

ECE 215/S – Principles of Electronic Cyber Warfare

Block 1: Resistive Circuits and Power Distribution

Lesson 8: Power and Efficiency

Department of Electrical and Computer Engineering
United States Air Force Academy

Fall 2026

Objective 1.5

I can calculate the efficiency of a system modeled as an electrical circuit.

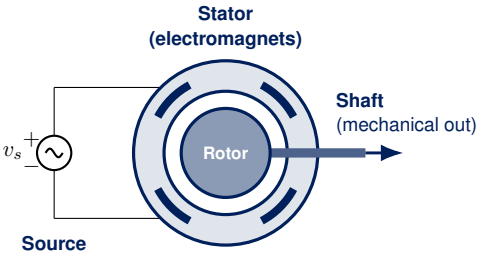
- Lesson 7's handoff: efficiency is about **real** power — η divides by P, **never** by S
- Every real component wastes some of what you put into it, and the waste is heat
- Today's tool is small, but it appears in **every remaining lesson of Block 1** — transformers, converters, and the whole of Project 1
- Assessed on **Quiz 2** along with Objectives 1.3 and 1.4

Where We Are Going

By the end of this lesson, you will be able to:

- Describe how a **motor** converts electrical energy to mechanical energy, and name its main parts
- List the four ways a motor **loses** energy
- Compute **efficiency** η for a single component — including when the input is an **AC line**, where you must get from S to P before you divide
- Model **power delivered vs. power dissipated** as a circuit
- Compute the **overall efficiency of a chain** of components in series

Electric Machines



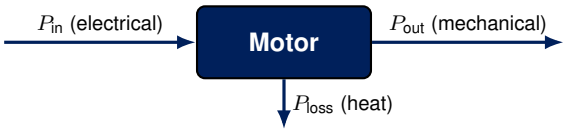
A **motor** turns electrical energy into mechanical energy. A **generator** runs the same physics backward.

- Current from the **source** through the **stator** coils creates a magnetic field
- The **rotor**'s field pushes against it
- Arranged correctly, that push becomes continuous **rotation**, delivered out the **shaft**

This is the same physics that makes transformers work in Lesson 9.

Motor Components

- **Source** — provides the electrical energy that drives the motor
- **Stator** — the stationary part, made of electromagnets
- **Rotor** — the spinning part that interacts with the stator's field to produce torque
- **Shaft** — the rod that delivers mechanical energy to whatever the motor is turning



Where the Energy Is Lost

Four leaks, and none of them are optional:

- **Electrical** — I^2R heating in the rotor and stator windings
- **Magnetic** — energy lost in the core material as the magnetic field alternates
- **Mechanical** — friction in the bearings and drag from moving air
- **Stray** — everything else: manufacturing imperfections, leakage fields, edge effects

Every loss becomes heat. Heat is the engineering constraint.

Efficiency

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100\%$$

- For a **motor**: P_{out} is mechanical, P_{in} is electrical
- For a **generator**: exactly the reverse
- Both terms are **real** power, in watts
- η is always less than 100%

The unit you will meet: mechanical output is often quoted in horsepower.

$$1 \text{ hp} = 745.7 \text{ W}$$

That constant is on your equation sheet. Convert to watts before doing anything else.

Whatever does not come out the far side is left as heat: $P_{\text{loss}} = P_{\text{in}} - P_{\text{out}}$.

Efficiency on an AC Line

Lesson 7's handoff: a bus gives you V_{rms} and I_{rms}, and their product is S — **not** P.

1. From the line you get **apparent** power, $S = V_{\text{rms}}\, I_{\text{rms}}$ (VA)
2. The power factor converts it to **real** power, $P = S \times \text{pf}$ (W)
3. Efficiency uses the real power at *both* ends, $\eta = P_{\text{out}}/P_{\text{in}}$ (W / W)

Bridge back to Lesson 7. When the load's P is what you know, run the two steps the other way: $S = P/\text{pf}$, then $I_{\text{rms}} = S/V_{\text{rms}}$.

Dividing by S is this objective's most common error — it always makes the machine look *worse* than it is, because $S \geq P$.

For the curious — not on any quiz: how much useful work does the source get *per volt-ampere it must supply*? Multiply by a clever form of one:

$$\frac{P_{\text{out}}}{S_{\text{in}}} = \frac{P_{\text{out}}}{P_{\text{in}}} \cdot \frac{P_{\text{in}}}{S_{\text{in}}} = \eta \times \text{pf}$$

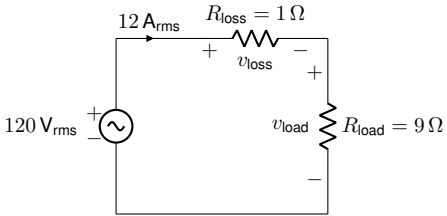
Call it **overall conversion effectiveness** — *not* a new efficiency, since η itself still never divides by S. It measures the *source's* burden per volt-ampere, not how well the load uses real power.

It sizes wiring and breakers: $I_{\text{rms}} = P_{\text{out}}/(V_{\text{rms}}\,\eta\,\text{pf})$. A **92%** motor at pf $= 0.70$ (**0.64**) stresses the supply *more* than an **88%** one at pf $= 0.90$ (**0.79**).

