ECE330: Power Circuits & Electromechanics

Lecture 18. Fundamental limits and realistic trajectories

Prof. Richard Y. Zhang
Univ. of Illinois at Urbana-Champaign
ryz@illinois.edu

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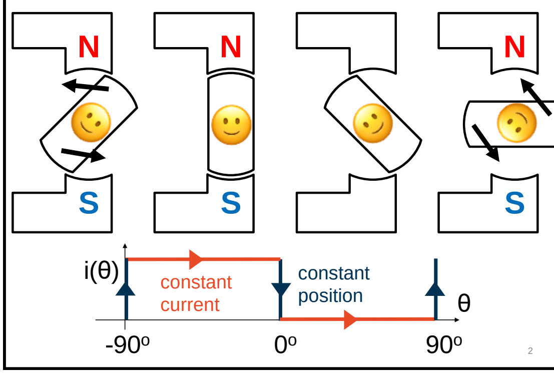
Last week: Switched reluctance system



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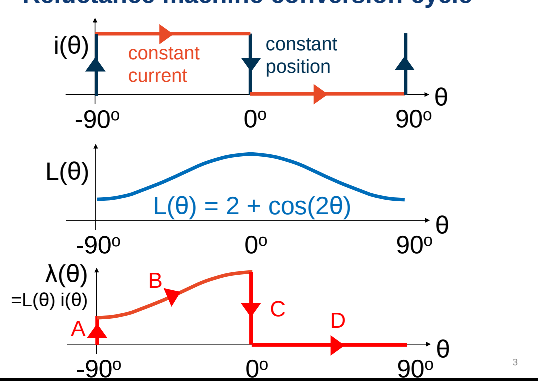
Reluctance machine conversion cycle



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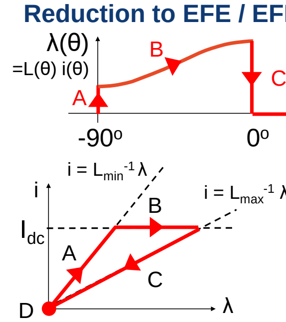
Reduction to EFE / EFM problem



$L(\theta) = 2 + \cos(2\theta)$ H

$I_{dc} = 1$ A

$EFE_A = +0.5$ J

$EFE_B = +2.0$ J

$EFE_C = -1.5$ J

$EFE_D = 0$ J

$EFE_{ABCD} = +1$ J

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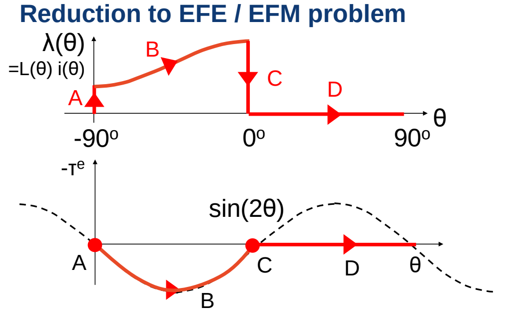
Reduction to EFE / EFM problem



$-\tau^e = i^2\sin(2\theta)$ Nm

$I_{dc} = 1$ A

$EFM_B = -1$ J

$EFM_{ABCD} = -1$ J

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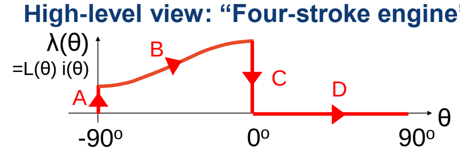
High-level view: "Four-stroke engine"



Input $P_e = vi$ → Output $P_m = f\frac{dx}{dt}$

Stored energy

	A	B	C	D
EFE [J]	+1/2 J	+2 J	-3/2 J	0
EFM [J]	0	-1 J	0	0

Av. power out = 1 J / half-cycle = **120 W @ 60 Hz**

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Today: Two lingering questions

Input $P_e = vi$ → Output $P_m = f\frac{dx}{dt}$

Stored energy

	A	B	C	D
EFE [J]	+1/2 J	+2 J	-3/2 J	0
EFM [J]	0	-1 J	0	0

Av. power out = 1 J / half-cycle = **120 W @ 60 Hz**

- How do we get more power out of this machine?
- How do we improve this machine?

Key weapon: Graphical technique

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Today

- Getting more power out of the machine
- Realistic and arbitrary trajectories
- Effect of saturation nonlinearity

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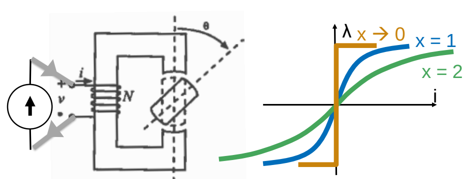
How do we get more power out of this machine?



