ECN

Energy research Centre of the Netherlands

A wind farm electrical systems evaluation with EeFarm-II

Jan Pierik – ECN Windenergie

Urban Axelsson, Emil Eriksson, Daniel Salomonsson – Vattenfall

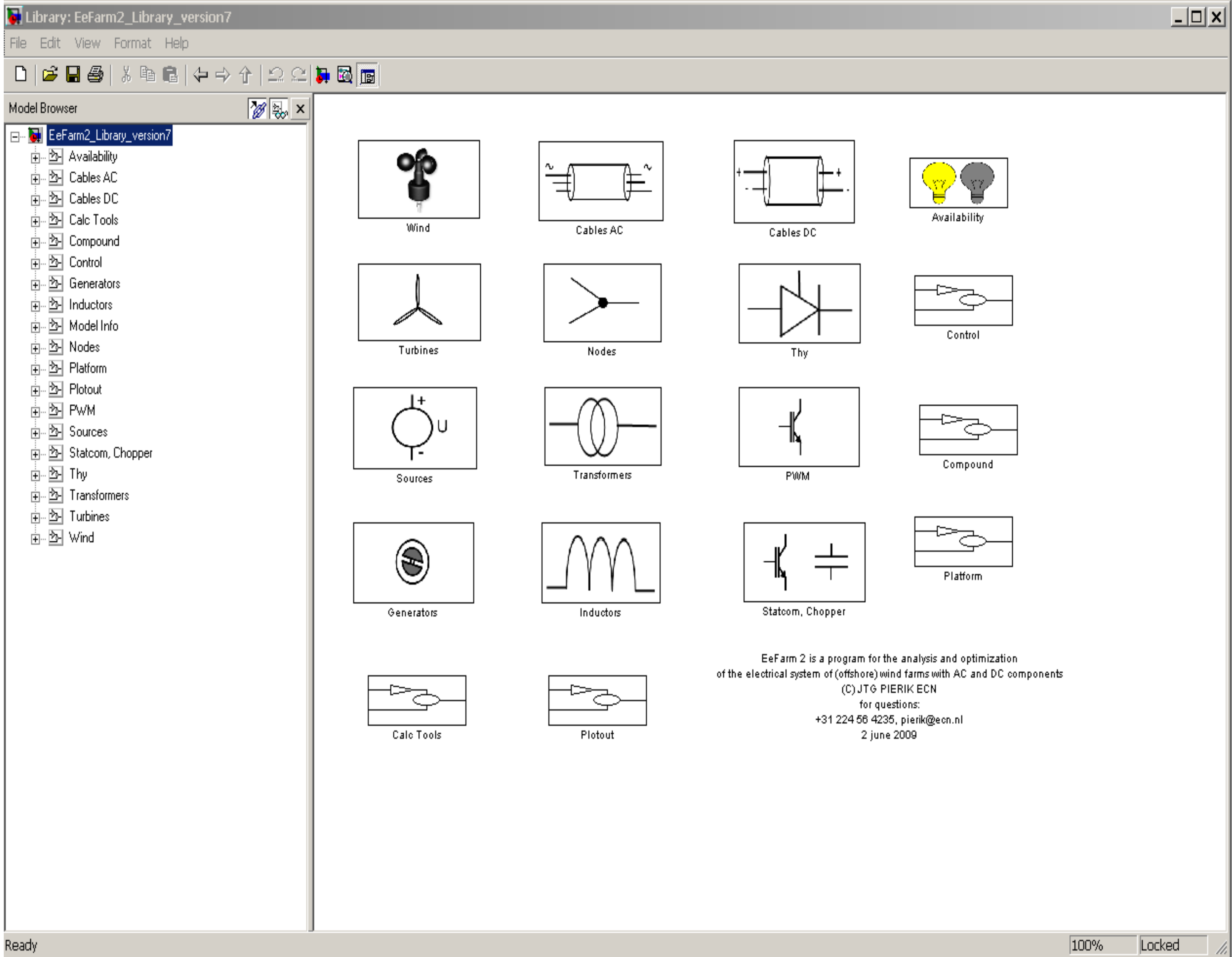
www.ecn.nl

Part 1: Wind farm electrical system evaluation

1. main WF specifications (size, location, distance shore etc.)
2. input power per WT and wind speed / direction
3. choice of electrical components (type: AC or DC, size)
4. choice of layout (location of cables and central platform)
5. preparation of steady state (load flow/voltage drop) model
   - voltages and currents in all components
   - electric losses
   - non-availability calculation (location dependant)
6. energy production for operating range
7. levelised production costs (LPC)

- system modification to improve LPC

EeFarm-II library



ECN

AC component models

- AC controllable source
- Generators:
  - Induction
  - Doubly Fed Induction
  - Full Converter Induction
  - Generic
- AC cable
- Transformer
  - fixed voltage ratio
  - variable ratio: automatic tapchanger
- Inductor
- AC node and splitter

DC component models

- Pulse Width Modulated (PWM) converter
  - TUD model
  - Kazmirkovsky model
  - Infineon model
- Thyristor converter
- DC cable
  - monopolar
  - bipolar
- Upchopper (DC-DC converter)
- Statcom
- DC node and splitter

