Selection and Control of Permanent Magnet Synchronous or Induction Machine, for Electric Vehicles

Technologies, Constraints, Possibilities & Outlook

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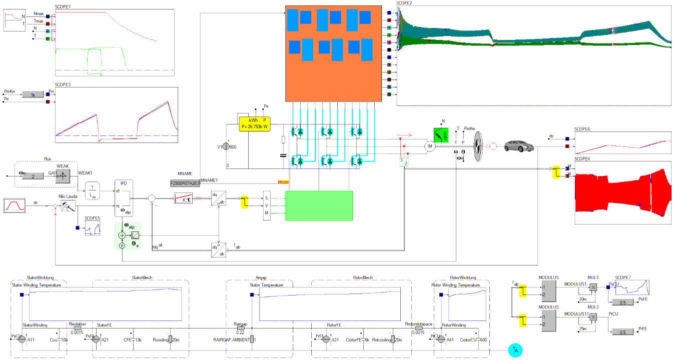
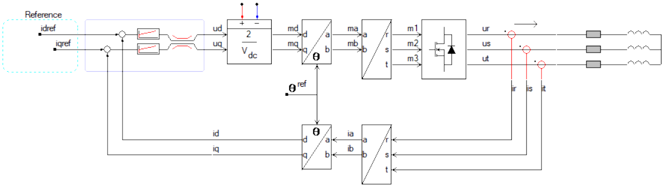


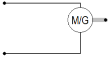
Start with a generic drive

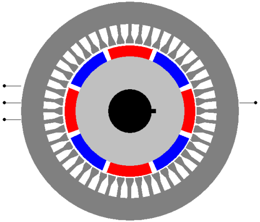
- Motor dynamics
- Control dynamics

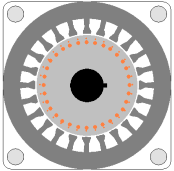


Type of motors, but what is a motor?

- DC motor
- Synchronous motor
- Induction motor

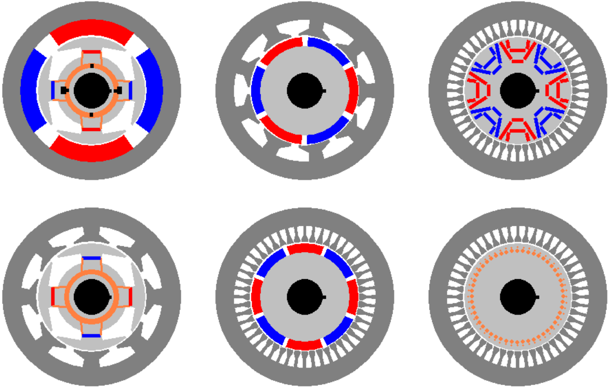






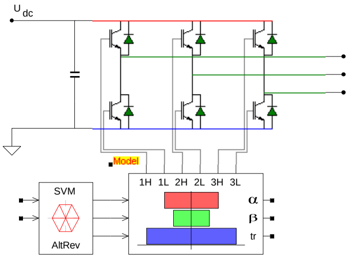
Relation between motor types

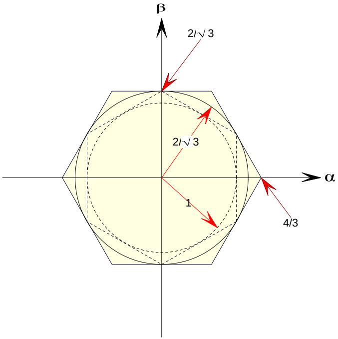
- DC
- Synchronous
- Brushless
- PMSM
- IPM
- IM



Most electrical machines have a three phase winding!

- Constant Torque
- Driving & Braking
- two-level inverter

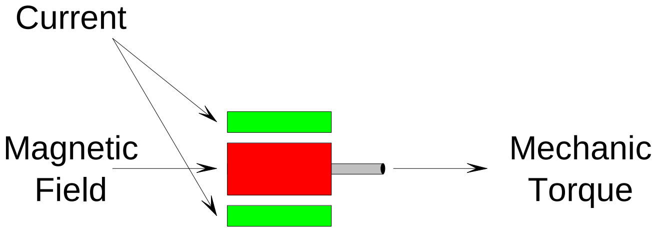




A Two-Level Inverter is mostly enough for controlling the current inside the electric machine

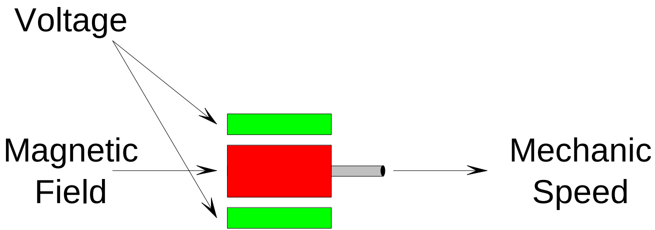
Where is the torque coming from?

