Assignment 1:
Economic Dispatch and DC-OPF

September 3, 2019

Deadline: Monday, Sept 30, 2019 20.00 hrs
Report: max 3.5 pages

Deliverables

- A 3.5-page report which will address the following questions:
  - Part A: Tasks 7, 8, 9
  - Part B: Task 2, 3, 4, 5, 6
  - Lessons Learned, and Sharing of Workload
- The source code (Matlab) for the implementation of all tasks and case studies

1 Introduction

The goal of this assignment is to implement an Economic Dispatch and a DC-OPF, that is an optimal power flow based on the linearized power flow equations, and investigate their properties.

The objectives to be achieved at the end of the assignment are the following:

- Implement an economic dispatch

- Implement a DC OPF based on the standard linearized power flow equations
- Calculate the dual variables
- Interpret the dual variables as Locational Marginal Prices (LMPs)
- Investigate the impact of congested lines on the LMPs
- Investigate the impact of different levels of wind infeed on LMPs

2 Linear Program

In the (general) form that we will use for this assignment, a linear program is formulated as follows:

$$\min \sum_{i=1}^{N} c_i x_i \tag{1}$$

subject to:

$$\sum_{i=1}^{N} a_{ij} x_i = b_j \quad \text{for all } j = 1, \ldots, p \tag{2}$$

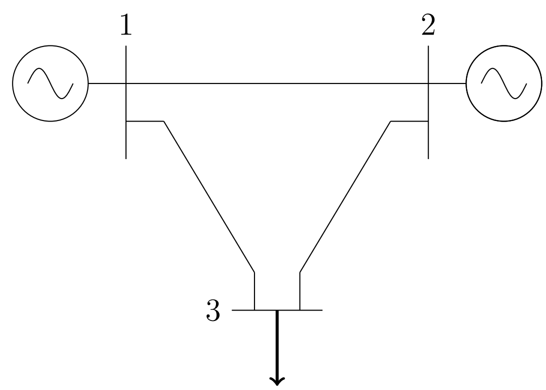
$$\sum_{i=1}^{N} g_{ij} x_i \leq h_j \quad \text{for all } j = 1, \ldots, M \tag{3}$$

$$x_i^{\min} \leq x_i \leq x_i^{max} \quad \text{for all } i = 1, \ldots, N \tag{4}$$

3 Part A: ED & DC-OPF on a 3-bus system

3.1 3-bus Test System

Assume a 3-bus system with one generator on Bus 1, one generator on Bus 2 and one load on Bus 3. Assume costs $c_{G1} = 60$ \$/MWh, $c_{G2} = 120$ \$/MWh. And $P_{load} = 150$ MW.



3.2 Case Studies

In this section we describe the case studies we will investigate within Section 3.3.

Operating as a Power Exchange *(e.g. Southern Power Pool, and the power exchanges in European countries such as European Power Exchange (EPEX), Amsterdam Power Exchange (APEX), and others)*:

1. Assume that the maximum power of G1 is $P_{G1}^{max} = 200$ MW and the maximum power of G2 is $P_{G2}^{max} = 200$ MW. There are no line limits (assume line limits of 10'000 MW).

2. Assume that the maximum power of G1 is $P_{G1}^{max} = 100$ MW and the maximum power of G2 is $P_{G2}^{max} = 200$ MW. There are no line limits (assume line limits of 10'000 MW).

Operating as an NTC-based market coupling *(Nordic market, and earlier Central West European market)*:

3. Assume $P_{G1}^{max} = 100$ MW, $P_{G2}^{max} = 200$ MW as above, **and** that line 1-3 has a line limit of $P_{13}^{max} = 70$ MW.

Operating as a nodal market *(e.g. PJM or California in the USA, and others). The flow-based zonal market in Central West Europe operates on the same principles (but it uses a different equivalent formulation based on Power Transfer Distribution Factors (PTDF), as we will see in later lectures, and is organized differently)*:

4. Assume line reactances: $X_{12} = 0.1$ p.u., $X_{13} = 0.3$ p.u., $X_{23} = 0.1$ p.u. and BaseMVA = 100 MVA. The rest of the values remain the same as in Case Study 3.

5. Assume same line reactances as above, $P_{G1}^{max} = 100$ MW, $P_{G2}^{max} = 200$ MW, **and** $P_{13}^{max} = 40$ MW.

3.3 Tasks

At DTU Inside, you will find a file `ed_pseudocode.m`. This is a Matlab file that contains some pseudocode which will help you with implementing the code for the Economic Dispatch.

1. Formulate the problem of the Economic Dispatch, i.e. equations for the objective function and the constraints.

2. Create a case study file with the provided data in matpower format. You can check the Matpower manual for the Matpower format, and you can open a random case file and use it as a guide for your case study file, e.g. type in the Matlab Command Line: `edit case9`

3. Implement the code for the economic dispatch. In DTU Inside, you can find the file `ed_pseudocode.m`, which you can use as a guide for your implementation.

4. Formulate the problem of the DC Optimal Power Flow based on the standard equations for a linear program (see Section 2).

5. Implement the code for the calculation of the bus susceptance matrix B.

6. Implement the linear program. In DTU Inside, you can find the file `dcopf_pseudocode.m`, which you can use as a guide for your implementation.

