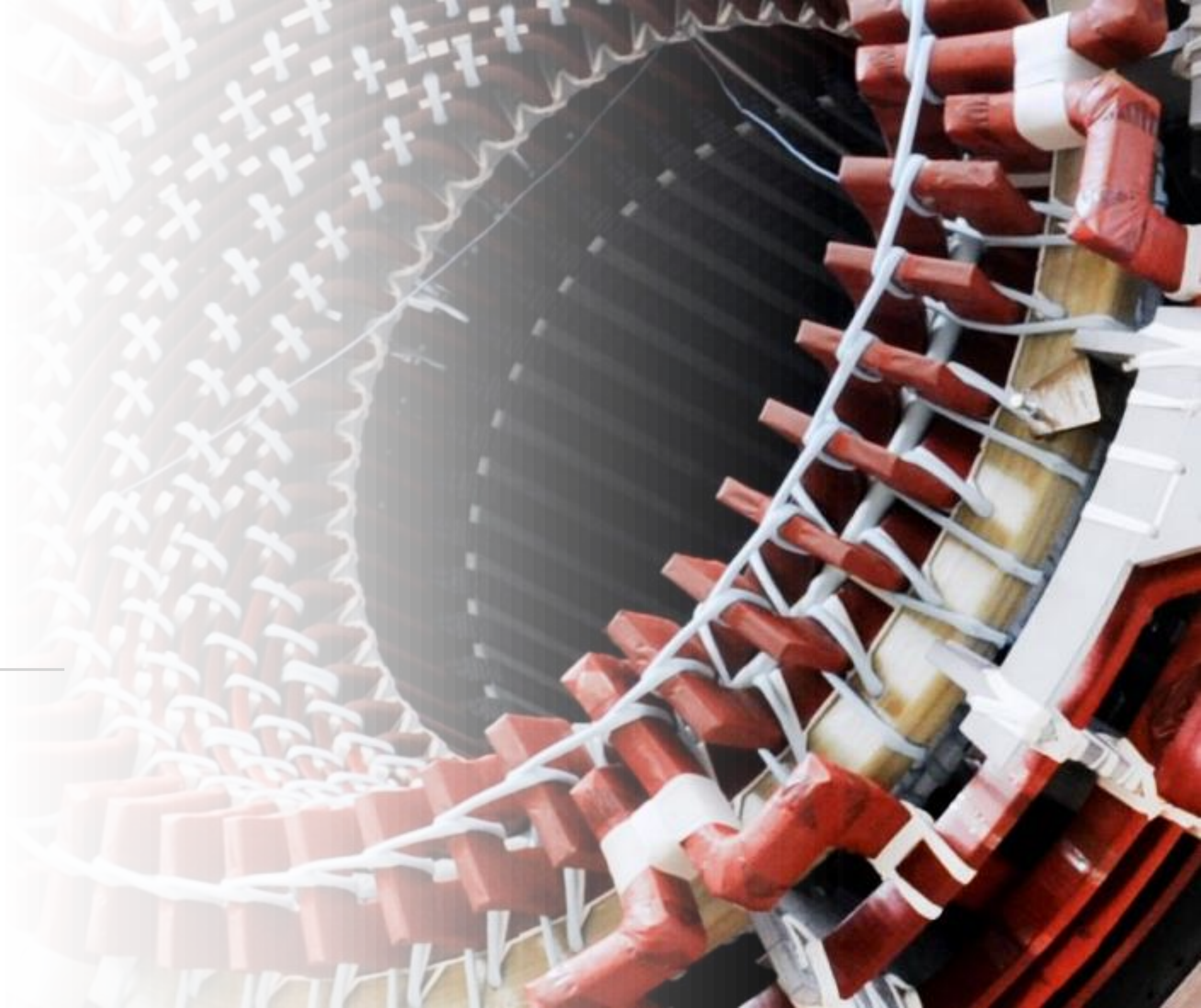
EE3124 Introduction to Electric Machines and Drives

1-Overview of Electric Machines

Prof. CQ Jiang



EE3124 Introduction to Electric Machines and Drives

LECTURES

2-hour

TUTORIALS

Starting week 3, as scheduled

1-hour after lecture

PROJECTS

Starting in March

9 hours of project work

No need to come to Campus

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EE3124 Intro to Elec Machines & Drive

Assign To | Edit

Welcome to EE3124!

I am Prof. CQ Jiang, the course leader and lecturer of EE3124 Intro to Electric Machines and Drives. In these Canvas pages, I will provide you with all the essential information about this course, including its aims, course synopsis, mini-project, and assessment methods.

Aims:

This course aims to introduce (i) the operating principles of electric machines and drives, including AC and DC machines; and (ii) the applications of various types of drives in automation systems, electric vehicles, and robotics. In particular, I will emphasize some most commonly used Electric Machines as motors and generators with fundamental knowledge of basic magnetic circuits, working principles, power calculations, and machine control and drive methods.

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Course Synopsis:

- **Getting started** (~1 week): The first lecture will provide an overview of electric machines including the history, topologies, popular applications, and the generators in power plants. I'll also tell you what you are expected to gain in this course.
- **Basics of magnetic circuit** (~2 weeks): This part will help to review the basic Ampere's law, Faraday's law, and basic magnetic concepts. The magnetic circuit will be introduced to analyze the flux linkage and calculate the inductance of an inductor or transformer.
- **DC machines and AC machine fundamentals**(~3.5 weeks): The DC and AC machines will be explored in this part, including the types of DC and AC machines, basic constructures, and the concept of rotating magnetic fields. The power and torque calculations will be deduced, as well as the motor drives and controls.
- **Synchronous and induction machines** (~3.5 weeks): The synchronous motors and generators will be explained for equivalent circuits, power and torque calculations, and grid synchronization and motor starting issues. As the induction motor has been widely used in industries, the induction torque-speed characteristics will be analyzed and the advanced motor drives and controls will be explained.
- **Special machines and emerging applications** (~1 week): In this part, the universal motors, permanent magnet motors, special single-phase motors will be introduced and compared, as well as double rotor or stator motors. The students are required to understand the basic principles but not comprehensively, where this part will not be examined in the final exam.

Project:

You will be required to perform a mini-project in a group as part of the practical training (replacing lab sessions). Details will be provided on the Assignment Page with an assignment entitled Mini-Project. The mini-project serves as the practical component of the course. You are expected to spend 9 hours on this mini-project with a detailed and informative investigation of the specific applications of motors.

Assessment:

Continuous assessment will account for 50% of the final assessment marks, including Assignments, quizzes/tests and project reports. The ***written exam*** will account for 50% of the final assessment marks. More details please refer to the course syllabus:
https://www.cityu.edu.hk/catalogue/ug/current/course/EE3124.htm

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Course Syllabus

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Overview

This year, the weekly 3-hour lecture is divided into 2-hour lectures and 1 hour tutorials. Please NOTE that ***there will be NO TUTORIAL in the first and second weeks of the semester.***

Lab/Practical Sessions

Lab sessions will be replaced by a mini-project. **This is self-study time, and you will not be required to come to any specific venue.** Each student will be expected to complete a mini-project in a group. The details will be announced in mid-March during the tutorials.

Lecture Schedule

Our tentative lecture schedule is as follows. Moreover, the tutorials following the lecture will be used to reinforce the material presented in the previous lecture.

EE3124 Intro to Elec Machines & Drive

LECTURE DATES	MODULES
Week 1	Lecture: Overview of Electric Machines (No tutorial in the first week)
Week 2	Lecture: Basics of Magnetic Circuit (No tutorial in the second week)
Week 3, 4	Lecture: DC Machines, Assignment 1 will be released. (Tutorial starts from the third week.)
Week 5	Lecture: AC Machine Fundamentals (Tutorial as scheduled, Q&A session for the oncoming Test)
Week 6	Lecture: AC Machine Fundamentals + Test 1 (Open-book test, only lecture slides are allowed.)
Week 7, 8	Lecture: Synchronous Machines (Tutorial as scheduled.)
Week 9, 10	Lecture: Induction Machines, Assignment 2 will be released. (Tutorial as scheduled.)
Week 11	Lecture: Test 2 (Open-book test, only lecture slides are allowed. Tutorial as scheduled.)
Week 12, 13	Lecture: Special Machines and Applications (Tutorial as scheduled. The final tutorial is for Q&A session of the final examination.)

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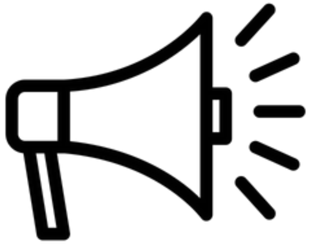
A special page will be created for the mini project on CANVAS.



Announcements will be made from time to time.

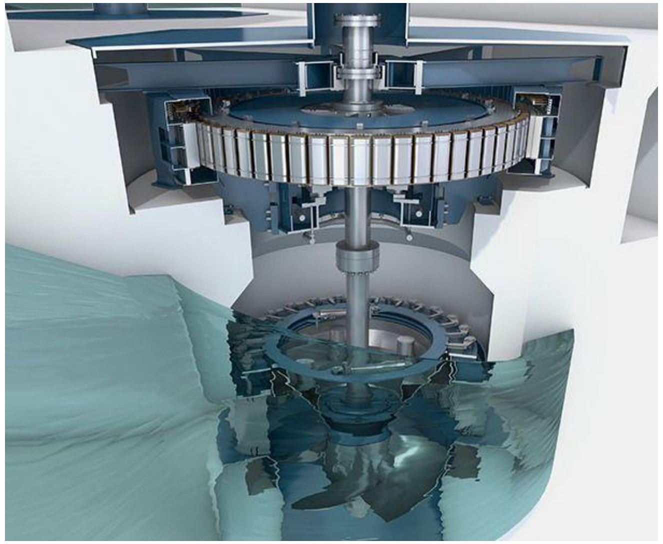
Please visit CANVAS frequently to get updated news.

