EERA DeepWind'2014 Deep Sea Offshore Wind R&D Conference, Trondheim, 22-24 January 2014

The Impact of Active Power Losses on the Wind Energy Exploitation of the North Sea

Hossein Farahmand , Leif Warland, Daniel Huertas-Hernando

SINTEF Energy Research,

Hossein.Farahmand@sintef.no

Leif.Warland@sintef.no

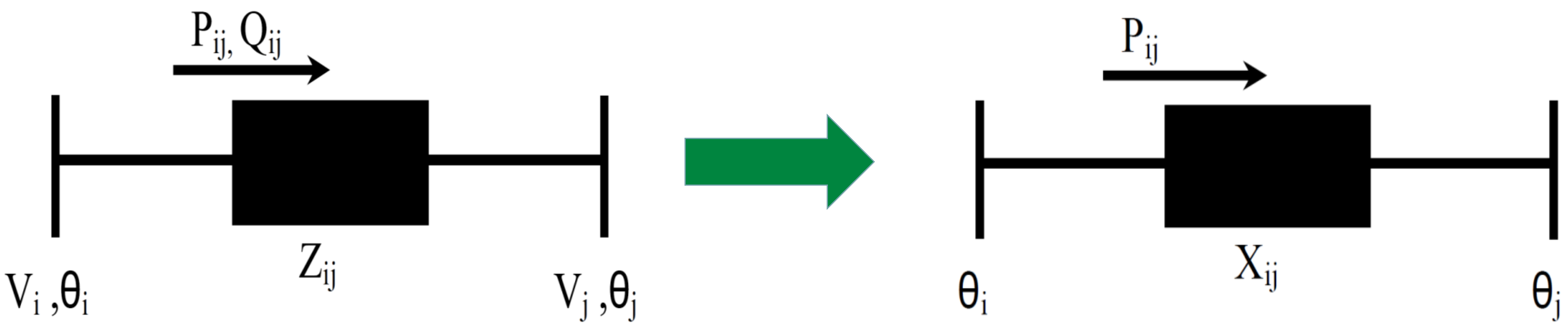
daniel.h.hernando@sintef.no

Outline

- Propose an approach based on linearized active power losses
- Compare the linearized approach with iterative approach and AC optimal power flow using IEEE 9-bus case study
- Study the effect of active power losses on the study case including the Nordic system and Germany

Assumptions for DC power flow approximation

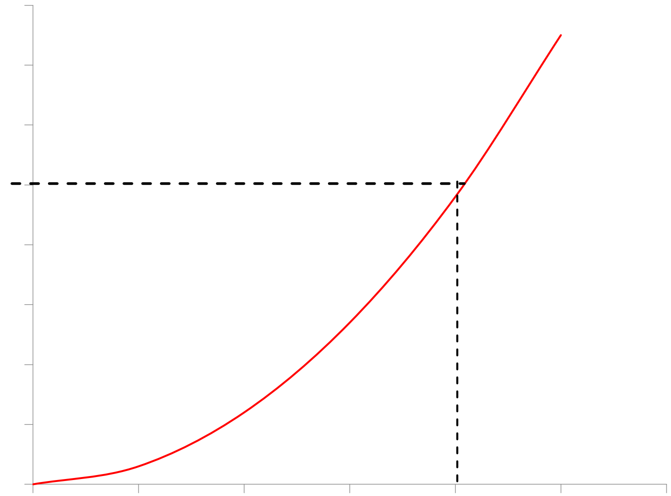
- Reactive power is neglecting ($Q_{ij} \approx 0$)
- Ignore line resistance ($Z_{ij}=R_{ij}+jX_{ij} \approx jX_{ij}$)
- Flat voltage profile, all voltage magnitudes are equal to 1 per unit ($V_i \approx V_j \approx 1$)
- Linearized: $\cos\theta \approx 1$, $\sin\theta \approx \theta$ (small θ)



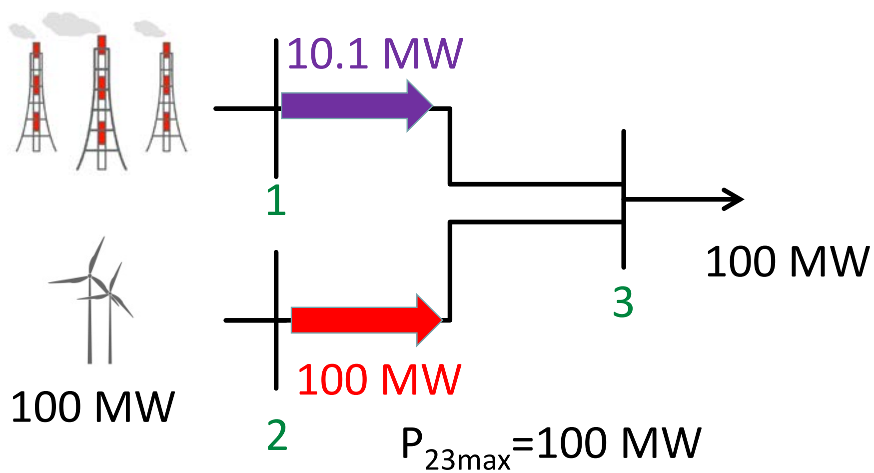
Incorporation of power losses

- Active power loss at transmission line "*ij*":

$$P_{loss} = r_{ij} \cdot I_{ij}^2 \approx r_{ij} \cdot \frac{(\theta_i - \theta_j)^2}{x_{ij}^2}$$



- Active power losses are proportional to the **square** of the flow through the transmission line