Control

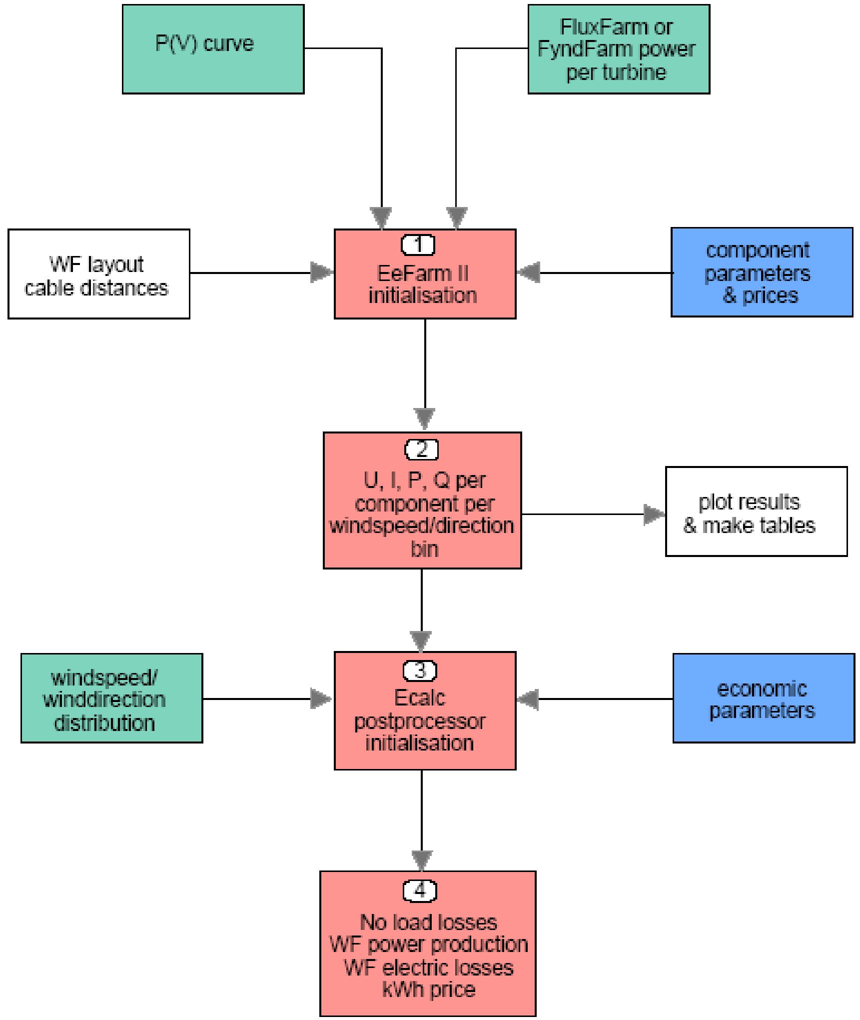
- reactive power feedback

  sets turbine reactive power

  for zero reactive power at PCC
- automatic tap changer

  improves voltage profile

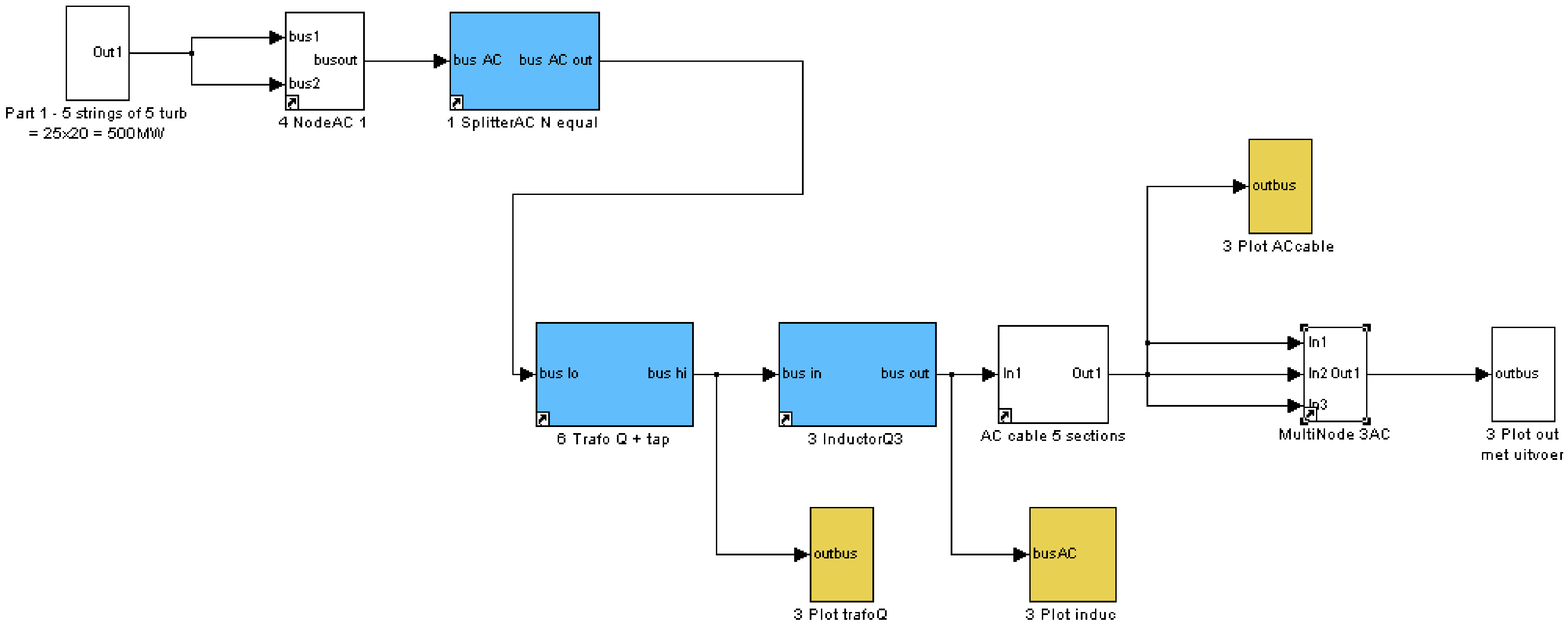
EeFarm-II structure



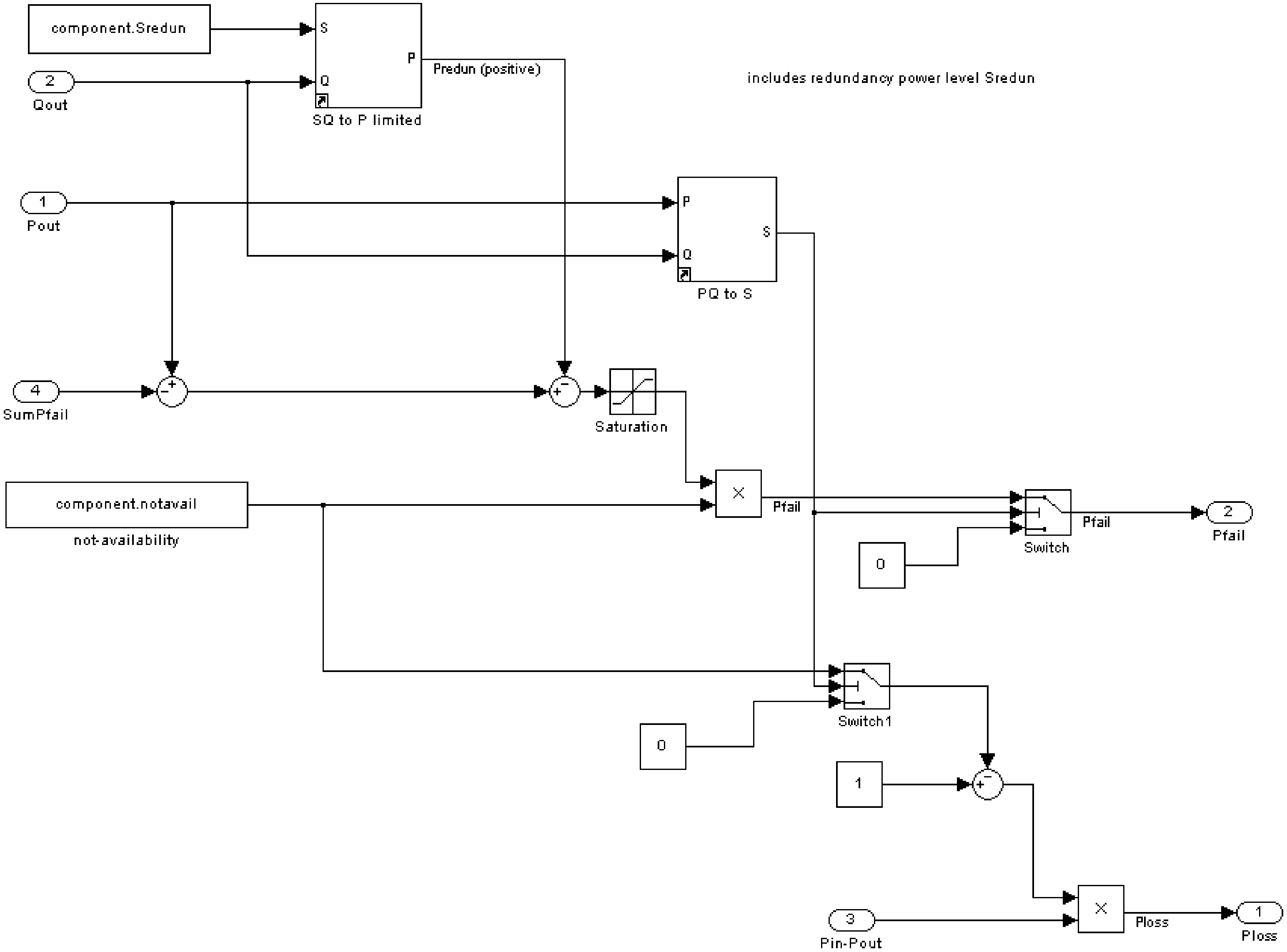
Database

- component properties and parameters:
  - manufacturer and type
  - rated voltage and current
  - electrical parameters (R, L, C, tandel, etc)
  - budget price supplied by manufacturer
- combined in a single variable (Matlab structure)
