Electricity Generation

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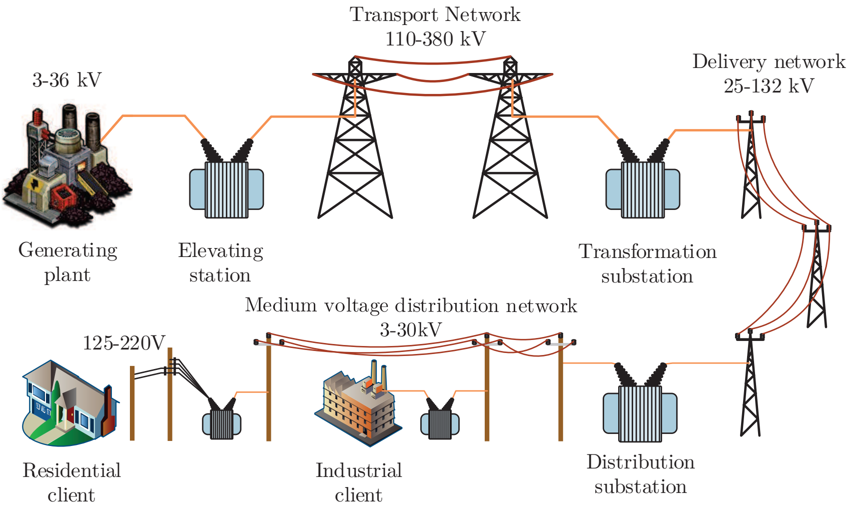
Content

Power systems network



Transport Network
110-380 kV

3-36 kV

Delivery network
25-132 kV

Generating plant

Elevating station

Transformation substation

Medium voltage distribution network
3-30kV

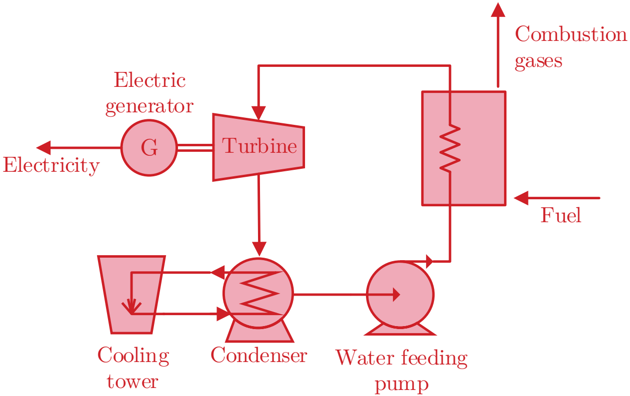
125-220V

Residential client

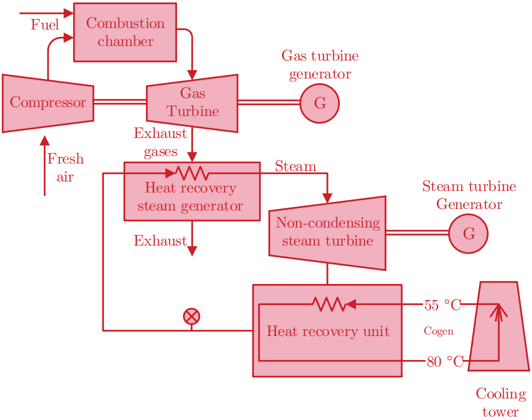
Industrial client

Distribution substation

Thermal power generation

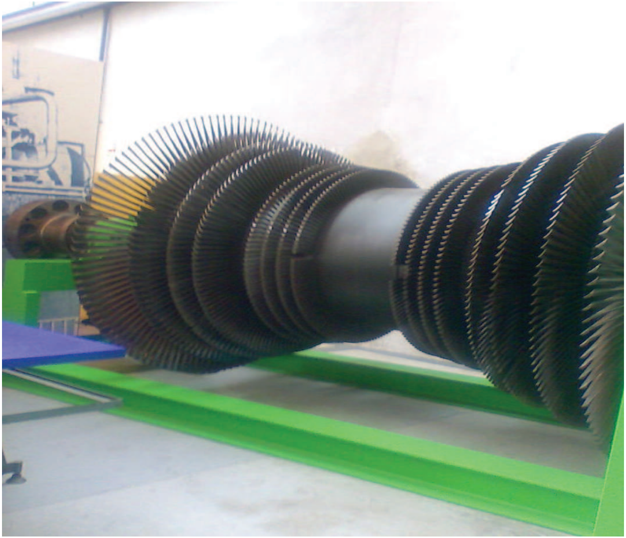


Combined-cycle generating plant



Representative energy flows for a combined-cycle, cogeneration plant with back-pressure steam turbine, delivering thermal energy to a heating system.