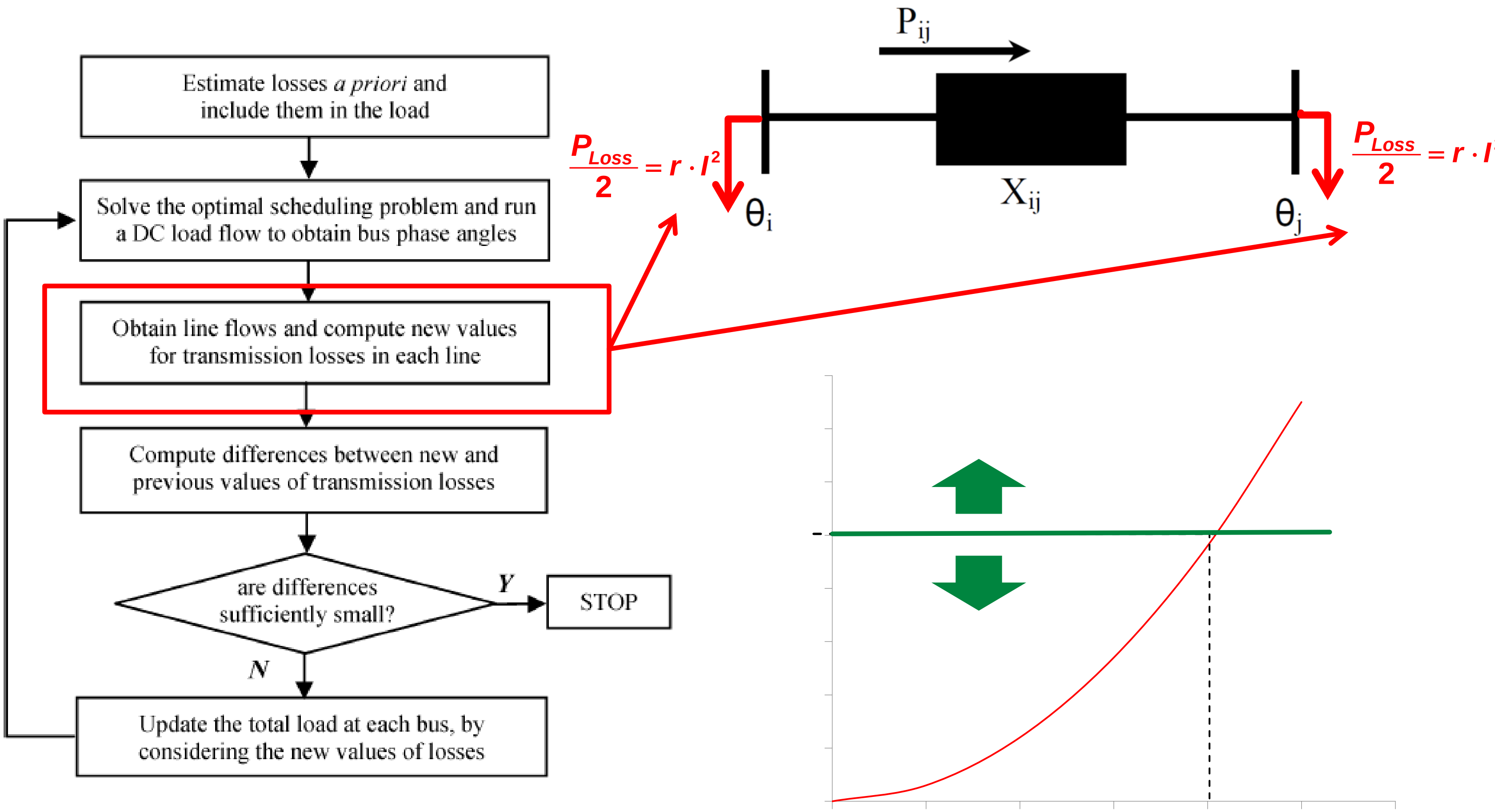
P_{Loss}=10%

Linearized power losses

- We compared two approaches
  - Iterative approach to consider losses
  - Our approach to incorporate linearized power losses in DC Optimal Power Flow

- AC Optimal Power Flow (AC-OPF) → benchmark

Iterative approach

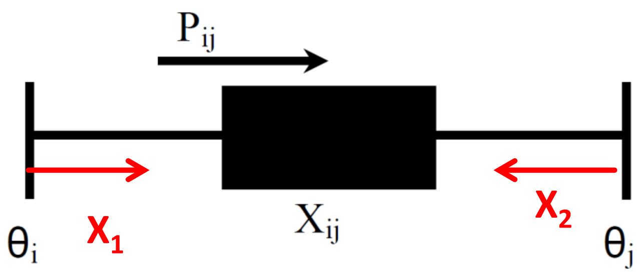


The optimisation problem is updated at each iteration with new information about the **value** of the losses

Proposed Approach

We linearize losses around operating point

$$P_L \approx a + b\Delta\theta = -\frac{r\Delta\theta_0^2}{x^2} + 2\frac{r\Delta\theta_0}{x^2}\Delta\theta$$



$$X_1 + X_2 = \Delta\theta$$

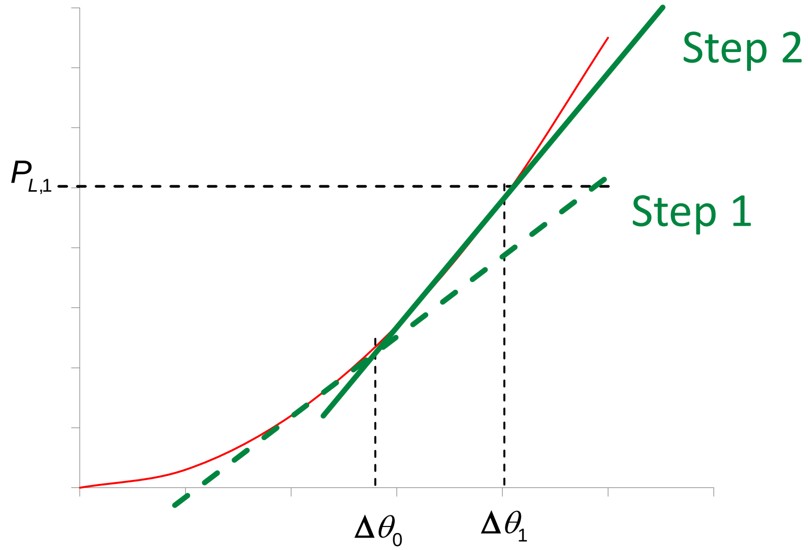
$$P_L \approx -\frac{r\Delta\theta_0^2}{x^2} + 2\frac{r\Delta\theta_0}{x^2}(x_1 + x_2)$$

This approach provides the feedback from active power losses to the optimisation routine → The optimisation problem can evaluate the trade-off between generation costs and transmission losses to find an optimum solution.

