DAT460 Förnyelsebar elproduktion och eltransporter lp2 HT20 (3,5 hp)

Ola Carlson, Chalmers

20201130

Hybridbilsteknik 2

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An introduction to…

Sustainable Transportation 2 (of 2)

…with focus on electrification of road transport

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Vehicle consumption/emission modeling

<u>In real vehicle:</u>

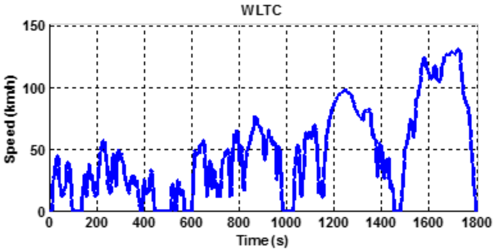
- Cause: driver push gas or brake pedal
- Effect: vehicle increase/decrease/hold the speed (speed and acceleration can be controlled)

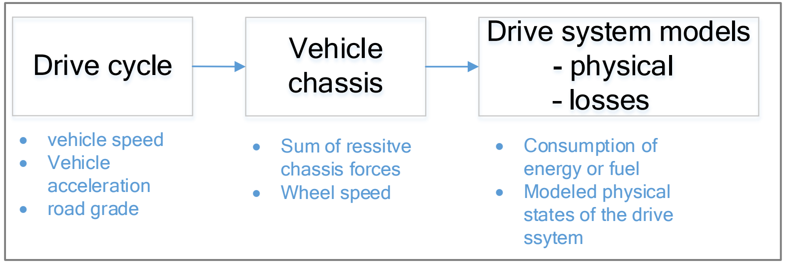
<u>Often in fuel economy and emission simulations:</u>

- Cause: predetermined speed and acceleration time series (sometimes also road grade)
- Effect: calculate for each time instant, how much force and speed that must come from the drive system in order to sustain such speed and acceleration, use look-up loss maps of drive system components

- We need to link vehicle motion and drive system operation

$$F_{trac} = \frac{1}{2}\rho C_d A\, v^2 + C_r mg\cos\alpha + mg\sin\alpha + m\frac{dv}{dt}$$



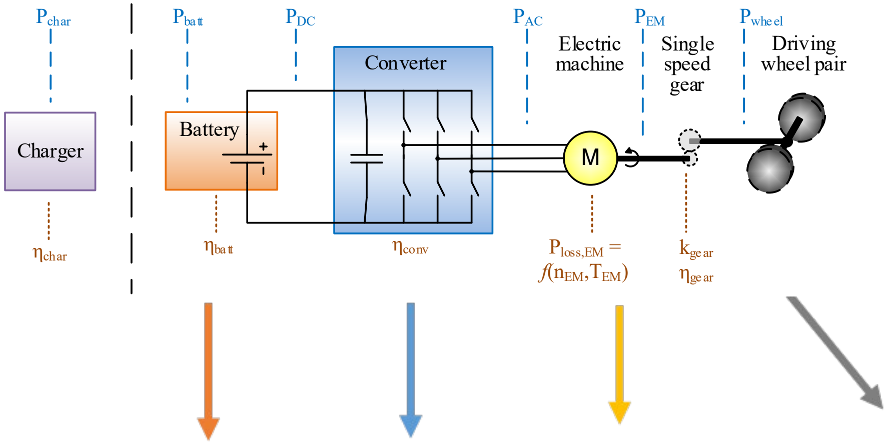


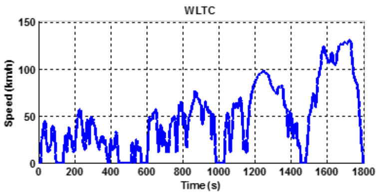
<u>Backward-looking approach</u>

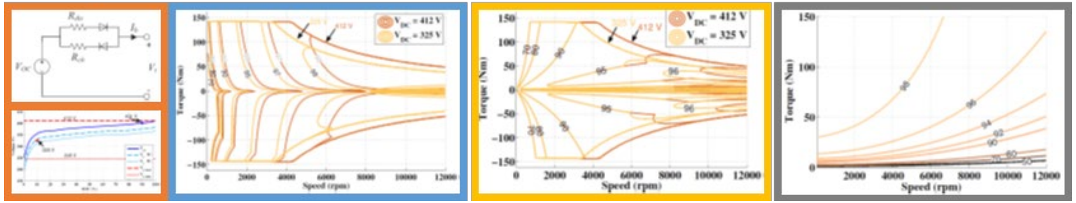
- Predefined speed must be followed exactly
- **Used in our assignment**

Vehicle consumption/emission modeling

Drive system loss modeling - BEV example







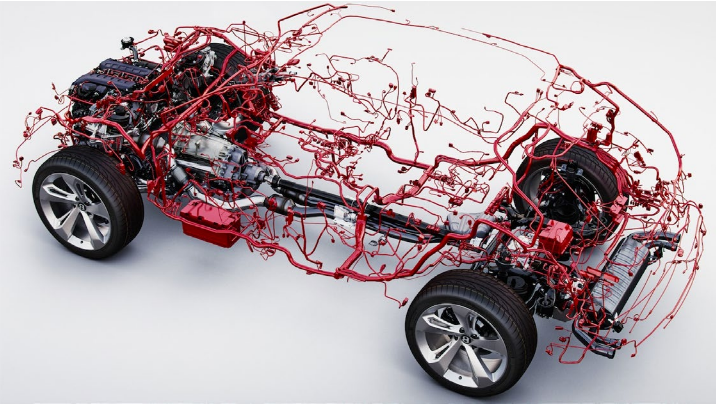
Other loads in vehicles – auxiliary loads

- Systems for security, safety, comfort, lighting, information

- Air conditioning (AC) compressor
  (conventionally driven via a belt from ICE, in HEV electrically), passenger cars ~4-6 kW, large bus up to 30kW
- Power steering, braking systems (air compressor), heaters, pumps, fans, etc (up to 100-1500 W each)
- Computers/controllers (30-100 micro controllers) (up to 500W)
- Head lights, wipers, radio, window elevators, seat heaters etc. (up to 500 W)

Low power loads are supplied by the 12V system

- How much power/energy do they use?
  - Up to 30% of average power
  - During acceleration >10%



Nielsen, F. (2016) *Automotive Climate Systems - Investigation of Current Energy Use and Future Energy Saving Measures*. Göteborg : Chalmers University of Technology (Doktorsavhandlingar vid Chalmers tekniska högskola. Ny serie, nr: 4080).

Brusokas, L. och Rajarathinam, N. (2015) *Evaluation of Electrical Loads on 48 V Supply in Future Mild Hybrid Electric Vehicles*. Göteborg : Chalmers University of Technology

Ways to reduce energy consumption

$$E_{drive\ system} = f(\text{car size}, \text{driving}, \text{drive system efficiency}, \text{road}, \text{climate})$$

- Minimize (energy needed due to chassis)
  - Mass: smaller cars, lighter materials
  - Aerodynamic drag: small front area, stream lined design
  - Rolling friction: low friction tires
- ECO-driving
  - Smooth acceleration
  - Low speed
- Efficient drive train components
  - Minimize losses
  - Integrated components, gear & ICE, electric motor & inverter & gear
- Using the right component in the right time - maximize system efficiency ← In case of Hybrid cars
  - Power management of whole driveline

Why not just do it?!

For a manufacturer to increase vehicle efficiency it has to invest in changes to the car = **higher cost**

- Who should pay for the improvement?
- Are the customers willing to pay?

Is it possible to increase the vehicle's efficiency **and** still maintain

- performance?
- comfort?
- safety?
- reliability?
- lifetime?

- Efficiency
- Acceleration
- Speed
- Design
- Comfort
- Safety
- Reliability
- Lifetime

https://webstore.iea.org/download/direct/2807?fileName=Global_EV_Outlook_2019.pdf

Charging

	Conventional plugs	Slow chargers	Fast chargers	
Level	Level 1	Level 2	Level 3	
Current	AC	AC	AC, Three-phase	DC
Power	≤ 3.7 kW	> 3.7 kW and ≤ 22 kW	> 22 kW and ≤ 43.5 kW	Currently < 400 kW

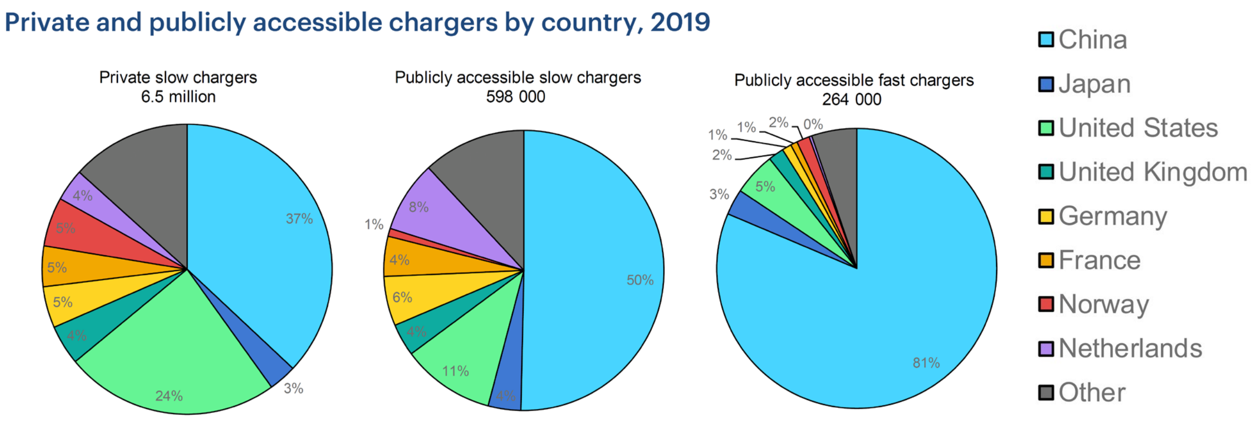
- Current method: conductive, future method: inductive (wireless)
- AC charging (Level 1 & 2, Mode 1-3)
  - On-board and external chargers regular power outlet
  - 2,0- 3.3-7.4 kW (1 phase), 11-43 kW (3 phase) – higher power = higher equipment cost
  - Charging times roughly 30 min – 8 h
- DC fast charging (Level3/Mode4) – external charger stations
  - CCS, 50-350 kW
  - CHAdeMO, 50-400 kW
  - Tesla super chargers, 120-250 kW
  - Charging times roughly 10 - 30 min
- Nominal charger efficiency ~94%
- Electric roads?! –smaller batteries on board
  - Over-head-lines – for specific type of vehicle
  - Ground tracks - accessible by any kind of road vehicle