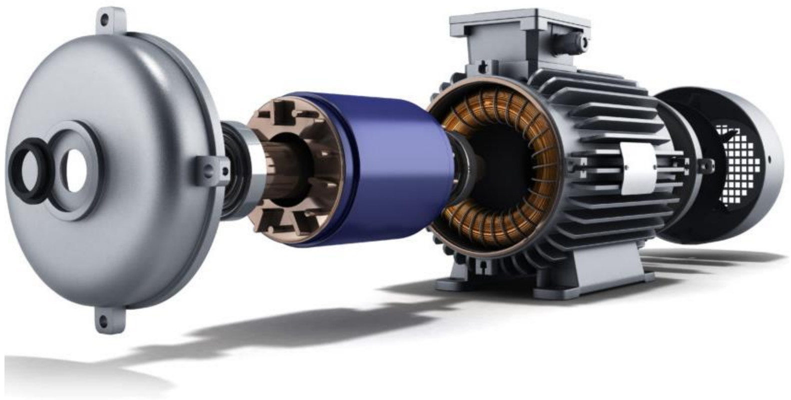
Contents

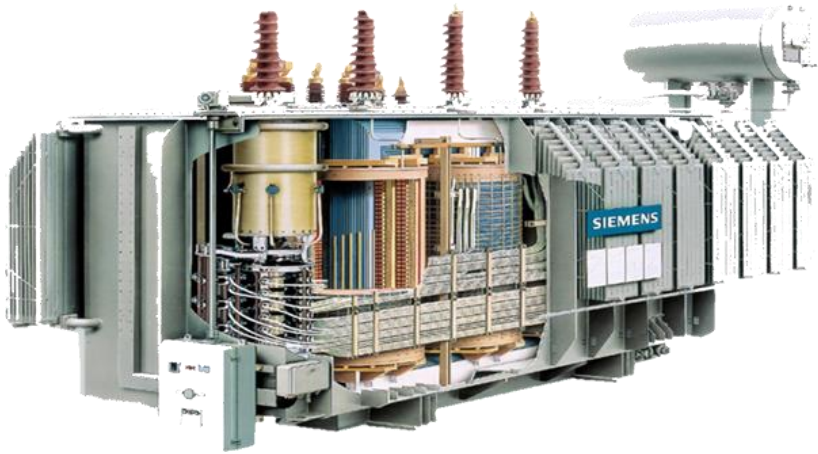
- Basic understanding of electric machines
- Structures and principles of different generators and motors
- Motor drives and controls

What are Electric Machines

- An **electrical machine** is a device which converts mechanical energy into electrical energy or vice versa.
- **Electrical machines** also include transformers, which do not actually make conversion between mechanical and electrical form but they convert AC current from one voltage level to another voltage level.


Electric Generator

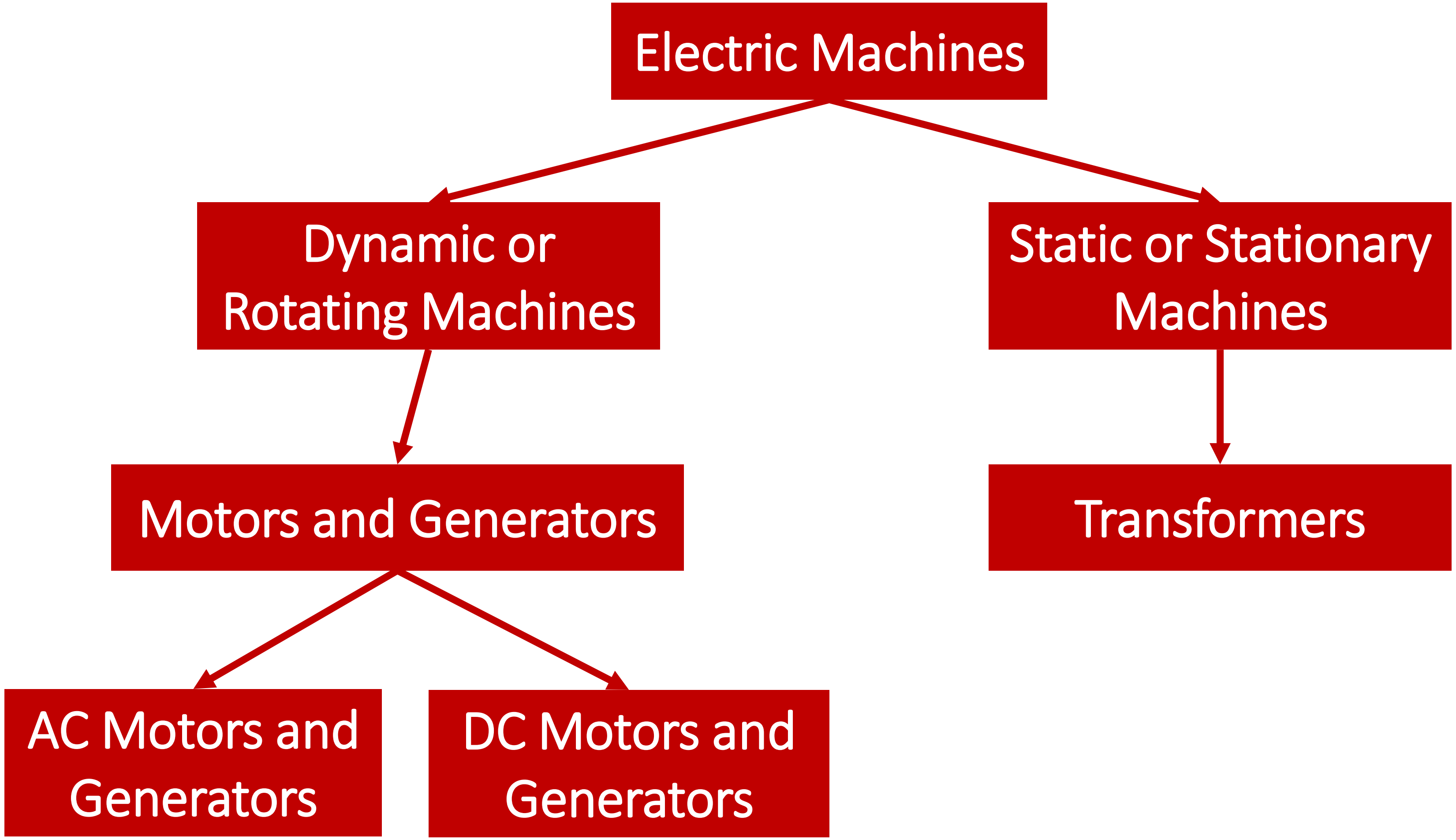

Electric Motor



Transformers

What are Electric Machines

- Types of Electric Machines



Where are Electric Machines applied

- Domestic

Electric Vehicle

Laptop

Air Conditioner

Vacuum Cleaner

Fridge

Fitness

Phone

- Industry

MTR Train

Ship

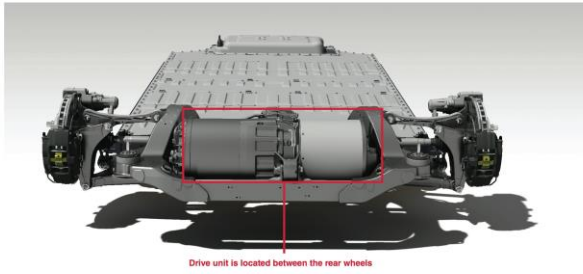
Crane

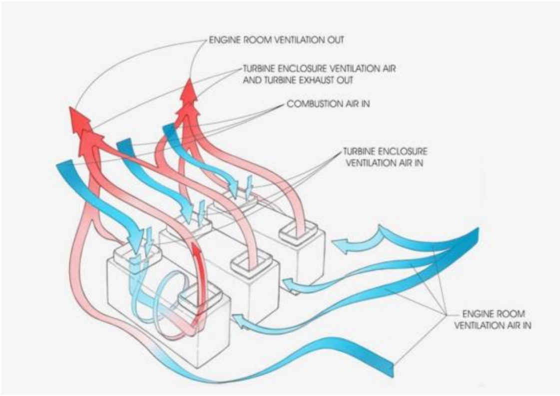
Robotic arm

3D Printer

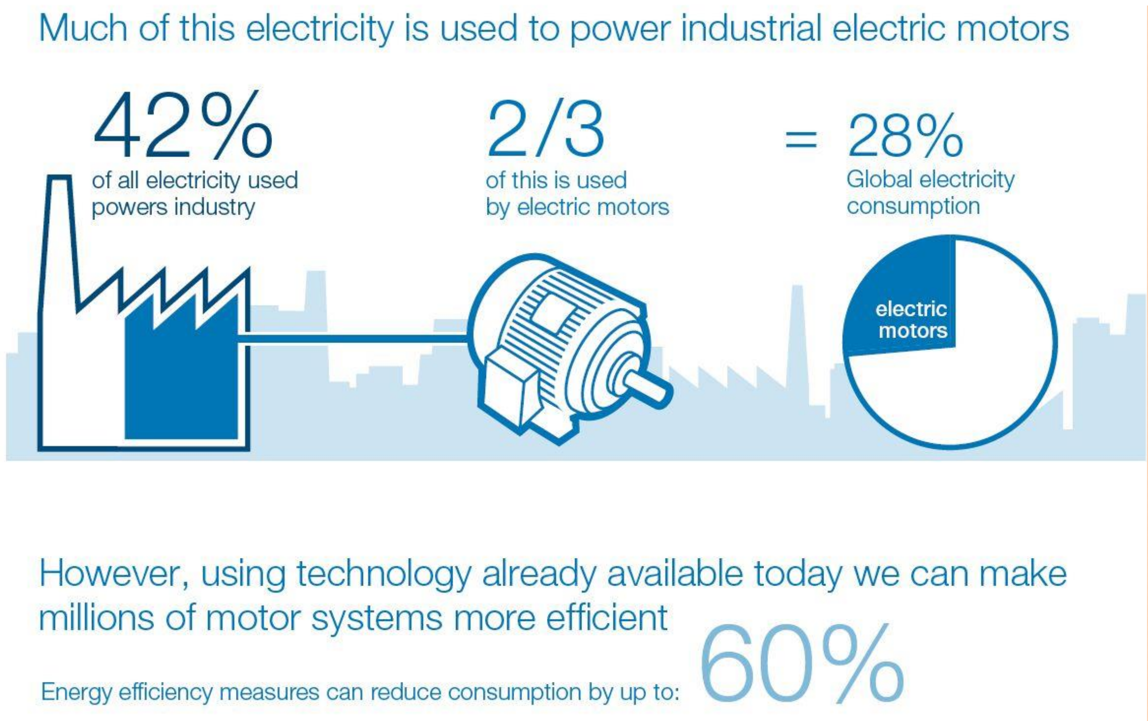
Why are Electric Motors and Generators so Common?

