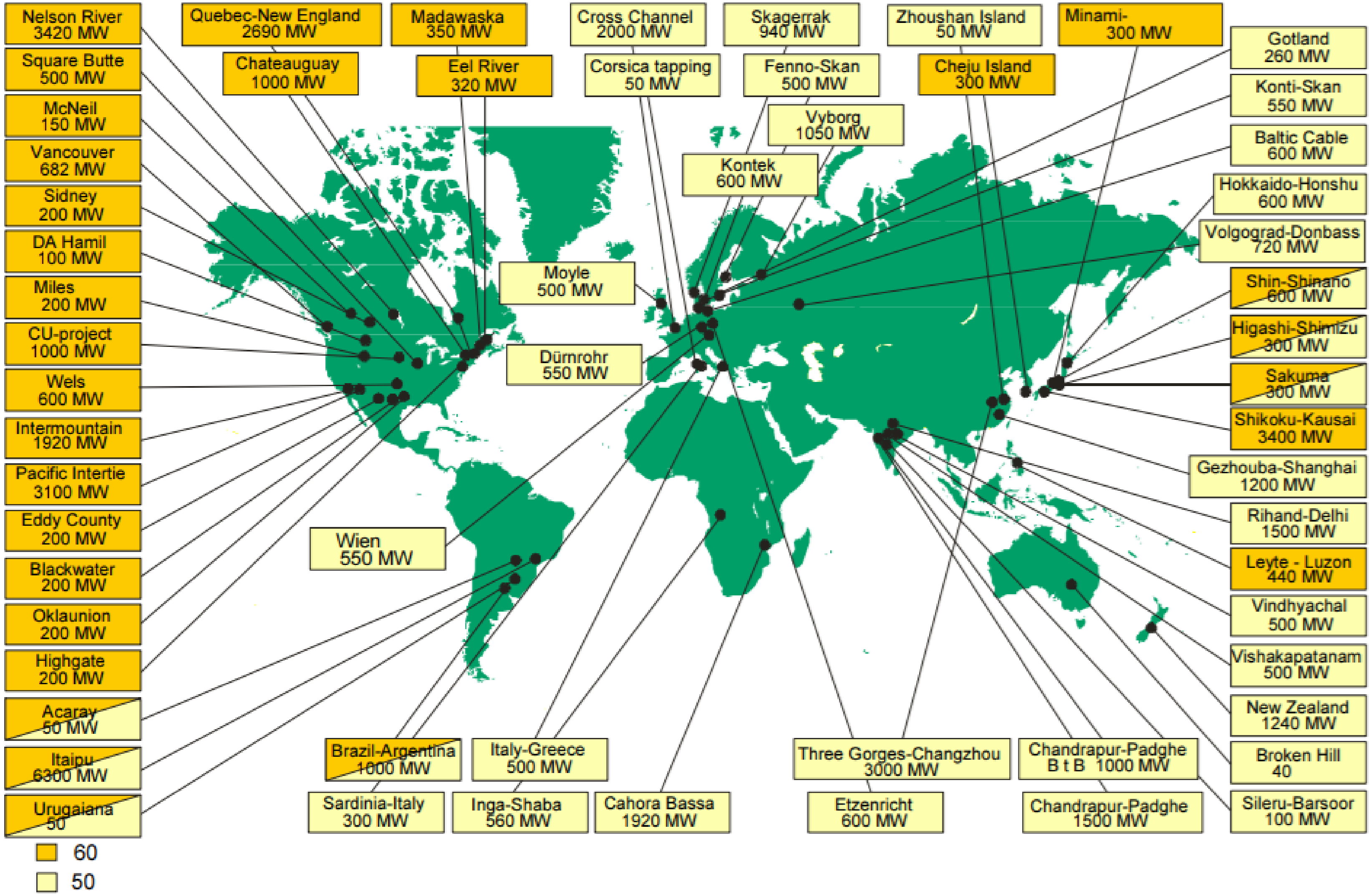


Fig. 1.13 - Block diagram of a bipolar system with ground return as used on ±800 kV UHVDC the Xiangjiaba–Shanghai project