Ongoing in Sweden, Gävle
Starting in Germany by Siemens

Ongoing in Sweden, Sthlm-Arlanda

https://www.iea.org/reports/global-ev-outlook-2020

Charging stations



Sources: IEA analysis based on country submissions, complemented by other sources. For more details, see figure 1.8 in the main report.

Sweden:
www.uppladdning.nu

Europa
https://ccs-map.eu/

World CCS/combo
https://www.plugshare.com/?combo_only=true&=SAE%20Combo%20CCS

Tesla
https://supercharge.info/

Calculation example

Useful relations:
1 J=1 Ws= 1/3600 Wh= 1/(3600 ·10^3) kWh= 1/(3600 ·10^{12}) TWh

How much fuel does the Swedish passenger cars consume each year?

- *Number of* passenger cars in Sweden at the end of 2015 *cars*[1]*:* ***4 669 063***
- *Total distance travelled*[2]*:* ***65 311 458 780 km****.*
- *Average gasoline consumption of Swedish car fleet 2015*[2] *:* ***8.0 liter/100km***

Estimated fuel consumption: 65 311 458 780 km/100 km ·8.0liter/100km=$\mathbf{5.22 \cdot 10^9}$ ***liter****.*
With gasoline density (820kg/m^3) and energy density (42 MJ/kg), the energy content of this fuel is ***50.0 TWh****.*

What if all the Swedish passenger cars were electric…how much electricity would they use during one year?

- Assume all cars are large and consume 20 kWh/k100m : 65 311 458.780/(100km) * 20 (kWh/100km) = **13.06 T Wh**

How much would the Swedish electricity production then need to increase?

- 13.06 (TWh) / 158.5 (TWh) *100 = **8.2 %**

	Per type	Share of total
Hydro	74.0 TWh	46.7%
Wind	16.6 TWh	10.5%
Nuclear	54.4 TWh	34.3%
Solar	0.1 TWh	0.06%
Other thermal	13.5 TWh	8.5%
Total production	158.5 TWh	100%

[1] *Trafik analys, Fordon 2015, Körsträckor 2015:* *http://trafa.se/sv/Statistik/Vagtrafik/Fordon/*
[2] RUS 2015: http://extra.lansstyrelsen.se/rus/Sv/statistik-och-data/korstrackor-och-bransleforbrukning/Pages/default.aspx
[3] *Elåret 2015;* http://www.svenskenergi.se/Elfakta/Statistik/Elaret/
[4] Oil, coal, natural gas and peat.

Calculation example

Useful relations:
1 J=1 Ws= 1/3600 Wh= 1/(3600 $\cdot 10^3$) kWh= 1/(3600 $\cdot 10^{12}$) TWh

What if everybody want to charge at the same time, is the **installed 40 GW** capacity enough?

- Assume 3.5 kW charging power
- 3.5 kW * 4 669 063 cars = **16.3 GW** (41% of installed capacity)

What if we use slow charging and all 24 h ?

- A typical car runs 39 km/24 h in Västar Götalandsregionen
- 2 kWh for 10 km gives 8 kWh
- 2 kW can be charged from a 10 A fuse
- Every car needs to be charge 4 h / 24 h = 1/6
- 2,0 kW * 4 669 063 cars = **9,4 GW** (23% of installed capacity)
- Equal chare of time=1/6 gives **1,6 GW** (4 % of installed capacity)

Calculation example

How much would the Swedish electricity production then need to increase?

- 13.06 (TWh) / 158.5 (TWh) *100 = **8.2 %**

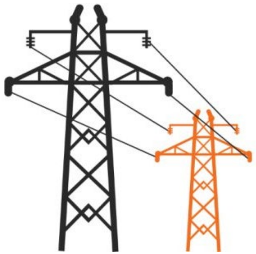


Table 3.2 Share of electricity consumption attributable to EVs by region and scenario, 2030

Country/region	2019	Stated Policies Scenario, 2030	Sustainable Development Scenario, 2030
China	1.2%	3%	3%
Europe	0.2%	4%	6%
India	0.0%	2%	3%
Japan	0.0%	1%	2%
United States	0.1%	1%	4%

Sources: Electricity demand from EVs was evaluated with the Mobility model (IEA, 2020); total final electricity consumption from (IEA, 2020) and IEA (forthcoming).

https://www.iea.org/reports/global-ev-outlook-2020

Calculation example

What if everybody want to charge at the same time, is the **installed 40 GW** capacity enough?

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- 3.5 kW * 4 669 063 cars = **16.3 GW** (41% of installed capacity)

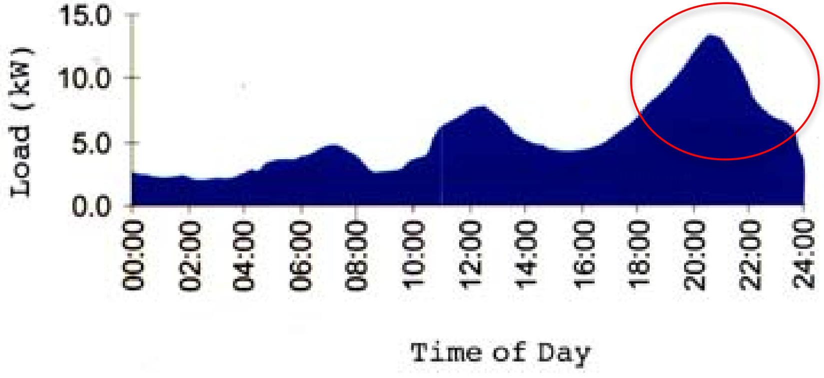
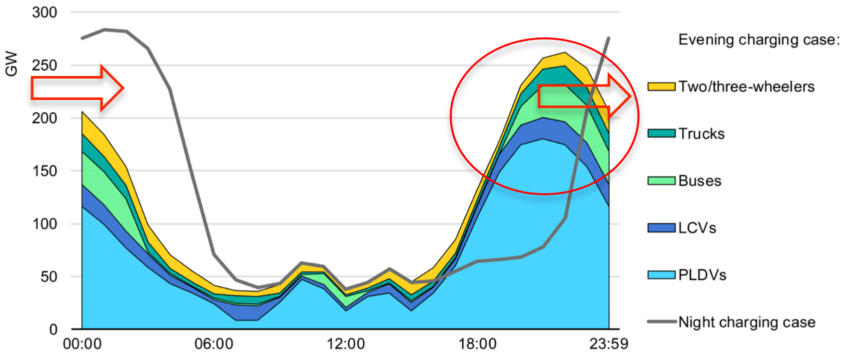


Figure 5.1 Global average weekday load profiles in an evening charging case and a night charging case by vehicle type in the Sustainable Development Scenario, 2030



Note: PLDVs = passenger light-duty vehicles; LCVs = light-commercial vehicles. EV load curves are aggregated at the global level. They are not accounting for varying time zones and might not be representative of regional patterns. They are representative of an assumed typical weekday.

https://www.iea.org/reports/global-ev-outlook-2020

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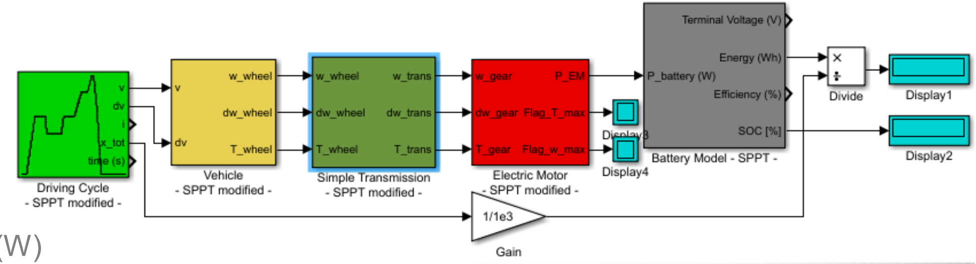
QSS Electric car modelling and simulation

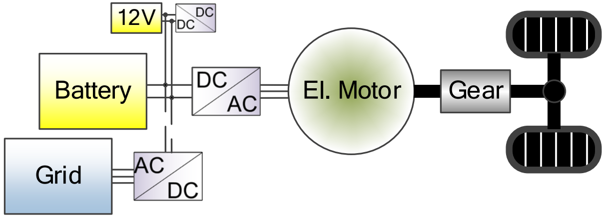


Model blocks:

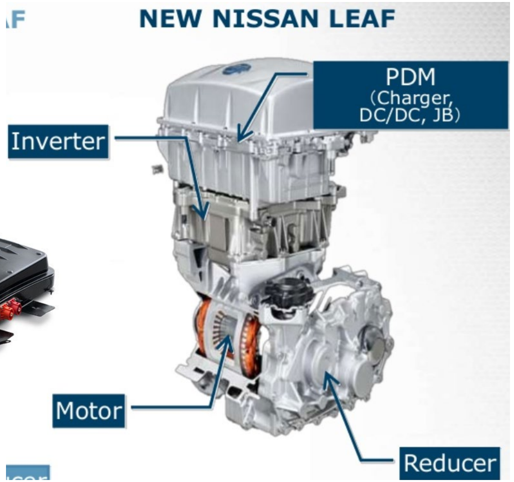
- Drive cycle
- Vehicle chassis
- Gear box (fixed speed reduction)
- Electric machine and inverter, incl. auxiliary power load (W)
- Battery

Not included components:

- Cables
- Battery 12V, dc/dc converter
- Charger

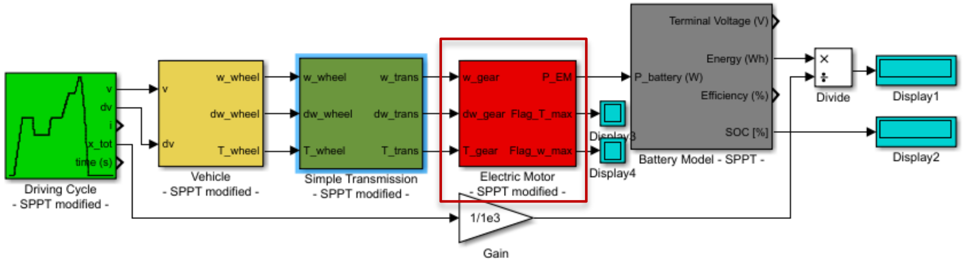


Nissan Leaf battery pack



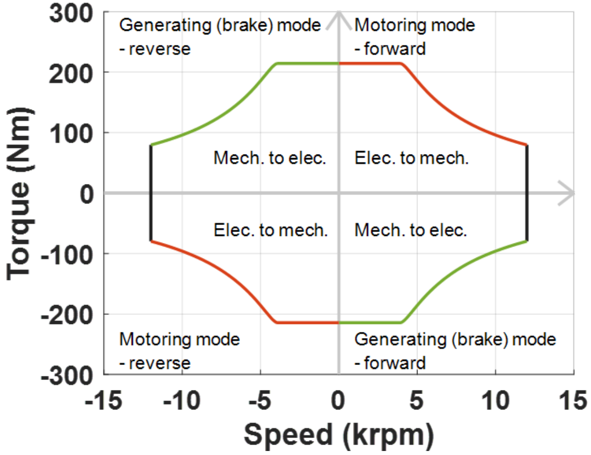
QSS Electric car modelling and simulation

Electric machine and inverter block:



Working principle:

- Electric machines (EM) converts between electric and mechanical power using electromagnetics
- Inverters convert DC to AC voltage
- Both EM and inverter conversions are reversible 4 quadrant operation



QSS model:

$$T_{EM} = T_{gear} + T_{inertia} = T_{gear} + J_E \frac{dw}{dt}$$

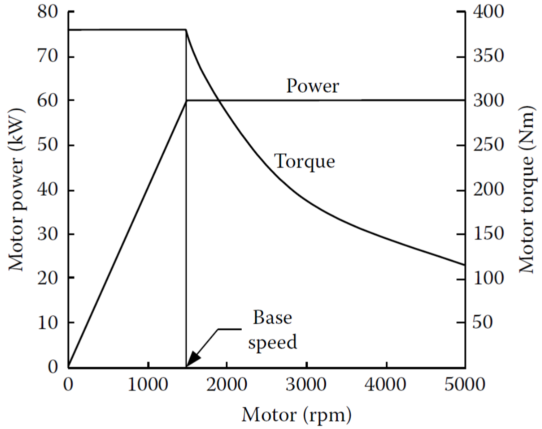
η_{EM}: machine and inverter efficiency $f(T_{EM}, n_{EM})$

Inverter efficiency:

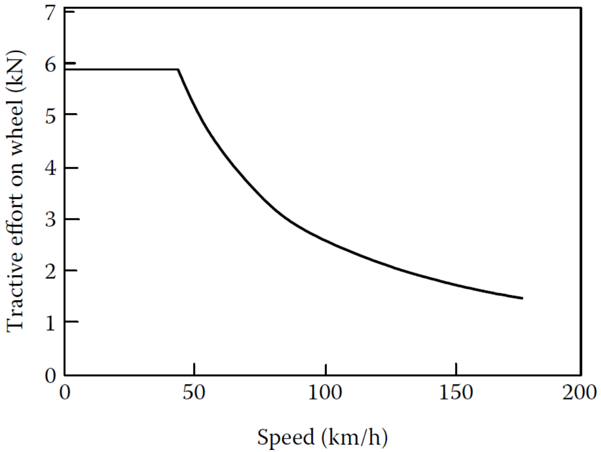
- Peak inverter efficiency ~97%-98 %
- High efficiency in a large operating area >90%
- Mainly speed dependent
- It can be modeled as a constant in system studies

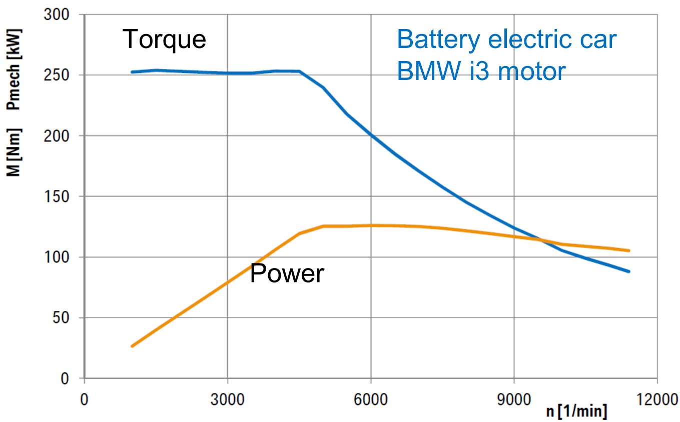
Machine speed torque domain ↔ gear ↔ Vehicle speed force domain

Ideal motor



Ideal motor, fixed gear ratio



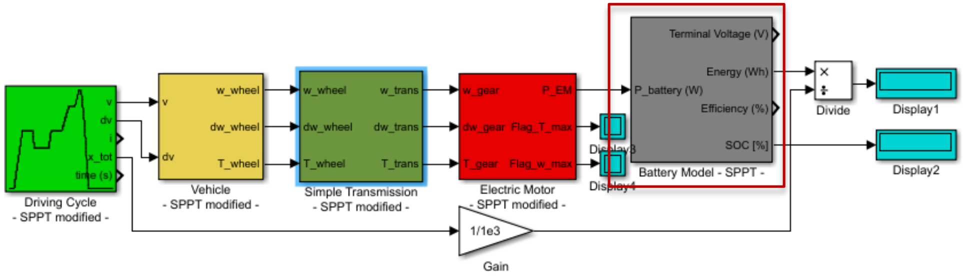


The fixed gear ratio gives the same max torque profile in motor speed-torque plane as in vehicle speed-force plane

QSS Electric car modelling and simulation

Battery block:

- Battery characteristics and modelling in next lecture
- Your task: implement a battery model from an article

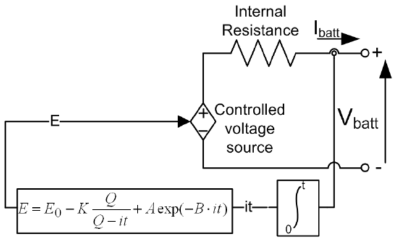


Working principle:

Stores electric power as chemical energy

Key terms:

- SoC: State of Charge 0-100%
- V_{oc}: No-load voltage, V_{batt}: terminal voltage
- R: Internal resistance/impedance
- C-rate: Charge/discharge rates



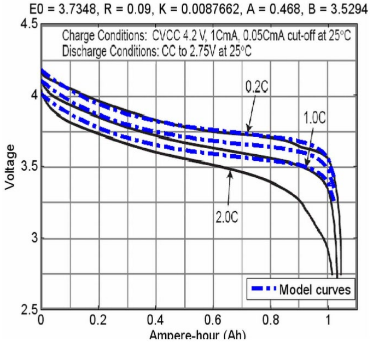


Fig. 7. Lithium-Ion battery 3.6V 1Ah

Block output:

- Terminal voltage (V)
- Net discharged energy, Energy (Wh)
- Efficiency (%) – can be ignored
- SOC (%)

O. Tremblay, L. Dessaint and A. Dekkiche, "A Generic Battery Model for the Dynamic Simulation of Hybrid Electric Vehicles," *2007 IEEE Vehicle Power and Propulsion Conference*, Arlington, TX, 2007, pp. 284-289. doi: 10.1109/VPPC.2007.4544139

Micro hybrid vehicles

- “stop-start” is already very common in passenger cars
- 12V battery must supply el-loads during “ICE-stop”…
- …possibly also when ICE work at low efficiency
- Utilize regenerative braking
- Need battery with lower resistance and longer life