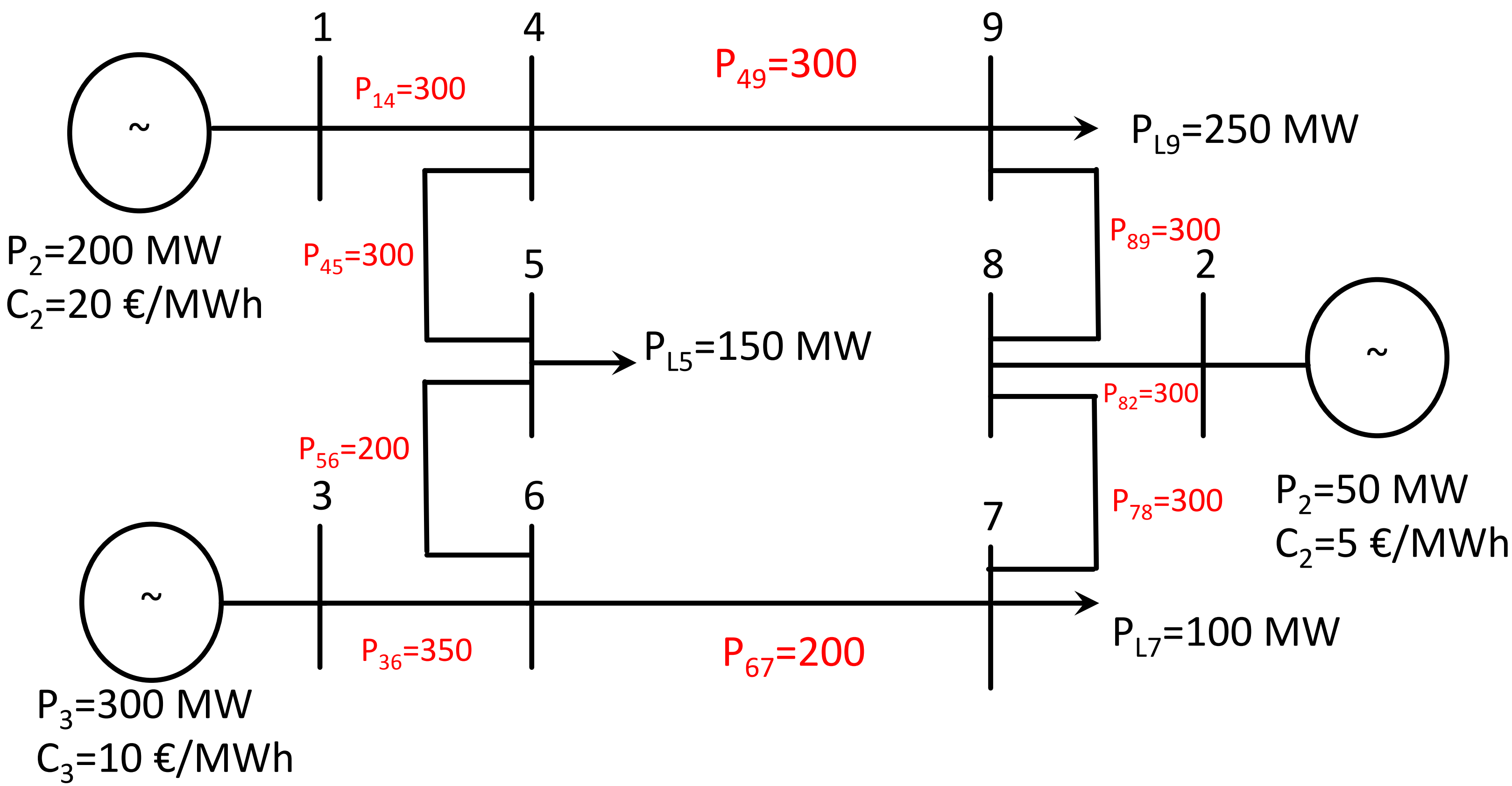
Iterative process to update coefficients of linearized losses

- Using the value of Δθ from previous step, a new linearized function of branch losses can be found → a,b can be updated

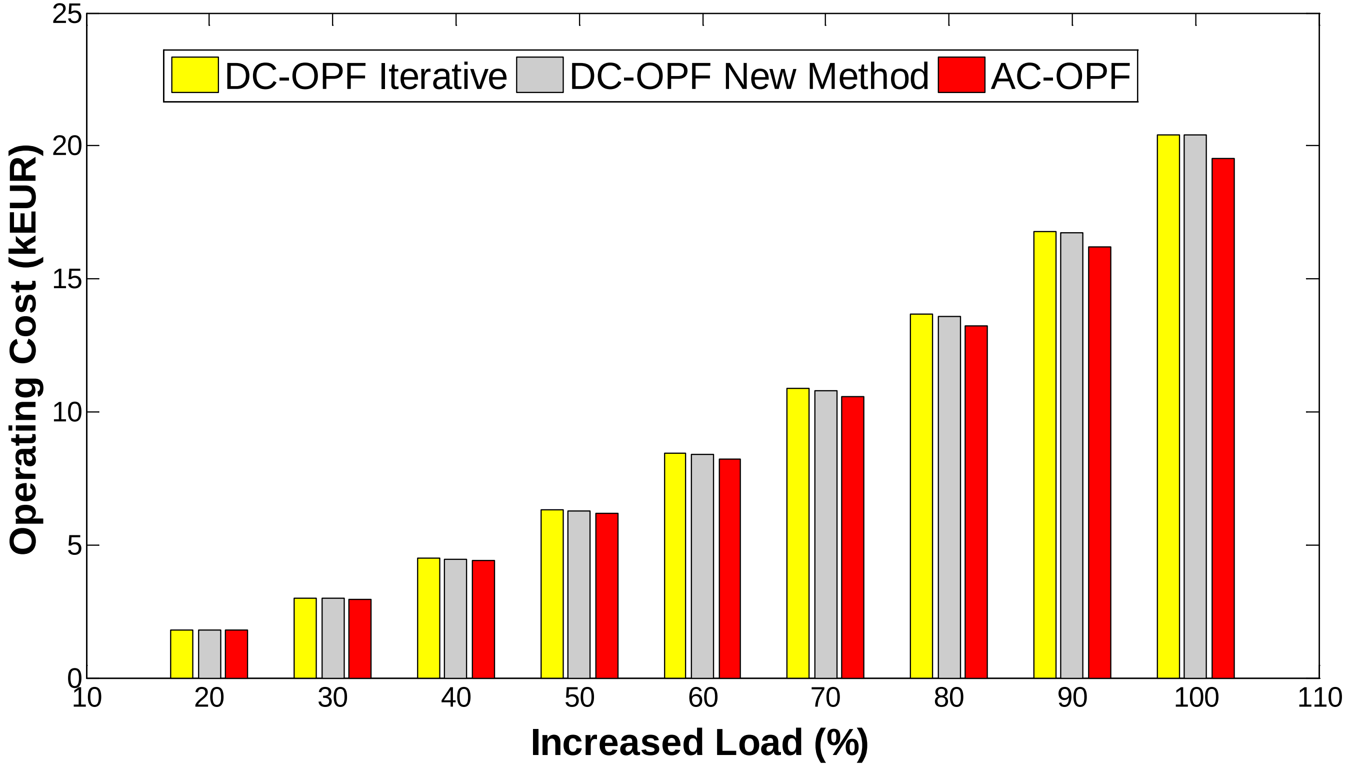
$$P_L \approx a + b\Delta\theta = -\frac{r\Delta\theta_0^2}{x^2} + 2\frac{r\Delta\theta_0}{x^2}\Delta\theta$$