1.7.3 HVDC Operating Configurations and Modes



1.7.4 HVDC Installations around the World



- The Cahora Bassa HVDC system is used to transmit the power generated in a hydroelectric plant on the Zambezi river in Mozambique to South Africa.
- Power rating: 1,920 MW, bipolar
- Type of plant: Long-distance transmission, 1,456 km
- Voltage levels: ±533 kV DC, 220/275 kV, 50 Hz

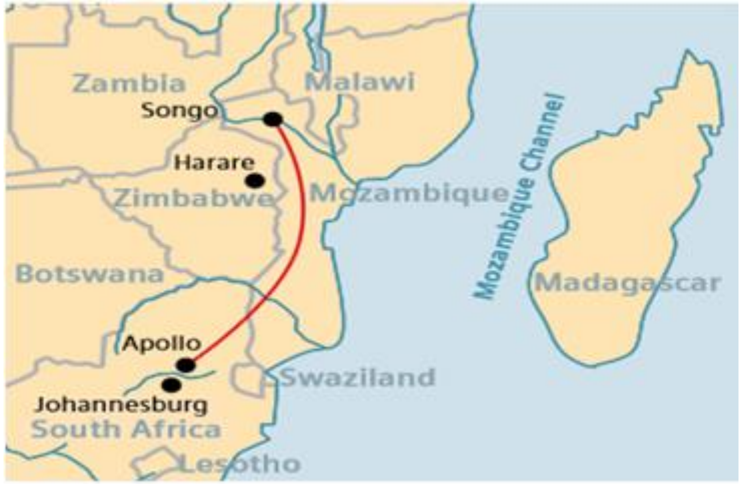


Fig. 1.16 - The Cahora Bassa HVDC system

- Type of thyristor: Electrically-triggered-thyristor, 1.65 kV/2.5 kV
- Commissioned in 1975.

1.7.5 Core Technologies

1. HVDC Classic

- Current source converters used
- Line-commutated thyristor valves used
- Requires 50% reactive power compensation (35% harmonic filtering)
- Converter transformers used
- Minimum short circuit capacity>2×converter rating, >1.3×with capacitor commutation.

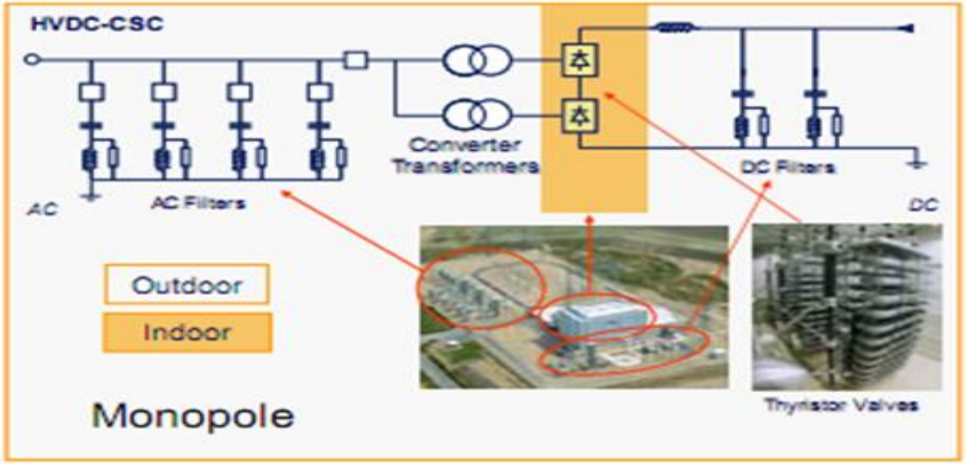


Fig. 1.17 - HVDC Classic

2. HVDC Light

- ➢Voltage source converters used
- ➢Self-commutated IGBT valves used
- ➢Requires no reactive power compensation (~15% harmonic filtering)
- ➢Standard transformers used
- ➢More compact