- Est. CO_2 reduction ~ 5-10%

- Possible to replace both start motor and alternator with a single e-machine that do the same + regenerate braking energy

https://theicct.org/sites/default/files/publications/ICCT_Pocketbook_2018_Final_20181205.pdf

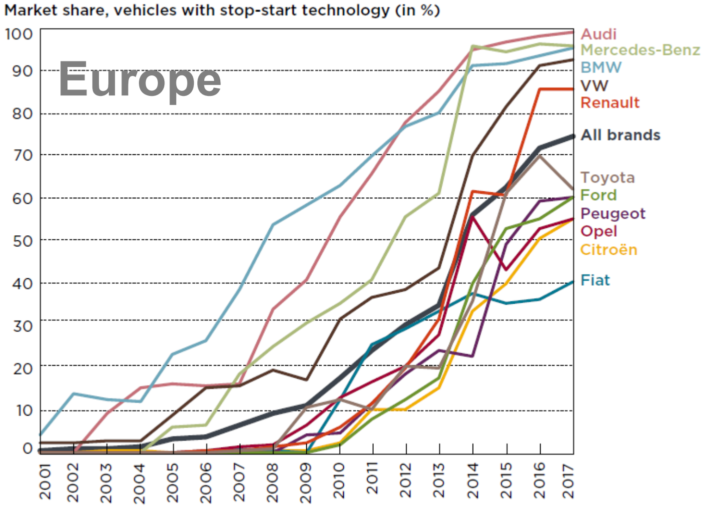
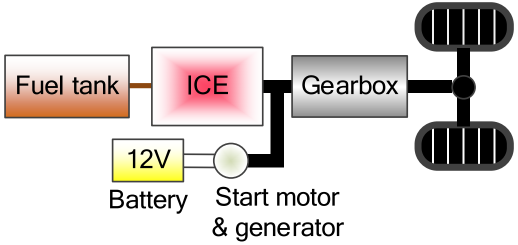


Fig. 4-13

Passenger cars: Market share, vehicles with stop-start technology by brand

	Micro HEV
Fuel cut-off (standard today)	x
IC engine stop/start	x
Brake energy recovery	x
Electric motor assist	
Pure electric drive	



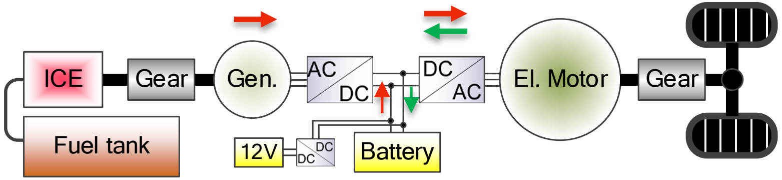
Series hybrid operating modes

E-motor only connection to wheels: it has to be large enough to manage all driving situations for the car

<u>Traction modes of operation</u>

- E-motor + battery
- E-motor + ICE&gen, + battery
- E-motor + ICE&gen + charging battery
- E-motor + ICE&gen, no battery

Need control strategy
"Energy management"

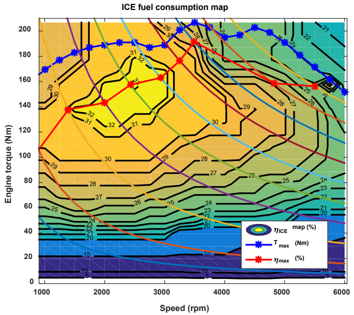


<u>Braking mode of operation</u>

- E-motor can work in generator mode and charge the battery

<u>Advantages:</u>

- ICE is decoupled from drive train → it can operate at optimal efficiency for the delivered power level
- Simple speed control since only one power source towards the wheels
- No need for multiple step gear transmission since E-motor
- ICE can be down-sized

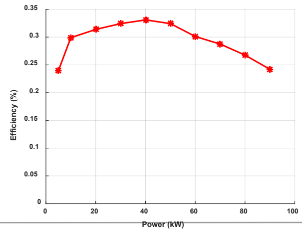


<u>Draw backs:</u>

- Many energy conversion result in rather low average system efficiency
- Need 2 E-machines & converters which cost money

<u>Example vehicle:</u>

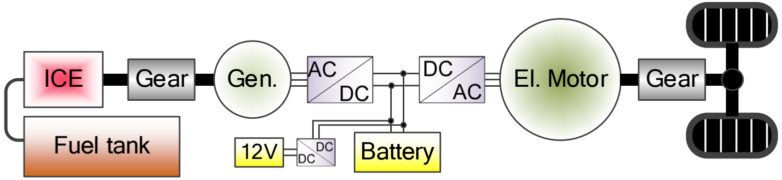
- BMW i3 range extender



Series hybrid - simple energy management strategy

<u>Simple energy management strategy:</u>

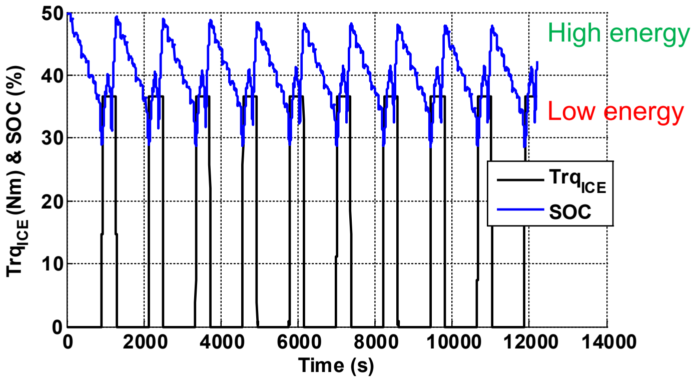
1. Battery provide propulsion power until energy is low
2. Start ICE
3. ICE&gen charge battery + provide propulsion power
4. When battery energy is high; turn ICE off



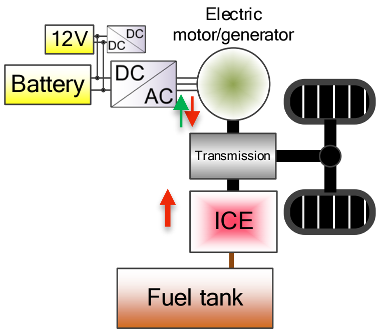
<u>Advantage</u>: Simple

<u>Disadvantage</u>: not optimal, does not consider effect of driving

Battery state of charge



Parallel hybrid operating modes



Both E-motor and ICE are attached to the wheels

Traction modes of operation

- Only ICE
  - Only propel the wheels
  - Also charge the battery via the E-motor in generating mode
    ICE can work at higher efficiency, since higher loaded!
- Only E-motor
- Both E-motor and ICE can propel the wheels (el. Boost)

Need control strategy
"Energy management"

Braking

- Motor can work in generator mode and charge the battery

Advantages:

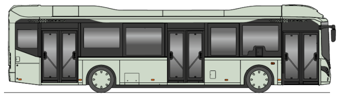
- Fewer energy conversions are possible (compared to series)
- No need for extra generator
- Can downsize both engine and electric motor which reduces cost

Draw backs:

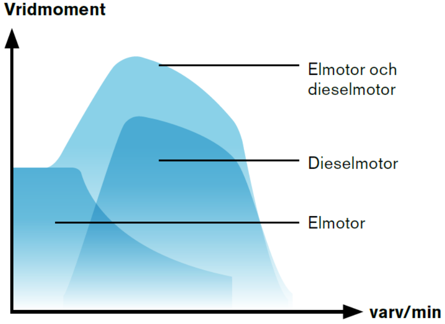
- Choice of ICE operating points is less "free" since attached to the wheels

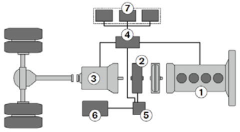
Example vehicles

- Volvo hybrid bus



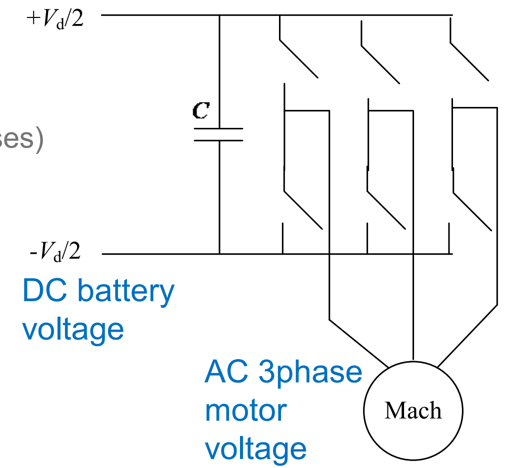
Volvo 7900 Hybrid





Komponenter i Volvos hybridsystem
1. Dieselmotor **2.** Elmotor/generator (I-SAM)
3. Växellåda **4.** Elektrisk styrenhet
5. Energiomvandlare DC/DC 600V/24V **6.** Batterier
7. Elektriska hjälpsystem

Power Electronic Converters



Working principle:

Converts input voltage source to desired voltage (DC, AC, magnitude, frequency, number of phases)

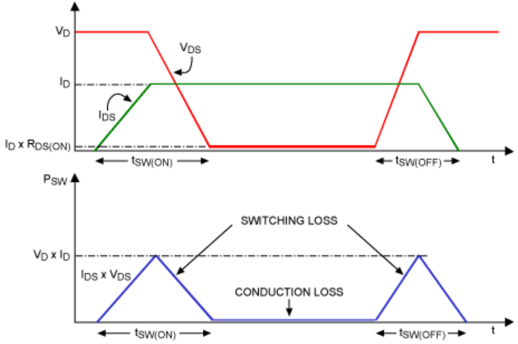
- DC/DC in electric cars: between high and low voltage dc-buses
- AC/DC in electric cars:
  - motor inverter between 3 phase AC motor and battery dc-bus
  - charger between high voltage dc-bus and grid)
- Using semiconductor devises as switches (MOSFET or IGBT transistors and diodes in parallel)