9-bus case study



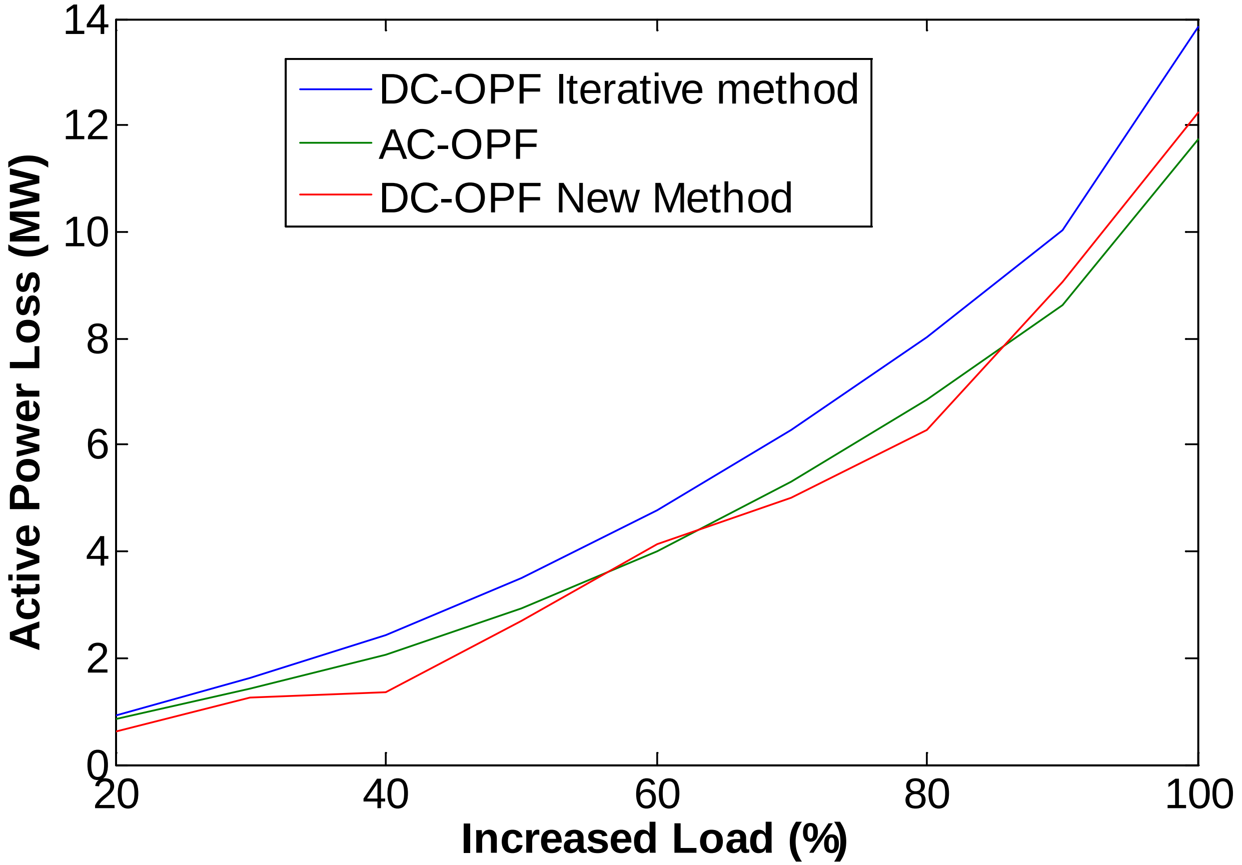
Cost comparison



Approaches	Cumulative Operating Cost kEUR
AC-OPF	83.05
Linearized loss	85.46
DC-OPF	85.77

Approaches	Average Generation		
	G1 (20 €/kWh)	G2(5 €/kWh)	G3(10 €/kWh)
AC-OPF	107.8	50	147.06
Linearized loss	107	50	152.67
DC-OPF	109.89	50	150.58

Loss comparison



Error	Cumulative error in loss calculation (MW)
|(DCOPF)-(ACOPF)|	**17.31**
|(linear loss)-(ACOPF)|	**7.41**

Warm start problem

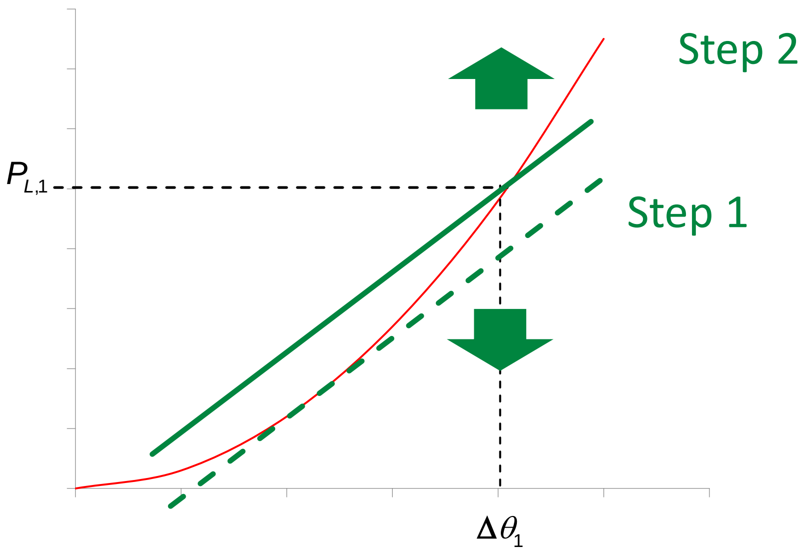
Our optimisation problem:

$$\text{minimize } F(\underline{x}) = \underline{C}\,\underline{x}$$

Subject to:

$$\underline{b}_{low} \leq \underline{A}\underline{x} \leq \underline{b}$$

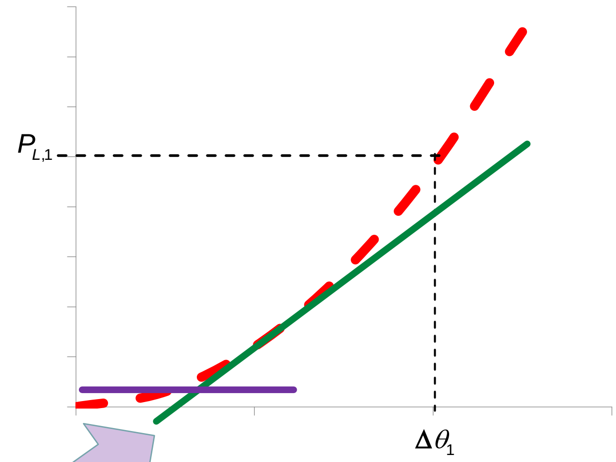
$$\underline{x}_{lb} \leq \underline{x} \leq \underline{x}_{ub}$$