Steam turbine for electricity generation



Hydraulic turbine

Solar generating system

11 MW Sevilla, Spain

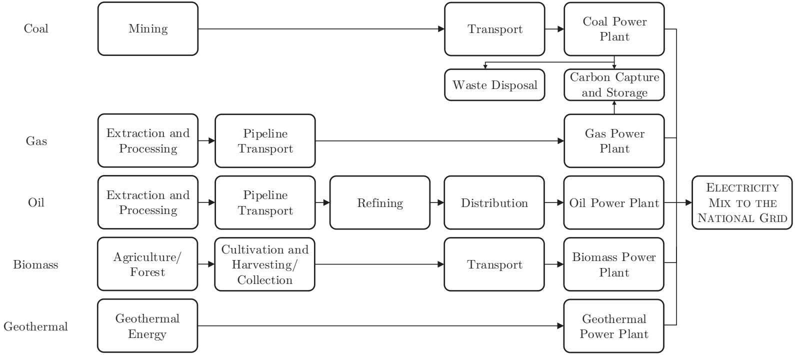
Wind energy generation system

2.5 MW from 8 turbines in Santa Catarina, N. L., Mexico

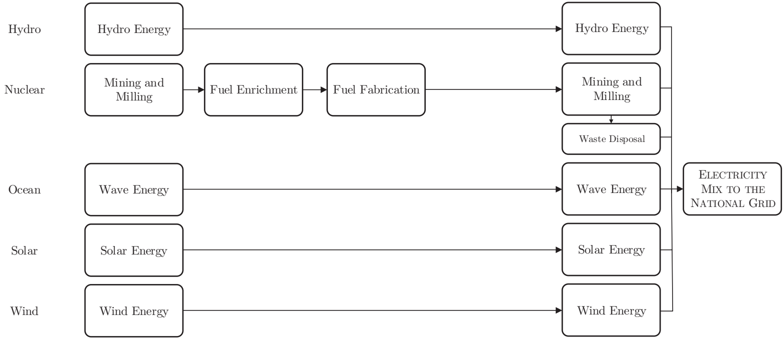
Typical efficiencies

Power plant technnology	Electrical efficiency [%]
Coal-fired steam turbine	35
Dual steam turbine	35
Fuel oil & gas steam turbine	34
Gas combined-cycle	44
Diesel combustion engine	37
Hydroelectric dam	35
Geothermal steam turbine	35
Wind turbine	35
Solar panels	9-12
Nuclear	32

Life cycle of electricity generation



Life cycle of electricity generation



Hydro

Hydro Energy → Hydro Energy

Nuclear

Mining and Milling → Fuel Enrichment → Fuel Fabrication → Mining and Milling → Waste Disposal