- loaded by a user specified Matlab file

Making an EeFarm model is easy: copy block from library and connect



Component reliability and redundancy



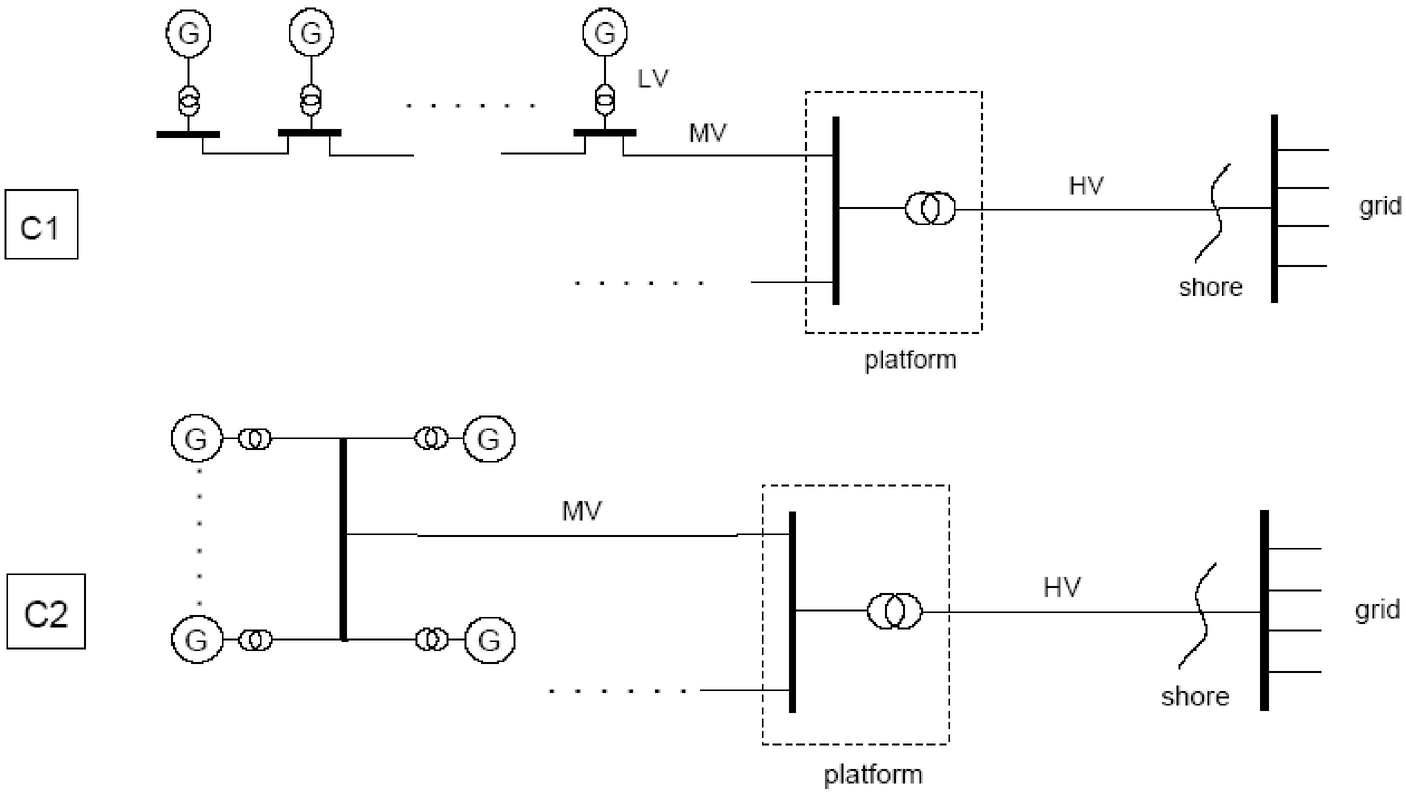
Postprocessing

- automatic calculation of
  - wind speed distribution dependent energy production
  - levelised production cost (LPC)
- automatic generation of characteristic output tables
  - max Pout, Ploss, Pfail (MW and %)
  - max Pnett (MW)
  - Etot (MWh/y), Eloss, Efail (MWh/y and %)
  - Pav (MW), CF
  - LPC (Euro/kWh)
- automatic generation of characteristic plots

