Energy Devices – Power systems (Lecture 3)

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Lecture outline:

- A short history; AC vs. DC.
- Ohm's law, power in electrical systems, Joule loss.
- Transmission subject to losses; transformers.
- Primary energy sources and generator schematics.
- Some statistics about generation and consumption.

At a fundamental level, AC is convenient because induction (used in generators, transformers, and motors) is due to time-varying currents. In terms of equations, $V = -d\Phi/dt$. Why do we need high voltages?:

- Consider a 500 kV wire that carries 1 kA of current and has $25\ \Omega$ resistance. The total power transmitted at the generating end is $P = IV = 500$ MW. The voltage drop across the transmission line is 25 kV, so at the receiving end one has 475 kV (or 475 MW). The total power lost is 25 MW (a 5% loss).
- Take the same generator power, but 125 kV as the transmission voltage. In this case, the current must be 4 times larger to produce the same power. The Joule loss is then 400 MW, or $(400\ \mathrm{MW})/(500\ \mathrm{MW}) = 80\%$. Only 20% of the power reaches the consumer!

Image sources:

Fig. 1 (left)	http://en.wikipedia.org/wiki/File:Carl_Saltzmann_Erste_elektrische_Stra%C3%9Fenbeleuchtung.jpg.
Fig. 1 (right)	http://en.wikipedia.org/wiki/File:Tour_Eiffel_1878.jpg.
Fig. 3 (top)	http://en.wikipedia.org/wiki/File:Court_of_Honor_and_Grand_Basin.jpg.
Fig. 3 (bottom)	http://en.wikipedia.org/wiki/File:WorldsFairTeslaPresentation.png.
Fig. 4	http://en.wikipedia.org/wiki/File:Transformer3d_col3.svg.

Table 1: Electrical power sources, nationwide vs. my July 2009 ComEd bill. Source: Electric Power Monthly, September 2009, EIA. Petroleum includes both liquids and coke. Renewables here includes biomass and geothermal. See http://www.comed.com/customerservice/billing/understandingyourbill/

Fuel	Nationwide %	Chicago ComEd %
Coal	45.0	32
Nuclear	20.8	62
Natural Gas	21.4	4
Petroleum	1.1	n.p.
Hydro	7.6	1
Renewables	3.8	1

Table 2: Energy consumption in the residential and commercial sectors. Quantities with stars are not strictly electrical consumption. In the commercial sector, “other” includes non-building commercial use: street and garage lighting, etc. Rather than new technologies, retrofitting technologies can make a big difference: thin insulation to install after the house is standing, timers, fluorescent bulbs with the same form factor as incandescent (“compact”), and so on. Source: Energy data book 2007, EERE, DOE. To read more, see the APS 2008 Energy report and “Sustainable energy–without all the hot air” http://www.withouthotair.com/.

Usage	Residential %	Commercial %
Lighting	12	27
Heating*	32	15
Cooling*	13	14
Water heating*	13	7
Electronics	8	7
Ventilation	n/a	6
Refrigeration	8	4
Computers	5	3
Cooking	5	2
Other	3	15

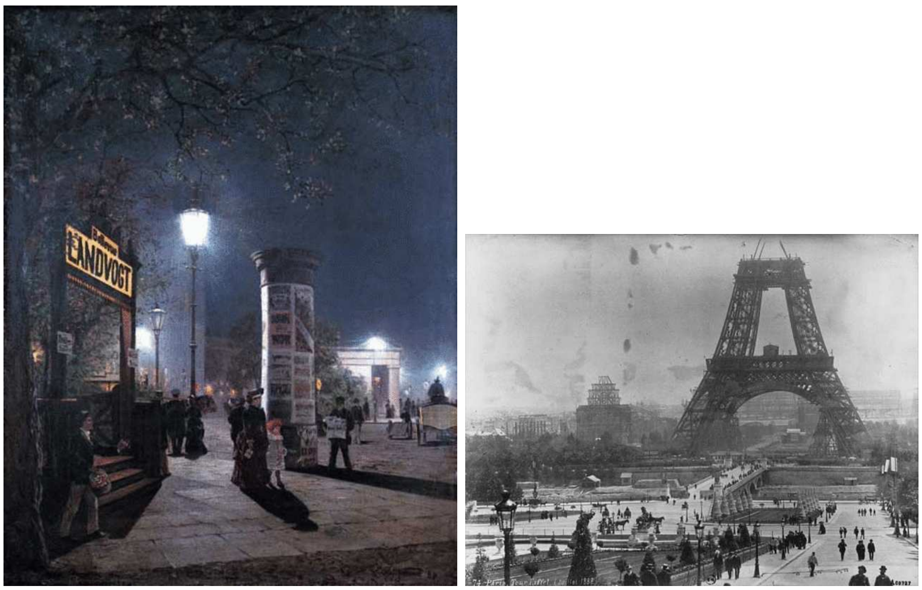

Figure 1: Building the industrial age, Eiffel Tower, 1878 and arc lamps in Berlin by Carl Saltzmann, 1884. Zènobe Gramme's dynamos powered Yablochkov arc lamps along Avenue de l'Opera and the Place de l'Opera for the 1878 Paris Expo. Early generation was heterogeneous and applications included street cars (hundreds of volts), arc lamps (thousands of volts), and Edison's lightbulb (~ 100 volts).