- Current I
- Flux Φ
- $T = I \cdot \Phi$



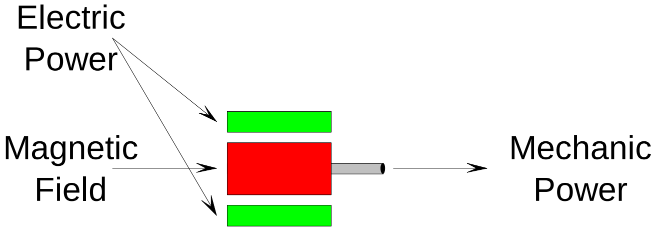
Where is the speed coming from?

- Voltage U
- Flux Φ
- $U = \omega \cdot \Phi$



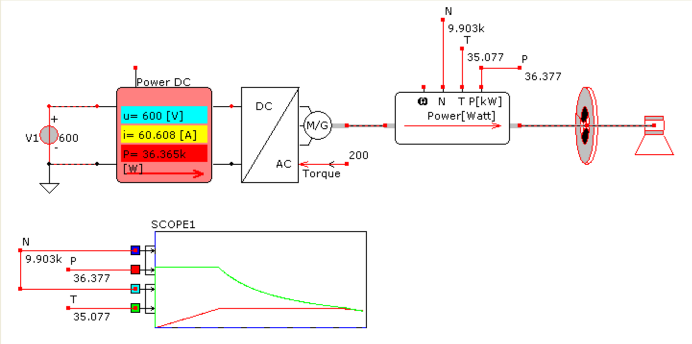
Where is the power coming from?

- $U = \omega \cdot \Phi$
- $T = I \cdot \Phi$
- $P = \omega \cdot T = U \cdot I$



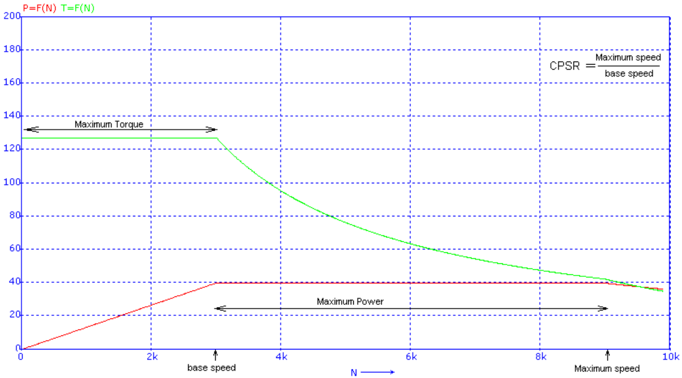
Maximum Voltage, Maximum Current?

- $U = \omega \cdot \Phi$
- $T = I \cdot \Phi$
- $P = \omega \cdot T = U \cdot I$



Maximum Torque, Maximum Power?

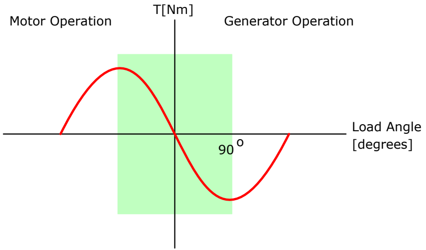
- $U = \omega \cdot \Phi$
- $T = I \cdot \Phi$
- $P = \omega \cdot T = U \cdot I$

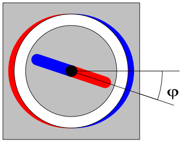


CPSR: Constant Power Speed Range

Motor versus Generator operation

- Load angle
- Motor
- Generator



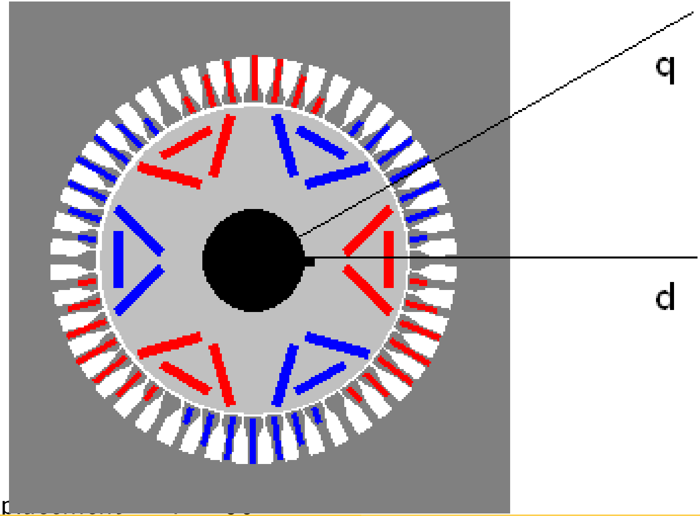


Maximum power when angular displacement $= \Phi = 90$ degrees

Is it a motor or is it a generator?