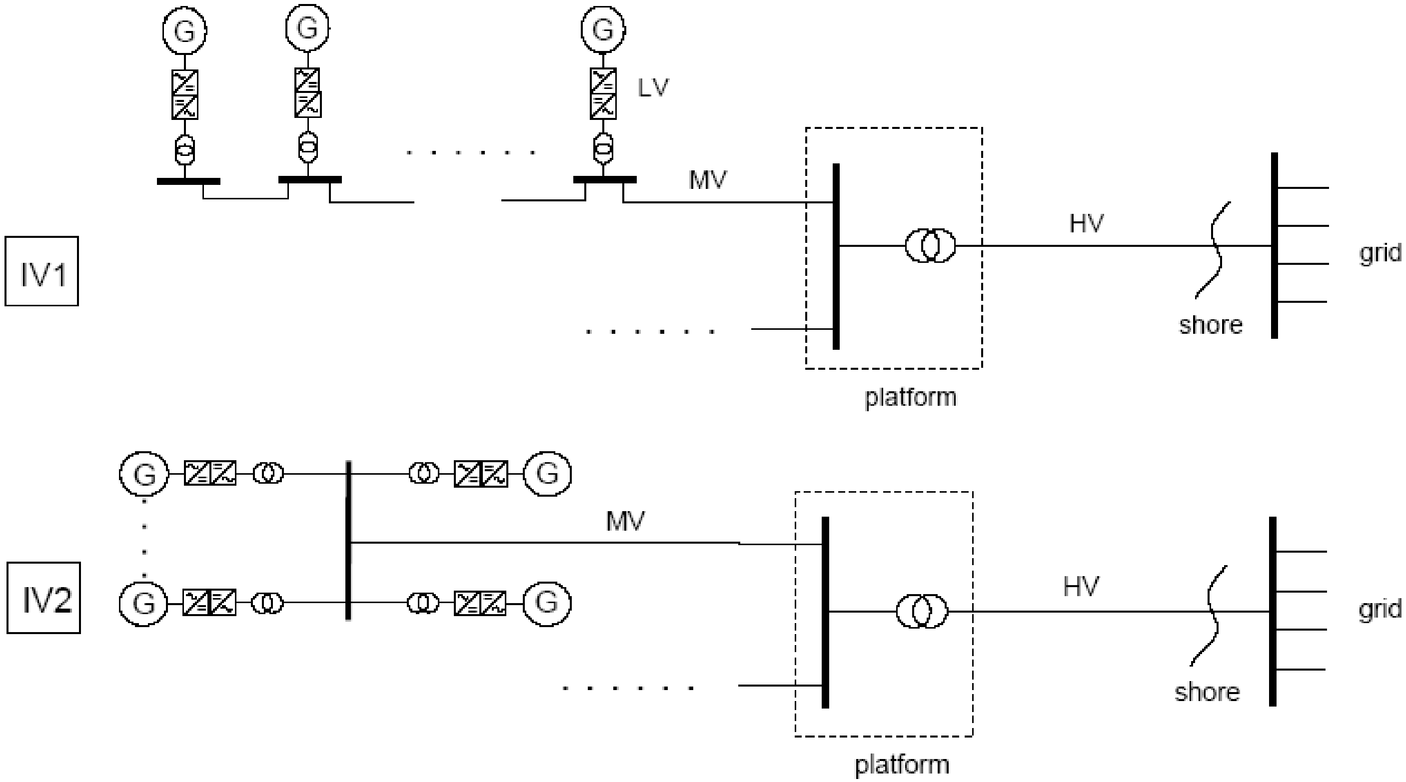
Part 2: Case study

- 200 MW wind farm with 5 MW wind turbines
- 100 km distance to shore
- 2 wind farm layouts:
  - strings of 5 turbines (daisy chain)
  - stars of 9 turbines with 1 at center
- central platform
- 4 types of electrical systems:
  - constant speed, all AC systems (C1, C2)
  - individual variable speed, AC to shore (IV1-IV5)
  - cluster variable speed, DC to shore (CV1-CV4)
  - park variable speed, DC to shore (PV1, PV2)