Ocean

Wave Energy → Wave Energy

Solar

Solar Energy → Solar Energy

Wind

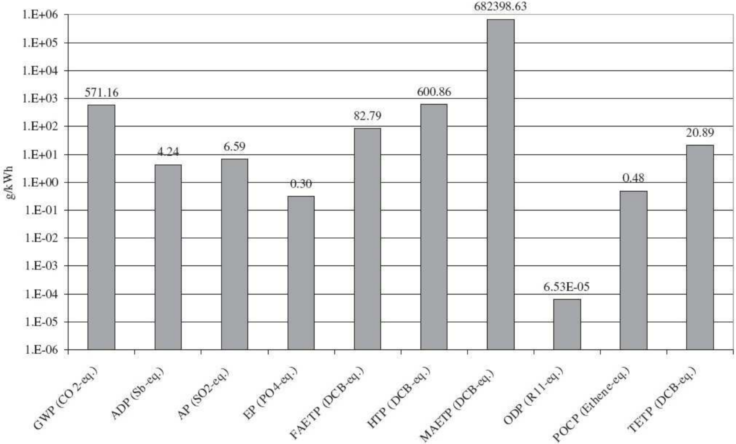
Wind Energy → Wind Energy

→ ELECTRICITY MIX TO THE NATIONAL GRID

Elements considered in life cycle analysis

- GWP Global warming potential (CO_2)
- ADP Abiotic depletion potential (Sb antimony)
- AP Acidification potential (SO_2)
- EP Eutrophication potential (NO_x and others)
- FAETP Freshwater aquatic ecotoxicity potential (heavy metals to air and water)
- HTP Human toxicity potential (nickel, vanadium y arsenic)
- MAETP Marine aquatic ecotoxicity potential (hydrogen fluoride)
- OLDP Ozone layer depletion potential
- POCP Photochemical ozone creation potential (SO_2 and NO_x)
- TETP Terrestrial ecotoxicity potential (Chromium, nickel, vanadium and mercury)

Environmental impact for each kWh, the case of Mexico

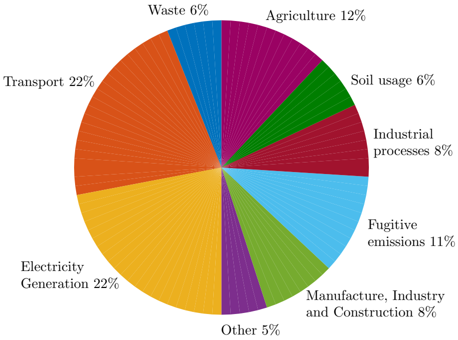


Santoyo-Castelazo, E., Gujba, H., Azapagic, A., "Life cycle assessment of electricity generation in Mexico." 2011. Energy 36 (3), 1488-1499.

CO_2 Emissions in Mexico

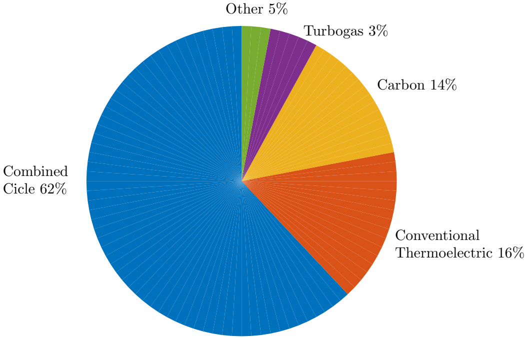
Emissions of greenhouse effect gases in Mexico in 2010, according to the Fifth National Communication to the United Nations Framework Convention on Climate Change.

Percentage of total emissions

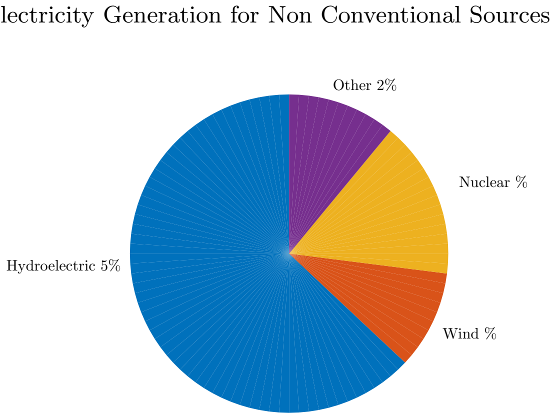


Generation from conventional sources

Electricity Generation for Conventional Sources (fossil fuel)



Generation from non conventional sources



Electricity Tariff

The tariff for electricity consumption depends mainly on the following elements:

- Type of installation and voltage level
- Period of the year

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- Hour of the day
- Power factor
- Maximum measured power during a period of time

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Electricity Tariff in Mexico

First Sunday of April to last Saturday of October (DST)

