Introduction to a high-performacne multi-period optimal power flow solver

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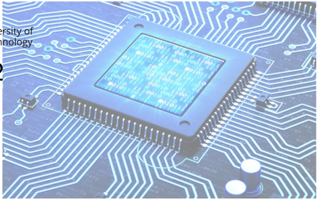
Hotel Scandic Lerkendal

Trondheim



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The presentation goal

Purpose: To discuss how to solve multi-period optimal power flow fast; **Large-Scale simulation with respect to time and space.**

Phase I: Background and Motivation

Phase II: Power Flow and Optimal Power Flow

Phase III: Solution Method

Phase IV: Speed up

Phase V: Future Work

Presentation Time: 15-20 min

Phase I:
Background and Motivation

Electricity Grid

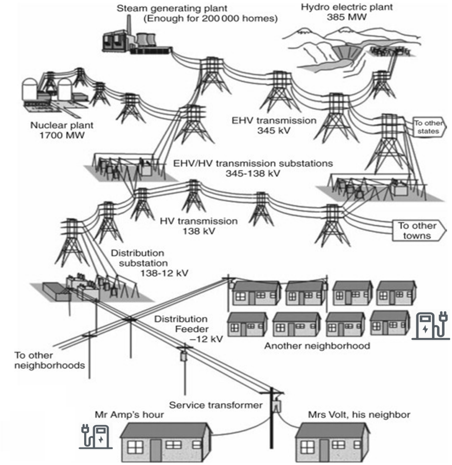


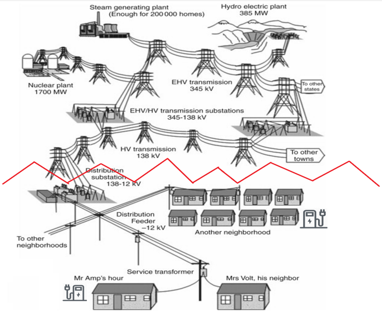
Figure 1: [www.sciencedirect.com/science/article/pii/B9781845697846500019]

Sustainability/Green shift/CO_2 reduction

For many reasons power electricity grid is facing decentralization

Phasing out coal (carbon-heavy sources of production) and nuclear power plants

This chain between large power producers and consumers is weakened.



Sustainability/Green shift/CO_2 reduction

For many reasons power electricity grid is facing decentralization

- Phasing out coal (carbon-heavy sources of production) and nuclear power plants
- Increase penetration of solar and wind production

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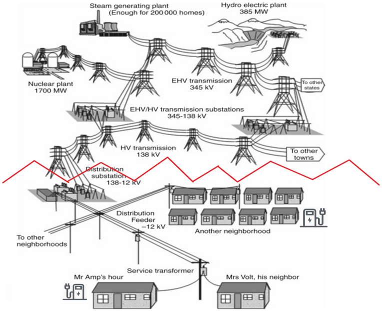


Background: cont.

Items

Green shift in electricity systems is needed for the reduction of CO_2 emissions

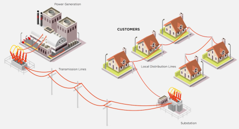


Figure 2: A Typical Power System [Rochester Gas & Electricity]

Background: cont.

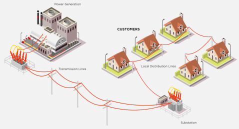
Items

Green shift in electricity systems is needed for the reduction of CO_2 emissions

Integration of Distributed Energy Resources (DER) is a huge challenge

Note

DER includes Renewable Energy, Energy Storage, Electric Vehicles and Flexible Demand



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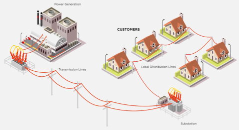
Grid companies must be able to analyse the impacts of DER



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Background: cont.