η divides by P, never by S.

Power Delivered vs. Power Dissipated

The objective says a system **modeled as an electrical circuit**. Model the waste as a **series resistor**: it is not a real part, but every watt it burns is a watt the load never sees.



Same answer from the resistances:

$$\eta = \frac{R_{\text{load}}}{R_{\text{load}} + R_{\text{loss}}} = \frac{9}{10}$$

Series, so **one current**: $I_{\text{rms}} = 120/(1+9) = 12\,\text{A}_{\text{rms}}$. Purely resistive, so pf $= 1$ and $S = P$.

$$P_{\text{load}} = I_{\text{rms}}^2 R_{\text{load}} = 12^2(9) = 1296\ \text{W}$$

$$P_{\text{loss}} = I_{\text{rms}}^2 R_{\text{loss}} = 12^2(1) = 144\ \text{W}$$

$$\eta = \frac{1296}{1296 + 144} = \frac{1296}{1440} = 90.0\%$$

Efficiency in a Chain

Real systems are several stages deep, and each stage's **output** is the next stage's **input**. Navy boxes are the **devices**; the η under each is that device's efficiency, not a stage of its own:



$$\eta_{\text{total}} = \frac{P_{\text{out}}}{P_{\text{in}}} = \eta_1 \times \eta_2 \times \eta_3 \times \cdots$$

- Efficiencies **multiply**, they do not average
- Three stages at 90% each give $0.9^3 = 72.9\%$, not 90%
- This is why a long power chain is expensive, and it is the core of Project 1

One caution. *Real* power is conserved stage to stage — which is why efficiencies cascade. *Apparent* power is **not**, so $\eta \times$ pf does **not** chain: it is a measurement at **one interface** (the wall plug, say), never a per-stage property. That is why Project 1 returns to apparent power at *each* AC interface.

Method

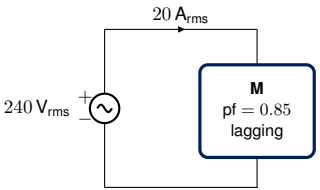
Working *backward* from the load is almost always easier than working forward:

1. Convert everything to **watts** — 1 hp $= 745.7$ W, and RMS values before anything else
2. On an **AC** segment, get the real power first: $S = V_{\text{rms}} I_{\text{rms}}$, then $P = S \times \text{pf}$
3. Start at the **load** — you usually know what it demands
4. Step back through each stage to the source: $P_{\text{in}} = P_{\text{out}}/\eta$
5. **Check:** $\eta_{\text{total}} = P_{\text{load}}/P_{\text{source}}$ should equal the product of the stage efficiencies

Dividing by η moves upstream. Multiplying moves downstream.

Worked Example

A **5 hp** motor draws 20 A RMS from a 240 V RMS line at a power factor of **0.85 lagging**.



Find:

1. The mechanical output power P_{out}, in watts
2. The apparent power S drawn from the line
3. The electrical input power P_{in}
4. The efficiency η
5. The power lost as heat, P_{loss}

Careful: the line hands you volts and amps, and that product is S.

Work it before the next slide.

Worked Example — Solution

Mechanical output

$$P_{\text{out}} = 5 \times 745.7 = 3728.5 \text{ W}$$

Apparent power from the line

$$S = V_{\text{rms}} I_{\text{rms}} = (240)(20) = 4800 \text{ VA}$$

Real power in

$$P_{\text{in}} = S \times \text{pf} = 4800(0.85) = 4080 \text{ W}$$

Efficiency

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{3728.5}{4080} = 0.9138 \rightarrow 91.4\%$$

Losses

$$P_{\text{loss}} = 4080 - 3728.5 = 351.5 \text{ W}$$

The trap: dividing by S gives $3728.5/4800 = 77.7\%$, which is **wrong**. S is what the line must carry; P_{in} is what the motor is actually given.

351.5 W of heat inside the motor housing. That is what the cooling has to remove.

Your Turn

An aircraft subsystem runs off a generator through three stages: a **transformer** (97% efficient), a **converter** (88%), and a **motor** (82%). The motor must deliver **2 hp**.

1. What is the overall efficiency of the chain?
2. How much power must the generator supply?
3. How much total power is lost as heat?
4. Which single stage would you improve first, and why?

The transformer and the converter are just **boxes with an efficiency** for now — Lessons 9 and 10 open them up.

Wrap-Up

Key ideas:

- **Motors** convert electrical to mechanical energy; **generators** run it backward. Source, stator, rotor, shaft
- Losses are **electrical, magnetic, mechanical, and stray** — and all of them end up as heat
- $\eta = P_{\text{out}}/P_{\text{in}}$, watts on both ends. On an AC line $S = V_{\text{rms}} I_{\text{rms}}$ and $P = S \times \text{pf}$ — η **never** divides by S
- Model the waste as a series resistor: $\eta = R_{\text{load}}/(R_{\text{load}} + R_{\text{loss}})$
- Cascaded efficiencies **multiply**, and the **worst** stage is the one worth improving

Next lesson:

- **Lesson 9 — Objective 1.6: Transformers and Power Transmission.** Why the grid is AC and why it runs at high voltage
- **Quiz 2** (Objectives 1.3–1.5) is due at Lesson 10