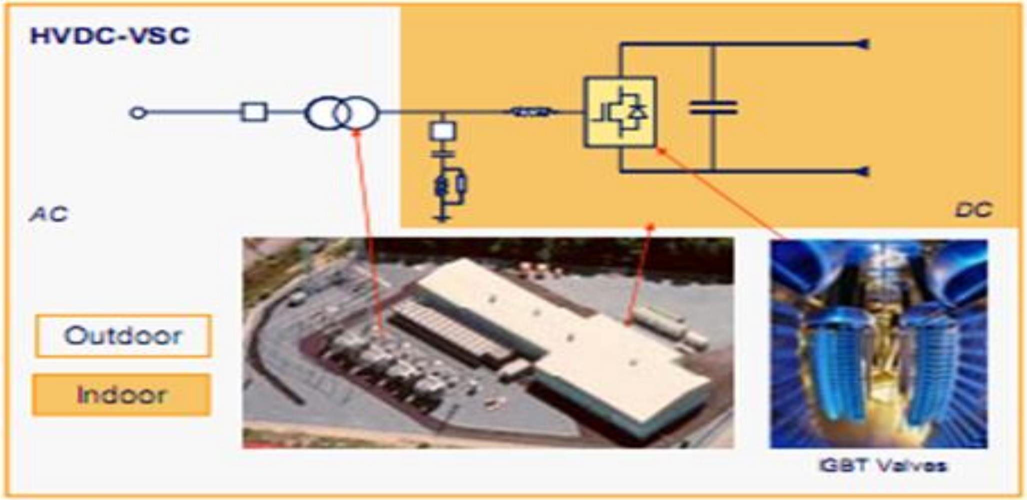


Fig. 1.18 - HVDC Light

1.7.6 Transmission Line Delivery Capability

1. AC Line Distance Effects

- ➢Intermediate switching stations required, e.g. about every 400 km maximum.
- ➢Lower stability limits (Voltage, angle).
- ➢Increase stability limits and mitigate parallel flow with FACTS: SVC & SC.
- ➢Higher reactive demand with load and higher charging at light load.
- ➢Parallel flow issues more prominent.
- ➢Thermal limit remains the same.

2. DC Line Distance Effects

- No distance effect on stability (Voltage, angle).
- No parallel flow issues due to control.
- Minor charge in short circuit levels.
- No increase in reactive power demand.

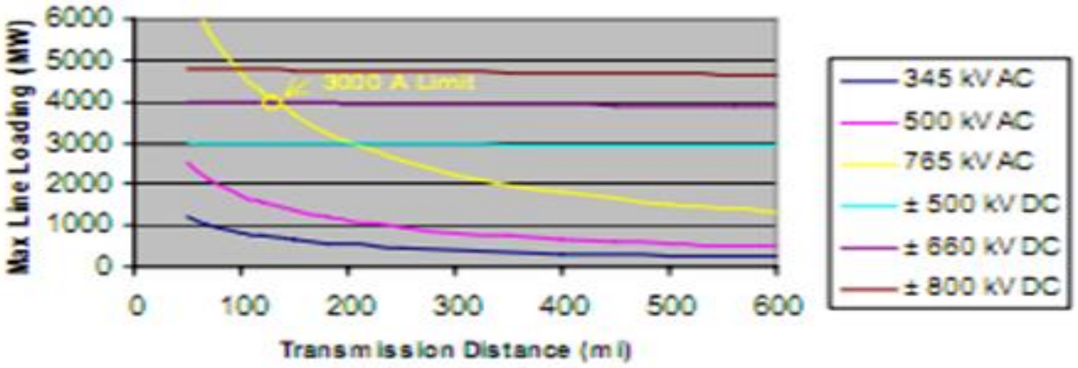


Fig.1.19 - Line Capacity V Distance (3000 A maximum line rating)