- Assume no modifications to the machine
  - $L(\theta) = L_1 + L_2 \cos(2\theta)$ remains unchanged.
- Respect material limits (otherwise take i → ∞)
  - Avoid saturation; assume maximum |λ|
  - Avoid I^2R losses; assume maximum |i|

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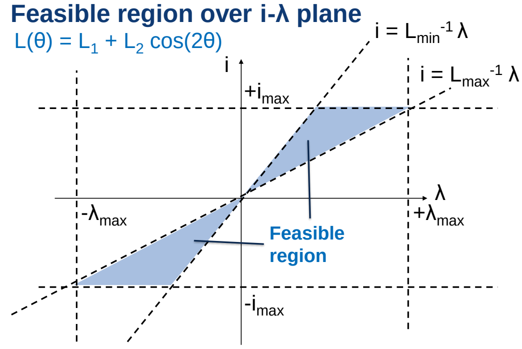
Feasible region over i-λ plane

$L(\theta) = L_1 + L_2 \cos(2\theta)$



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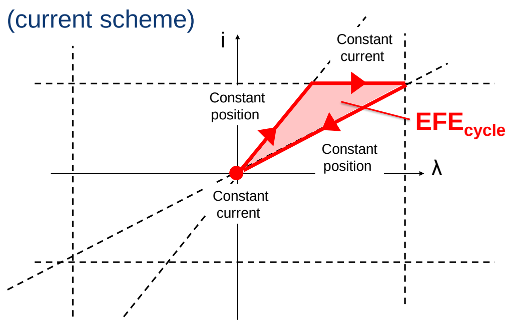
Switch current max to zero
(current scheme)



Pav = (EFE_{cycle}) (Cycles per second)
maximize area = maximize power

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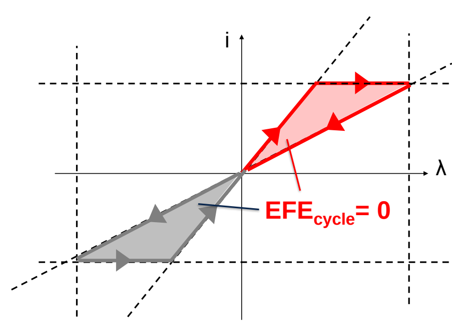
Switch current +max to –max?



Two cycles cancel out, resulting in zero net power.
Big degradation!

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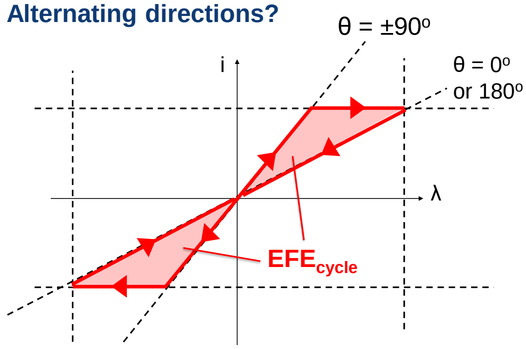
Alternating directions?



Cannot instantly switch θ, but waiting for θ to change results in two cycles. **No improvement.**

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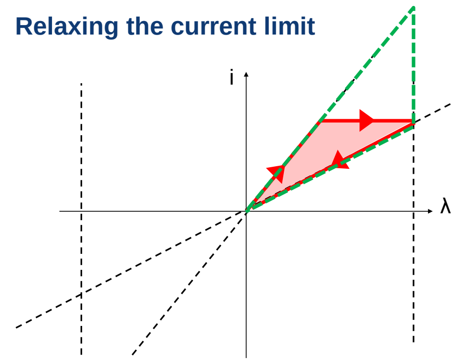
Relaxing the current limit



Exploits the fact that smaller inductances need more current to saturate. **Potential improvement!**

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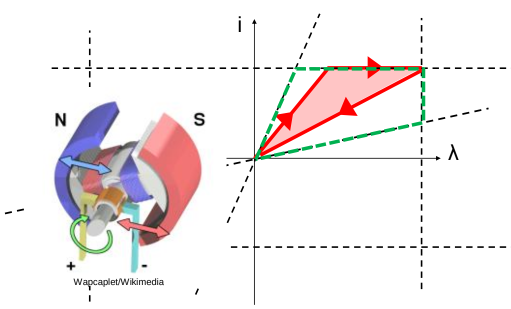
Widening the gap b/w Lmax & Lmin



L proportional to area/gap. Lmax limited by min gap size. **Potential improvement!**

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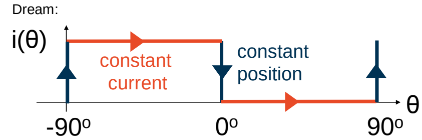
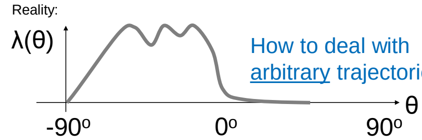
Problem solved?

Dream:



Reality:



How to deal with arbitrary trajectories?