Direct-Quadrature Axis, Direkte-Quer Achse

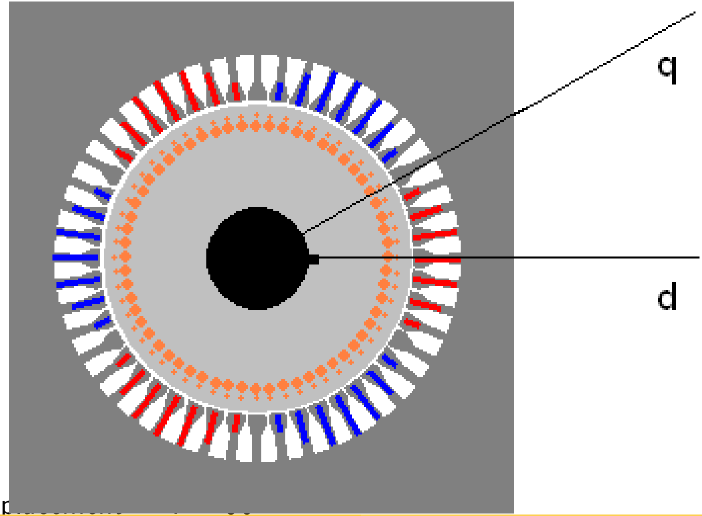
- d Direct Axis - Field
- q Quadrature Axis - Torque
- $T = \Phi_d \cdot I_q$



Maximum power when angular disp

Direct-Quadrature Axis, Direkte-Quer Achse

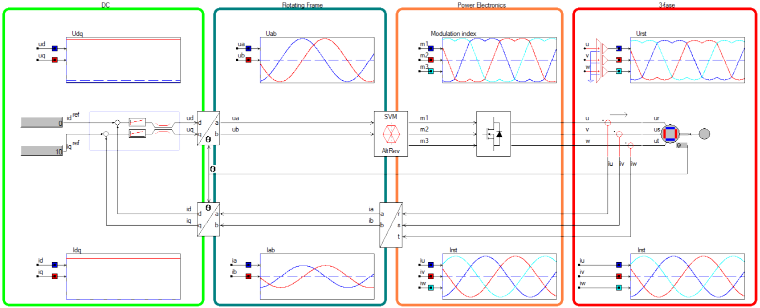
- d Direct Axis - Field
- q Quadrature Axis - Torque
- $T = \Phi_d \cdot I_q$



