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SMAGRINET
POWERING SMART GRID EXPERTISE IN EUROPE

Planning and Operation in Smart Grids

Technische Universität Berlin

25th November 2020 – Train the Trainers Workshop

Agenda

1. Module Overview
2. Lectures and Content
3. Intended Learning Outcomes
4. Learning and Teaching Methods
5. Assessment and Grading
6. Conclusion

Module Overview

Module Overview
Motivation

Old World:

„supply follows demand“

New World:

„demand follows supply“

Source: Pixabay, https://pixabay.com/

Module Overview
Lecture Topics

- Modern Power Systems
- Renewable Generation
- Distribution Network
- Demand Characteristics
- Forecasting
- Power Quality
- State Estimation
- Energy Storage Technologies
- Electric Vehicle
- Virtual Power Plant

Lectures and Content

Lectures and Content
Technische Universität Berlin

- Modern Power Systems
- Renewable Generation
- Distribution Network
- Demand Characteristics
- Forecasting
- Power Quality
- State Estimation
- Energy Storage Technologies
- Electric Vehicle
- Virtual Power Plant

Lectures and Content
Technische Universität Berlin

- Modern Power Systems
- **Renewable Generation**
- **Distribution Network**
- **Demand Characteristics**
- Forecasting
- Power Quality
- State Estimation
- **Energy Storage Technologies**
- Electric Vehicle
- **Virtual Power Plant**

Lectures and Content

Renewable Generation + Distribution Network I

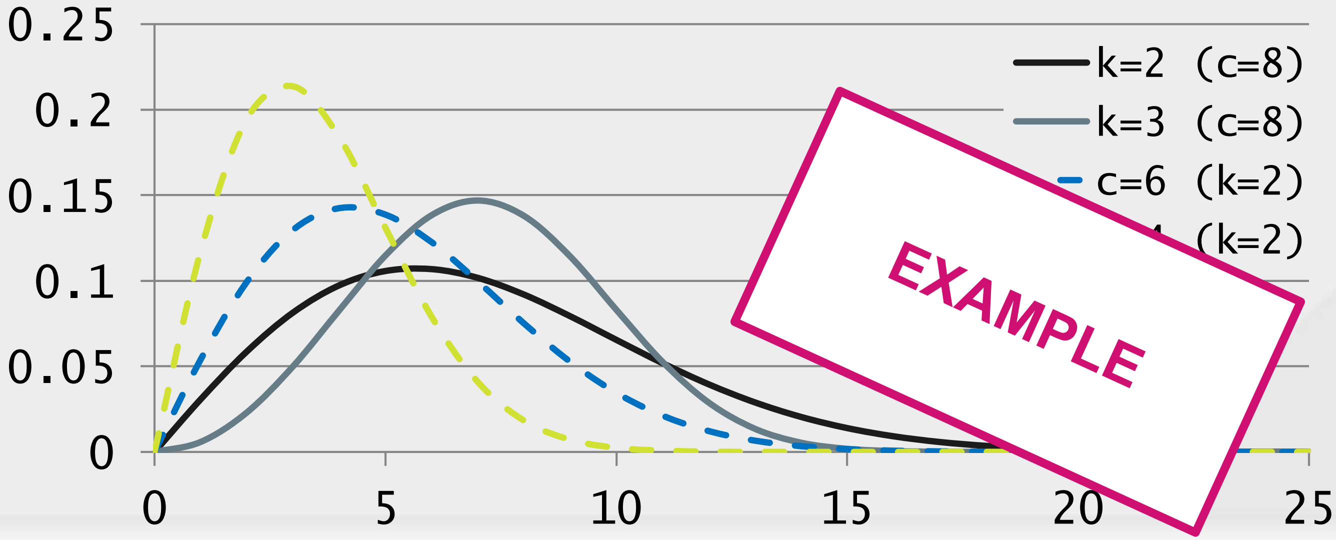
Content:

- Renewable Energies
  - Photovoltaics: Generation, Planning, and Measurement
  - Wind: Generation, Planning, and Measurement
- Network Structure Basics
  - Properties of Electric Energy Networks
  - Network Operation

Wind: Dimensioning and Planning
Wind Statistics – Weibull Function

For describing $f(v)$, the Weibull probability density function $f_W(v)$ is used:

$$f_W(v) = \left(\frac{k}{c}\right) \cdot \left(\frac{v}{c}\right)^{k-1} \cdot e^{-\left(\frac{v}{c}\right)^k}$$