7. Calculate for each case study:

   (a) the power dispatch of each generator

   (b) the total generation costs

8. When is the result of the economic dispatch equal to the result of the DC-OPF?

9. What do you observe is the relationship between congestion and total generation costs?

4 Part B: DC-OPF & LMP on a 10-bus system

4.1 10-bus system

In this system, the grid is assumed to be a 10-bus network, as described in [1], with a minor modification. Instead of having a generator on bus 7, the wind farm is assumed to be connected at bus 10. Large production units are installed in the top left area. The generator on bus 3 is representing aggregated production of nuclear units. Generator 5 is an aggregation of conventional thermal units. On bus 2 hydro power installations are assumed, while thermal generator 8 in the lower right part of the network has high production costs. Large loads are located at buses 3, 7, 8, and 10, forming two main load areas: one close to the production in the top left part of the network and one in the lower part close to the expensive generator 8. The peak demand of the system is 12.11 p.u. (we assume 1 p.u. = 1'000 MW).

4.2 Tasks

At DTU Inside, you will find a file `dcopf_pseudocode.m`. This is a Matlab file that contains some pseudocode which will help you with implementing the code for the DC-OPF.

- System data available on DTU Inside in the Assignment 1 folder: `swiss_dcopf_LP.m`
- Note: "Nodal prices" or "Locational Marginal Prices" denote exactly the same thing. We use them interchangeably.

1. Run your DC-OPF algorithm based on the standard formulation on the 10-bus system.

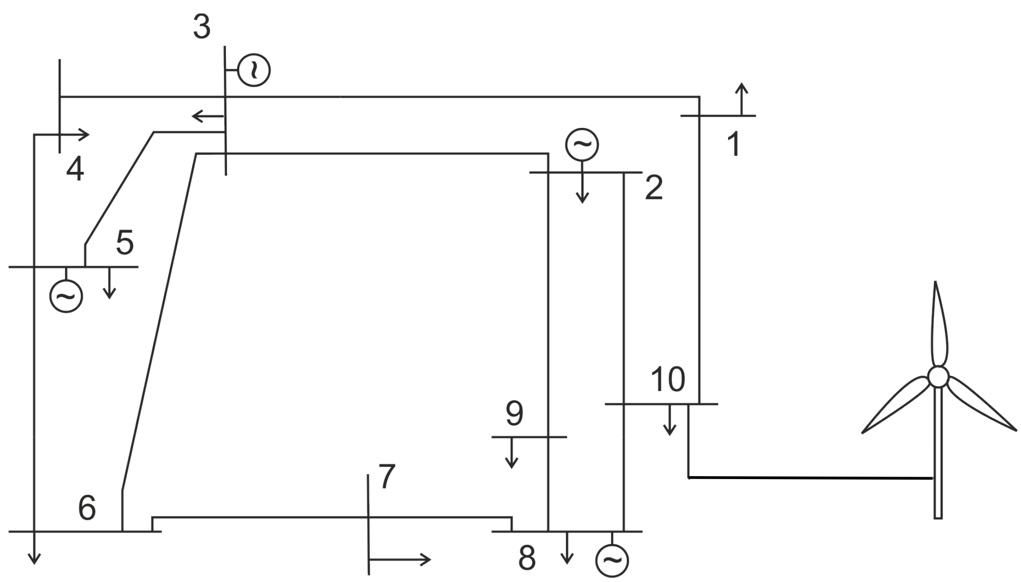


Figure 1: 10-bus system

2. Calculate the Lagrangian multipliers for the Equality Constraints. These are the nodal prices.

3. Assume a system loading 70% of the nominal loading (reduce all loads to 70% of the nominal). Calculate the nodal prices. Compare your findings with Task 2. What do you observe?

4. Calculate the Lagrangian multipliers for the *line flow inequality* constraints, assuming the nominal loading, i.e. 100%. What do you observe?

5. Plot the LMP on Bus 10 in a 3D plot, where you will vary:

   - the loads uniformly from 20% to 100% of their nominal value, and
   - the wind infeed (P_{wind}^{max}) from 0% to 100%.

6. How does the LMP on Bus 10 behave? What are the reasons for this behaviour? Describe your observations.

5 Lesssons Learned – Reflection

During the development of your code for this assignment there were definitely several issues that came up until you got it running correctly.

In no more than half a page, please list 2-3 main points that you think you should remember for the next time you code a DC-OPF or you have to evaluate results from an OPF.

Please list at least one issue that had to do with coding, i.e. what should you remember to do in some specific way, or avoid, next time you code a DC-OPF? And please list at least one main takeaway from the evaluation of your results, i.e. what did you learn from evaluating all those different cases (this may have to do with how the nodal prices change, what happens when we consider the power flows, what happens when there is congestion, etc.).

6 Sharing of Workload

Please mention what were the responsibilities or the tasks that each group member carried out in order to accomplish this assignment.

References

[1] T. Krause. *Evaluating Congestion Management Schemes in Liberalized Electricity Markets Applying Agent-based Computational Economics.* PhD thesis, Diss. ETH No. 16928, available online from ETH Zurich, Switzerland, 2007.