Maximum power when angular disp

Encoder for the position

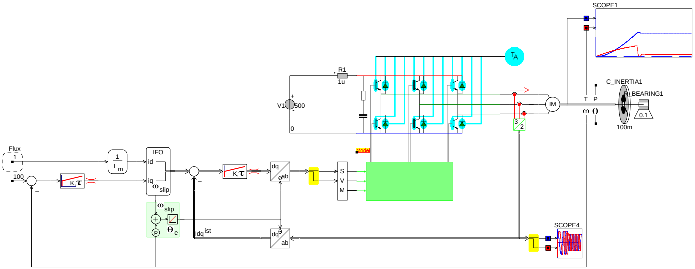
- Encoder for position
- Sensorless



Easy implementation, but requires expensive encoder
or Sensorless: Instaspin

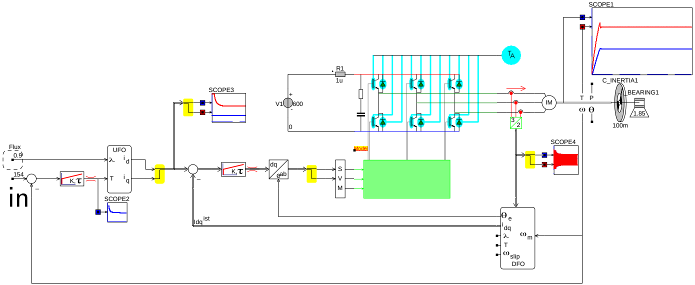
Easy implementation

- Encoder for angular speed
- Calculation of Slip



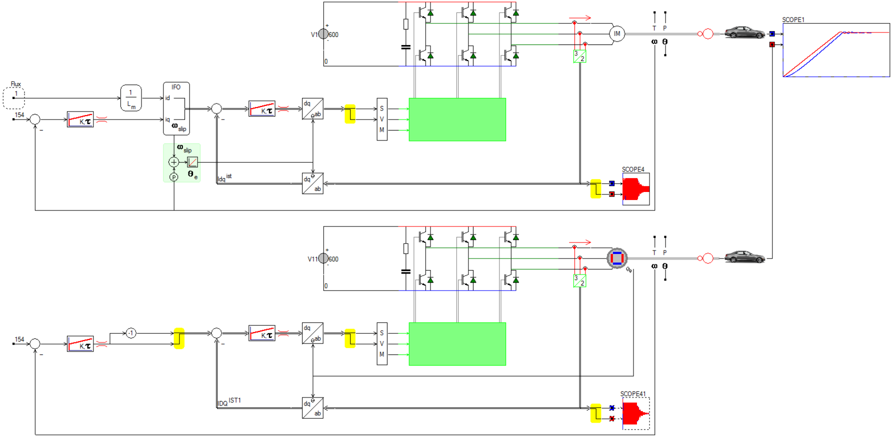
Calculation done by observer

- Encoder for angular speed
- Direct Field Observer
- No need for Field sensors
- Circuit and control simulation in `https://www.caspoc.com/`

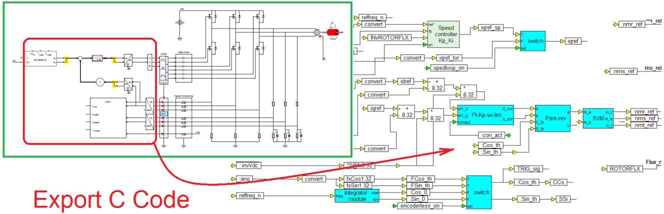


Difference in Control

- IM
- Calculation
- IPM
- Encoder

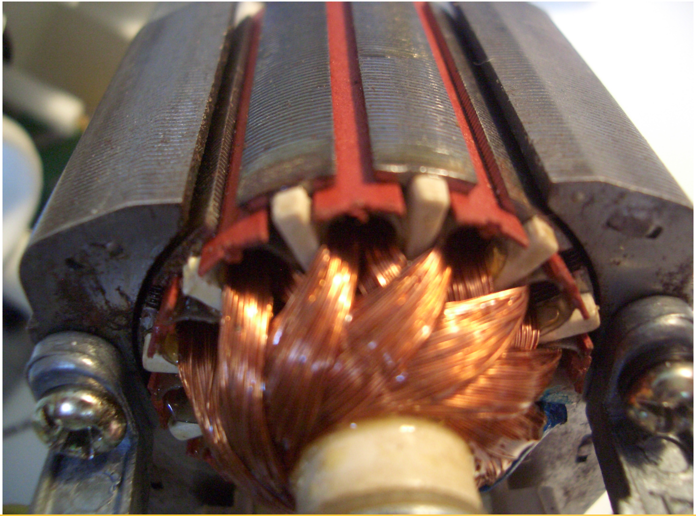


- Digital control
- Floating Point
- Fixed Point
- Export of C-code using `https://www.altair.con`



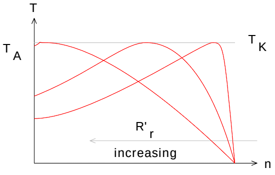
Winding loss, Iron Loss

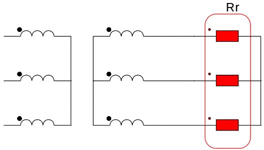
- Winding loss
- $R_s \cdot I^2$
- Core loss
- $c \cdot B^x H^y$
- Stray loss
- Mechanical loss