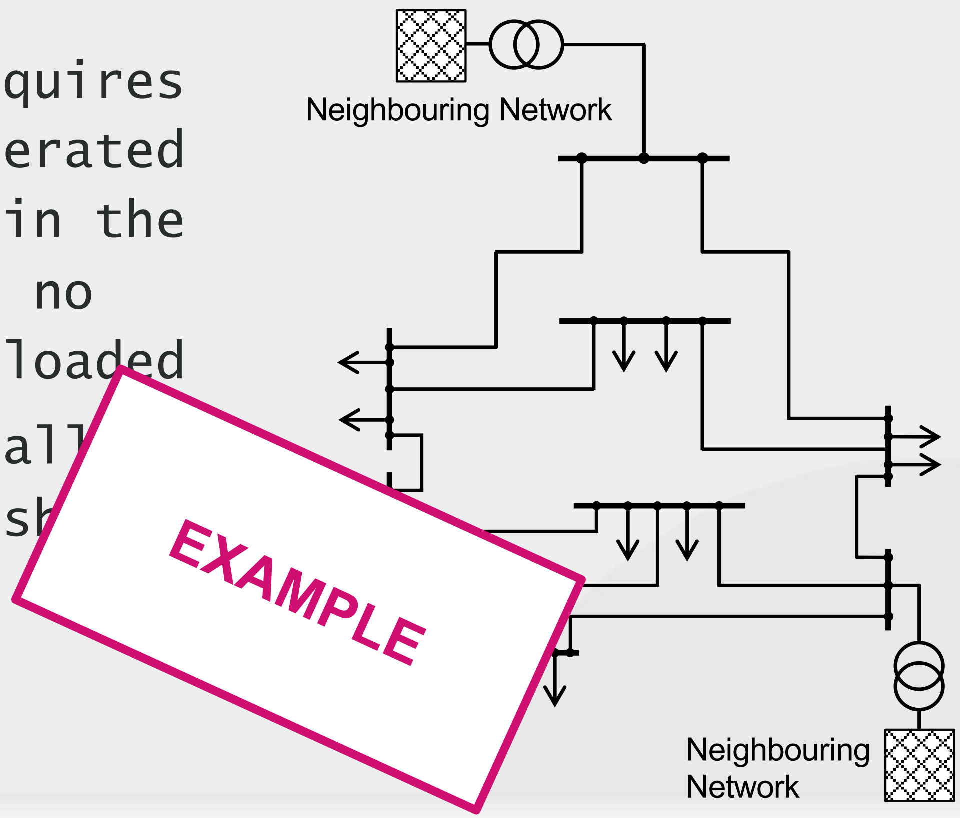


k shape parameter

c scale parameter

Network Operation: N-1 Criterion

- The N-1 criterion requires that a network be operated in such a way that, in the case of any failure, no other device is overloaded
- The N-1 criterion shall be discussed with a sh[…] example



Lectures and Content
Renewable Generation + Distribution Network I

Learning Outcomes:

Students should be able to...

- ...know the generation principles of renewable energies such as wind and photovoltaics.
- ...have the statistical knowledge to plan wind and PV generation units.
- ...evaluate grid structures and network operation.

Lectures and Content

Renewable Generation + Distribution Network I

Teaching Methods:

Lecture + **Lab Work**

Topic: Rayleigh statistics

Paper and pen exercise

Lectures and Content
Distribution Network II

Content:

- Motivation for Power Flow Calculations
- Per-Phase Formulation for Balanced Systems
- Gauss Method
- Three-Phase Power Flow Formulation
- Three-Phase Load and Line Model
- Three-Phase Distribution Power Flow

Power Flow Calculations
Per-Phase Formulation for Balanced Systems

Node Voltages:

$$V_n = V_s - Z_n I_n$$

$$V_{n-1} = V_n - Z_{n-1} I_{n-1}$$

$$= V_s - Z_n I_n - Z_{n-1} I_{n-1}$$

$$= V_s - \sum_{t=n-1}^{n} Z_t I_t$$

EXAMPLE

$$V_s - \sum_{t=i}^{n} Z_t I_t$$

Line currents:

$$I_1 = \frac{P_1 - jQ_1}{V_1^*}$$

$$I_2 = I_1 + \frac{P_2 - jQ_2}{V_2^*}$$

$$= \sum_{m=1}^{2} \frac{P_m - jQ_m}{V_m^*}$$

$$\vdots$$

$$I_t = \sum_{m=1}^{t} \frac{P_m - jQ_m}{V_m^*}$$

Power Flow Calculations
Three-Phase Distribution Power Flow

- Then the iteration scheme for the three-phase power flow is given in detail as follows:

$$\underline{V}_i^{a(k)} = \underline{V}_s^a - \sum_{t=i}^{n} \left\{ \underline{Z}_t^1 \sum_{m=1}^{t} \left(\frac{P_m^a - jQ_m^a}{\underline{V}_m^{a(k-1)*}} \right) + \underline{Z}_t^2 \sum_{m=1}^{t} \left(\frac{P_m^b - jQ_m^b}{\underline{V}_m^{b(k-1)*}} \right) + \underline{Z}_t^3 \sum_{m=1}^{t} \left(\frac{P_m^c - jQ_m^c}{\underline{V}_m^{c(k-1)*}} \right) \right\}$$

$$\underline{V}_i^{b(k)} = \underline{V}_s^b - \sum_{t=i}^{n} \left\{ \underline{Z}_t^2 \sum_{m=1}^{t} \left(\frac{P_m^a - jQ_m^a}{\underline{V}_m^{a(k-1)*}} \right) + \underline{Z}_t^4 \sum_{m=1}^{t} \left(\frac{P_m^b - jQ_m^b}{\underline{V}_m^{b(k-1)*}} \right) + \underline{Z}_t^5 \sum_{m=1}^{t} \left(\frac{P_m^c - jQ_m^c}{\underline{V}_m^{c(k-1)*}} \right) \right\}$$

[illegible]

$$\sum_{t=i}^{n} \left\{ \underline{Z}_t^3 \sum_{m=1}^{t} \left(\frac{P_m^a - jQ_m^a}{\underline{V}_m^{a(k-1)*}} \right) + \underline{Z}_t^5 \sum_{m=1}^{t} \left(\frac{P_m^b - jQ_m^b}{\underline{V}_m^{b(k-1)*}} \right) + \underline{Z}_t^6 \sum_{m=1}^{t} \left(\frac{P_m^c - jQ_m^c}{\underline{V}_m^{c(k-1)*}} \right) \right\}$$

EXAMPLE

Lectures and Content
Distribution Network II

Learning Outcomes:

Students should be able to...

- ...explain the importance of three-phase power flow calculations in the distribution network.
- ...understand the per-phase formulation of three-phase power flow equations.
- ...use the Gauss method.
- ...perform a three-phase power flow.