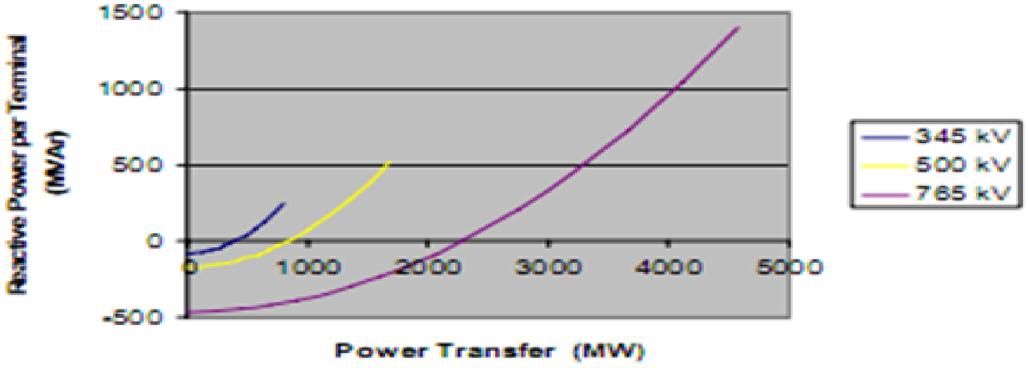
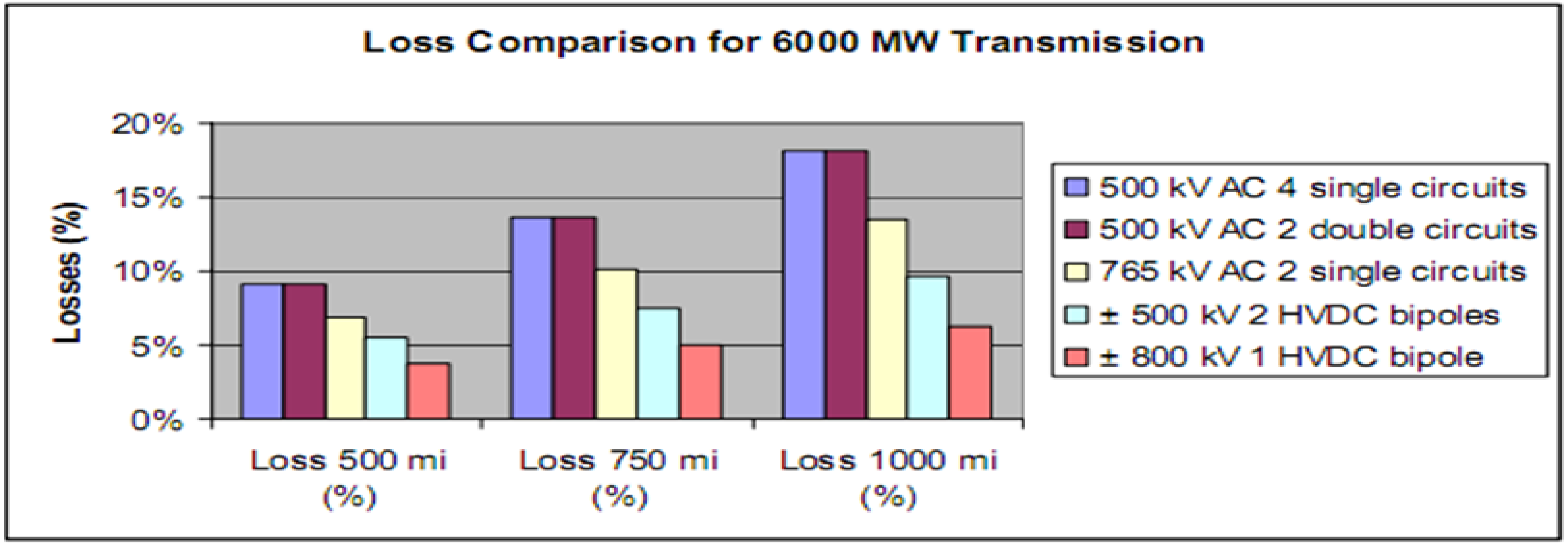


Fig. 1.20 Reactive Power V Power Transfer (200 mi line)



Note - Conductor areas based on comparable current densities, operating temperatures and power factors.

Fig. 1.21 - Loss comparison for 6000 MW transmission

1.7.7 Advantages of HVDC over HVAC transmission

- The most common reason for choosing HVDC over HVAC transmission is that HVDC is more economical than HVAC for transmitting large amounts of power point-to-point over long distances.

- A long distance, high power HVDC transmission scheme generally has lower capital costs and lower losses than an HVAC transmission link.

- Even though HVDC conversion equipment at the terminal stations is costly, overall savings in capital cost may arise because of significantly reduced transmission line costs over long distance routes.

- HVDC needs fewer conductors than an AC line, as there is no need to support three phases.

- Also, thinner conductors can be used since HVDC does not suffer from the **skin effect.**

- HVDC schemes can transfer power between separate AC networks.