Stator and Rotor Loss

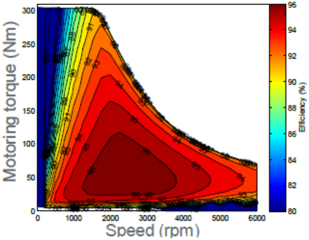
- Winding loss
- Rotor winding

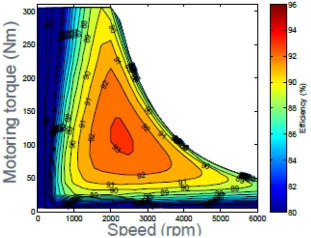




Efficiency Map

- Rotor winding loss
- Same stator winding loss
- 4% more loss for the IM

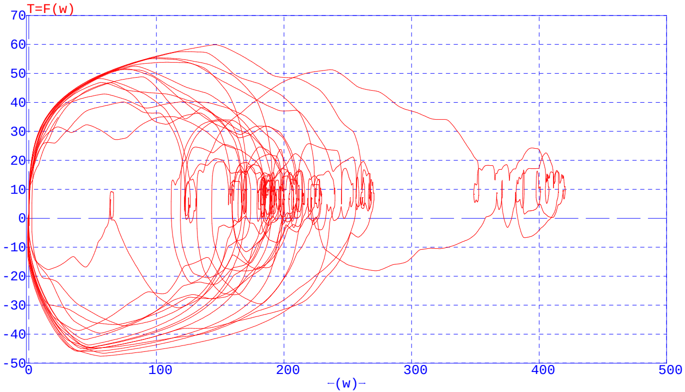




From: Performance/cost comparison of induction-motor & permanent-magnet-motor in a hybrid electric car, Malcolm Burwell International Copper Association

Efficiency reduction

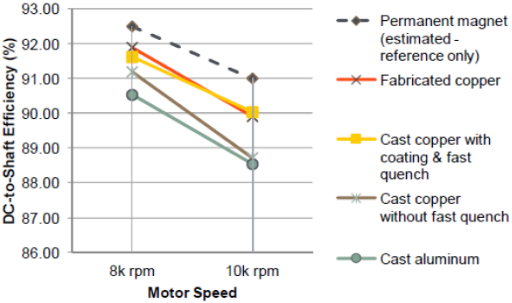
- Drive cycle
- UDDS
- Urban road
- Many stops



The motor is never operated at maximum efficiency!

Efficiency reduction

- Rotor copper winding loss
- Rotor copper cast loss
- Rotor alu cast loss

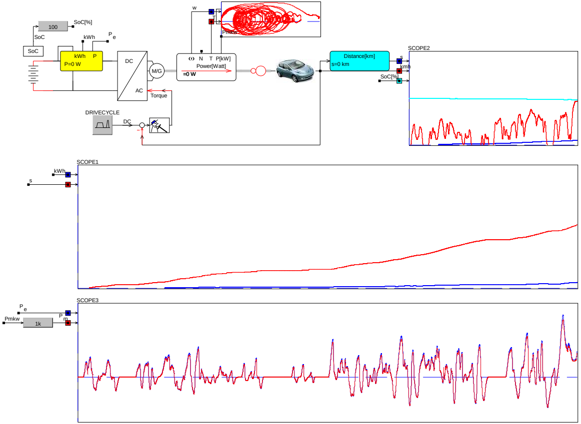


From: Improved high speed efficiency of induction motors/rotors for xEV traction, Malcolm Burwell International Copper Association

How bad is this?

On average : $1kWh = 5km$
But depends on the Drive Cycle

- Nissan Leaf: $15kWh = 100km$
- Tesla X: $27kWh = 100km$
- Audi Etron: $28kWh = 100km$
- I-Pace: $30kWh = 100km$
- eBike: $1kWh = 120km$



Price difference?

IPM: Price for the magnets
IM: Price for the extra fuel

- Average life time of a car: $200.000 km$
- Required energy: $200.000 km \cdot \frac{1 kWh}{5 km} = 40.000 kWh$
- Lost Energy(4%): $0.04 \cdot 40.000 kWh = 1600 kWh$
- Lost Energy more accurate(4%): $\frac{4\ \%}{96\ \%} \cdot 40.000 kWh = 1667 kWh$
- Lost money: $1667 kWh \cdot \frac{Euro\ 0.25}{1\ kWh} = Euro\ 417$

Suggestion: Solar power to charge your car?

Outlook for the Next Generation?

- Costs? Magnets?
- Manufacturing costs
- Optimization geometry to reduce ripple torque
- Optimize thermal design, not over-design
- Modeling and simulation, but know what to optimize
- Materials 6.5% Silicon steel

Traction Motor: IPM or IM?

- Field Oriented Control of IPM or IM, No difference!
- IPM: Pay for the magnets, definitely! IM: Euro 417 over a lifetime
- IPM: Pay for the encoder, definitely! IM: DTC or Sensorless
- IPM: Encoder wiring breakdown, possible! IM: Very rugged, no sensor wiring
- IPM: Higher power density? IM: Pay for the fuel, Solar power?

Thank you!

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