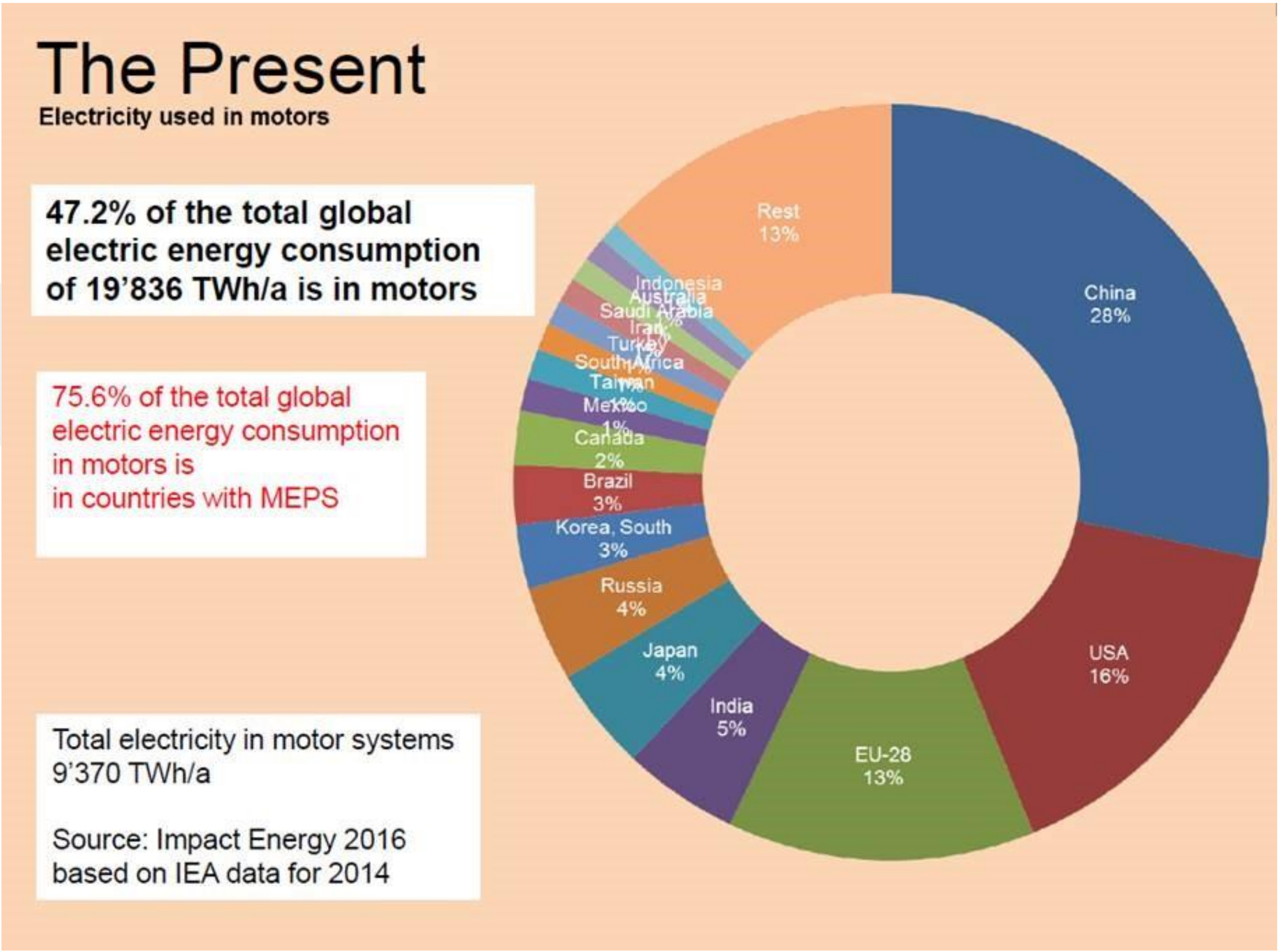
- **The answer is very simple**: Electric power is a clean and efficient energy source that is easy to transmit over long distances, and easy to control.
- An electric motor does not require constant ventilation and fuel the way that an internal-combustion engine does, so the motor is very well suited for use in environments where the pollutants associated with combustion are not desirable.
- Instead, heat or mechanical energy can be converted to electrical form at a distant location, the energy can be transmitted over long distances to the place where it is to be used, and it can be used cleanly in any home, office, or factory.
- Transformers aid this process by reducing the energy loss between the point of electric power generation and the point of its use.





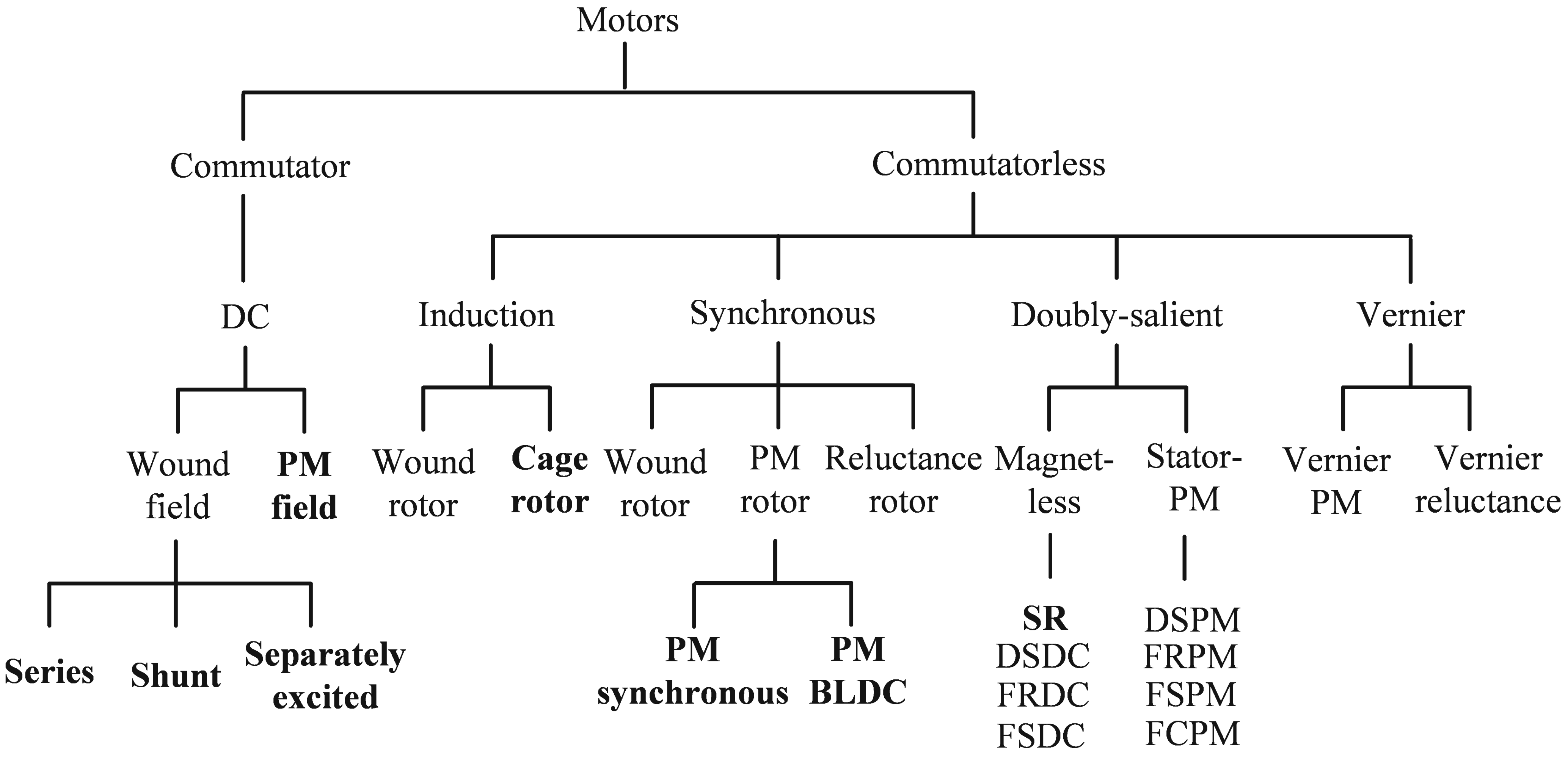
Some truths



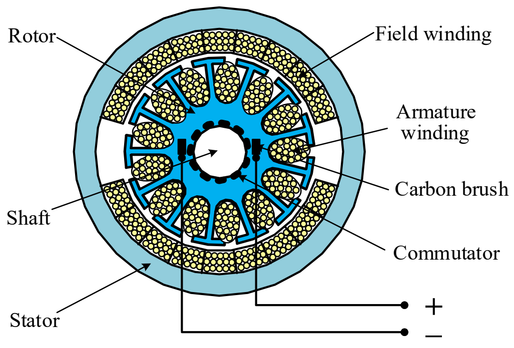


Source: https://www.windpowerengineering.com/company-says-34-billion-saved-installed-electric-drives/