Losses

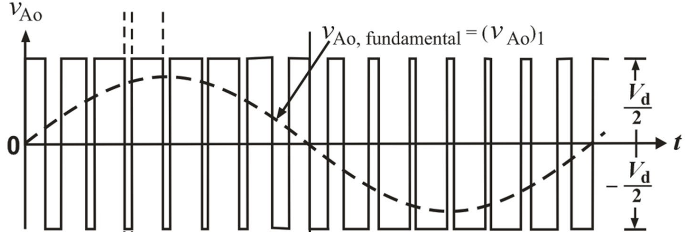
- on-state losses
- Switching losses (depend on frequency ~motor speed)

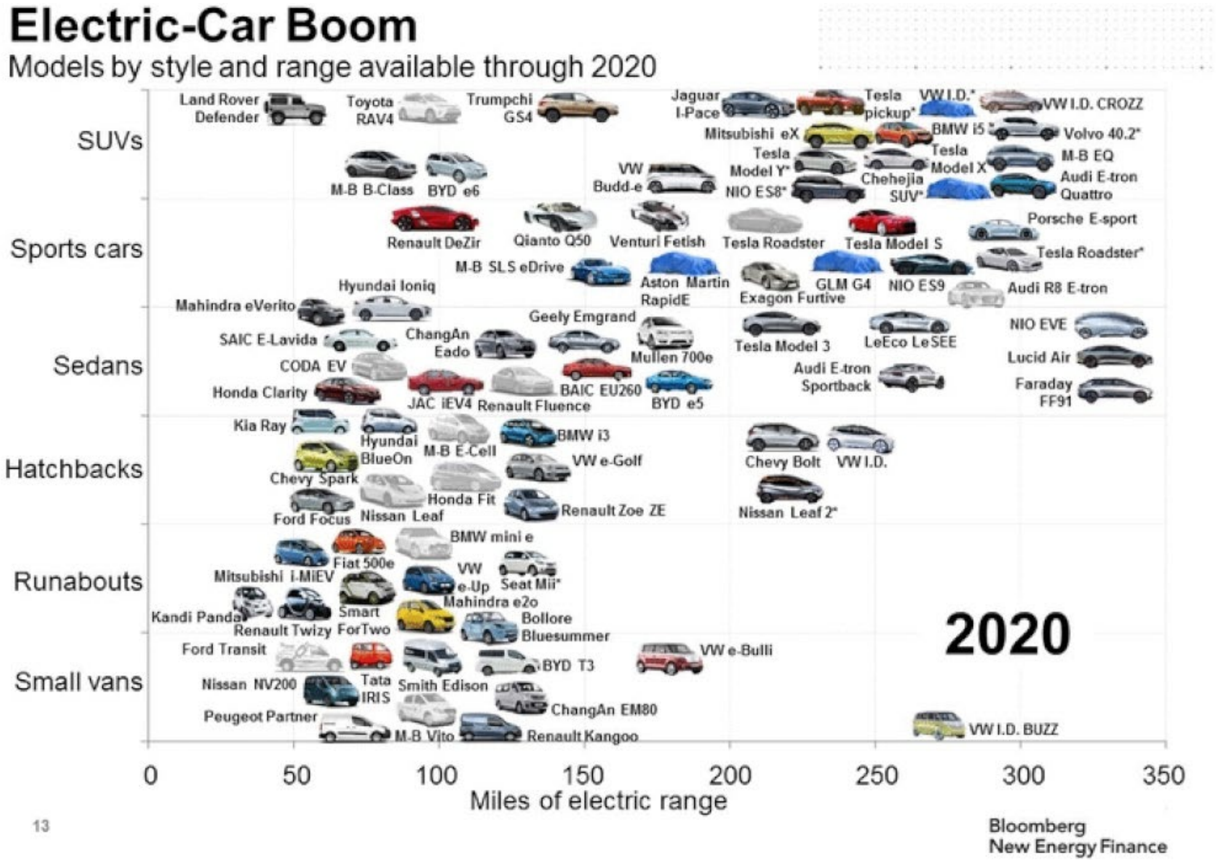
Cooling

- Often liquid cooled



Output AC phase voltage & fundamental

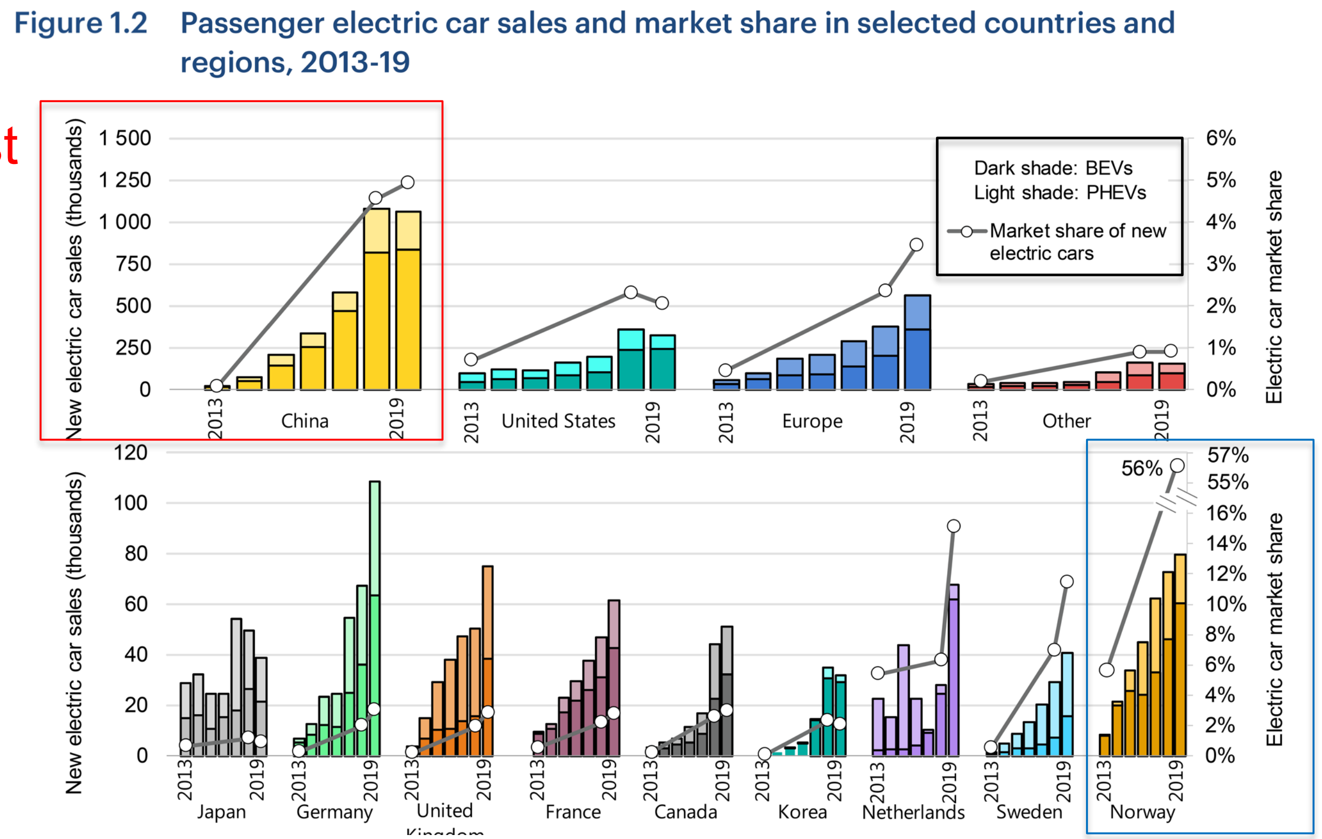




https://about.bnef.com/blog/long-range-ev-market-set-get-crowded-2020/

P-HEV BEV market

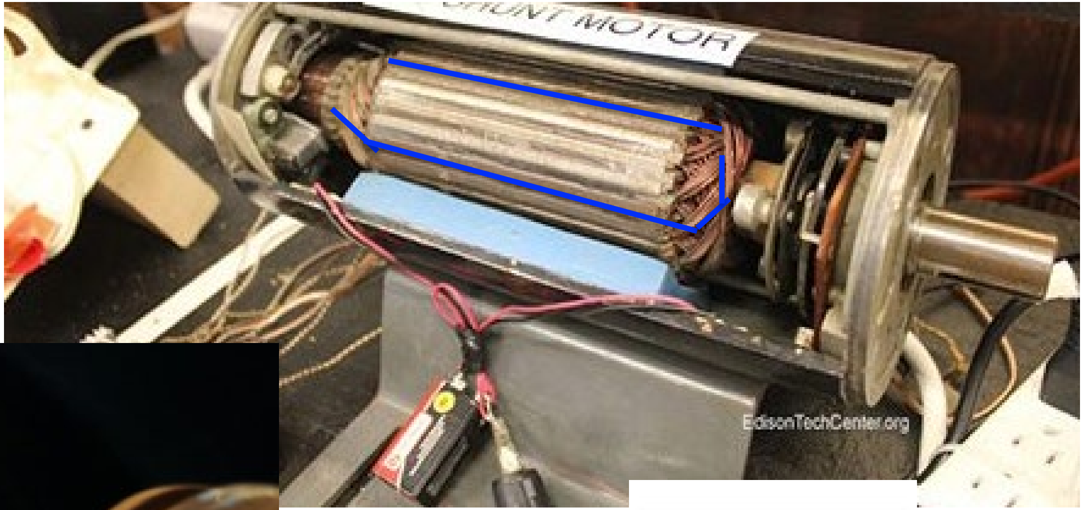
Largest total