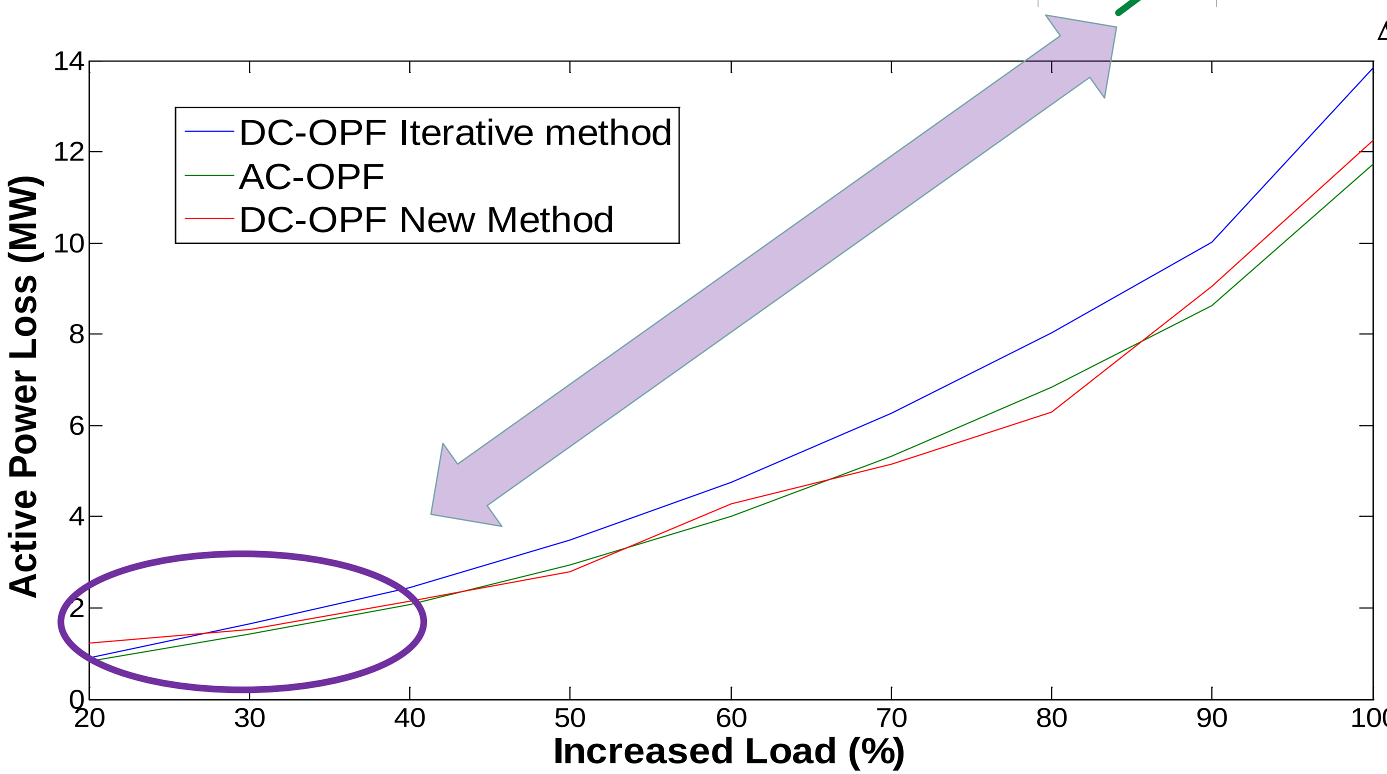


In order to use warm start functionality we cannot update "**A**" matrix →only "a" value in linearized function of branch losses can be updated

$$P_L \approx a + b\Delta\theta = -\frac{r\Delta\theta_0^2}{x^2} + 2\frac{r\Delta\theta_0}{x^2}\Delta\theta$$

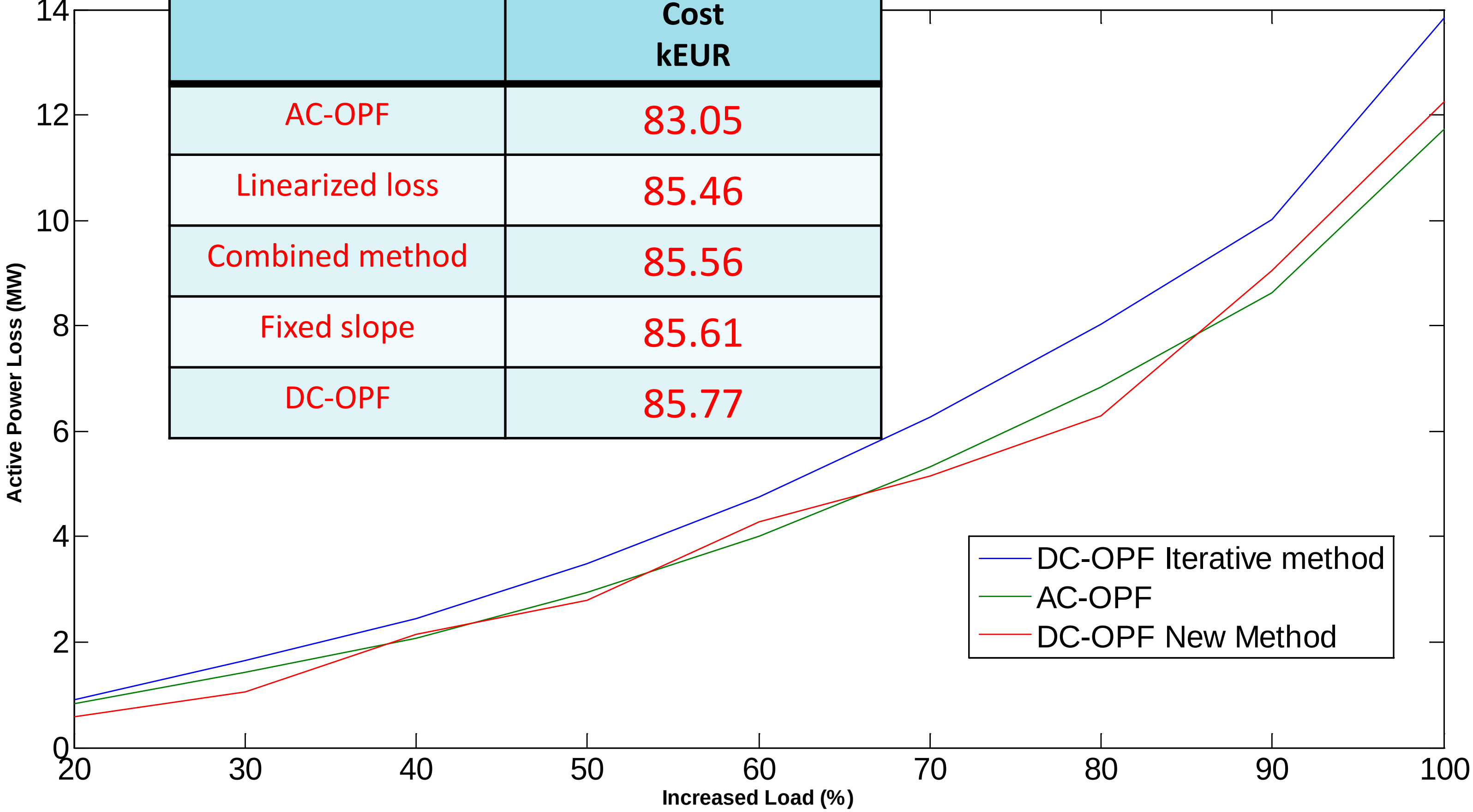
Warm start problem (fixed slope)