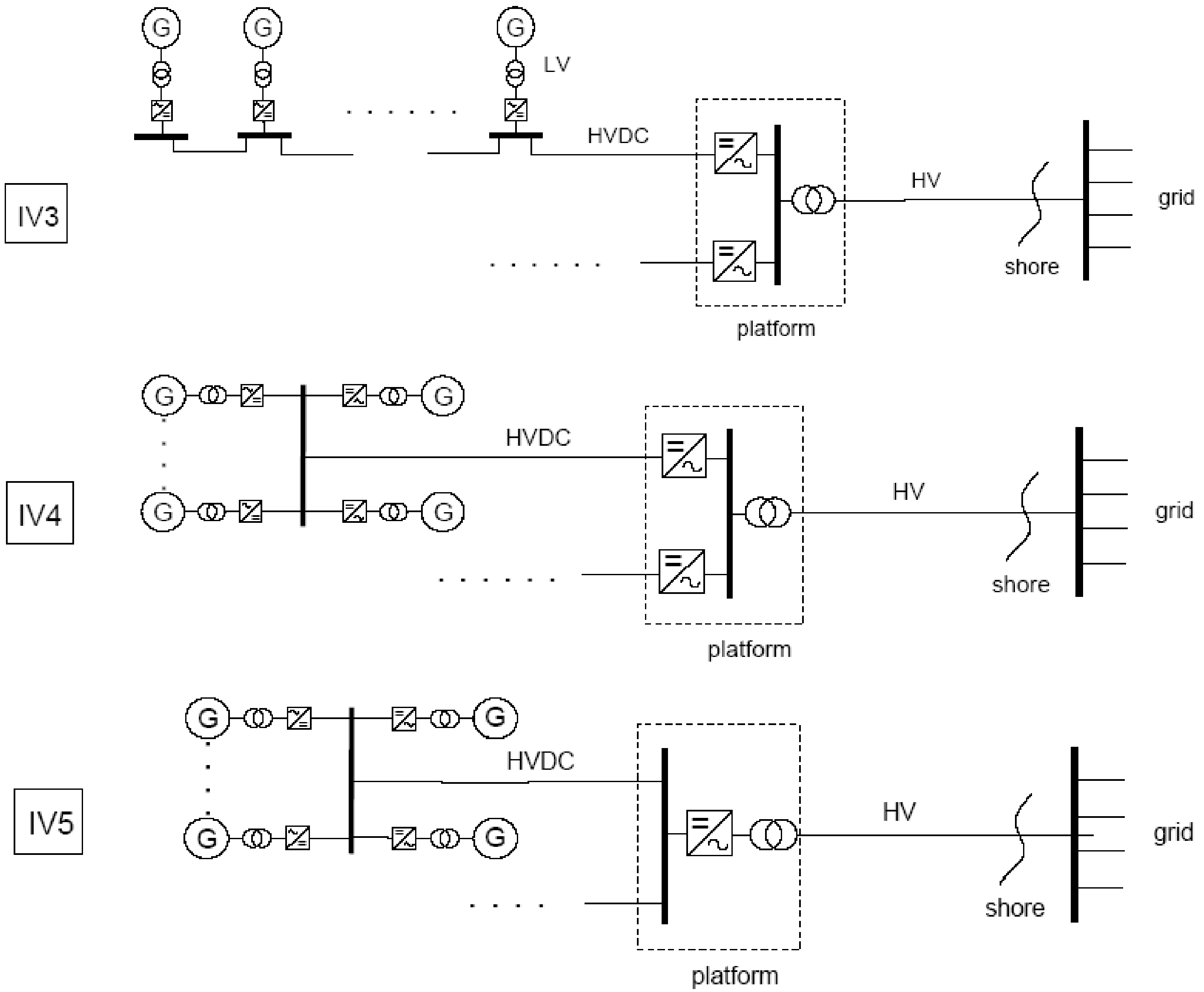
Constant speed, all AC



Individual variable speed, AC connected

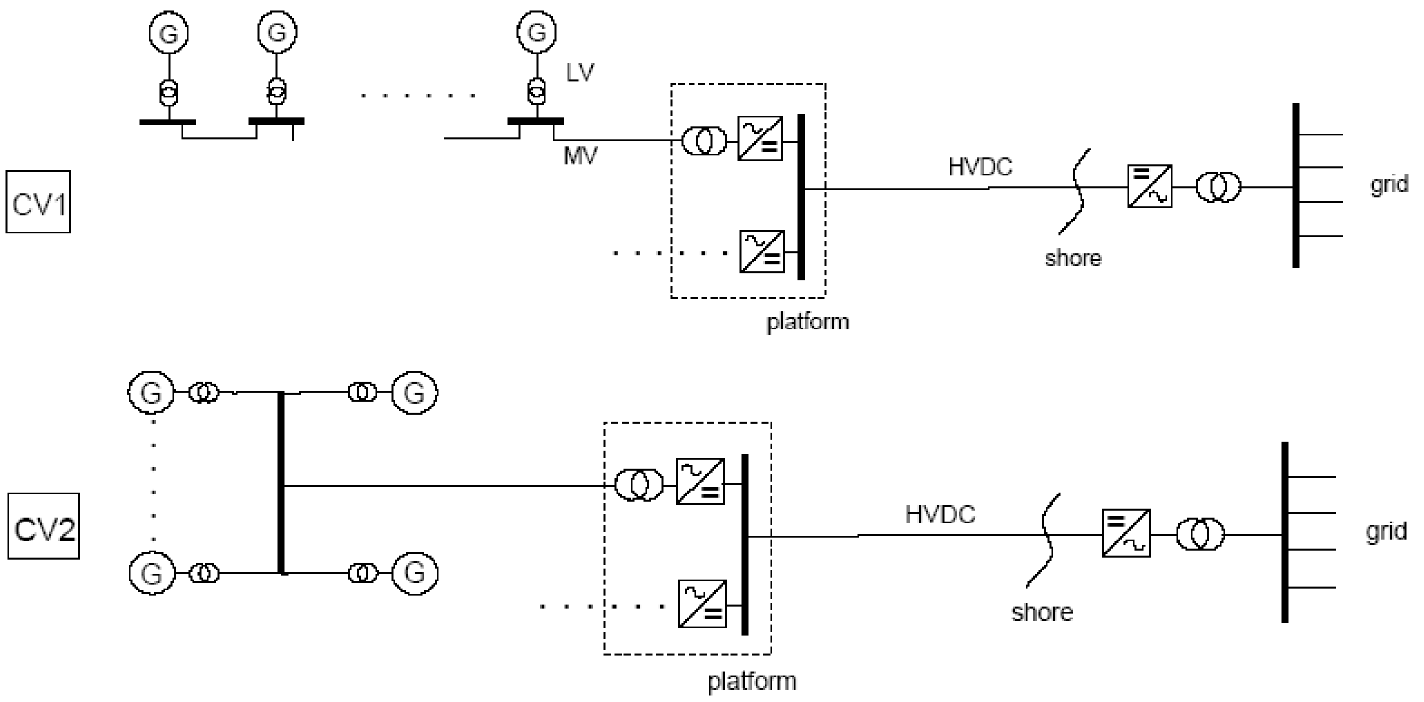


Individual variable speed, HVDC connected

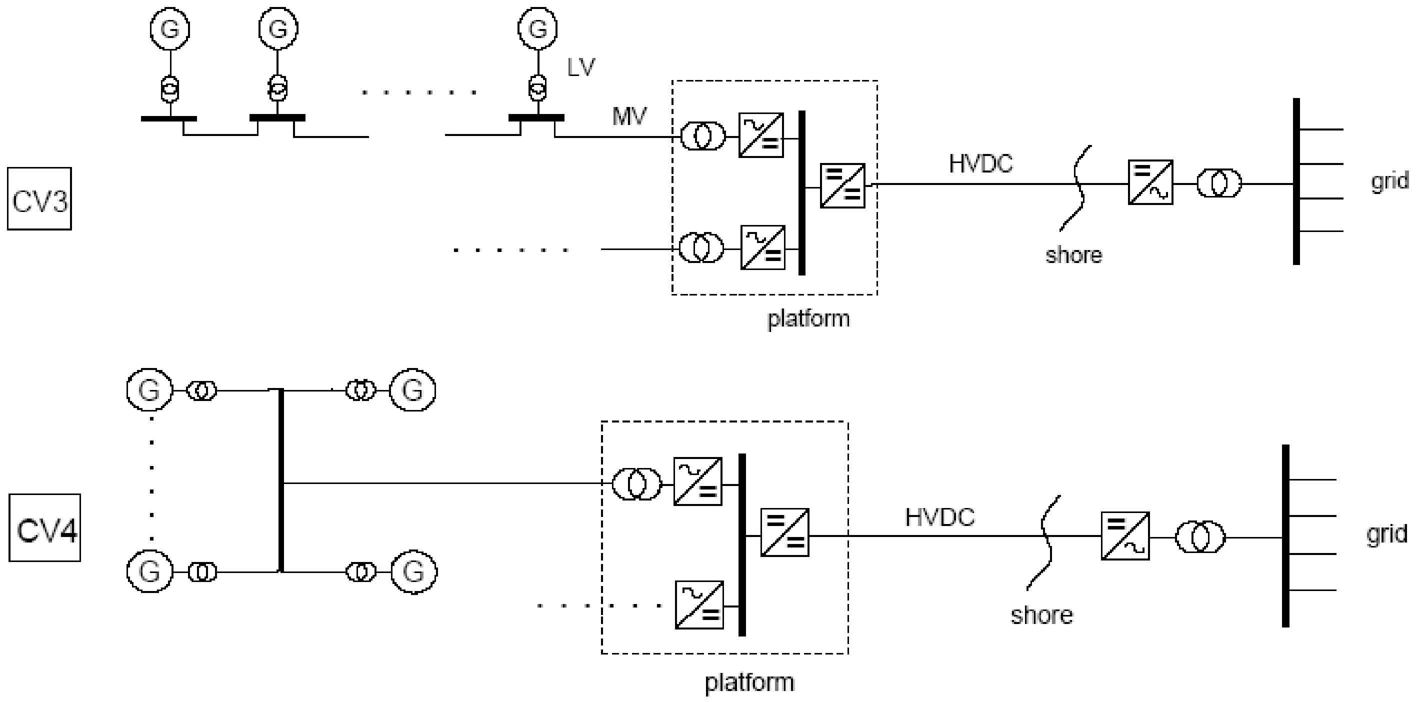


ECN

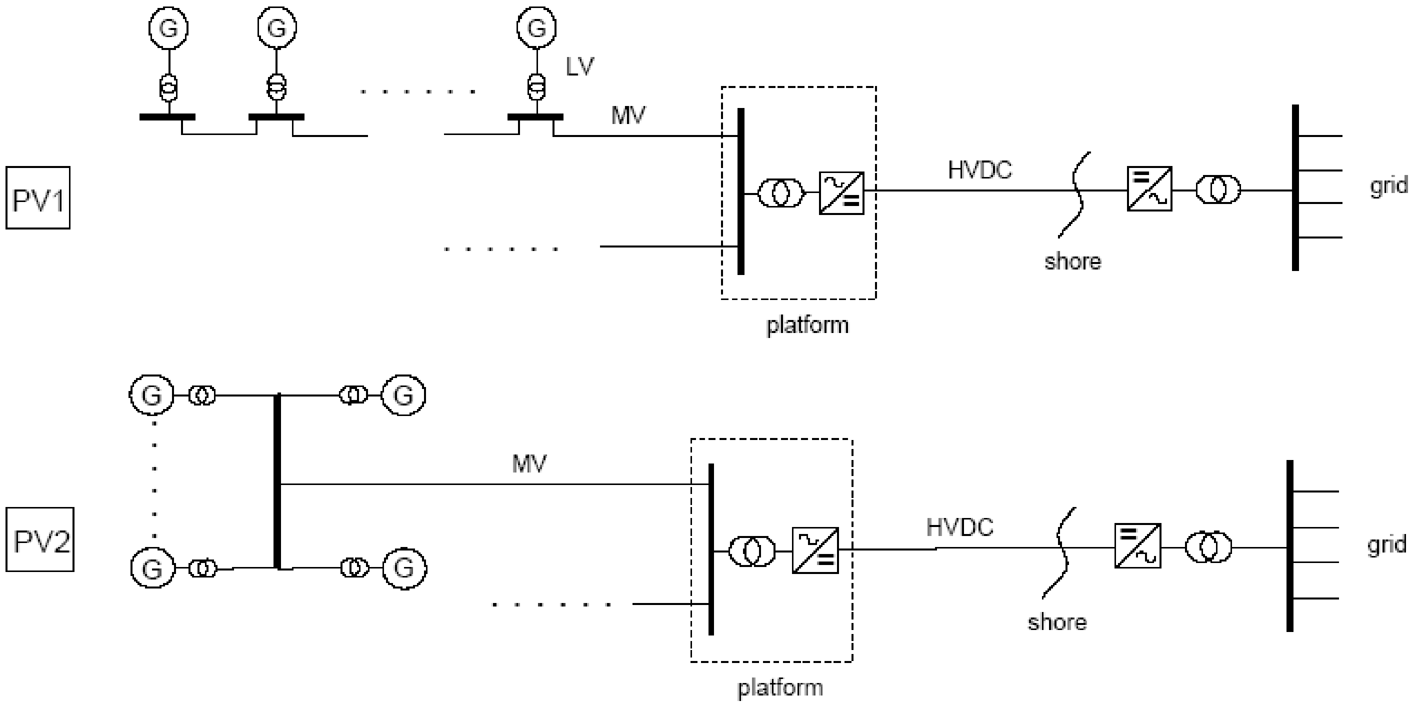
Cluster variable speed, HVDC connected



Cluster variable speed, HVDC + upchopper



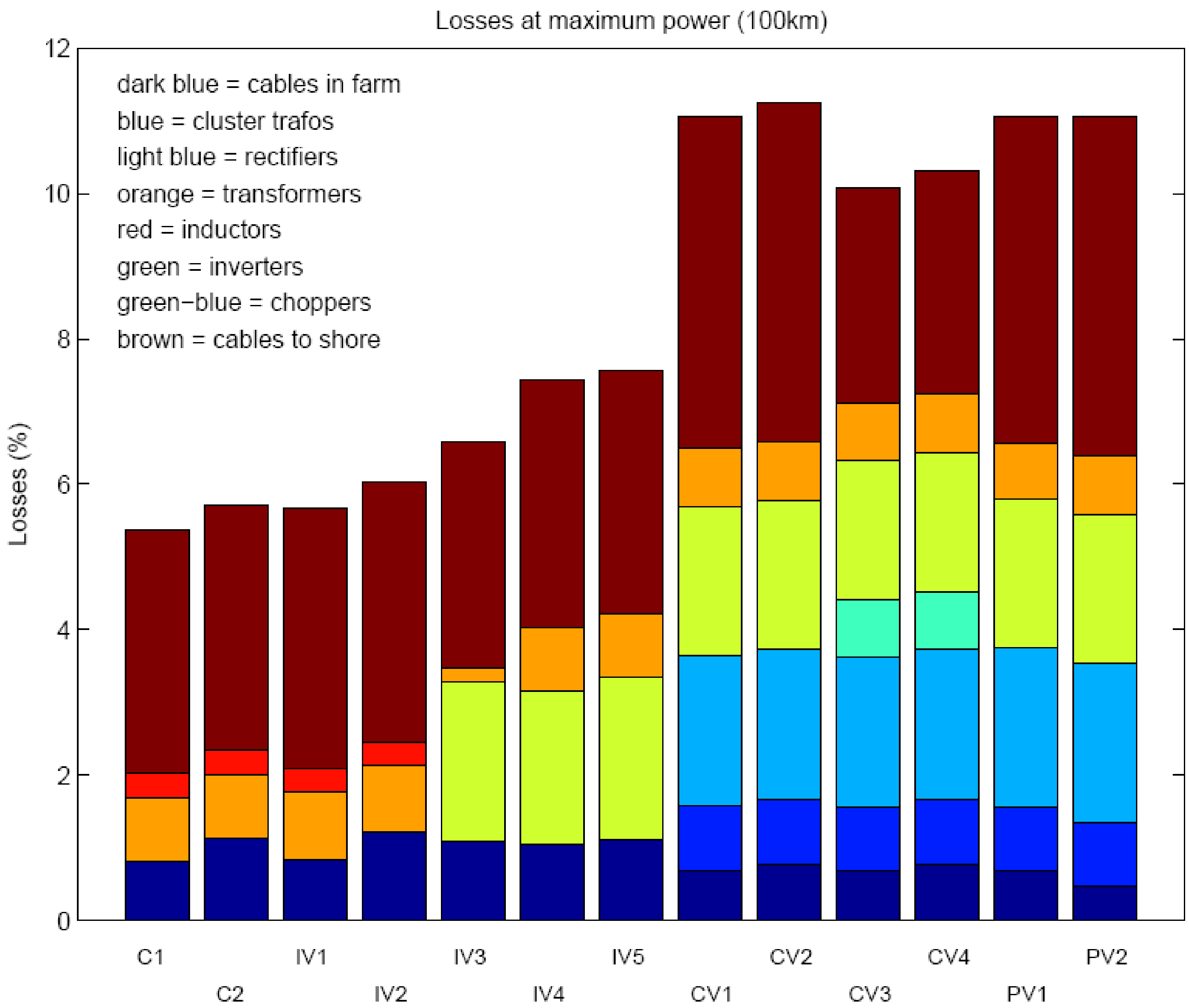
Park variable speed