Lectures and Content

Distribution Network II

Teaching Methods:

Lecture + **Lab Work**

Topic: 3-phase power flow

MATLAB exercise

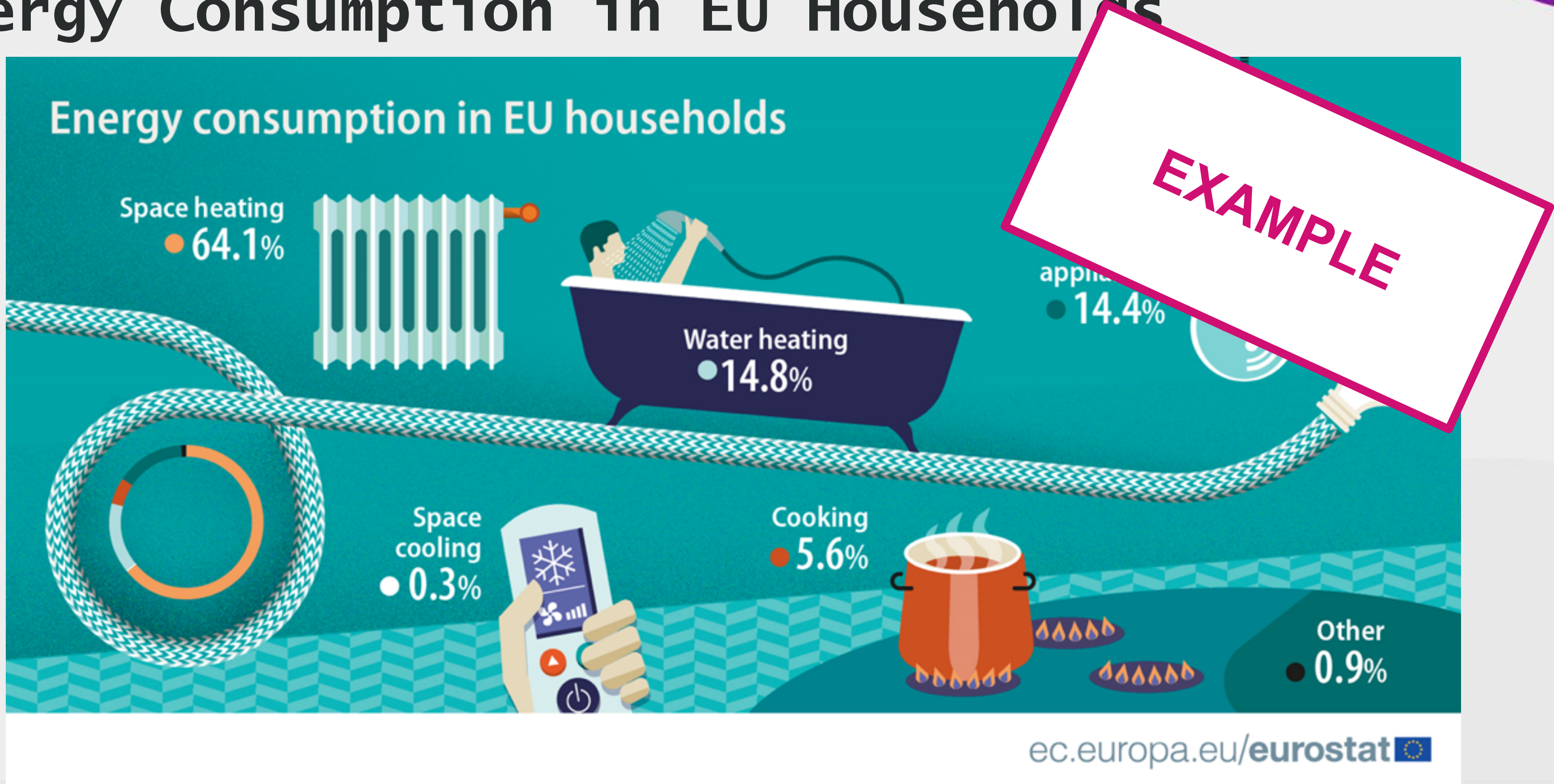
Lectures and Content
Demand Characteristics

Content:

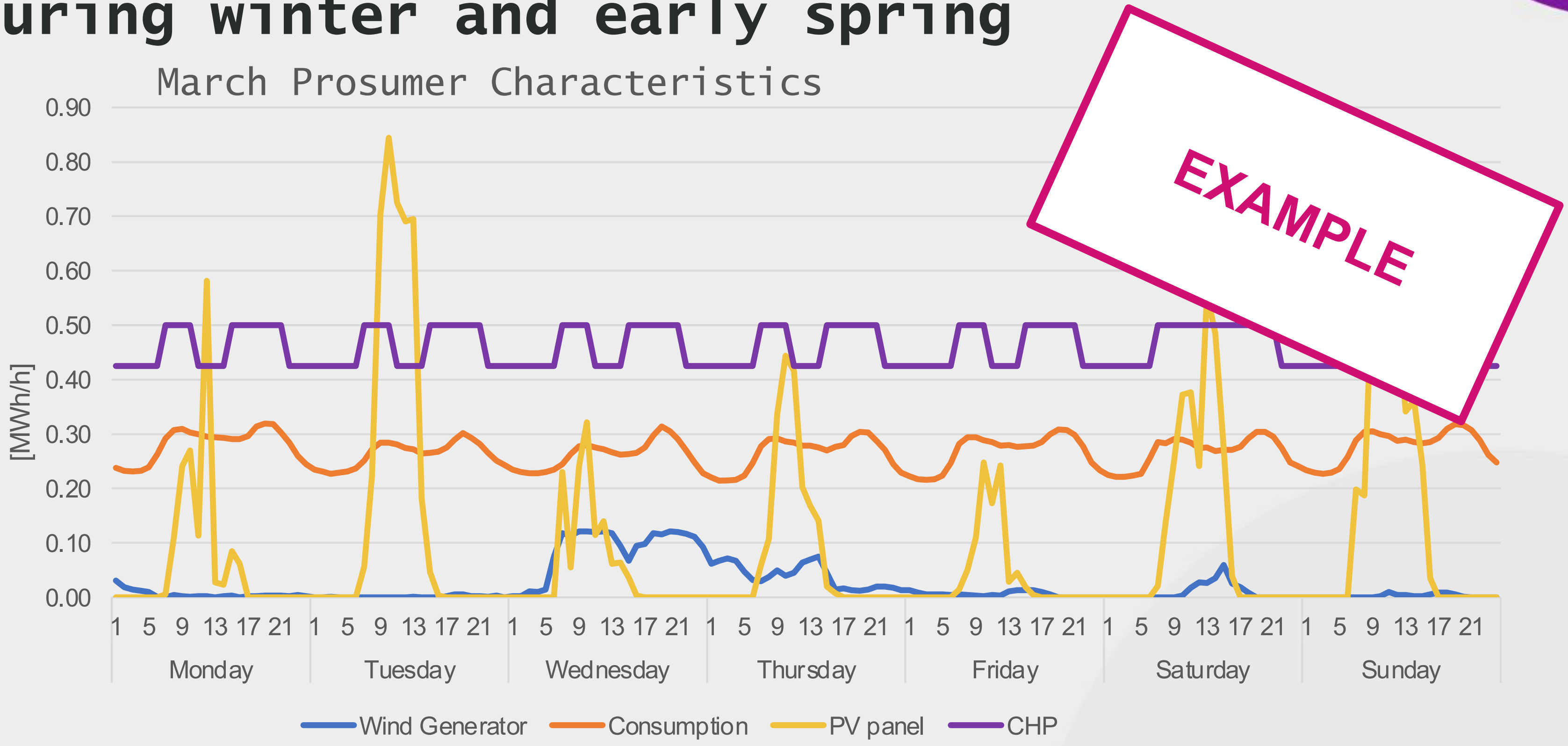
- From Consumer to Prosumer
- Household Energy Demand and Production
- Business Prosumer Characteristics
- Industry Prosumers
- Energy Passport

Household Energy Demand and Production

Energy Consumption in EU Households



Business Prosumer Characteristics During winter and early spring



Lectures and Content
Demand Characteristics

Learning Outcomes:

Students should be able to...

- ...know the difference between consumer and prosumer and why the focus is shifting.
- ...understand different demand characteristics, as observed in households, businesses and industry.
- ...evaluate the European energy passport approach.

Lectures and Content
Demand Characteristics

Teaching Methods:

Lecture + **Lab Work**

Topic: prosumer

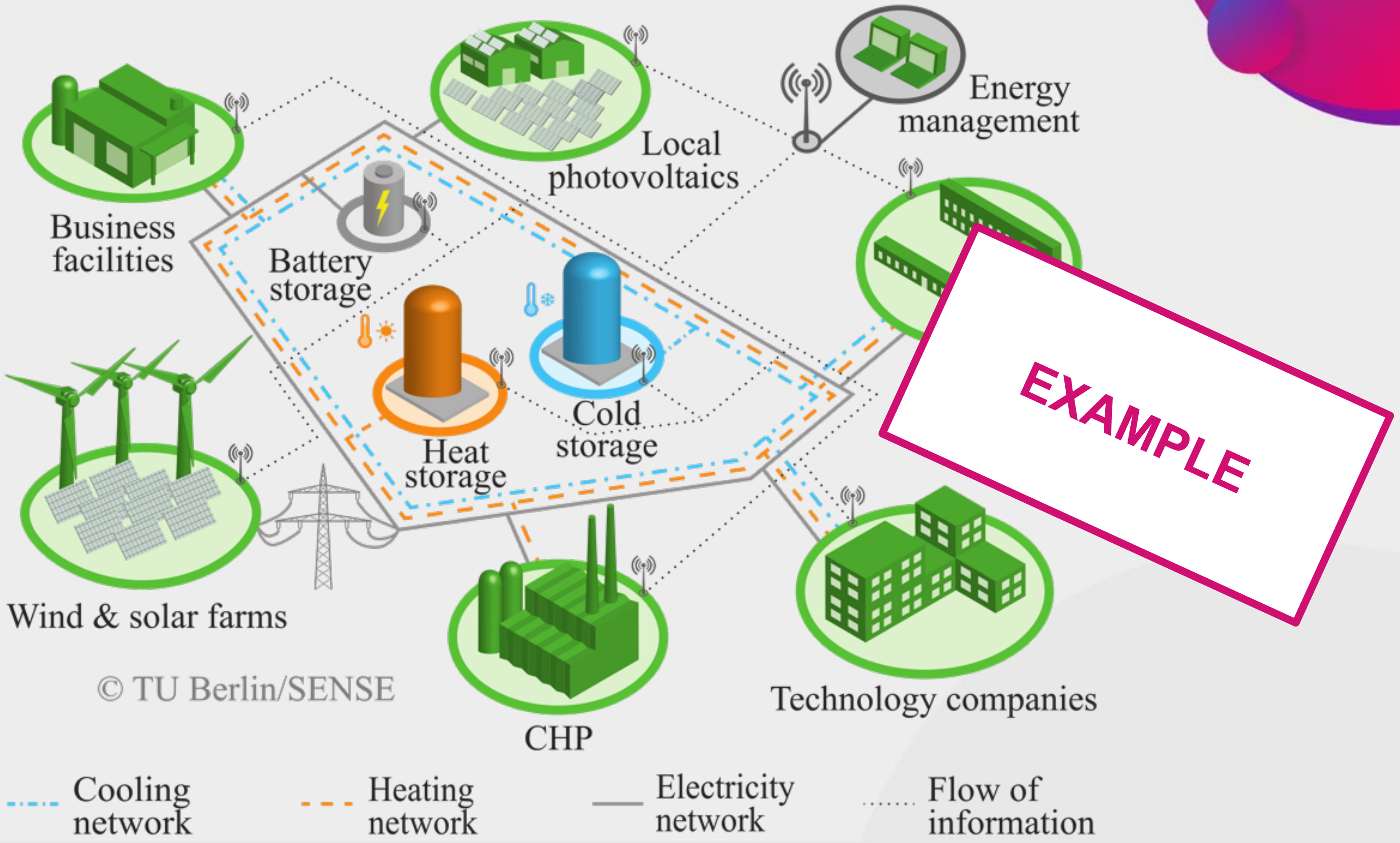
Spreadsheet program exercise

Lectures and Content

Energy Storage Technologies

Content:

- Energy Systems in Transition
- Energy Storage in Smart Grids
- Multi-energy Smart Grids
- Modeling Framework for Planning and Control of Multi-energy Systems
- Modeling of Selected Resources
- Introduction to Optimization
- Research Project „Energy Network Berlin Adlershof“



Energy management
Local photovoltaics
Business facilities
Battery storage
Heat storage
Cold storage
Wind & solar farms
CHP
Technology companies
EXAMPLE
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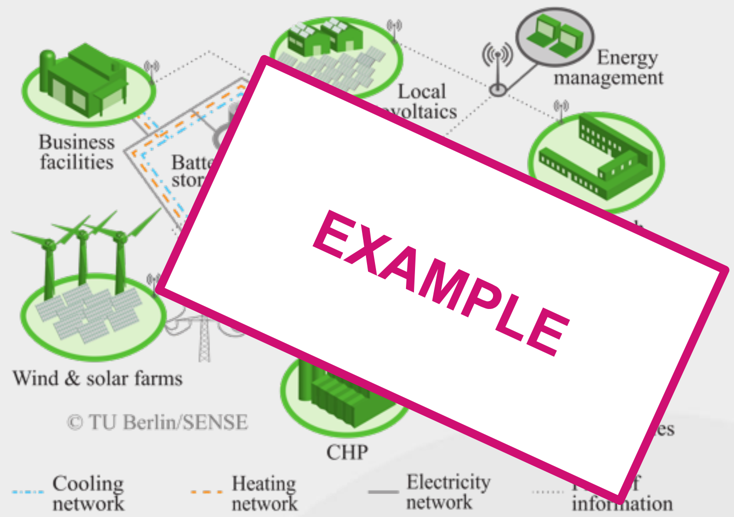
Cooling network
Heating network
Electricity network
Flow of information

3. Multi-energy Smart Grids Overview

- Multi-energy systems (MES) can provide increased flexibility for integration of volatile renewable power generators.
- Electric part of power system benefits from available flexibility in networks of other energy carriers.



- Those networks are connected to the electric power system by power conversion units.

Lectures and Content
Energy Storage Technologies

Learning Outcomes:

Students should be able to...

- ...explain the importance of energy storage in smart grids.
- ...describe the concepts of multi-level storage and multi-energy smart grids.
- ...set up a model for multi-energy smart grids.
- ...formulate optimization problems including objective function, constraints and bounds.

Lectures and Content
Energy Storage Technologies

Teaching Methods:

Lecture + **Lab Work**

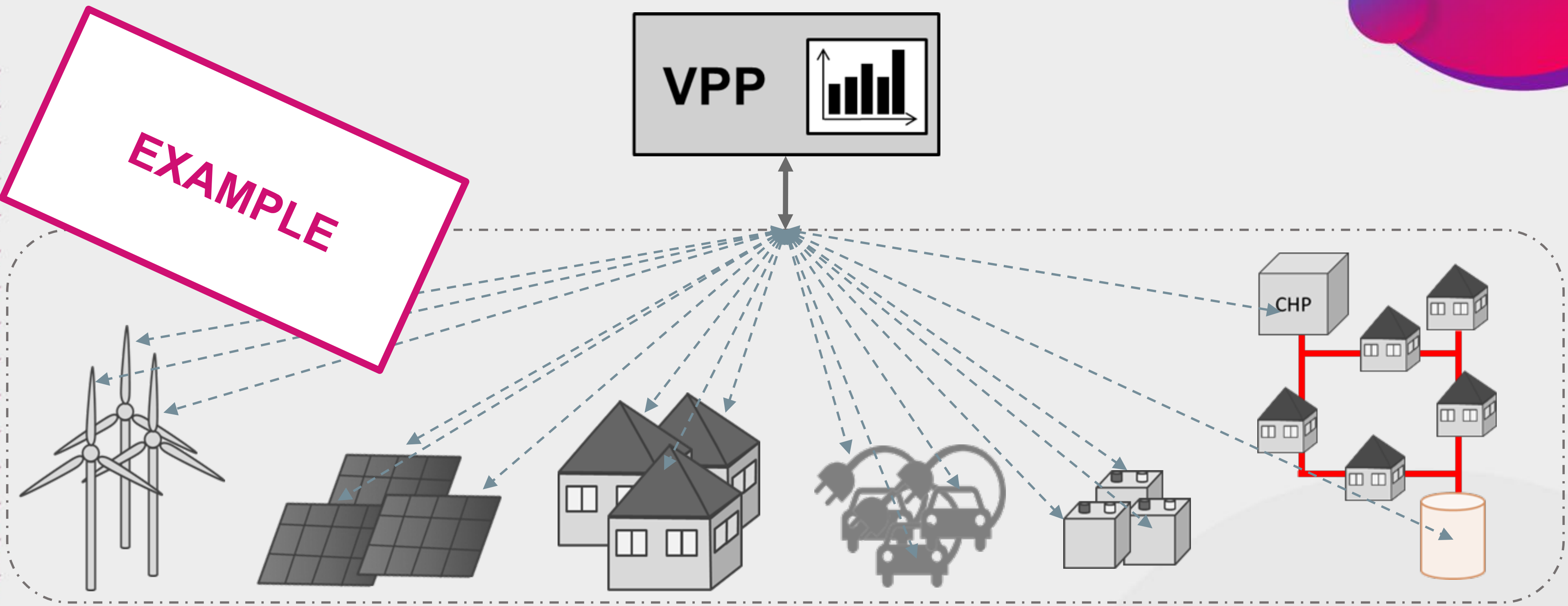
Topic: linear optimization

Paper and pen exercise

Lectures and Content
Virtual Power Plant

Content:

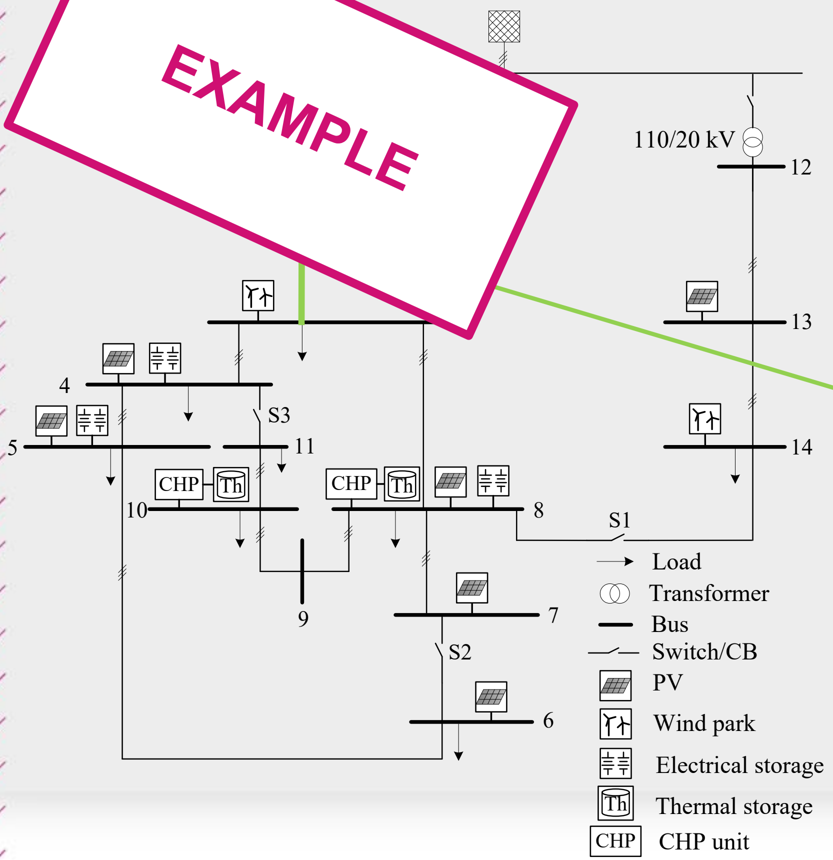
- Necessity for Virtual Power Plants
- Structure of Virtual Power Plant
- Modelling and Market Integration of Resources
- Provision of System Services: Congestion Management in Distribution Networks

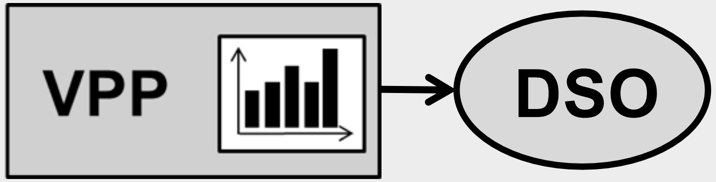


Bidirectional communication with single resources
Bidirectional communication at higher aggregation level

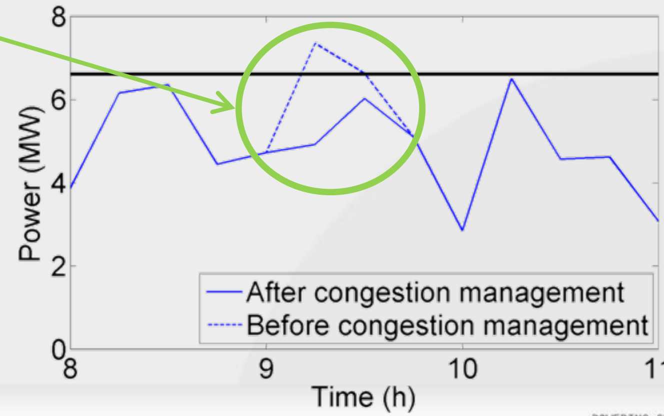
Successful congestion relief

EXAMPLE





Congestion relieved without curtailment of renewables



Lectures and Content
Virtual Power Plant

Learning Outcomes:

Students should be able to...

- ...understand the role of a virtual power plant for the market integration of small distributed energy resources.
- ...comprehend the operation of a virtual power plant and account for uncertainties in the renewable power generation forecasts in different time frames, in particular the day-ahead and intraday operation.
- ...understand the role of a virtual power plant for the provision of a congestion relief service to the distribution system operator.

Lectures and Content
Virtual Power Plant

Teaching Methods:

Lecture

Intended Learning Outcomes

Intended Learning Outcomes
Technische Universität Berlin

- Modern Power Systems
- Renewable Generation
- Distribution Network
- Demand Characteristics
- Forecasting
- Power Quality
- State Estimation
- Energy Storage Technologies
- Electric Vehicle
- Virtual Power Plant

Students should be able to...