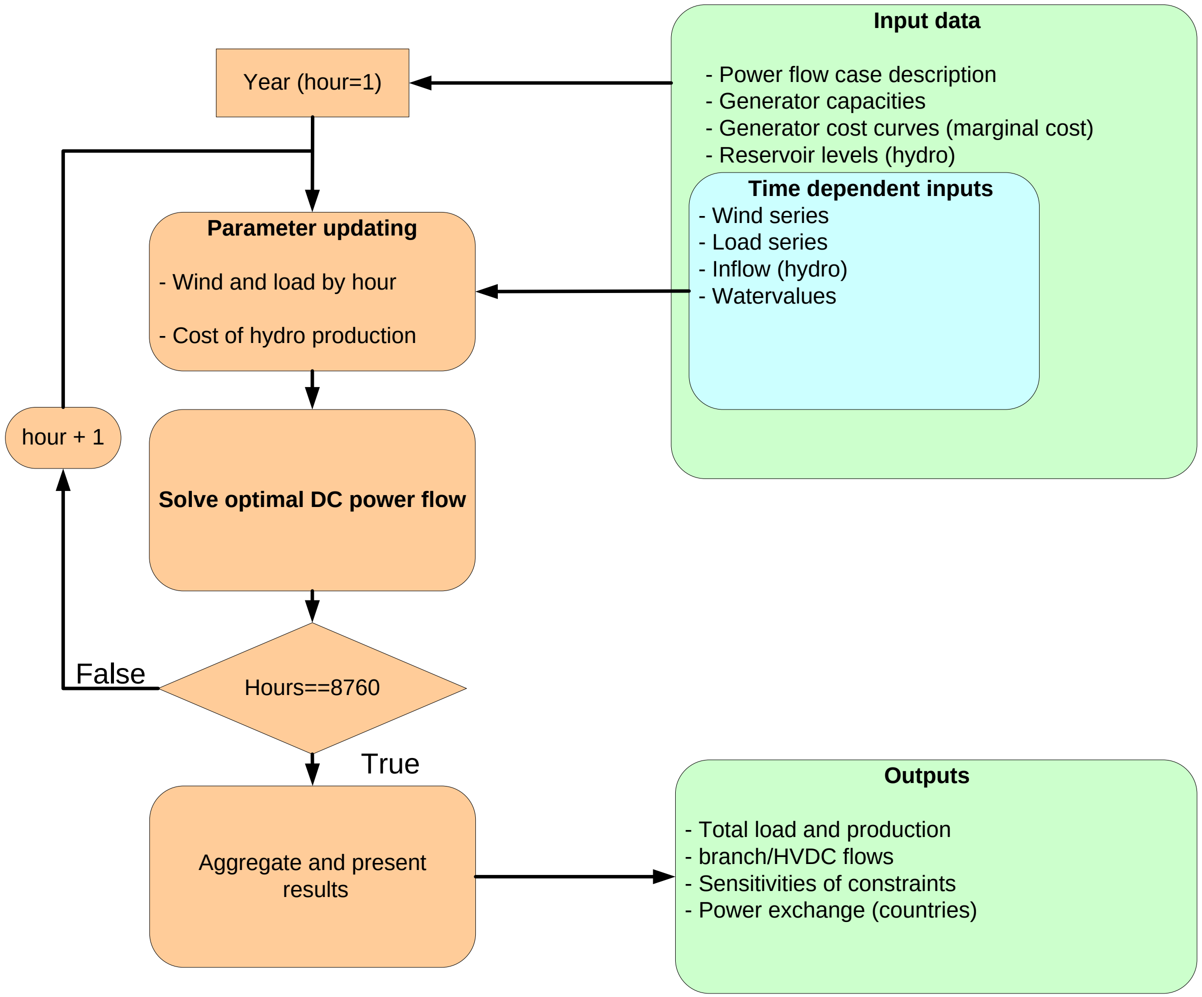


Combination of fixed value of losses and linearized losses with fixed slope

Approaches	Cumulative Operating Cost kEUR
AC-OPF	83.05
Linearized loss	85.46
Combined method	85.56
Fixed slope	85.61
DC-OPF	85.77