ECN

Results

	Voltage (kV)	Current (A)	Power (MW)	Reactive Power (MVA)	Losses (MW)	Relative losses (-)
C1	133	902	189.2	87.3	10.8	0.0538
C2	133	903	188.6	86.6	11.4	0.0570
IV1	128	914	188.7	74.0	11.3	0.0566
IV2	127	915	187.9	73.3	12.1	0.0604
IV3	138	912	186.8	112.6	13.2	0.0659
IV4	132	993	185.1	132.2	14.9	0.0743
IV5	133	980	184.9	129.9	15.1	0.0755
CV1	142	725	177.9	-12.2	22.1	0.1106
CV2	140	733	177.5	-12.4	22.5	0.1125
CV3	128	813	179.9	-12.0	20.1	0.1007
CV4	125	829	179.4	-12.5	20.6	0.1031
PV1	143	718	177.9	-11.9	22.1	0.1104
PV2	141	732	177.9	-12.4	22.1	0.1105


Losses at maximum power (100km)
dark blue = cables in farm
blue = cluster trafos
light blue = rectifiers
orange = transformers
red = inductors
green = inverters
green−blue = choppers
brown = cables to shore
Losses (%)
0
2
4
6
8
10
12
C1
C2
IV1
IV2
IV3
IV4
IV5
CV1
CV2
CV3
CV4
PV1
PV2