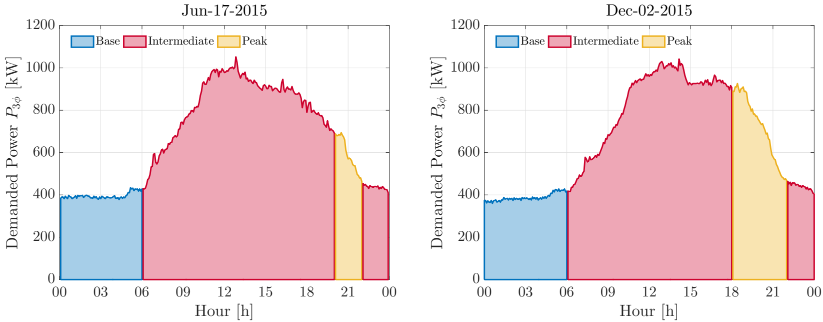
Days	Base	Intermediate	Peak
Monday to Friday	0:00-6:00	6:00-20:00 22:00-24:00	20:00-22:00
Saturday	0:00-7:00	7:00-24:00	
Sunday and non-working days	0:00-19:00	19:00-24:00	

Electricity Tariff in Mexico

Last Sunday of October to Saturday before first Sunday of April

Days	Base	Intermediate	Peak
Monday to Friday	0:00-6:00	6:00-18:00 22:00-24:00	18:00-22:00
Saturday	0:00-8:00	8:00-19:00 21:00-24:00	19:00-21:00
Sunday and non-working days	0:00-18:00	18:00-24:00	

Typical demand in UAM Azcapotzalco



Electricity Tariff in Mexico: Invoice Demand

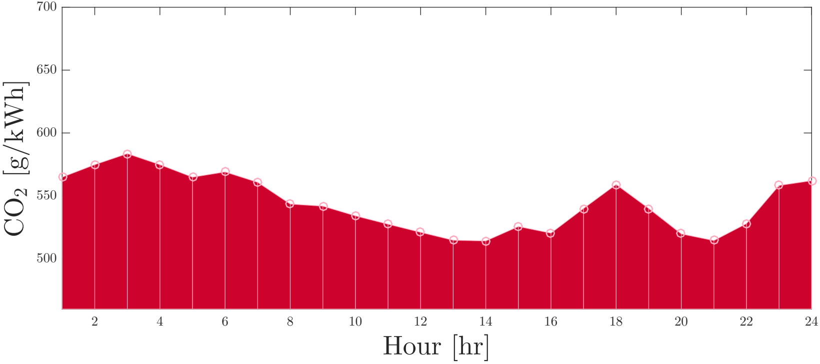
2016	Demand* ($/kW)	Peak ($/kWh)	Intermediate ($/kWh)	Base ($/kWh)
June	10.79	0.0954	0.0406	0.0339

$$^{\star}D = DP + FRI \times \max\left(DI - DP, 0\right) + FRB \times \max\left(DB - DPI, 0\right)$$

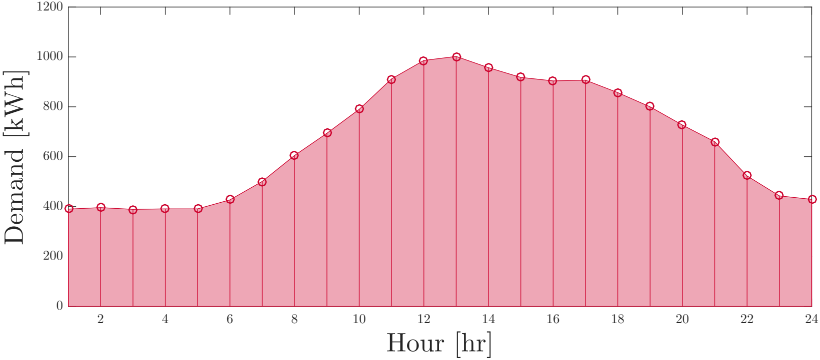
where:

$D =$ Invoice Demand
$DP =$ Peak demand in peak period
$DI =$ Peak demand in intermediate period
$DB =$ Peak demand in base period
$DPI =$ Peak demand in intermediate and peak periods
$FRI =$ 0.30
$FRB =$ 0.15

CO_2 emissions in every hour of a Wednesday in Mexican power plants.



Typical electric demand during a Wednesday at UAM-A.