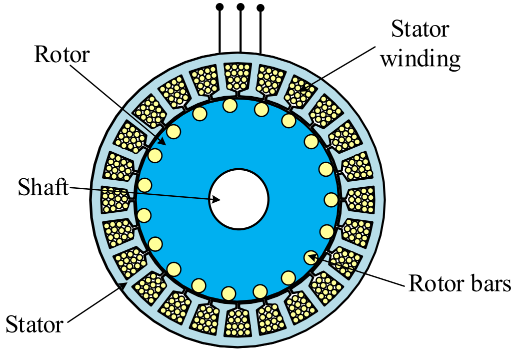
Electric Motor Classification



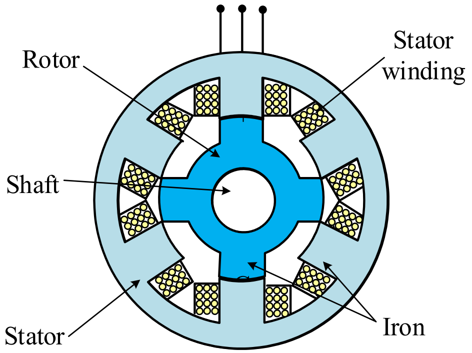
Electric Motors – Rotary Motion



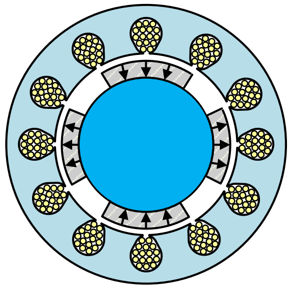
DC machine



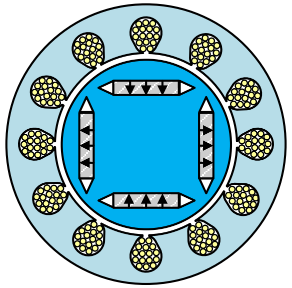
Induction machine



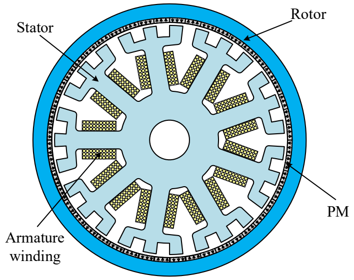
Switched reluctance machine



Surface -mounted

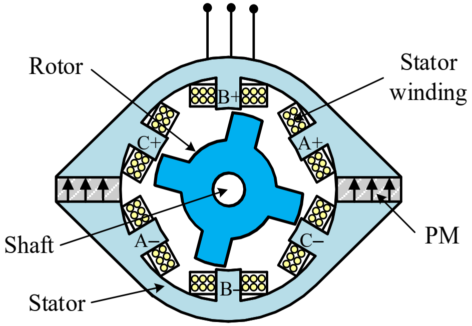


Interior-radial

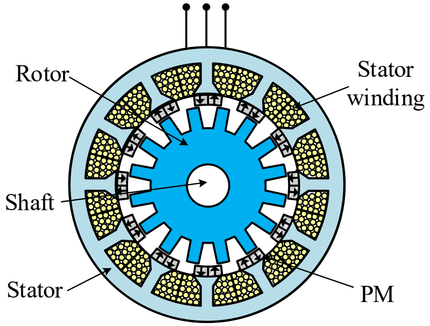


PM surface-mounted vernier machine

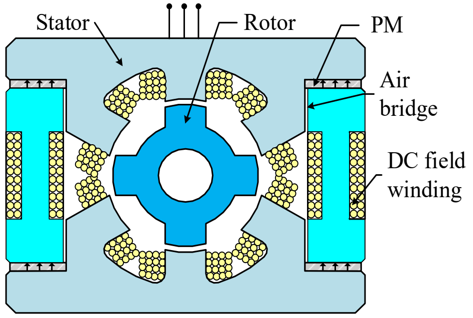
Rotor PM brushless machine



DSPM



FRPM



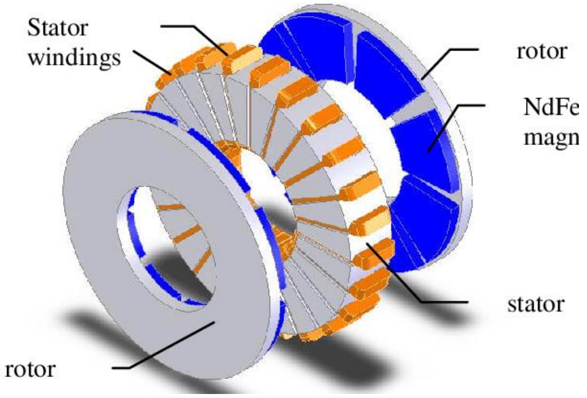
FCPM

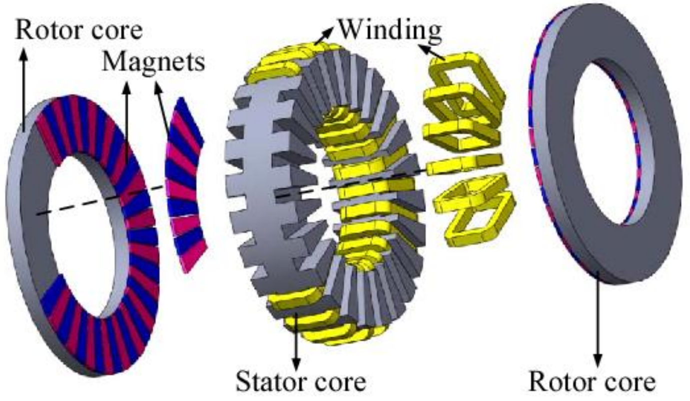
Stator PM brushless machines

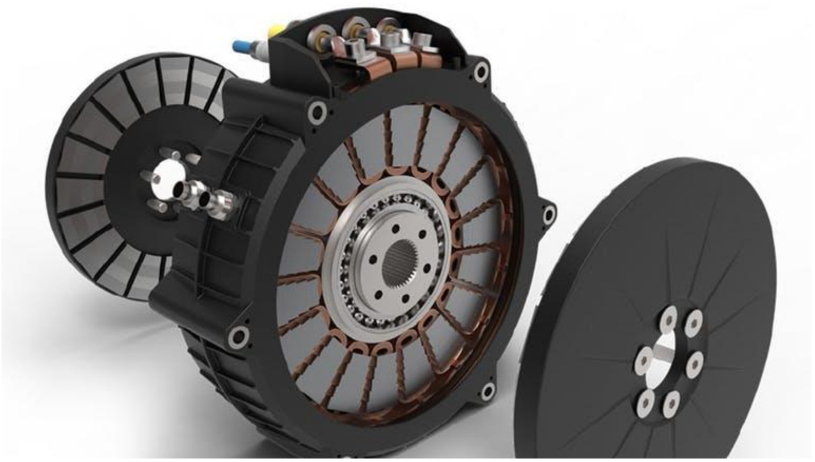
- Three/Four core components: Stator, Rotor, Winding, and Permanent Magnet.
- Most machines used in daily life are rotary motion machines.

Electric Motors – Linear Motion

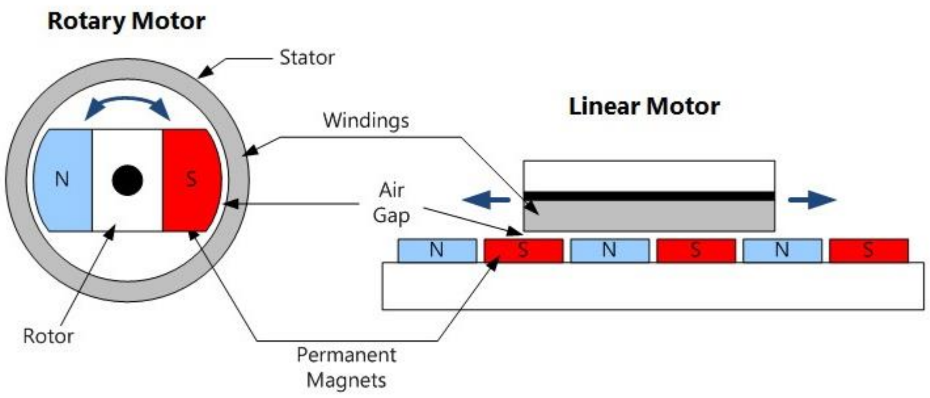
❑ Axial flux motor

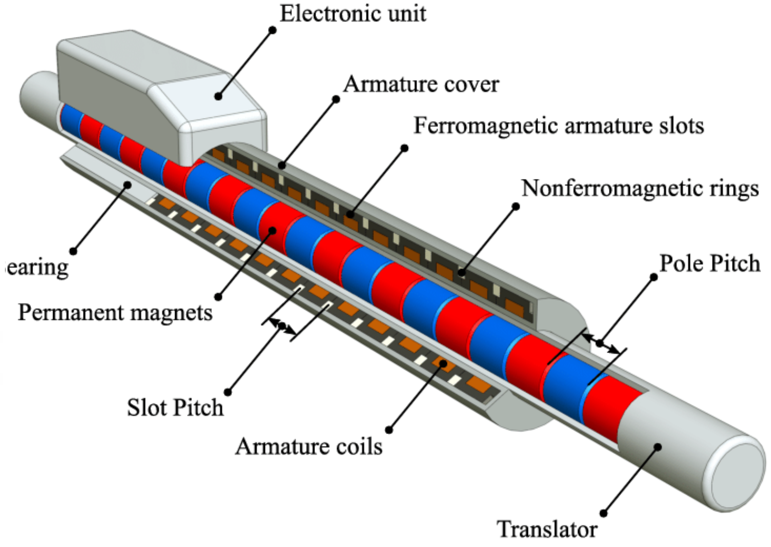


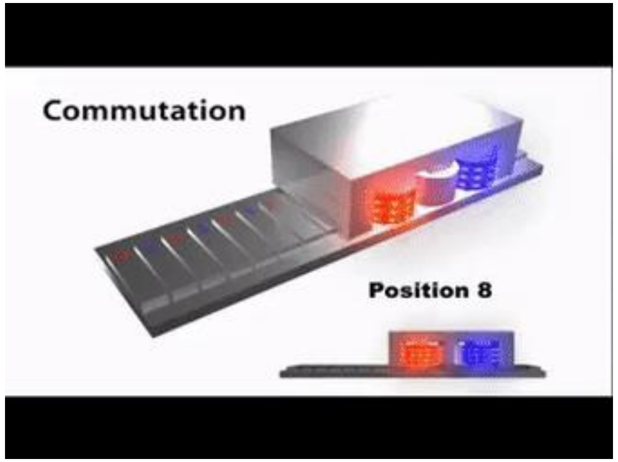




❑ Linear motor







- Motion is along the Shaft.

Sources: Zamanian, Amir Hosein, and Edmond Richer. "Identification and compensation of cogging and friction forces in tubular permanent magnet linear motors." *Dynamic Systems and Control Conference*. Vol. 58288. American Society of Mechanical Engineers, 2017. https://www.powerelectronics.com/markets/automotive/article/21864194/axialflux-motors-and-generators-shrink-size-weight.

Historical Machines

❖ DC Machine:

- In 1832, William Sturgeon invented a DC motor.

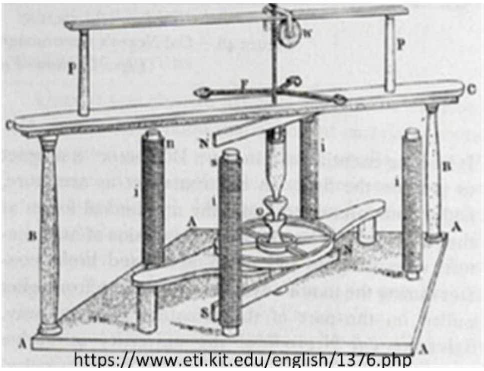
❖ Induction Machine:

- In 1882, Nikola Tesla invented a 2-phase induction motor.
- In 1885, Galileo Ferraris invented a similar 2-phase induction motor.
- In 1889, Michael Dolivo-Dobrowolsky invented a 3-phase cage induction motor.