Intended Learning Outcomes

Technische Universität Berlin

Modern Power Systems	**Renewable Generation**	Distribution Network	Demand Characteristics	Forecasting
Power Quality	State Estimation	Energy Storage Technologies	Electric Vehicle	Virtual Power Plant

Students should be able to...

- …know the fundamentals about generation and planning of renewable energies.

Intended Learning Outcomes
Technische Universität Berlin

Modern Power Systems	Renewable Generation	**Distribution Network**	Demand Characteristics	Forecasting
Power Quality	State Estimation	Energy Storage Technologies	Electric Vehicle	Virtual Power Plant

Students should be able to...

- …describe the distribution network structure and perform three-phase-power-flow analysis.

Intended Learning Outcomes

Technische Universität Berlin

Modern Power Systems	Renewable Generation	Distribution Network	**Demand Characteristics**	Forecasting
Power Quality	State Estimation	Energy Storage Technologies	Electric Vehicle	Virtual Power Plant

Students should be able to...

- …know different demand characteristics and define the terms consumer and prosumer.

Intended Learning Outcomes
Technische Universität Berlin

Modern Power Systems	Renewable Generation	Distribution Network	Demand Characteristics	Forecasting
Power Quality	State Estimation	**Energy Storage Technologies**	Electric Vehicle	Virtual Power Plant

Students should be able to...

- …evaluate the impact of energy storage possibilities and multi-energy smart grids.

Intended Learning Outcomes
Technische Universität Berlin

Modern Power Systems	Renewable Generation	Distribution Network	Demand Characteristics	Forecasting
Power Quality	State Estimation	Energy Storage Technologies	Electric Vehicle	**Virtual Power Plant**

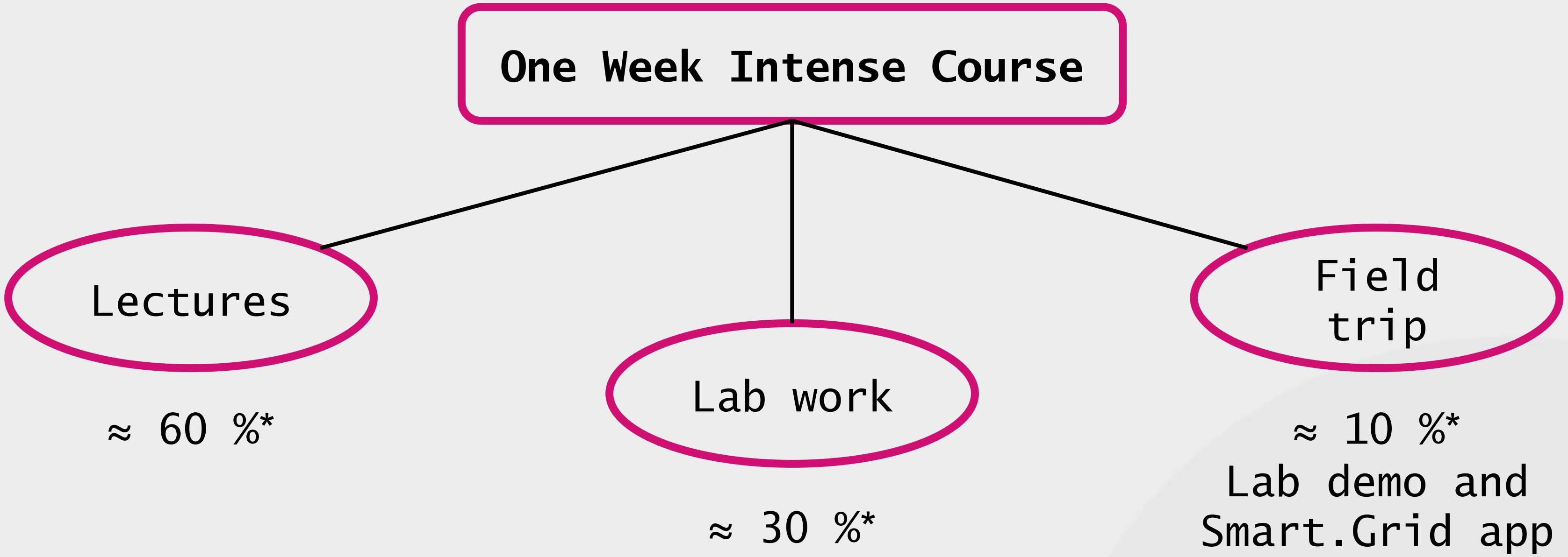
Students should be able to...

- …evaluate the impact of virtual power plants, in particular the day-ahead and intraday operation.