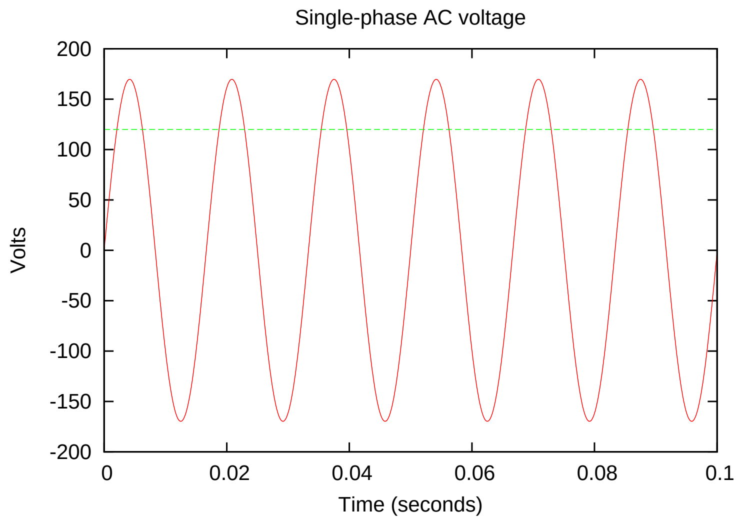

Figure 2: Single-phase AC voltage. The standard frequency of oscillation of the AC line is either 50 or 60 Hz, and depends on region. The voltage normally quoted is square root of the average of the voltage-squared – in the US, this is 120 Volts. This is shown by the straight line, and can be thought of as the equivalent DC voltage that would produce the same power dissipation in a resistor (such as a lightbulb). Why 60 Hz? – 1) higher frequencies have higher impedance from inductance and capacitance in the transmission lines and 2) lower frequency would cause lights to flicker. The 60 Hz buzz near electrical equipment is often due to magnetostriction.

Figure 3: The Jackson Park pavilion and Tesla's AC exhibit at the Columbian Exposition. This was a decisive battle between DC and AC, and AC won.

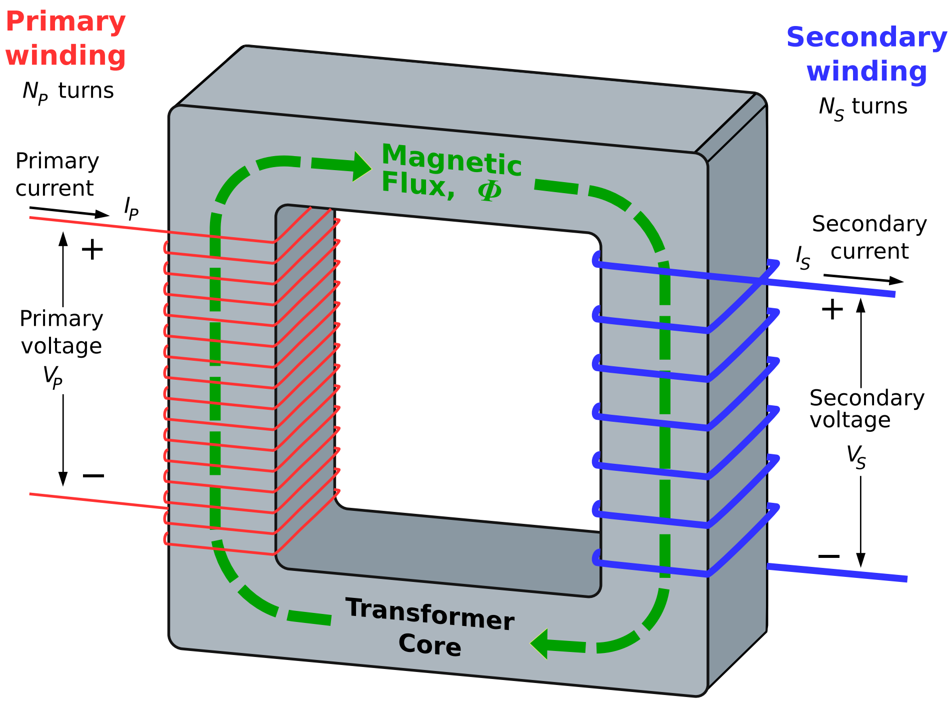

Figure 4: The transformer coil. Transformers can step voltages up and down to permit high voltage transmission and low-voltage consumption. Let the number of primary windings be N_p and secondary windings be N_s. Then the ratio of the voltage through the secondary divided by the voltage through the primary is the ratio of the number of windings, or $\frac{V_S}{V_P} = \frac{N_S}{N_P}$. This seems like we get something for nothing – a boost in the voltage! Yet, for the gain in voltage, there is a proportional loss in current so that the power transmitted is the same (assuming 100% efficiency), or $P_p = I_p V_p = I_s V_s = P_s$.