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Today

- ~~Getting more power out of the machine~~
- Realistic and arbitrary trajectories
- Effect of saturation nonlinearity

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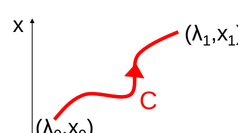
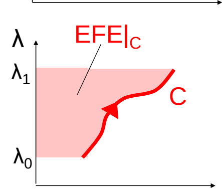
EFE / EFM: Monotone electrical path





1. Integrate trajectory for EFE

$$\mathrm{EFE}|_C = \int_C i(\lambda', x')\,\mathrm{d}\lambda' = \int_{\lambda_0}^{\lambda_1} i(\lambda')\,\mathrm{d}\lambda'$$

Assumes dλ/dt > 0 or dλ/dt < 0

2. Compute expression for energy

$$\mathrm{Energy} = \int_0^{\lambda} i(\lambda', x)\,\mathrm{d}\lambda'$$

3. Infer EFM from energy

$$\mathrm{EFM}|_C = \mathrm{Energy}(\lambda_1, x_1) - \mathrm{Energy}(\lambda_0, x_0) - \mathrm{EFE}|_C$$

4. Quote the unit as joules

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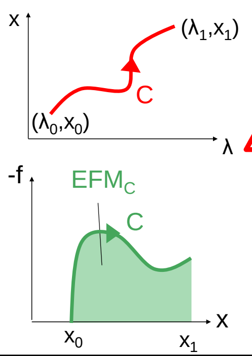
EFE / EFM: Monotone mechanical path



1. Integrate trajectory for EFM

$$\mathrm{EFM}|_C = \int_C -f(\lambda', x')\,\mathrm{d}x' = \int_{x_0}^{x_1} -f(x')\,\mathrm{d}x'$$

Assumes dx/dt > 0 or dx/dt < 0

2. Compute expression for energy

$$\mathrm{Energy} = \int_0^\lambda i(\lambda', x)\,\mathrm{d}\lambda'$$

3. Infer EFE from energy

$$\mathrm{EFE}|_C = \mathrm{Energy}(\lambda_1, x_1) - \mathrm{Energy}(\lambda_0, x_0) - \mathrm{EFM}|_C$$

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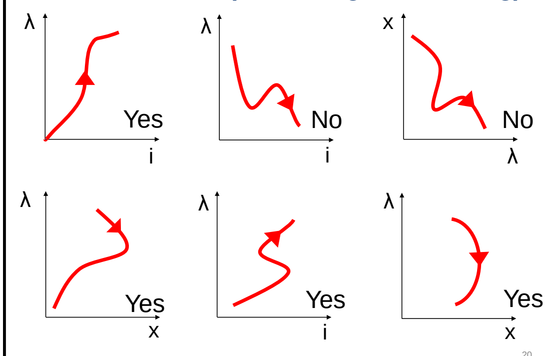
Monotone in λ? (Increasing / decreasing)



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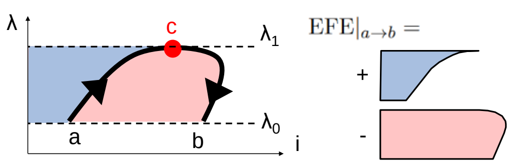
EFE and EFM: General electrical path

1. Add break-points where dλ/dt = 0.
2. Do each segment separately and sum.



$$\mathrm{EFE}|_{a\to b} =$$

$$\mathrm{EFE}|_{a\to b} = \mathrm{EFE}|_{a\to c} + \mathrm{EFE}|_{c\to b}$$
$$= \int_{\lambda_0}^{\lambda_1} i_{a\to c}(\lambda')\,\mathrm{d}\lambda' + \int_{\lambda_1}^{\lambda_0} i_{c\to b}(\lambda')\,\mathrm{d}\lambda'$$

$$\mathrm{EFM}|_{a\to b} = \mathrm{EFM}|_{a\to c} + \mathrm{EFM}|_{c\to b}$$

Examples: Homework!! 21

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Today

- ~~Getting more power out of the machine~~
- ~~Realistic and arbitrary trajectories~~
- Effect of saturation nonlinearity

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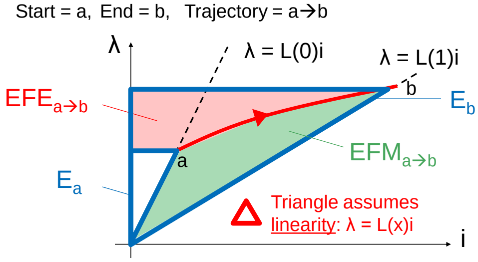
EFE / EFM of an arbitrary trajectory

Start = a, End = b, Trajectory = a→b



$$\mathrm{EFE}|_{a\to b} = \int_{a\to b} i(\lambda, x)\,\mathrm{d}\lambda = W_m|_b - W_m|_a - \mathrm{EFM}|_{a\to b}$$

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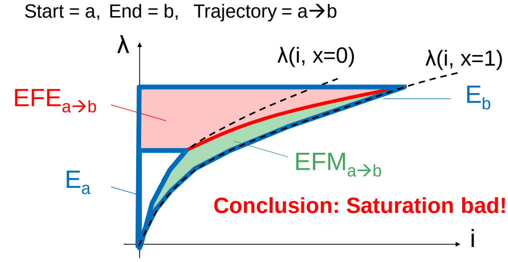
Effects of saturation on EFE and EFM

Start = a, End = b, Trajectory = a→b



$$\mathrm{EFE}|_{a\to b} = \int_{a\to b} i(\lambda, x)\,\mathrm{d}\lambda = W_m|_b - W_m|_a - \mathrm{EFM}|_{a\to b}$$

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