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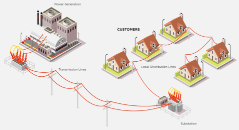
Optimal Power Flow (OPF)solvers are essential



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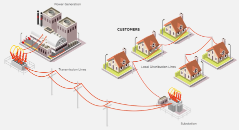
Grid companies must be able to analyse the impacts of DER

The inegration of DER in smart grids calls for **much more sophisticated solvers** for OPF



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Challenges in the planning and operation of the grid

Planning: Optimizing the right type, size and timing of new grid investments

- Local generation (e.g. PV) and increased load (e.g. EVs) can be located in areas where the grid is weak
- Energy storage and demand flexibility are alternatives to grid reinforcements

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- Energy storage and demand flexibility are alternatives to grid reinforcements

Operation: Optimize the use of controllable assets such as energy storage and flexible demand to secure, reliable and economic operation of the distribution grids. This means:

- Making the right use of Demand Response
- being able to value the use of end-user flexibility for local or system-wide grid services
- Simulating and optimizing the grids in the presence of **future local markets for energy and flexibility**

Limitations of traditional grid operation and planning

Notes

Classical single-period OPF does not offer a possibility for optimal operational scheduling of storage and flexible demand

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We therefore aim to develop the foundations for a new generation of Multi-Period OPF (MPOPF) solvers

i. Solves the OPF problem over several coupled time-steps
ii. Computation time is an issue when using both commercial or free optimization solvers

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i. Nonlinearity
ii. Large-scale problem with respect with to time and space
iii. Involves stochastic generations and load

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i. Nonlinearity

ii. Large-scale problem with respect with to time and space

iii. Involves stochastic generations and load

Hardware is reaching its limit with respect to CPU clock speed

Solution:

High-Performance Solver [1-2]

Algorithmic design tailored to the conventional OPF algorithms speed-up the solution proposal

Prototype model shows convincing results for real-sized system with distributed renewables, storages and EVs

i. A high-performance and memory-efficient sparse algorithm

ii. Utilizing the structure of the underlying mathematical formulation

1. S. Zaferanlouei, H. Farahmand, V. V. Vadlamudi, M. Korpås,"BATTPOWER Toolbox: Memory-Efficient and High-Performance Multi-Period AC Optimal Power Flow Solver", IEEE Transactions on Power Systems, Jan. 16th, 2021.

2. S. Zaferanlouei, et al., "BATTPOWER Application: Large-Scale Integration of EVs in an Active Distribution Grid —A Norwegian Case Study", Under review in the journal of EPSR

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Benefits

Optimal utilization of **stored energy** and **flexibility** where and when it creates the highest value for the system

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Optimal utilization of **stored energy** and **flexibility** where and when it creates the highest value for the system

Can be used for grid planning, grid operation and local markets

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Power System— Today

Power System— Future

Phase II:

Power Flow and Optimal Power Flow

Power Flow Equations

Source of Non-linearity

Nonlinear relationship between the voltage phasors and the power injections

Node i

$S_i = P_i + jQ_i$
$= V_i.\bar{I}_i$

Power Line with conductance G and susceptance B

$Y = G + jB \; and \; G = \frac{R}{R^2 + X^2}, B = \frac{-X}{R^2 + X^2}$

Where R and X are resistance and reactance respectively

Node j

$S_j = P_j + jQ_j$
$= V_j.\bar{I}_j$

$$\begin{aligned} P_i + jQ_i &= V_i.\bar{I}_i \\ &= V_i.(\bar{\mathrm{Y}}_i.\bar{V}) \\ &= V_i.(\mathrm{G}_i - j\mathrm{B}_i)\bar{V} \\ |V_i|^2 &= V_i.\bar{V}_i \end{aligned}$$

"Power Flow Equations"
"Load Flow Equations"

Y admittance matrix

G and B conductance and susceptance matrices

$\mathrm{Y} = \mathrm{G} + j\mathrm{B}$

> Coupled quadratics in complex voltage phasors

Power Flow Equations in Different Coordinates

The bus injection model

Power Line with conductance G and susceptance B

Node i
$S_i = P_i + jQ_i = V_i.\bar{I}_i$

Node j
$S_j = P_j + jQ_j = V_j.\bar{I}_j$

$$Y = G + jB \text{ and } G = \frac{R}{R^2 + X^2}, B = \frac{-X}{R^2 + X^2}$$

Where R and X are resistance and reactance respectively

Polar Voltage Coordinates $\quad V_i = |V_i|\angle\theta_i \quad \theta_1 = 0$

$$P_i = |V_i| \sum_{j=1}^{N} |V_j| (\boldsymbol{G}_{ij} cos(\theta i - \theta j) + \boldsymbol{B}_{ij} sin(\theta i - \theta j))$$

$$Q_i = |V_i| \sum_{j=1}^{N} |V_j| (\boldsymbol{G}_{ij} sin(\theta i - \theta j) - \boldsymbol{B}_{ij} cos(\theta i - \theta j))$$