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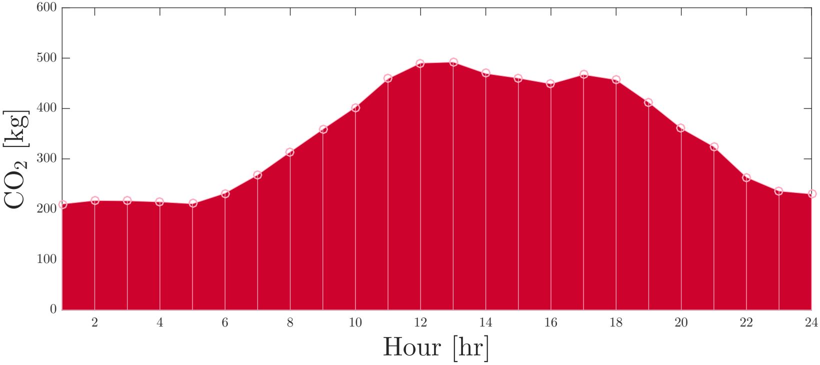
Casa abierta al tiempo

CO_2 equivalent emissions in every hour of a Wednesday at UAM-A.



Generation Basics: Magnetic circuits

The basic theory of electricity generation is available in *Fitzgerald and Kingsley's Electric Machinery*

Umans, S., Fitzgerald, A., & Kingsley, C. (2013). Electric machinery. McGraw-Hill Higher Education.

Generation Basics: Magnetic circuits

Simplifying assumptions for engineering solutions:

- Consider Ampère's law

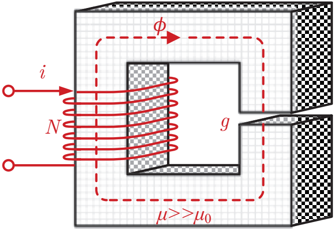
$$\oint_C \mathbf{H} \cdot d\mathbf{l} = \int_{S_C} \mathbf{J} \cdot d\mathbf{a}$$

where

$\mathbf{H} =$ Magnetic field intensity $\quad d\mathbf{l} =$ Line differential

$\mathbf{J} =$ Current density $\quad d\mathbf{a} =$ Surface differential

Generation Basics: Magnetic circuits



Basic scheme of a magnetic circuit.

Generation Basics: Magnetic circuits

- Consider Gauss' law

$$\oint_S \mathbf{B} \cdot d\mathbf{a} = 0$$

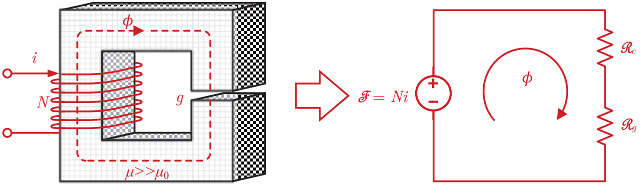
  where

  $\mathbf{B} =$ Magnetic field density $d\mathbf{a} =$ Surface differential

- the presence of a high-permeability ($\mu \gg \mu_0$) material tends to cause magnetic flux to be confined to the paths defined by the structure
- for uniform cross-sectional areas $\phi = B_c A_c$

Generation Basics: Magnetic circuits

- a three-dimensional magnetic circuit can be represented by a one-dimensional equivalent circuit similar to an electric circuit



then the

$$\mathscr{F} = Ni = \phi \mathscr{R}$$

where:

$$\mathscr{R} = \frac{l_c}{\mu A_c}, \qquad \phi = \int_S \mathbf{B} \cdot d\mathbf{a}$$

Generation Basics: Flux linkage and inductance

- Time-varying magnetic fields produce electric fields according to Faraday's law:

$$\oint_C \mathbf{E} \cdot d\mathbf{s} = -\frac{d}{dt} \int_S \mathbf{B} \cdot d\mathbf{a}$$

Generation Basics: Flux linkage and inductance

- A winding consists of N closed contours C, so

$$e = N\frac{d\phi}{dt} = \frac{d\lambda}{dt}, \qquad \lambda = N\phi$$

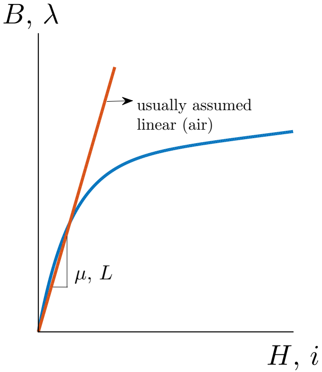
- for a magnetic circuit composed of magnetic material of *constant* magnetic permeability or with a dominating air gap, the linear relation between flux and current is called *inductance*:

$$L = \frac{\lambda}{i}$$

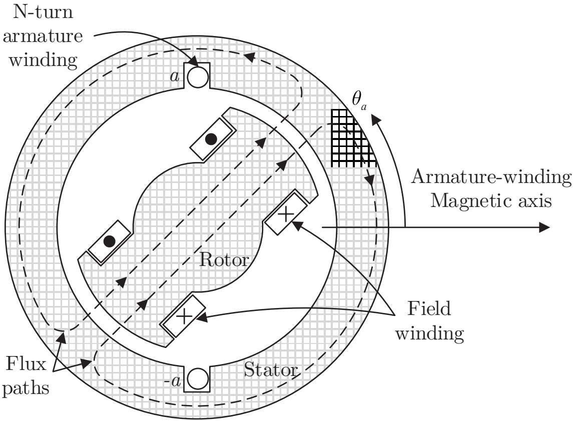
Generation Basics: Flux linkage and inductance

Assuming the magnetic flux is uniform through most of the core $H \propto \mathscr{F}$ $B \propto \phi$, and hence, $B \propto \lambda$.

Hence, a plot of flux versus current is of the same shape as a $B - H$ curve.



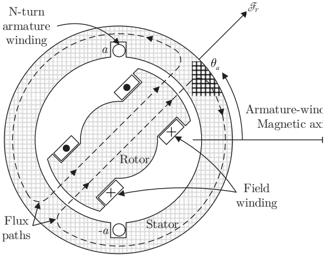
Generation Basics: Synchronous Generator



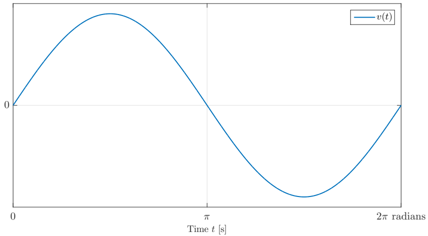
The field-winding of this machine produces a single pair of magnetic poles (similar to that of a bar magnet), and hence this machine is referred to as a two-pole machine.

Generation Basics: Synchronous Generator

The rotating magnetic field generates a sinusoidal time-varying emf (electromotive force) in the stator windings.
When currents circulate in both rotor and stator windings, magnetic flux is created in the air gap between. The electromagnetic torque is produced by the tendency of both magnetic fields to align.



(a)



(b)

Generation Basics: Synchronous Generator

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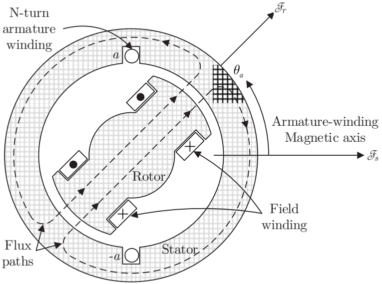
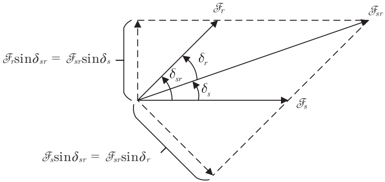




$$T = \frac{\pi}{2}\left(\frac{\text{poles}}{2}\right)^2 \Phi_{sr}\mathscr{F}_r \sin\delta_r$$

Generation Basics: Synchronous Speed

As the rotor rotates, the flux-linkages of the armature winding change with time. Under some assumptions, the resulting coil voltage will be sinusoidal in time.

In a two-pole machine, the coil voltage passes through a complete cycle for each revolution of the machine. Thus, its frequency in cycles per second (Hz) is the same as the speed of the rotor in revolutions per second:

the electric frequency of the generated voltage is synchronized with the mechanical speed.