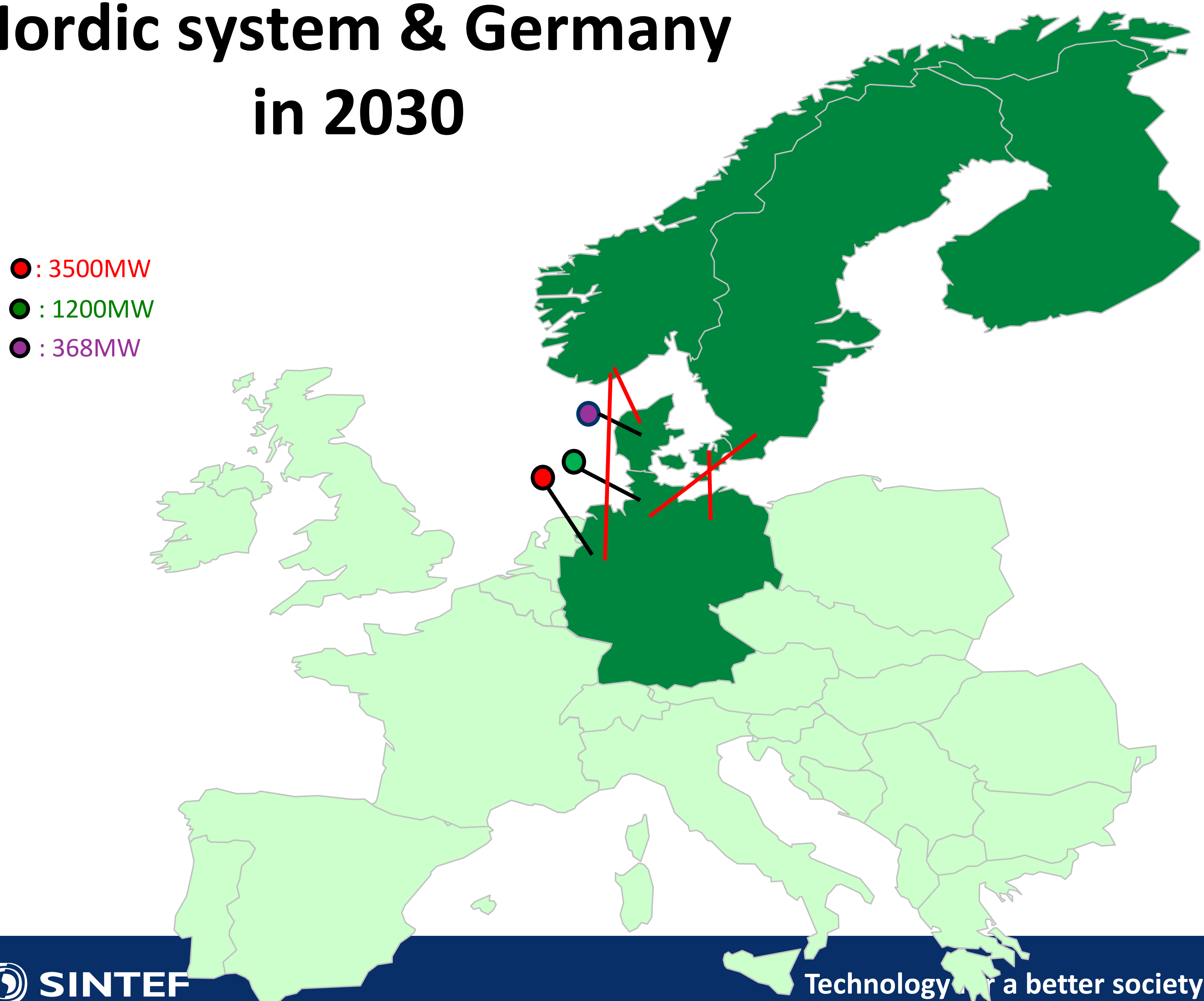


PSST Model (Flow-Based Market Model)

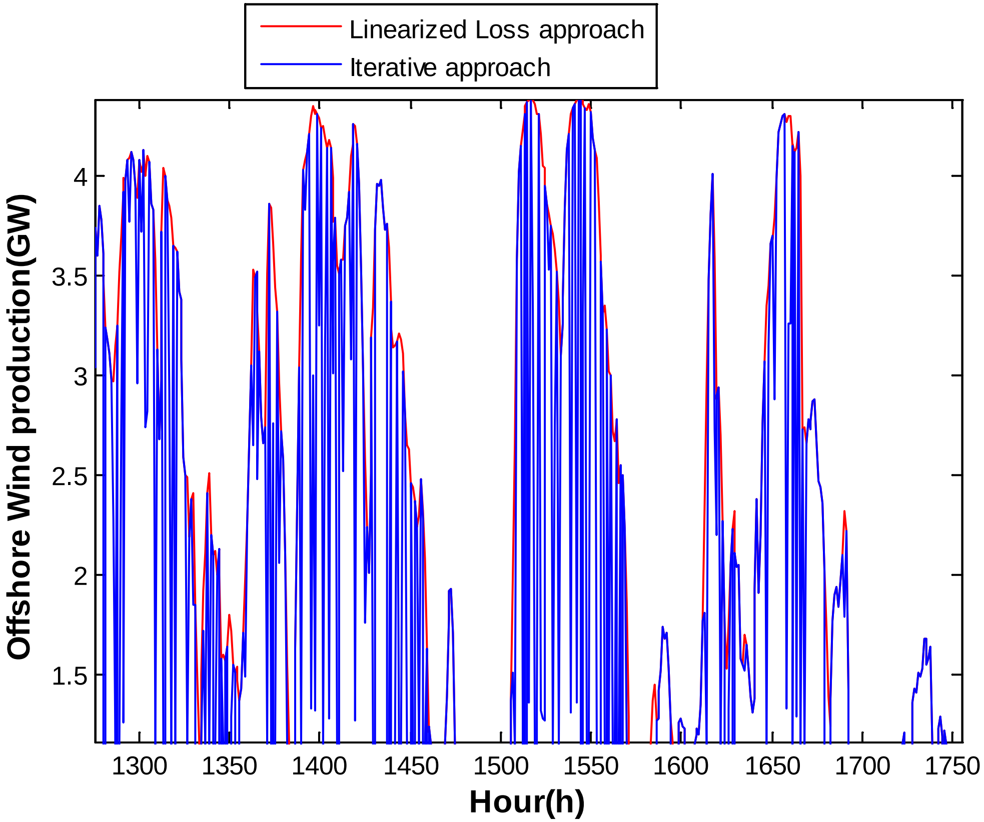


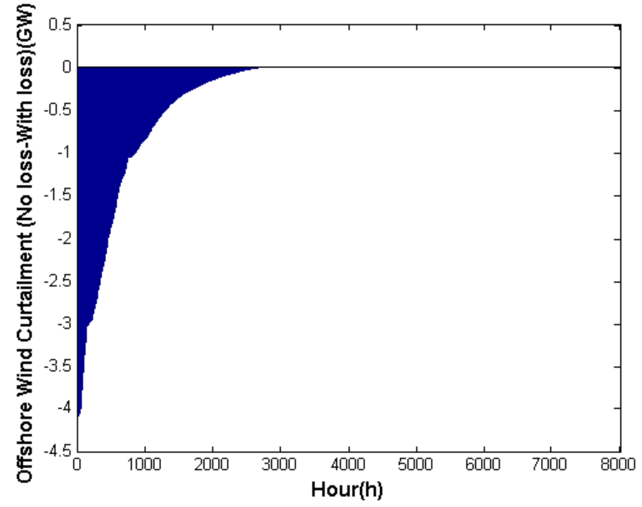
M. Korpås, L. Warland, J. O. G. Tande, K. Uhlen, K. Purchala, and, S. Wagemans, “Grid Modelling and Power System Data,” SINTEF Energy Research, TradeWind EU project, Tech. Rep. D3.2, Dec. 2007.