- HVDC power flow between separate AC systems can be automatically controlled to provide support for either network during transient conditions, but without the risk that a major **power system collapse** in one network will lead to a collapse in the second.

1.7.8 Cost Structure

- The cost of an HVDC transmission system depends on many factors, such as power capacity to be transmitted, type of transmission medium, environmental conditions and other safety, regulatory requirements etc.

- An example of cost comparisons between HVAC & HVDC for a 2000 MW transmission is presented opposite.

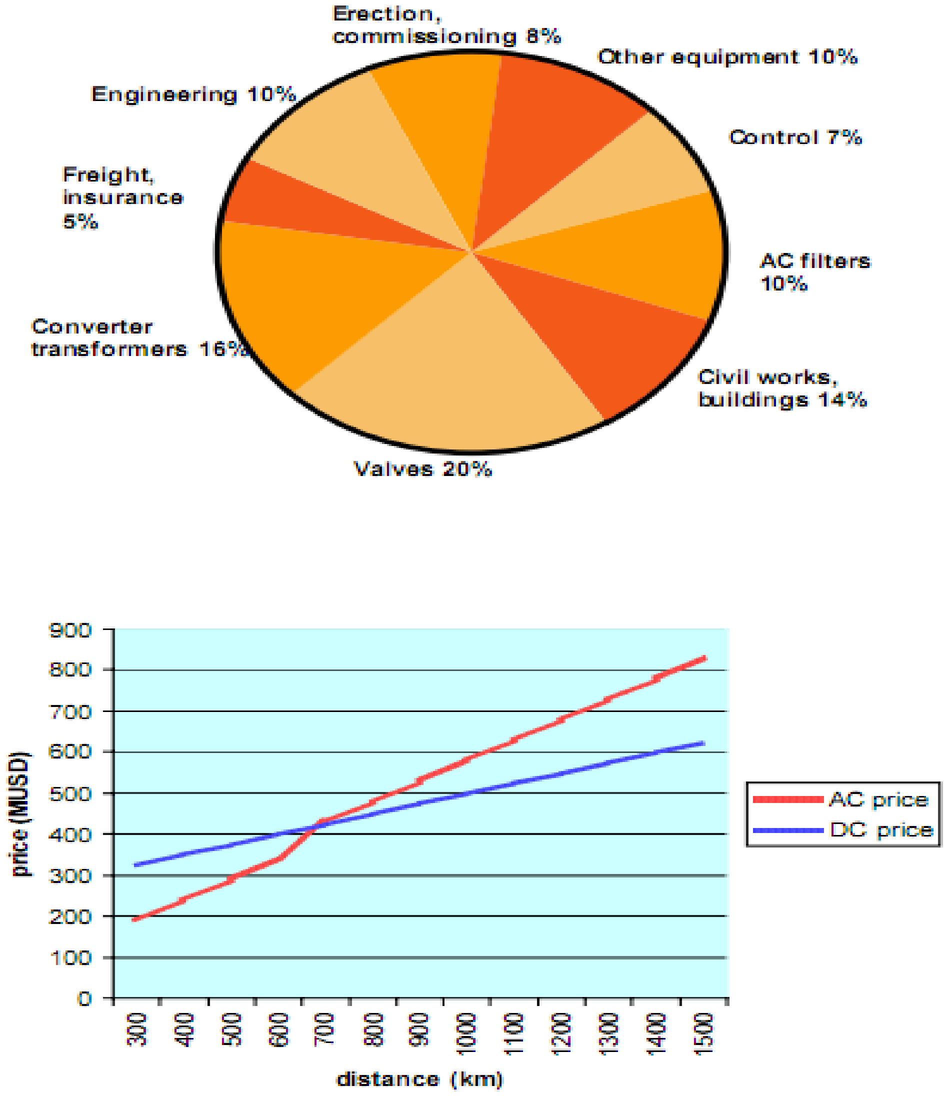
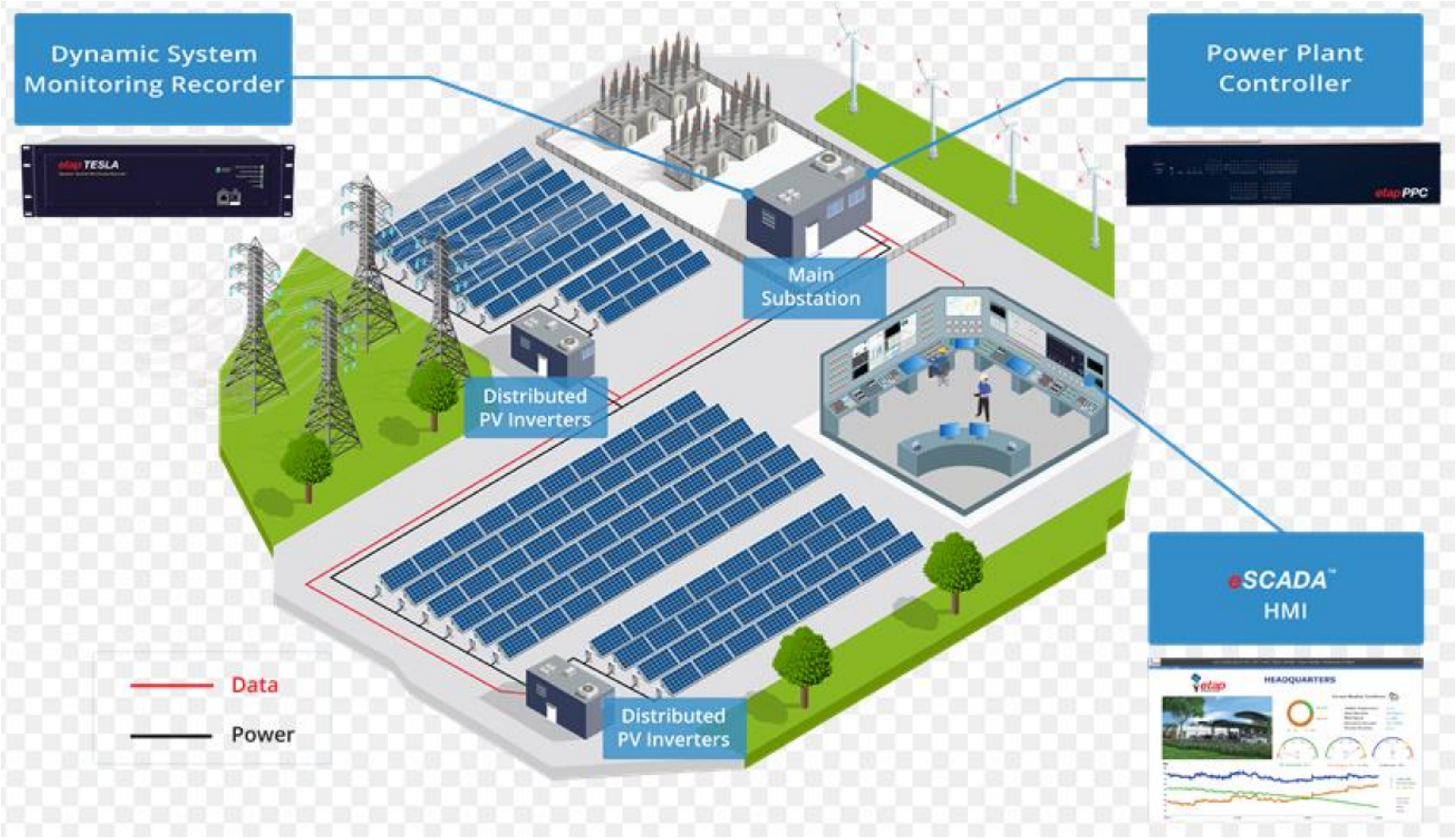


Fig. 1.22 - Cost structure comprising the pie chat above and the graph below

1.7.9 Basic Control Functions

- Constant power control
- Constant DC voltage control
- Constant current control
- Extinction angle control
- Voltage dependent current order control

1.8 Renewable Energy Systems



Assignment 1:

1. Write down the symbol and sketch the operating characteristics of each of the following devices:

   (a) Diode (b) Thyristor (c) IGBT (d) TRIAC (e) LASCR (f) NPN BJT

   (g) N-Channel MOSFET

2. Briefly state how power electronics is applied in each of the following areas:

   (a) Aerospace (b) Commercial (c) Industrial (d) Residential

   (e) Telecommunication (f) Transportation (g) Utility Systems

End!