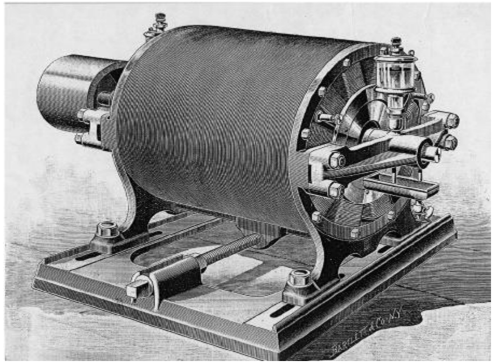
❖ Synchronous Machine:

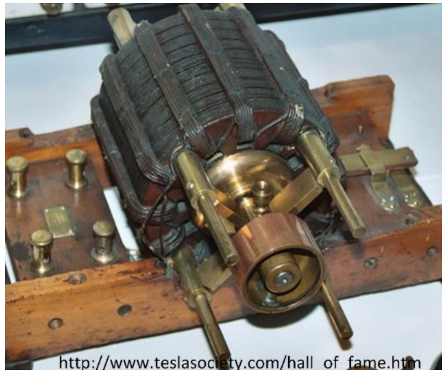
- In 1887, Friedrich August Haselwander invented a 3-phase synchronous motor with salient poles.

Sturgeon's DC Motor

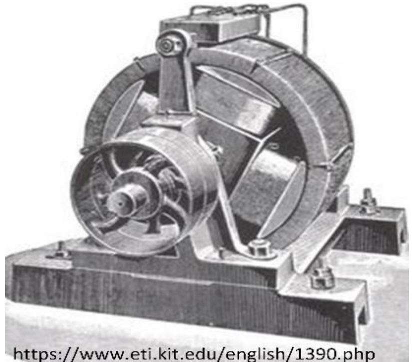


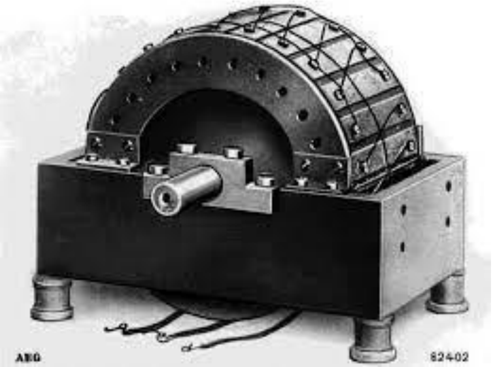
Tesla's Induction Motor





Haselwander's Sync. Motor



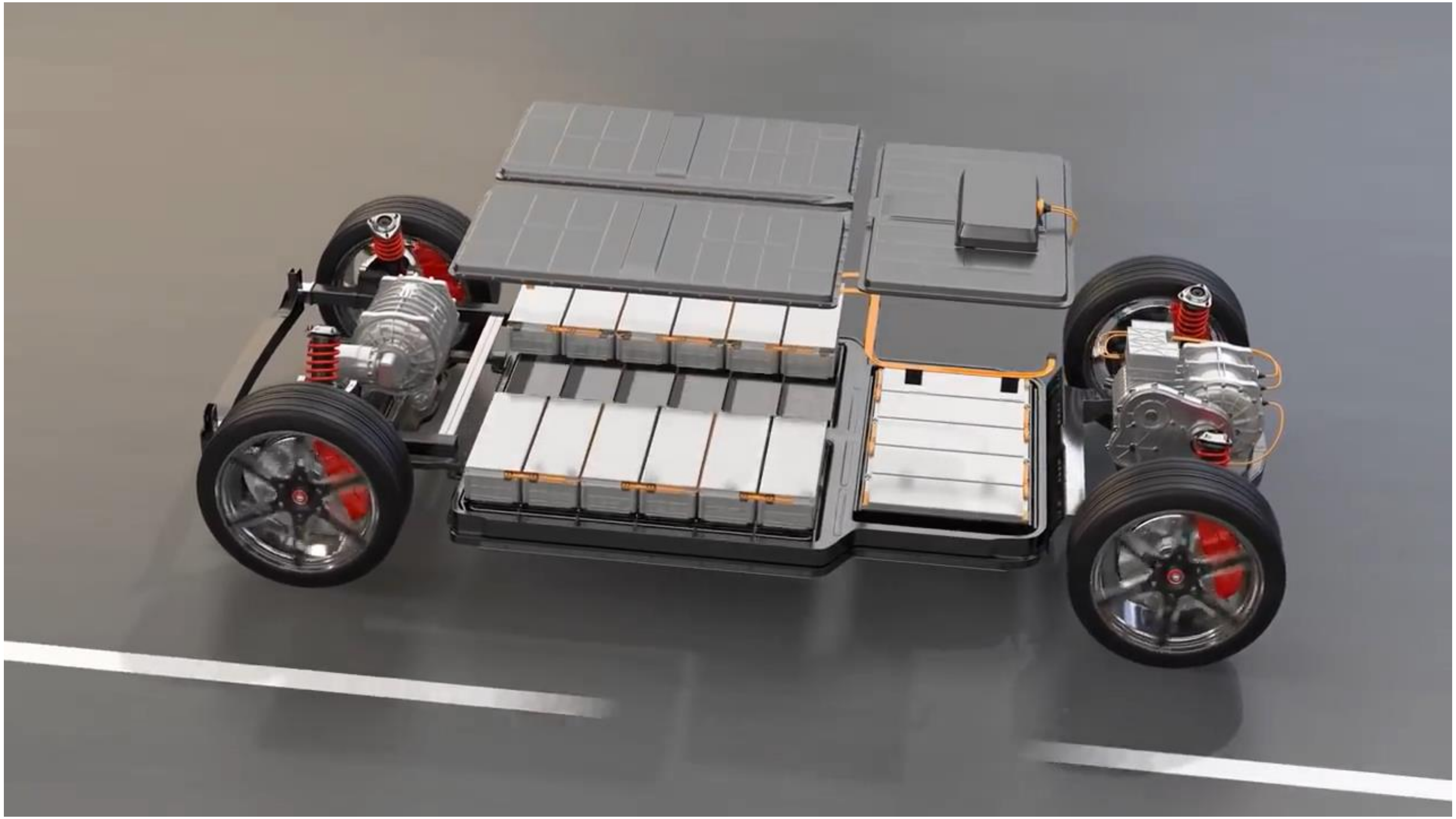


Popular Application - Electric Vehicles (EVs)

- In 1834, Thomas Davenport invented the 1st battery powered EV.
- In 1899, Camille Jenatzy drove an EV to set a record - 1st vehicle running over 100km/h.
- In 1900, among an annual sale of 4200 autos in America - 38% EVs, 22% ICEVs, 40% steam.
- In 1911, Kettering invented the starter motor for ICEVs, which eliminated major EV market.
- In 1925, Ford produced low-cost Model T which almost finished off EVs.
- Starting from 1970s, EVs resurrected due to energy crisis, environmental concern and new business.

Popular Application - Electric Vehicles (EVs)

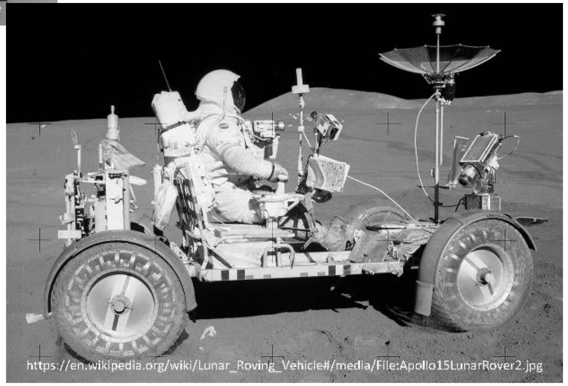
❑ How Do Electric Vehicles Work?



https://www.youtube.com/watch?v=GHGXy_sjbgQ

DC Machines for EVs

- GMC Conceptor Electric G-Van used the separately excited DC motor to produce 45 kW and 323 Nm.
- Fiat Panda Elettra used the series DC motor to provide 9.2 kW at 2500 rpm.
- Lunar Roving Vehicle (LRV) used four series DC motors to drive four wheels and output 745 W.
- Global Electric Motorcars (GEM), a major model of neighborhood EVs, uses the separately excited DC motor to offer 5.6 kW at 4950 rpm.



Induction Machines for EVs

- **GM Impact** used two 42.5 kW induction motors, one for each front wheel. It spun up to 11,900 rpm.
- **GM EV1** used an induction motor with differential to produce 102 kW and 149 Nm at 0–7000 rpm.
- **Tesla Roadster** used an induction motor with differential to produce 215 kW, and spun up to 14,000 rpm.
- **Tesla Model S P90D** uses dual induction motors in front and rear axles with differentials to output up to 568 kW.


https://en.wikipedia.org/wiki/General_Motors_EV1#/media/File:Gm-impact.jpg


https://en.wikipedia.org/wiki/General_Motors_EV1#/media/File:EV1A014_%281%29_cropped.jpg


https://en.wikipedia.org/wiki/Tesla_Roadster#/media/File:Roadster_2.5_windmills_trimmed.jpg

https://upload.wikimedia.org/wikipedia/commons/c/c3/2013_Tesla_Model_S_%2811322176214%29_cropped.jpg

PM Synchronous Machines for EVs

- **Nissan Leaf** uses a PM synchronous motor in front axle with differential to produce 80 kW.
- **Honda Fit EV** uses a PM synchronous motor in front axle with differential to output 92 kW.
- **BMW i3** uses a PM synchronous motor (with high reluctance torque) in the rear axle with differential to produce 125 kW.
- **Porsche Mission E** uses a pair of PM synchronous motors in front and rear axles with differentials to output up to 440 kW.