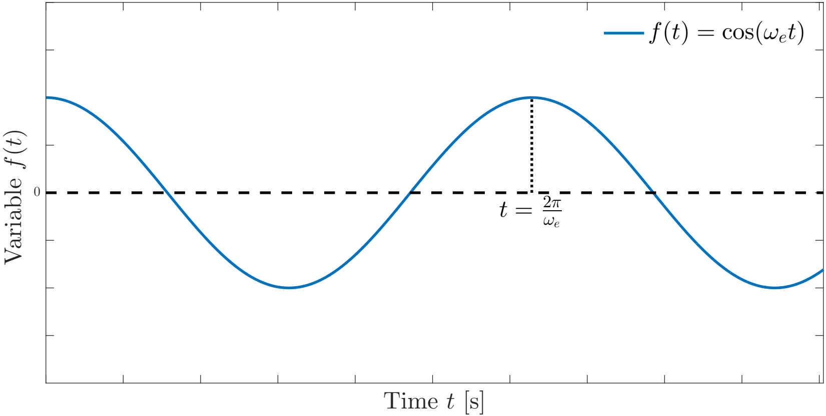
As seen in the equation:

$$f_e = \frac{\omega_e}{2\pi}$$

where ω_e is the electrical angular frequency.

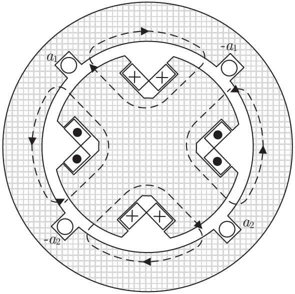
Generation Basics: Synchronous Speed

Generated armature voltage of a two pole machine ($\omega_m = \omega_e$):



Generation Basics: Synchronous Speed

When a machine has more than two poles, it is convenient to express angles in electrical degrees.

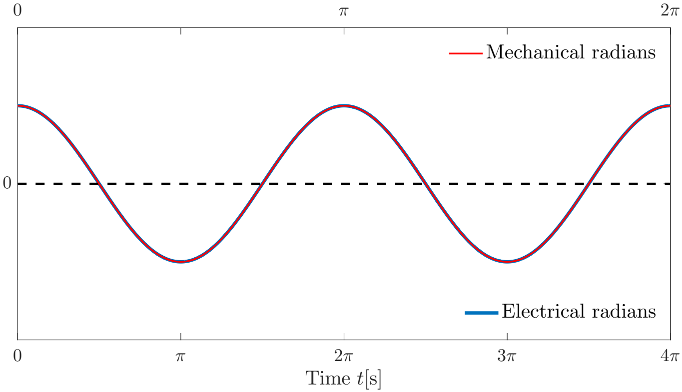


One pair of poles in a multipole machine or one cycle of flux distribution equals 360 electrical degrees or 2π electrical radians. Since there are poles/2 complete wavelengths, or cycles, in one complete revolution, it follows that

$$\omega_e = \left(\frac{\text{poles}}{2}\right)\omega_m$$

Generation Basics: Synchronous Speed

Generated armature voltage for a 4-pole machine. The mechanical frequency is half the electrical frequency



Generation Basics: Synchronous Speed

To maintain a constant frequency, machines with more than 2 poles must rotate at a lower speed than that of a 2 pole machine.

The typical frequency of operation in America is 60 Hz, yielding an angular velocity of 3600 rpm for a two pole machine.

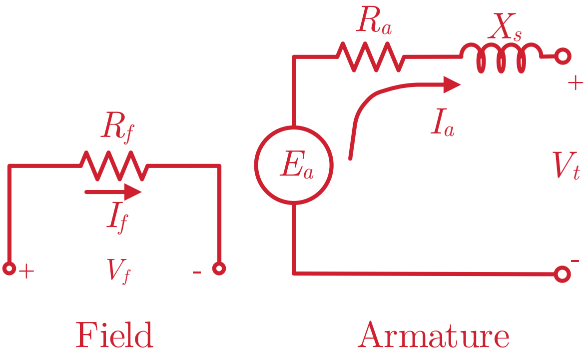
The rotational speed of a synchronous generator, in revolutions per minute, as a function of the electrical frequency is:

$$n = \frac{120}{\text{poles}} f_e$$

Synchronous Generator: Example

A synchronous generator is to produce 50 Hz sinusoidal voltages. What must be its speed if the machine has, a) 2 poles, b) 4 poles and c) 40 poles?

Synchronous Generator One-Phase Equivalent Circuit



V_t, E_a, V_f = Terminal, generated and field voltage
I_a, I_f = Armature and field currents
R_a, R_f = Armature and field resistances
L_f = Field inductance
X_s = Synchronous reactance, $X_s = \omega L_s$