Nordic system & Germany in 2030

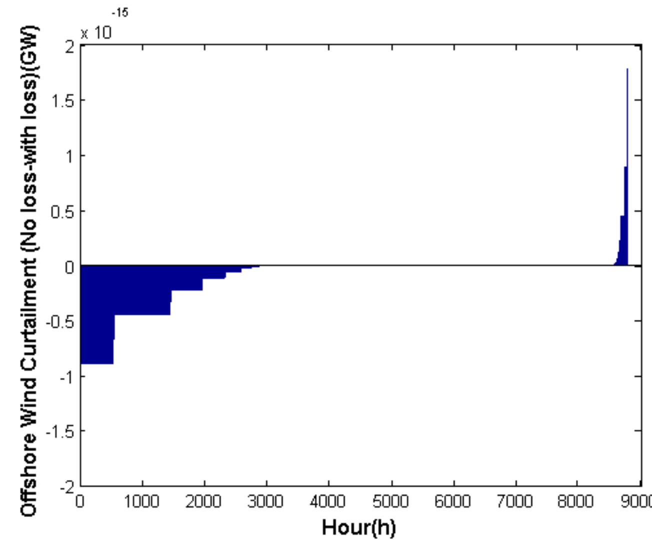


Offshore Wind Production





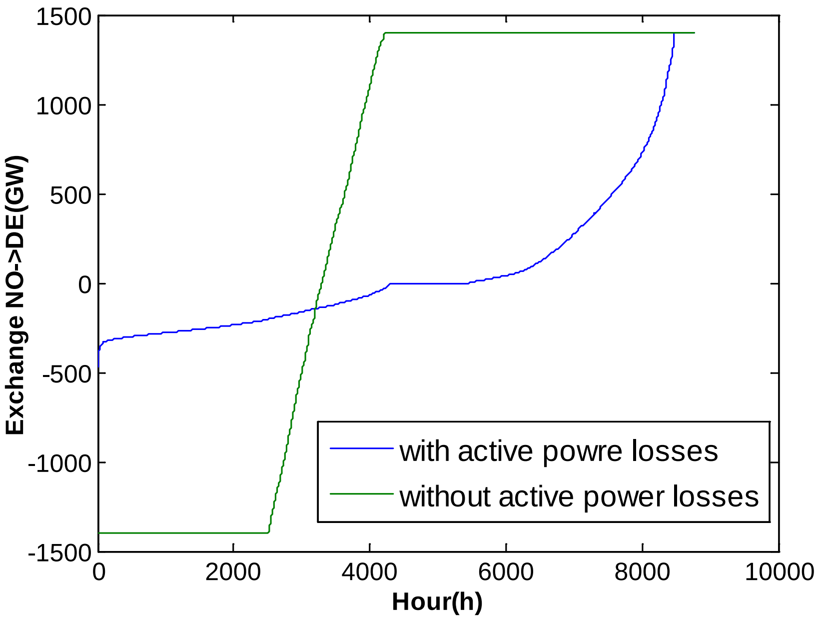
Iterative Approach

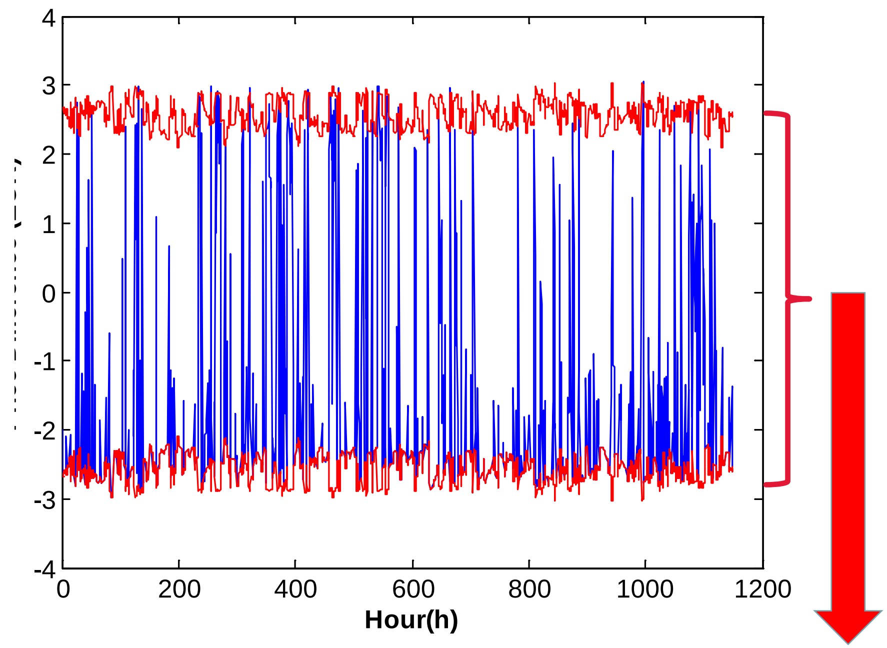


Linearized Loss Approach

Approaches	Annual operating cost (bn Euro)
No Loss	41.43
Linearized loss	43.41
Iterative	44.46

The effect of power losses on exchange power across NorGer link (Loss percentage =3.5%)





Min(Pr) . loss%

Jaehnert, Stefan; Wolfgang, Ove; Farahmand, Hossein; Völler, Steve; Huertas-Hernando, Daniel.(2013) Transmission expansion planning in Northern Europe in 2030—Methodology and analyses. *Energy Policy.*

Concluding Remark

- New methodology to include active power losses is proposed→ linearized loss curve
- This approach provides the feedback from active power losses to the optimisation routine
- Including losses may reduce the utilisation of offshore wind, therefore it is important to let the optimisation routine to evaluate the trade-off between generation costs and transmission losses to find an optimum solution
- Including power losses reduce the power exchange on HVDC link because the price difference at both ends of HVDC link should be sufficient to cover the losses on the link