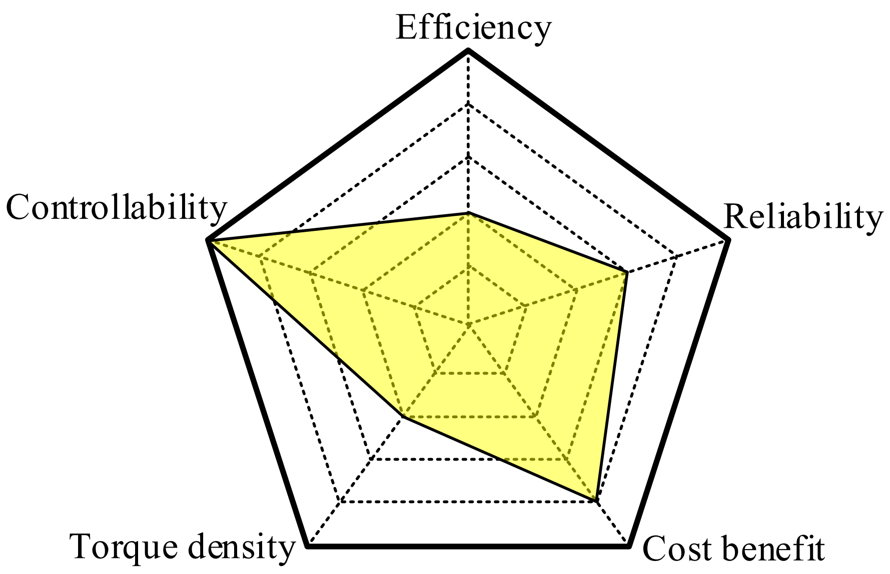

https://en.wikipedia.org/wiki/Nissan_Leaf#/media/File:2011_Nissan_Leaf_SL_--_10-28-2011.jpg


https://en.wikipedia.org/wiki/Honda_Fit#/media/File:Honda_Fit_EV_2011_LA_Auto_Show.jpg

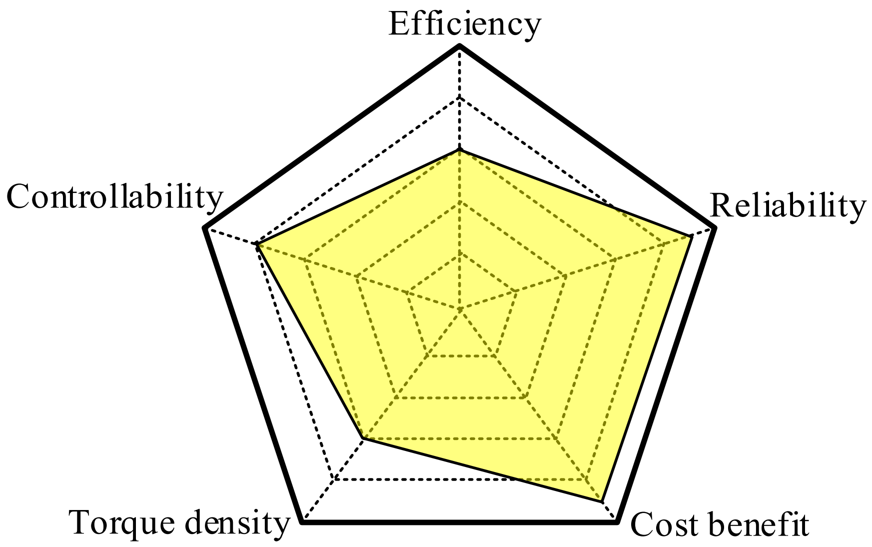

https://en.wikipedia.org/wiki/BMW_i3#/media/File:BMW_i3_01.jpg


http://www.digitaltrends.com/cars/2020-porsche-mission-e-specs-rumors-performance/

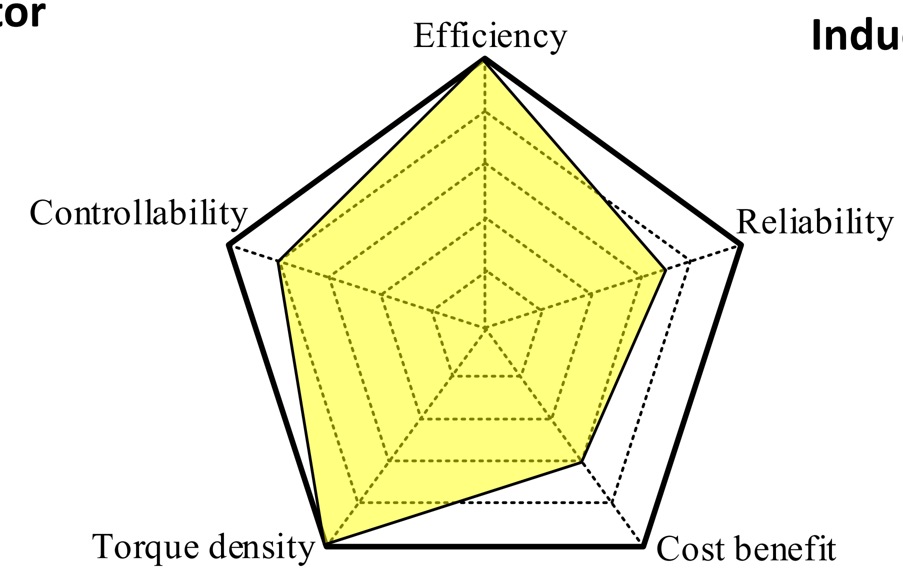
Comparison of Existing EV Machines



DC Motor

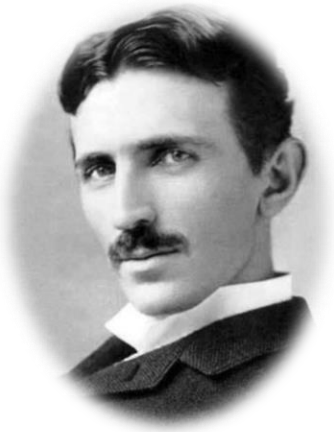


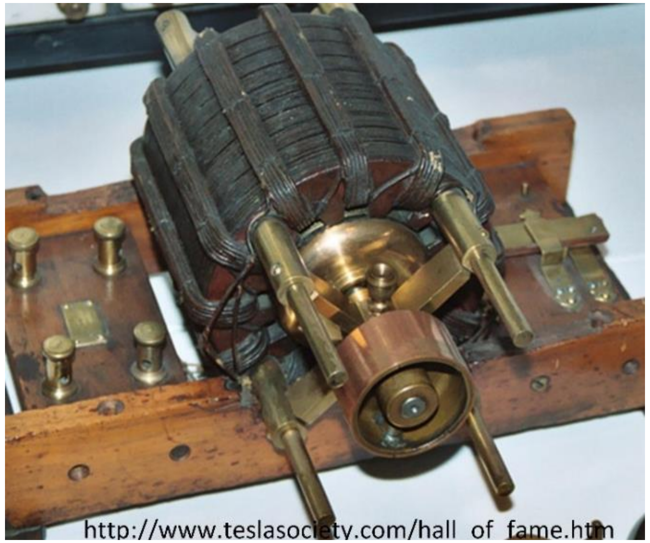
Induction Motor



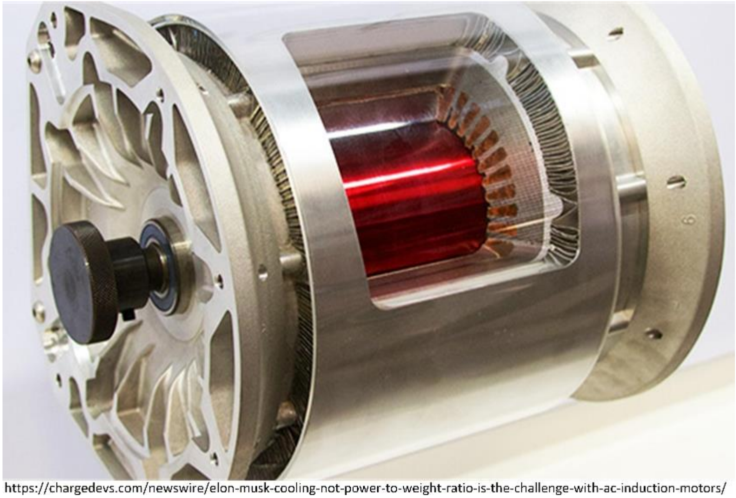
Permanent magnet (PM) Sync. Motor

Tesla VS Tesla





Tesla's Induction Motor



Tesla Motors' Induction Motor

❑ **Similarities**:

- Same principle of operation
- Same type of induction motor – cage type

❑ **Differences**:

- Advanced design software, power electronics and control theory
- Excellent cooling arrangement to achieve very high power density

Fast Growing Various Electric Vehicles

Porsche Taycan
Type: Pure EV
Max power: 560 kW
Max Battery: 93.4 kWh

Polestar 2
Type: Pure EV
Max power : 300 kW
Max Battery : 78 kWh

Tesla Model S
Type: Pure EV
Max power : 760 kW
Max Battery : 100 kWh

Audi e-tron
Type: Pure EV
Max power : 300 kW
Max Battery : 95 kWh

NIO eT7
Type: Pure EV
Max power : 480 kW
Max Battery : 100 kWh

BYD Han EV
Type: Pure EV
Max power : 363 kW
Max Battery : 77 kWh

Toyota RAV4 E+
Type: Plug-in Hybrid
NEDC fuel: 1.1 L/100km
Max Battery : 18.1 kWh

BYD Qin PLUS DM-I
Type : Plug-in Hybrid
NEDC fuel : 1.3 L/100km
Max Battery : 18.3 kWh

Benz E350eL
Type : Plug-in Hybrid
NEDC fuel : 1.4 L/100km
Max Battery : 15.6 kWh

BMW 545e
Type : Plug-in Hybrid
NEDC fuel : 1.5 L/100km
Max Battery : 17.7 kWh

Toyota MIRAI
Type : Fuel Cell EV
Max range: 575 km
H2 : 5.6 kg
Max Battery : 1.24 kWh

Hyundai NEXO
Type : Fuel Cell EV
Max range: 664 km
Max Battery : 1.56 kWh

After entering commercial markets in the first half of the decade, electric car sales have soared. Only about 17 000 electric cars were on the world's roads in 2010. By 2019, that number had swelled to 7.2 million, 47% of which were in China. Nine countries had more than 100 000 electric cars on the road. At least 20 countries reached market shares above 1%.