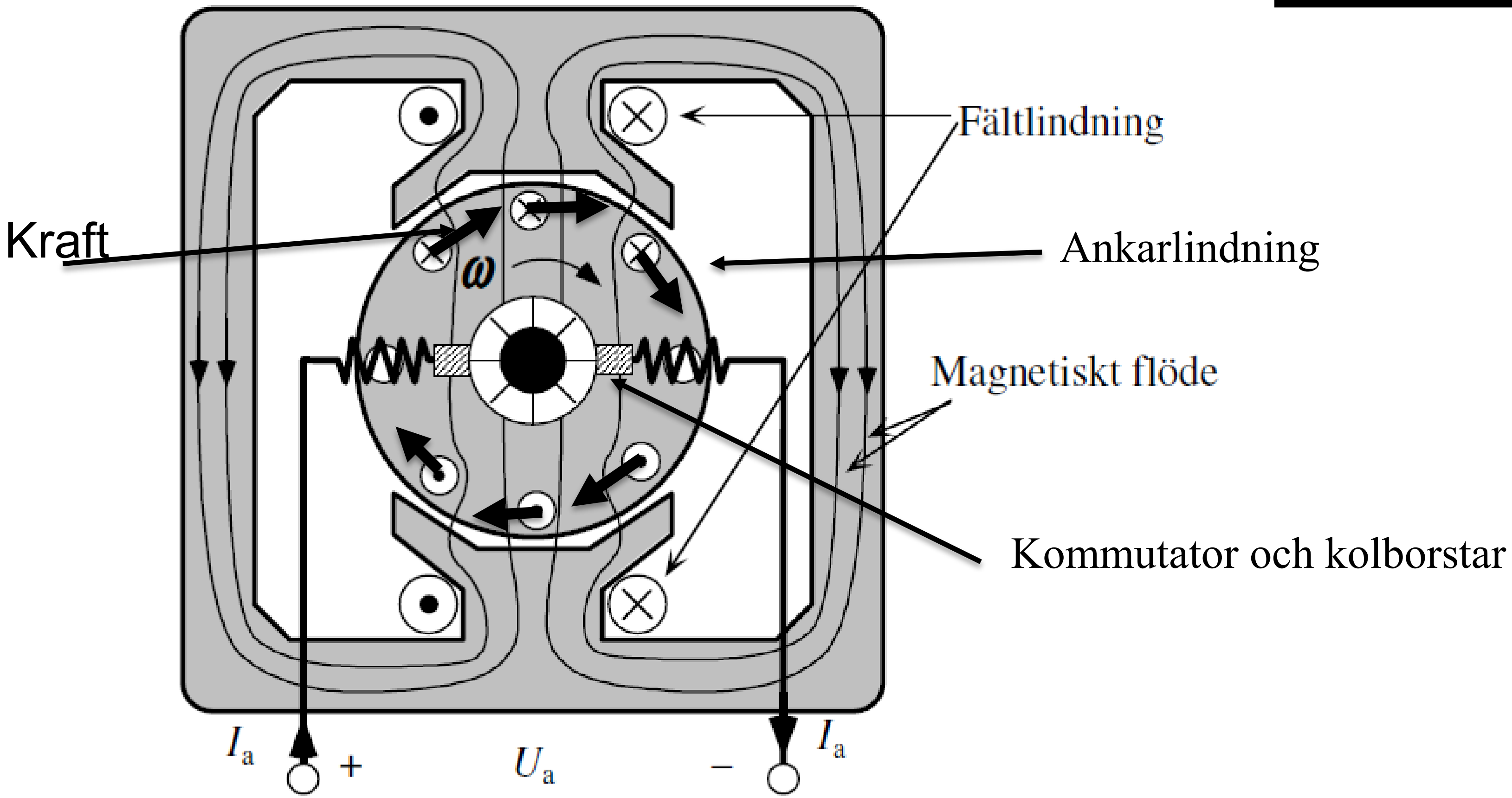


Largest market share

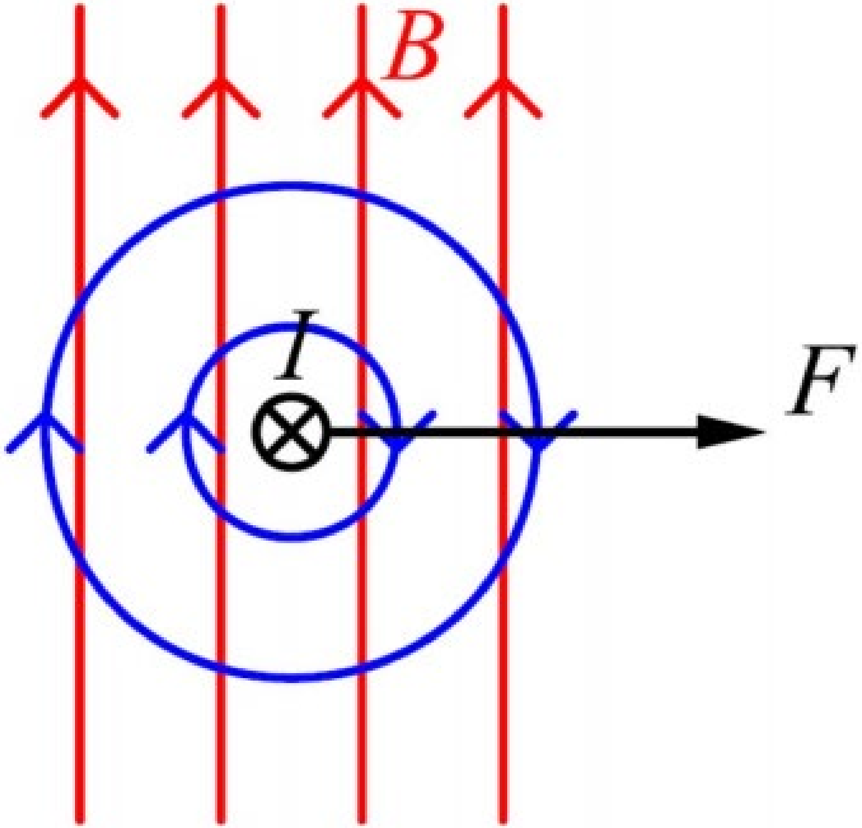
https://www.iea.org/reports/global-ev-outlook-2020

Likstömsmaskiner finns i alla storlekar och har funnits sedan slutet på1800-talet. Innan om-riktarna var det den maskin som var lättast att varvtalstyra

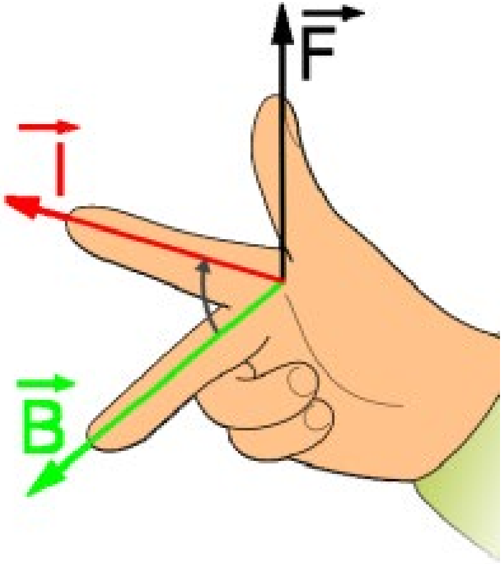




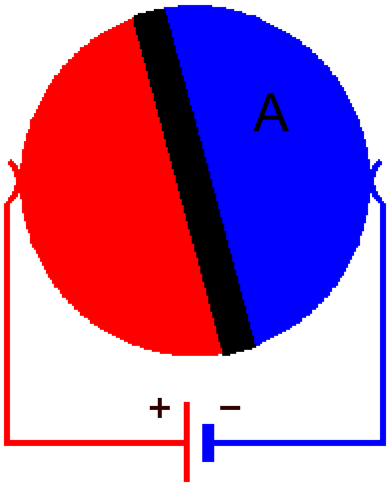
Figur 4.28 En principbild av en likströmsmaskin (i motordrift).