Remarks

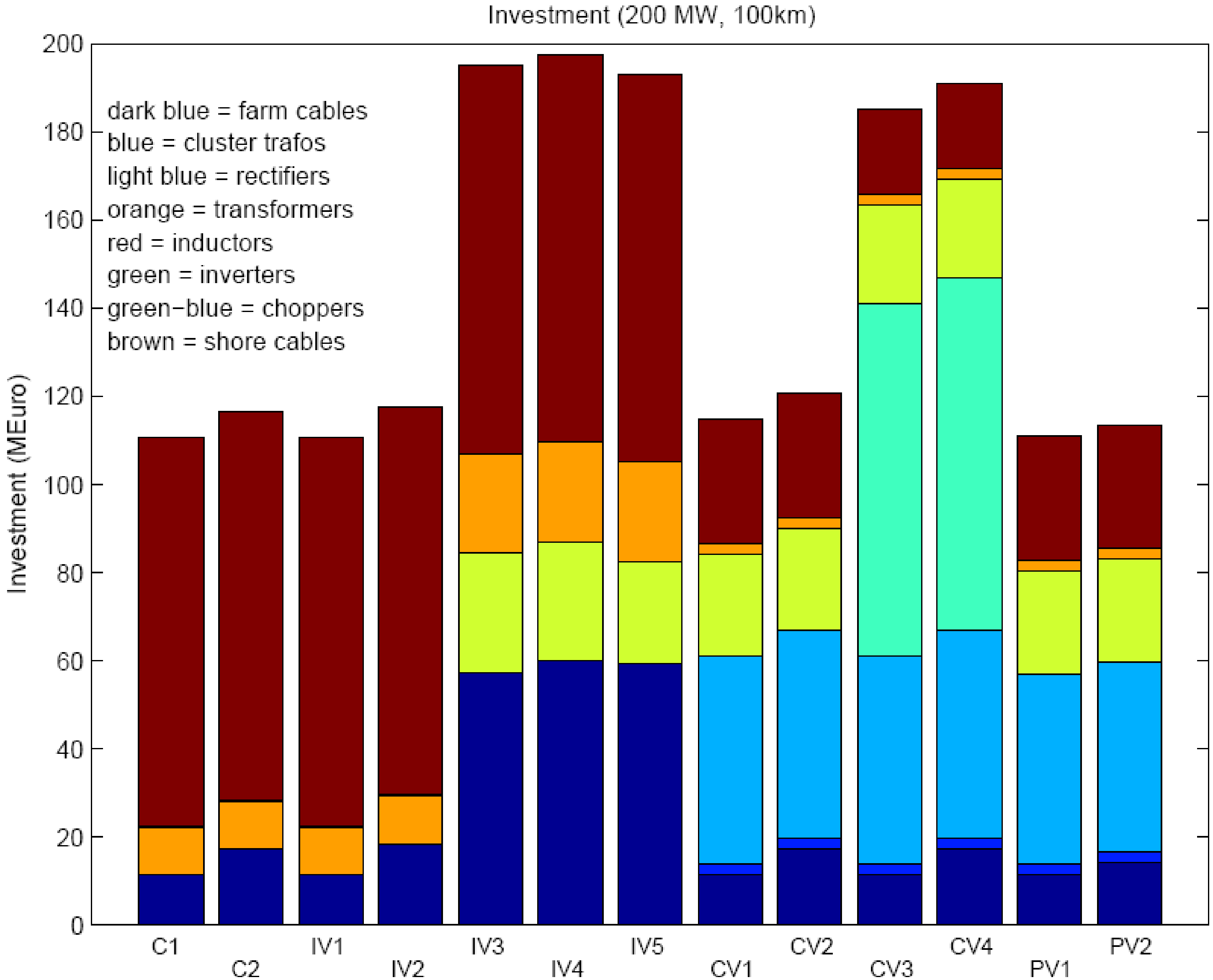
- losses depend on voltage level and type of component (AC, DC)
- IV3, IV4 and IV5 have DC in farm and AC to shore
- all CV and PV systems have DC to shore
- transformer losses not negligable

  (may be too high due to upscaling)
- DC (+/-80kV) cable losses slightly higher than AC (150kV)
- systems with DC have relatively high losses caused by
  - extra transformer losses
  - converter losses

    (converter losses compatible with independent info)
  - relatively high DC cable losses

Results: Energy Production

	Energy produced (MWh/y)	Energy losses (MWh/y)	Relative losses (-)
C1	938940	55638	0.0593
C2	936141	58437	0.0624
IV1	937275	57303	0.0611
IV2	934051	60527	0.0648
IV3	923253	71341	0.0773
IV4	917979	76611	0.0835
IV5	915285	79299	0.0866
CV1	889662	104875	0.1179
CV2	889597	104944	0.1180
CV3	897070	97480	0.1087
CV4	896641	97913	0.1092
PV1	889702	104835	0.1178
PV2	891353	103189	0.1158


Investment (200 MW, 100km)
dark blue = farm cables
blue = cluster trafos
light blue = rectifiers
orange = transformers
red = inductors
green = inverters
green−blue = choppers
brown = shore cables
Investment (MEuro)
200
180
160
140
120
100
80
60
40
20
0
C1
C2
IV1
IV2
IV3
IV4
IV5
CV1
CV2
CV3
CV4
PV1
PV2

ECN

Remarks

- DC cables relatively cheap compared to equivalent AC
- counteracted by converter investment costs
- platform costs are considerable,
  especially for transformer + converter
- IV3-IV5 combine DC in farm with AC cable to shore
  - DC cables (+/-80kV,65MW) in farm relatively expensive
  - AC cable to shore relatively expensive
- DC-DC choppers very expensive (not standard)
- systems with DC in farm (IV3, IV4, IV5) or DC-DC converter: high investment costs

- investment costs of C1, C2 about same as PV1, PV2 (100km/200MW)

Investment and LPC

	Investment (MEuro)	Energy produced (MWh/y)	Specifi c investment (MEuro/MW)	LPC (Euro/kWh)
C1	110.6	935227.7	0.5530	0.0137
C2	116.4	932445.8	0.5820	0.0144
IV1	110.6	933371.3	0.5530	0.0137
IV2	117.6	930167.4	0.5881	0.0146
IV3	195.0	921950.9	0.9751	0.0244
IV4	197.6	917680.2	0.9881	0.0249
IV5	193.1	913794.9	0.9655	0.0244
CV1	114.8	884801.7	0.5742	0.0150
CV2	120.6	886043.7	0.6031	0.0157
CV3	185.1	892104.8	0.9256	0.0240
CV4	190.9	892962.7	0.9546	0.0247
PV1	110.9	884866.5	0.5544	0.0145
PV2	113.6	887782.1	0.5680	0.0148

ECN

Remarks

- LPC relatively high: economic life time only 12 y

- electrical component unavailability not included
  - effect substancial (few % of produced power)
  - depends on redundancy
  - what failure rate for offshore cables?
- voltage control not included
  - effect relatively small (few 0.1% of produced power)

Conclusion

wea@sea project EeFarm- II resulted in:

- a flexible (AC as well as DC), easy to use and fast computer program for WF electrical evaluation
- a comparison of 13 WF electrical systems
- a report with detailed model description
- a paper in the Energies Journal

- EeFarm-II is commercially available
- part of the database is confidential and not included in the supply

Questions or time for coffee?