Fast Growing Various Electric Vehicles

BYD K8
Type: Pure EV
Max range : 370 km
Max Battery : 250 kWh

Volvo 7900
Type: Pure EV
Max range : 370 km
opportunity charge

VDL Citea SLF-120
Type: Pure EV
Max range : 600 km
Max Battery : 216 kWh

Urbino 12 electric
Type: Pure EV
Max range : 200 km
7 x battery pack

Smith EV (Avia)
Type: Pure EV
Max range : 241 km
Max Battery : 120 kWh

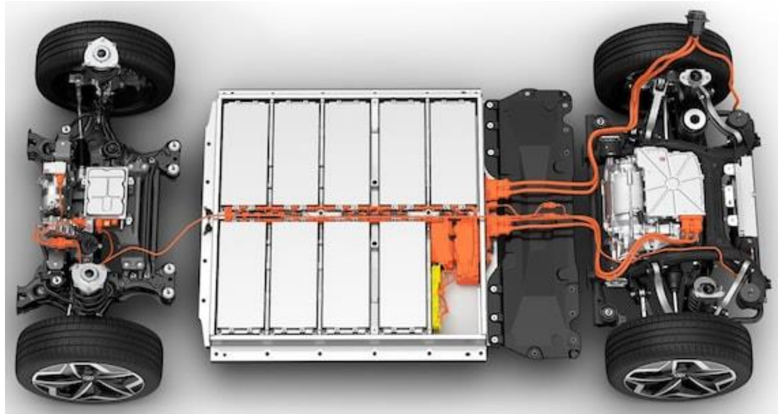
Renault Kangoo ZE
Type: Pure EV
Max range : 200 km
Max Battery : 33 kWh

Tesla Semi
Type: Pure EV
Max range : 804 km
Max Battery : 500 kWh

Daimler Freightliner eM2
Type: Pure EV
Max range : 370 km
Max Battery : 325 kWh

Machine Requirements for EVs

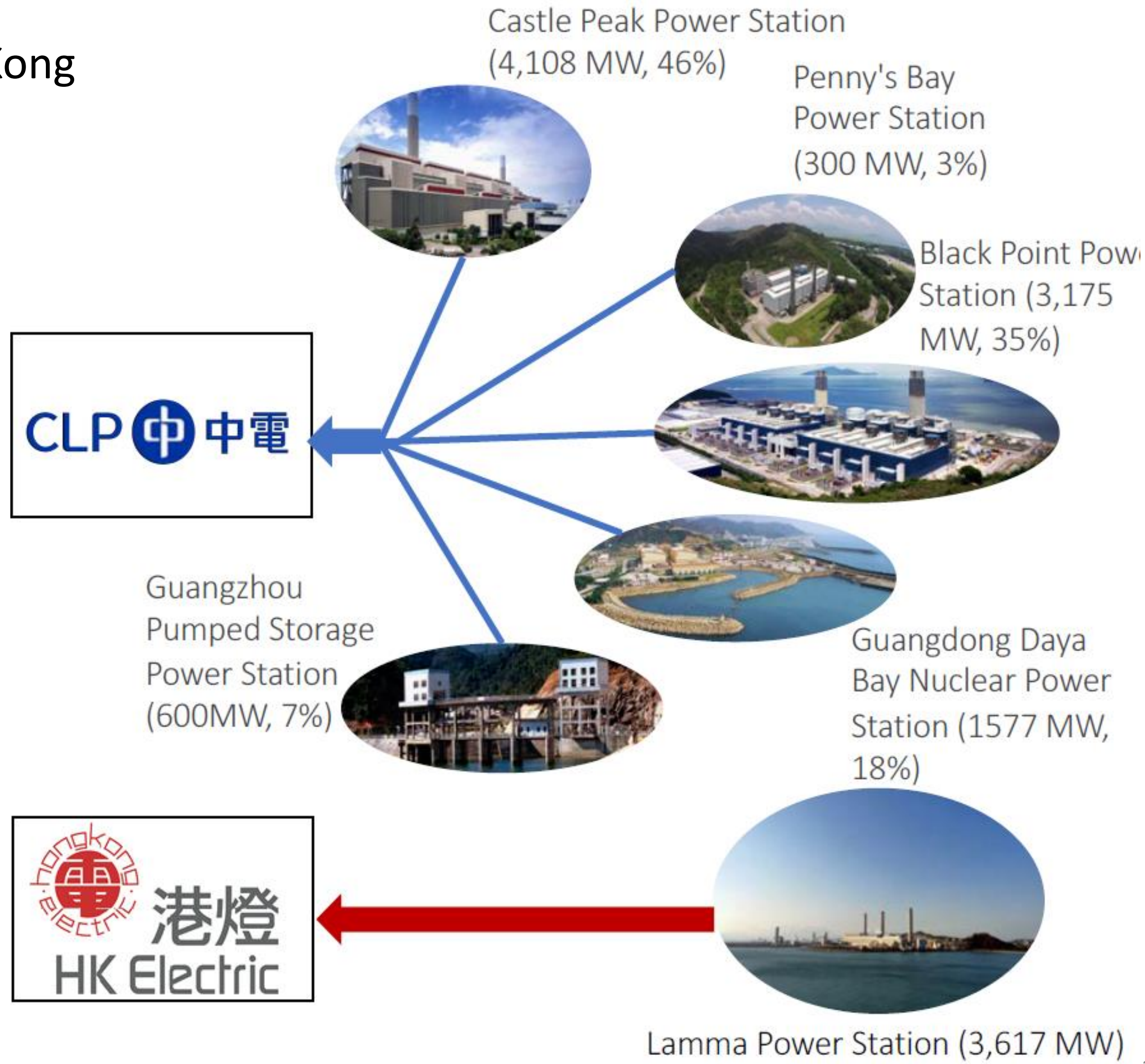
- EV machine requirements are much more stringent than that of industrial machines:
  - High torque and power densities.
  - High torque capability for electric launching and hill climbing.
  - High efficiency over wide torque and speed ranges.
  - Wide-speed operating range for low-speed creeping and high-speed cruising.
  - Wide constant-power operating capability.
  - High intermittent overload capability for overtaking.
  - High reliability and robustness for vehicular environment.
  - Publicly acceptable cost.



Power Generation in Hong Kong

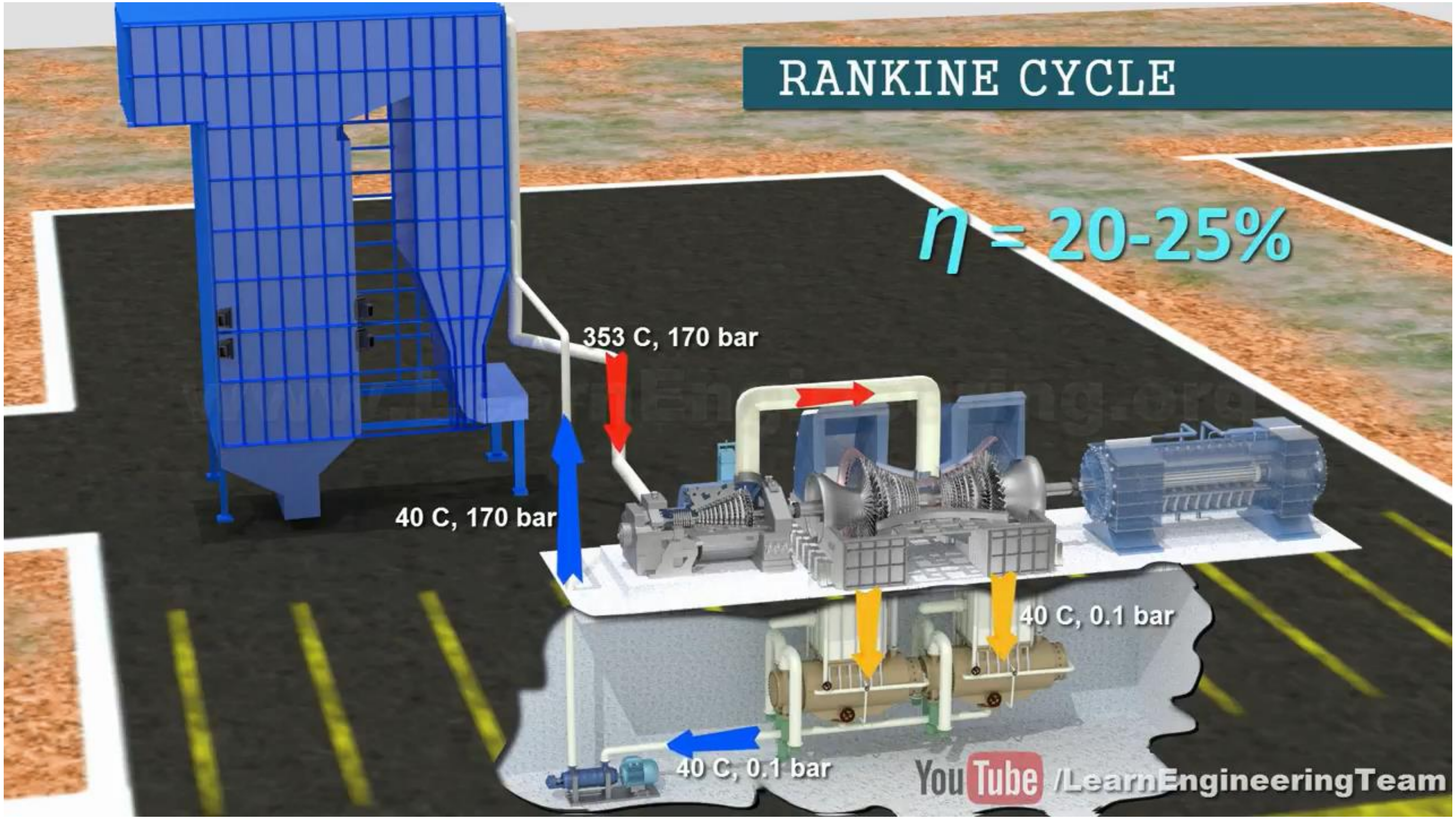
In 2024, the fuel mix for power generation in Hong Kong is shown in the following table (in sent-out basis):

Fuel	Percentage of Installed Capacity
Natural Gas	55.5
Nuclear Energy and renewables	24.5
Coal	20