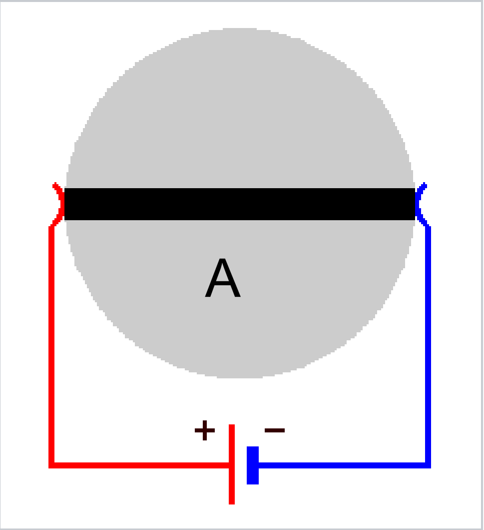


$$F = BIl$$

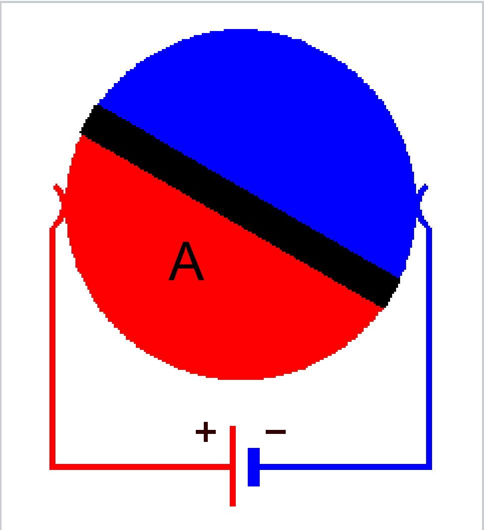


Kommutatorns funktion





Kommutatorn byter riktning på strömmen genom rotorns lindningar.

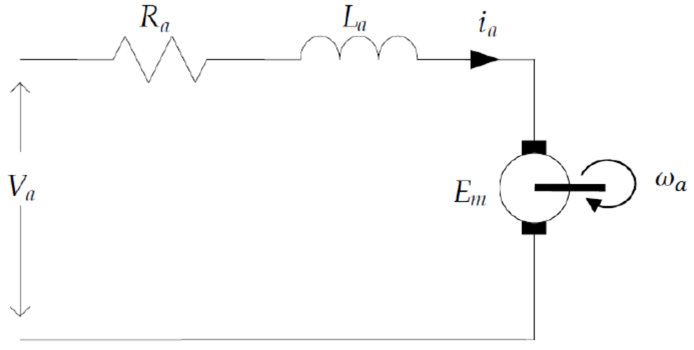


Kommutatorn byter riktning på strömmen genom rotorns lindningar.

Likströmsmotor – Wikipedia

(rött är ström in i planet,
blått är ström ut ur planet)

Modell av likströmsmaskin



V_a	Armature voltage (V)	Ankarspänning
i_a	Armature current (A)	Ankarström
R_a	Armature winding resistance (ohm)	Ankarresistans
L_a	Armature winding inductance (H)	Ankarinduktans
E_m	Induced voltage (back emf) (V)	Inducerad spänning
ω_a	Rotor speed (rad/s)	Varvtal
n_a	Rotor speed (rpm, rotations per minute) $n_a = \omega_a \cdot \frac{60}{2\pi}$	

$$E_m = k_{v\omega}\omega_a$$

$$V_a = R_a i_a + E_m = R_a i_a + k_{v\omega}\omega_a$$

$$T_e = k_{it} i_a$$

Stationära värden=U=L*di/dt=0

where $k_{v\omega}\left[\frac{V}{rad/s}\right]$ and $k_{it}\left[\frac{Nm}{A}\right]$ are electric machine constants that depend on flux density (in this case magnet strength), number of turns of the armature winding etc. T_e [Nm] is the electrodynamical torque.

Power balance

$$T_{mec} - T_{el} = J\frac{\partial \omega}{\partial t}$$

T_{mec} = mechanical torque from the turbine,
T_{el} = electric torque from the generator
J = inertial from rotating electrical machines
w = rotation speed of the generator
= frequency of the voltage

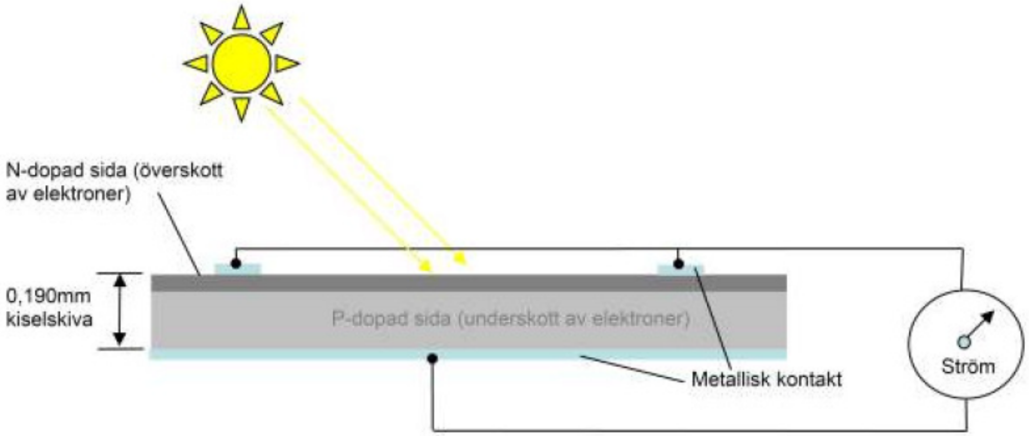
$$J\frac{d\omega_a}{dt} = (T_e - T_{internal\ load}) - T_{external\ load} = T_{shaft} - T_{external\ load}$$

where J [kgm^2] is the rotational inertia of the system, $T_{internal\ load}$ is the internal mechanical losses in the motor mainly due to friction, T_{shaft} is the net output torque on the motor shaft, and finally $T_{external\ load}$ represent the torque required to run the applied load.

Kort om solkraft inför Jan-Olof Dalenbäck

Solar cell - Semiconductor

- Photons (light) carries energy down in the cell to the electrones that make them jump/move ..
- A curcuit will guide the electrones .. a current is created ..



Size: 1 dm²

Voltage: 0,5 V

Current: 2 A

Power: 1 W

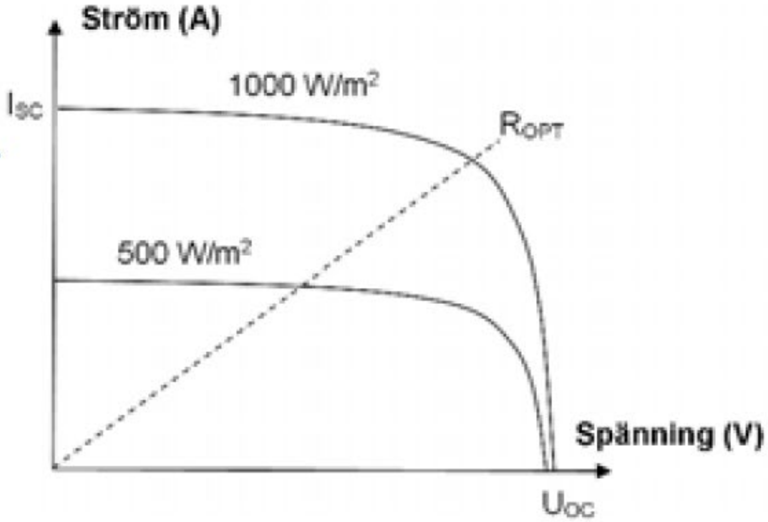
$\eta \sim 10\ \%$

1 kWh/a in SE

1 m2: ger 100 W, solen lyser under 1000 timmar/år, 100 kWh/år

PV characteristics

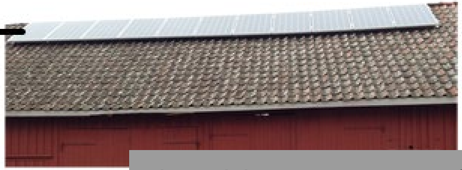
- **U_{OC}** - open circuit voltage – not dependant on solar radiation intensity ..
- **I_{SC}** - short circuit current - proportional to solar radiation intensity ..
- **R_{OPT}** – resistance/load for optimum energy output ..