Rectangular Voltage Coordinates $\quad V_i = V_{di} + jV_{qi} \quad V_{q1} = 0$

$$P_i = V_{di}(\boldsymbol{G}_{ij} V_{dj} - \boldsymbol{B}_{ij} V_{qj}) + V_{qi}(\boldsymbol{B}_{ij} V_{dj} + \boldsymbol{G}_{ij} V_{qj})$$

$$Q_i = -V_{di}(\boldsymbol{B}_{ij} V_{dj} + \boldsymbol{G}_{ij} V_{qj}) + V_{qi}(\boldsymbol{G}_{ij} V_{dj} - \boldsymbol{B}_{ij} V_{qj})$$

$V_{di} = Re(V_i) \quad V_{qi} = Im(V_i) \qquad N =$ number of Nodes

Power Flow Equations in Different Coordinates

The bus injection model

Power Line with conductance G and susceptance B

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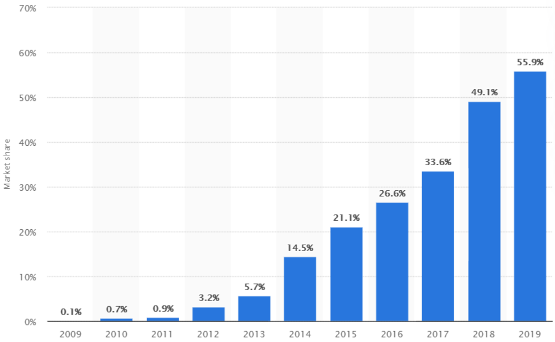
Power Flow

PF equations are a set of nonlinear algebraic equations which can be solved with Newton-Raphson, Gauss–Seidel, Fast-decoupled-load-flow method and etc.

Statistics

Market Share

Market share of electric cars (BEV and PHEV) in Norway from 2009 to 2019



Statistics

Penetration

Around 9% EV penetration in Norwegian transport sector. The Norwegian Parliament has decided on a national goal that all new cars sold by 2025 should be zero-emission (electric or hydrogen)[a].

[a] https://elbil.no/

Motivation

1. Sustainability: Need tools for analysing operating conditions resulting from renewables, EV, storage and flexible demand.

[1] https://www.nve.no/energy-market-and-regulation/retail-market/electricity-disclosure-2018/
[2] https://www.nordpoolgroup.com/Market-data1/Dayahead/Volumes/NO/Hourly/?view=table
[3] http://publikasjoner.nve.no/rapport/2018/rapport2018_74.pdf
[4] Samdal, K., Kjolle, G. H., Singh, B., & Kvitastein, O. (2006, June). Interruption costs and consumer valuation of reliability of service in a liberalised power market. In 2006 International Conference on Probabilistic Methods Applied to Power Systems (pp. 1-7). IEEE.

Motivation

1. Sustainability: Need tools for analysing operating conditions resulting from renewables, EV, storage and flexible demand.
2. Economics: Norway electric industry revenues of 61.6 billion NOK in 2018[1]. 1% savings worth 615 million NOK (estimated using [1] and [2])

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[2] https://www.nordpoolgroup.com/Market-data1/Dayahead/Volumes/NO/Hourly/?view=table

[3] http://publikasjoner.nve.no/rapport/2018/rapport2018_74.pdf

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3. Reliability: Annual cost of power interruptions to Norway economy is 1600 MNOK/year (estimated using [3] and [4])

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Summary

Highlights

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Thank you for your attention!

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