Generators in Power Plants

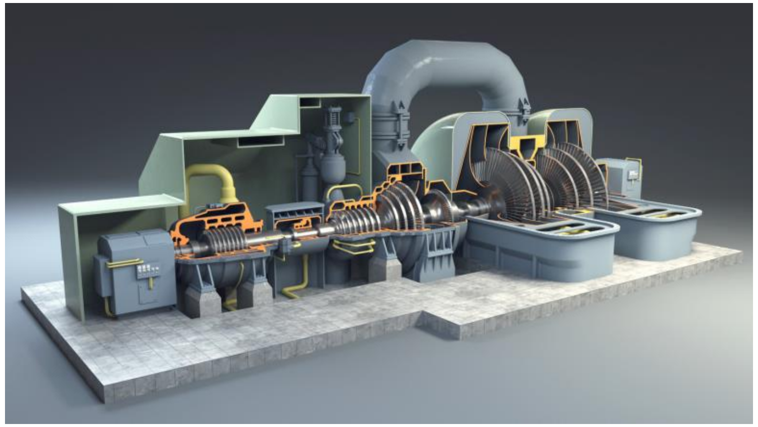
❑ **How does a Thermal power plant work ?**



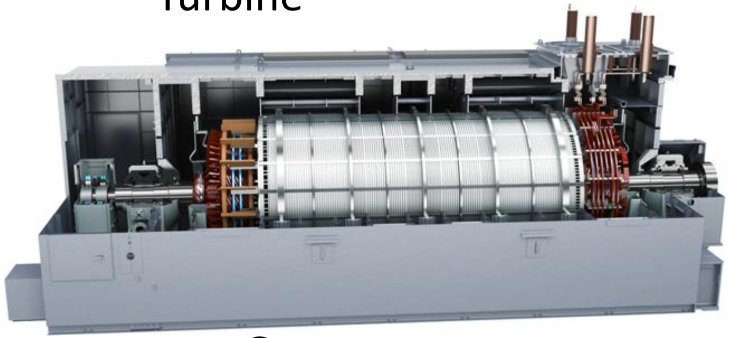
https://www.youtube.com/watch?v=IdPTuwKEfmA

Generators in Power Plants

❑Thermal Power Plants



Turbine

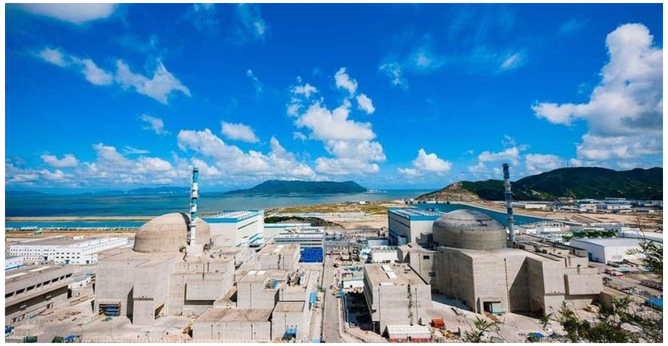


Generator structure

Generator rotor

Coal-fired Power Plant

Gas Turbine Power Plant



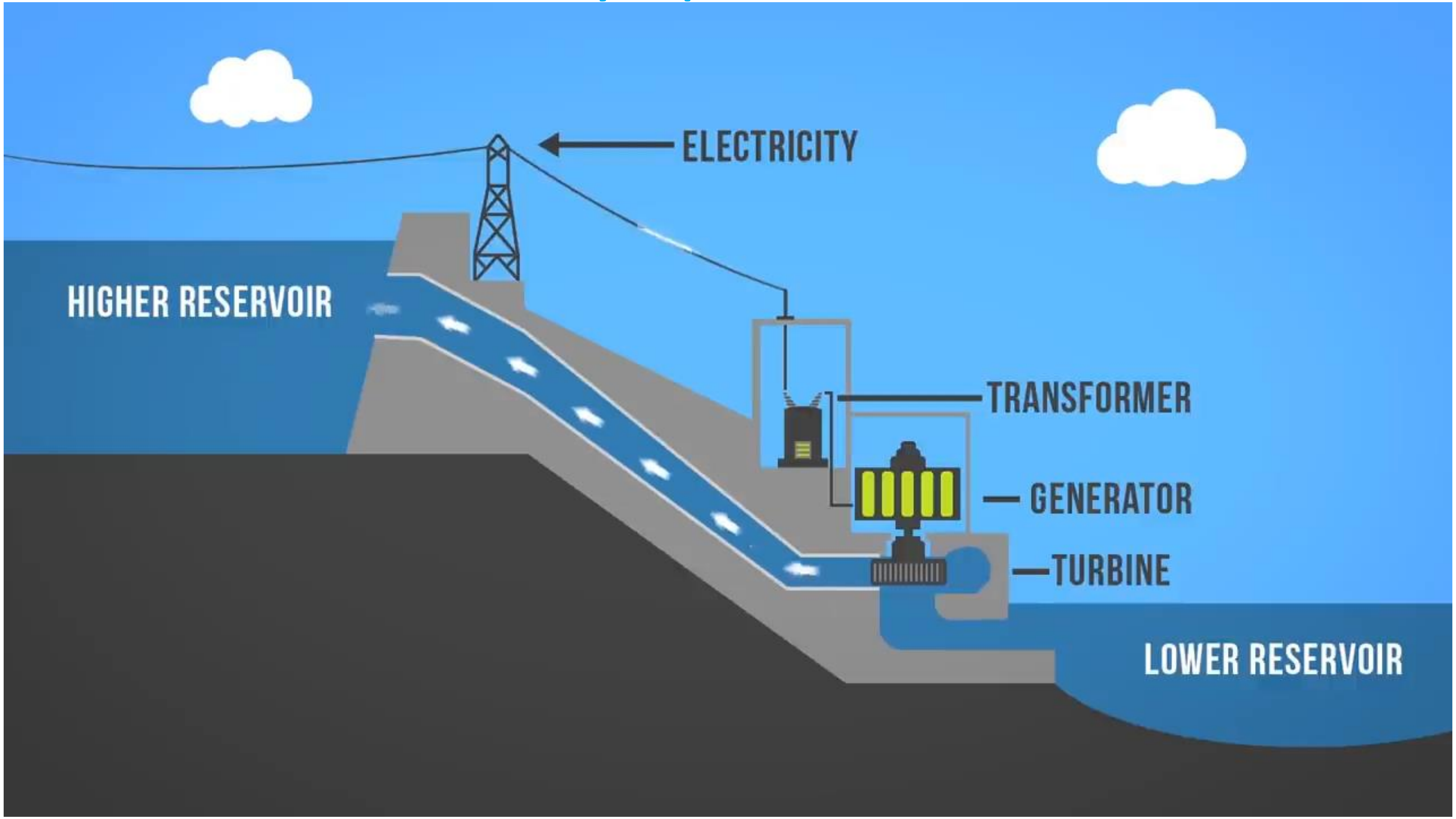
Nuclear Power Plant

Features: (50 Hz)

- High rotating speed: 3000 r/min for 2-pole machine in Coal plant , 1500 r/min for 4-pole machine in Nuclear plant
- Generator with long shaft but small diameter size due to higher speed and less pole-pair

Generators in Power Plants

- **Hydropower Plants**



https://www.youtube.com/watch?v=q8HmRLCgDAI

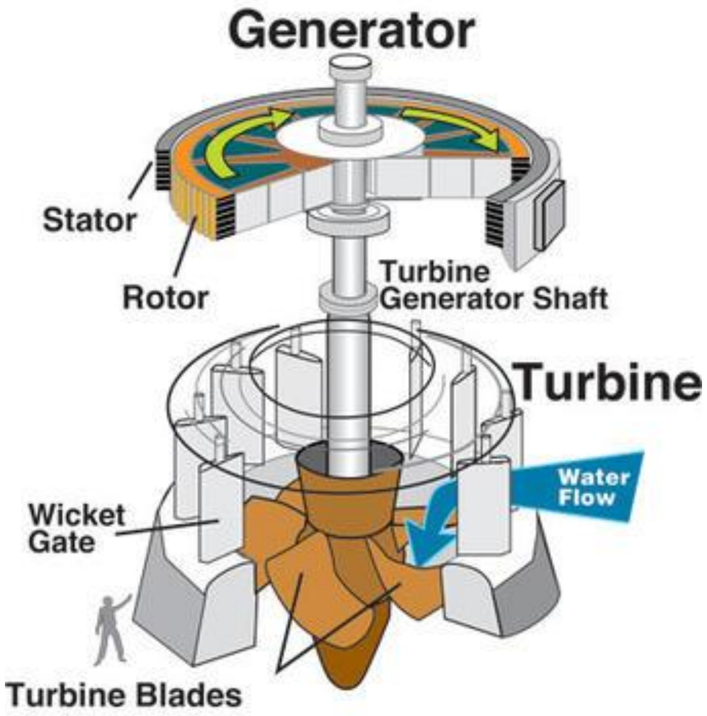
- **Questions. What else other renewable energy sources you know?**

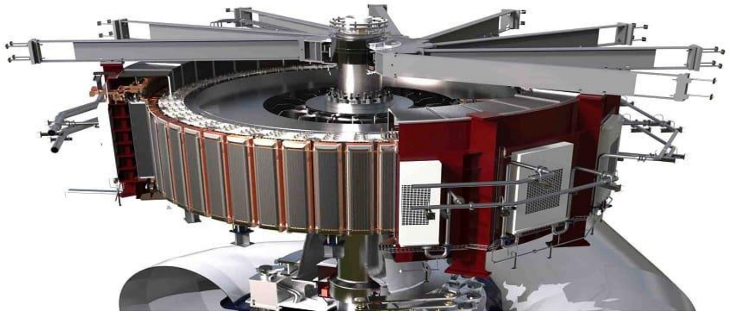
Most popular:

- Solar energy.
- Wind energy.
- Hydro energy.
- Tidal energy.
- Geothermal energy.
- Biomass energy.

Generators in Power Plants

❑ Hydropower Plants



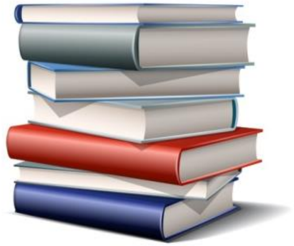


Generator rotor

Features: (50 Hz)

- Low rotating speed: 150 r/min for 40-pole, 300 r/min for 20-pole. In general, less than 1000 r/min
- Generator with short shaft but big diameter size due to lower speed and more pole-pair

Some References



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