Learning and Teaching Methods

Learning and Teaching Methods

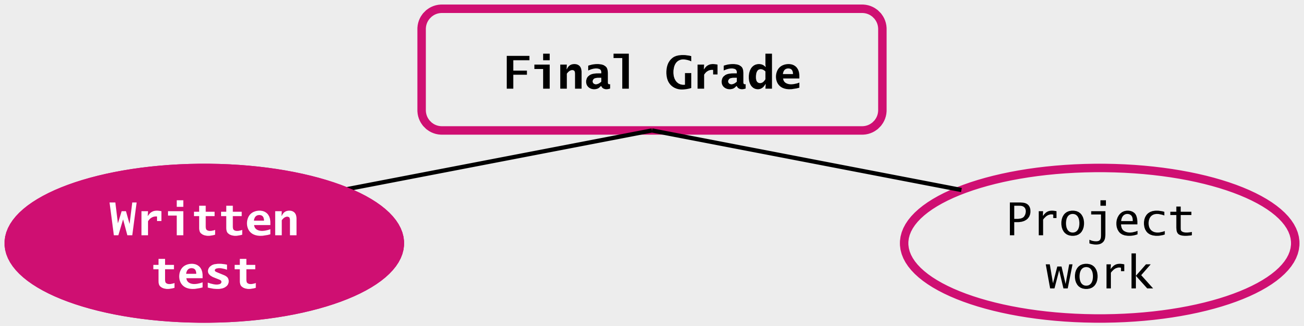
Berlin January 2020



* only TUB content, without guest lecturers

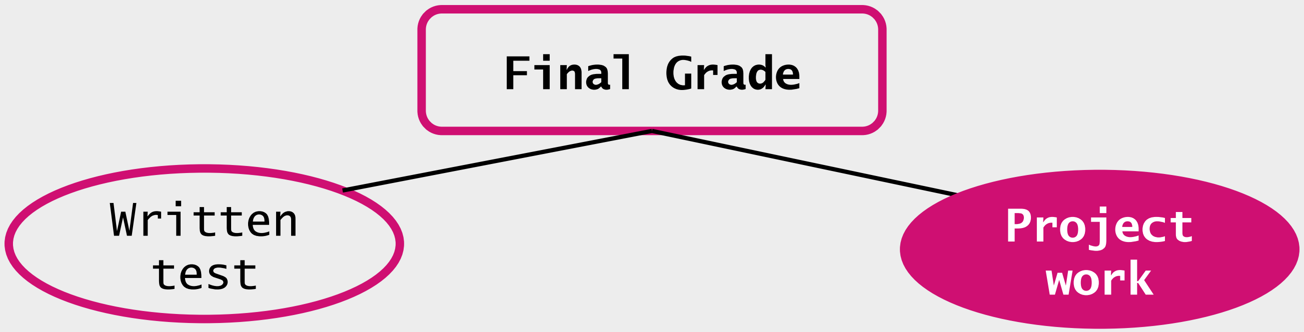
Assessment and Grading

Assessment and Grading
Technische Universität Berlin



- 50 % of total grade
- 80 minutes written test
- Focus on paper and pen and spreadsheet exercises, as well as general knowledge questions

Assessment and Grading
Technische Universität Berlin

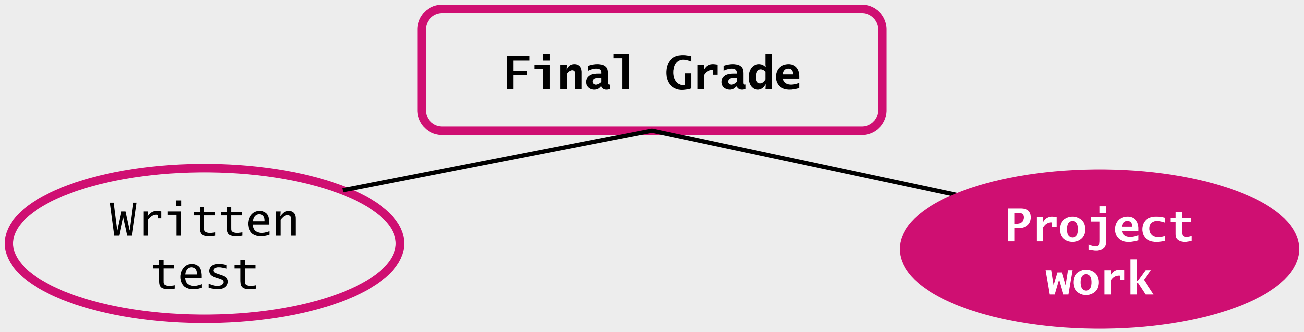


Project Outcome:

- Independent student work, 2-3 students per project group
- Given task to be solved with research, MATLAB simulation, and result analysis

Assessment and Grading

Technische Universität Berlin



Preliminary Presentation:

- 15 % of total grade
- 10 minutes presentation

Written Report:

- 35 % of total grade
- 15-40 pages

Assessment and Grading

Technische Universität Berlin

6 ECTS = 150-180 hours

Class presence

Lectures and exercises

40-60 hours

Preparation time

Lectures and written test

45 hours

Project work

Including presentation and report

65-75 hours

Conclusion

Conclusion

State of the Art Topics on Smart Grid

Distribution Network

Forecasting

Power Quality

Energy Storage Technologies

Conclusion
Further Benefits

- **Modern media**: computers, app, video conferences, CAD
- International compatibility: ECTS points, language **English**
- **Integrated structure**: lectures, assignments in class and at home, projects
- Soft skill training: **team orientation and cooperation**, presentation in oral and in writing, project-orientation with scheduling

Conclusion

Further Readings

Renewable Energies:

G. M. Masters: Renewable and Efficient Electric Power Systems, 2. Auflage, John Wiley & Sons inc., 2013, Hoboken, New Jersey, USA.

Multi-energy Smart Grids:

S. Bschorer, M. Kuschke and K. Strunz, "Object-oriented modeling for planning and control of multi-energy systems," in *CSEE Journal of Power and Energy Systems*, vol. 5, no. 3, pp. 355-364, Sept. 2019, doi: 10.17775/CSEEJPES.2019.00650.

K. Strunz and H. Louie, “Cache Energy Control for Storage: Power System Integration and Education Based on Analogies Derived From Computer Engineering,” in *IEEE Transactions on Power Systems*, vol. 24, no. 1, pp. 12-19, Feb. 2009.

Virtual Power Plant:

D. Koraki and K. Strunz, "Wind and Solar Power Integration in Electricity Markets and Distribution Networks Through Service-Centric Virtual Power Plants," in *IEEE Transactions on Power Systems*, vol. 33, no. 1, pp. 473-485, Jan. 2018, doi: 10.1109/TPWRS.2017.2710481.

Thank you for your attention!

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