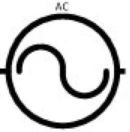
Solceller hos Ola

Totalt installerat 8900 W
Solceller vilket ger 8000 kWh/år

2 x 11 celler mot SW,
280 W/cell



1 x 11 celler mot SO
250 W/cell



Energimätare för
gröna certifikat

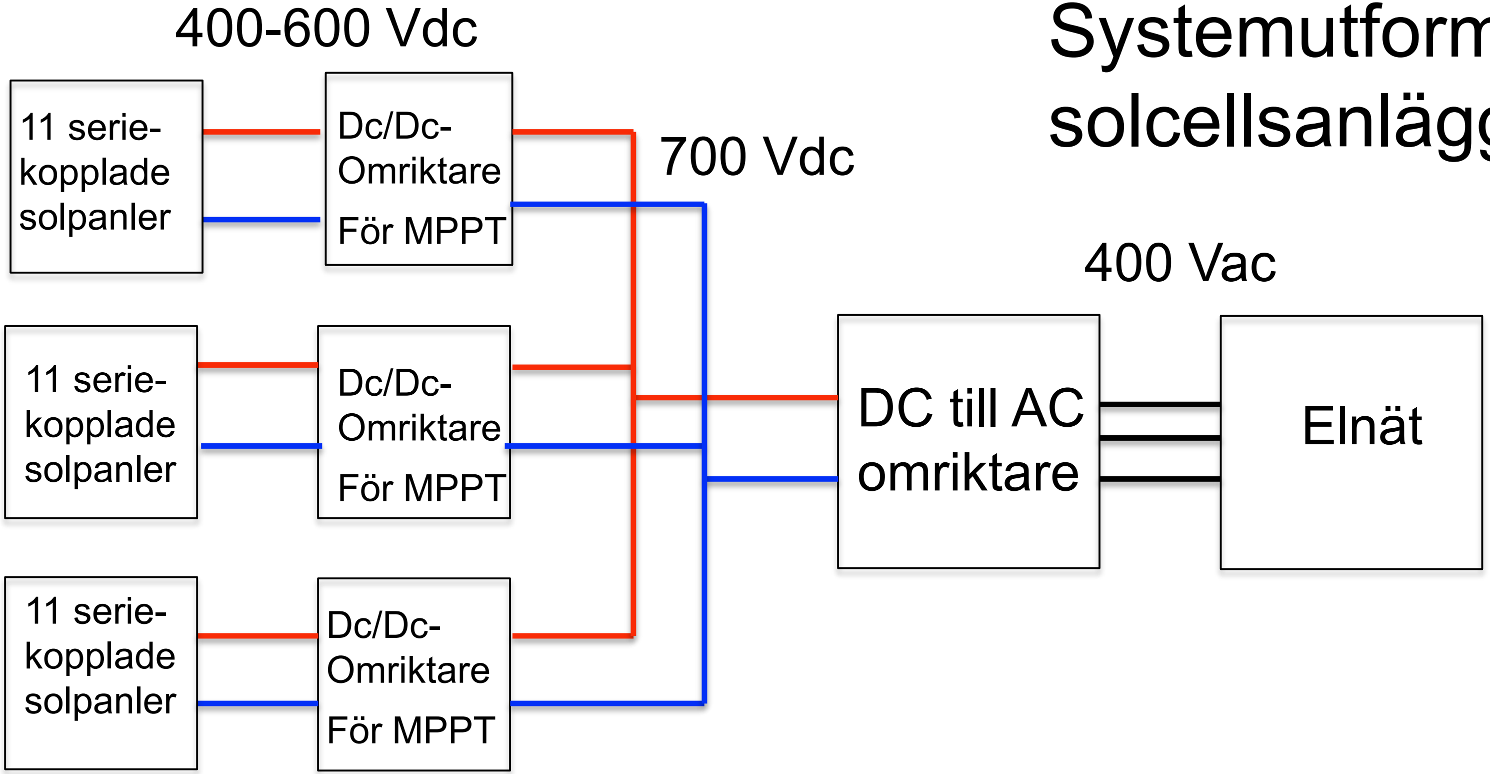
Max effekt
omriktare 5500 W

En solpanel kan bestå av 72 solceller och ger
48 V i tomgång, 35 V i fullt lastad, 8A och 280 W.

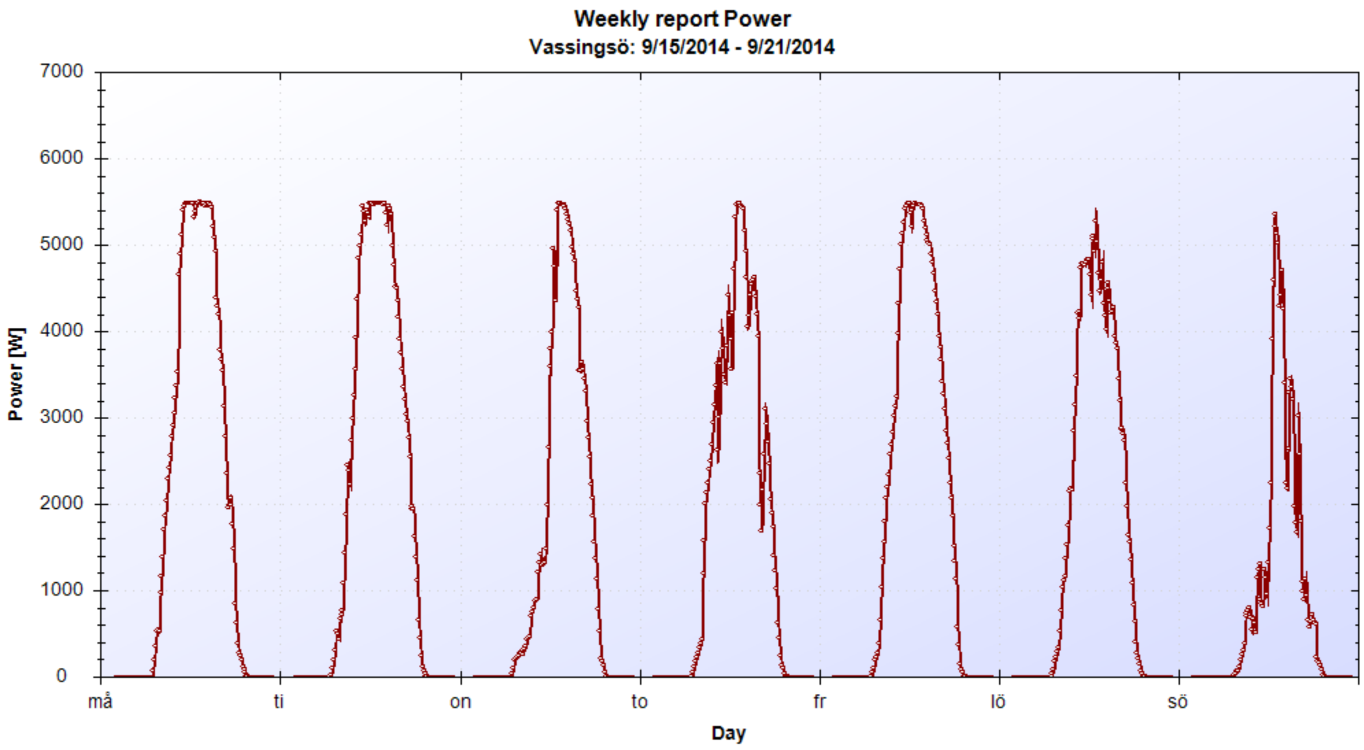
Kopplas i serie för att höja spänningen 11 st ger 528 V i tomgång.

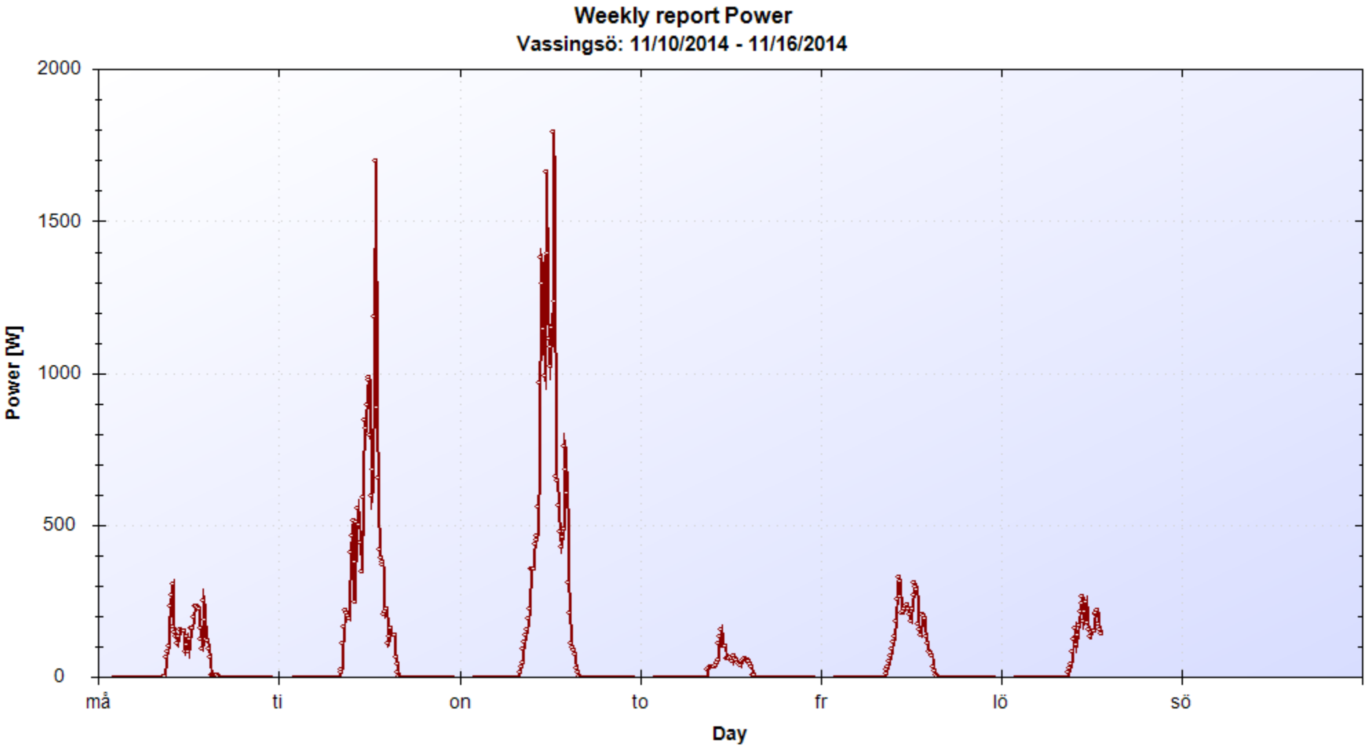
I Olas fall 3 strängar med solceller. Detta för att undvika skuggning av en sträng, skuggning av en panel kan hindra strömmen genom alla panelerna

Systemutformning för solcellsanläggning



MPPT = Maximun Power Point Tracking


Weekly report Power
Vassingsö: 9/15/2014 - 9/21/2014
Power [W]
7000
6000
5000
4000
3000
2000
1000
0
må
ti
on
to
fr
lö
sö
Day


Weekly report Power
Vassingsö: 11/10/2014 - 11/16/2014
Power [W]
2000
1500
1000
500
0
må
ti
on
to
fr
lö
sö
Day