SMAGRINET
POWERING SMART GRID EXPERTISE IN EUROPE

TRAIN THE TRAINERS WORKSHOP

Module 3: Connection Planning in Smart Grids

University of Ljubljana

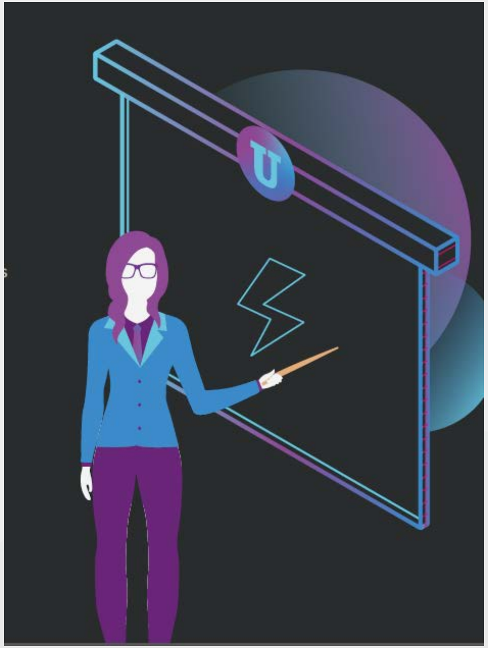
24/11/2020

1. Introduction
2. Lectures
3. Exercise sessions
4. Project work
5. Teaching methods
6. Students feedback

Introduction

MODULE 3

1. General Characteristics of Distribution Network with Distributed Generation
2. **Load and Distributed Generation Forecasting**
3. Demand Characteristics Consumers Prosumers
4. **Allocation of Distributed Generation - State Estimation**
5. Integration of Energy Storages
6. **Electric Vehicle Impact on Distribution Network**
7. **Smart Grid Technologies**
8. **Power Quality**
9. Virtual Power Plant
10. **Planning of Distributed Network Expansion,** I & **II**

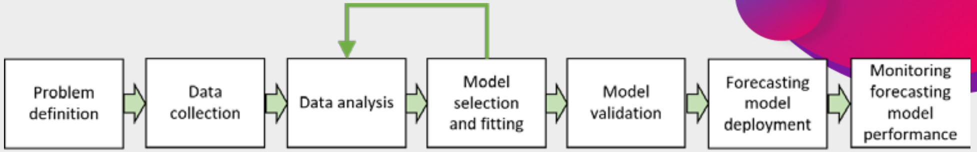


MODULE 3

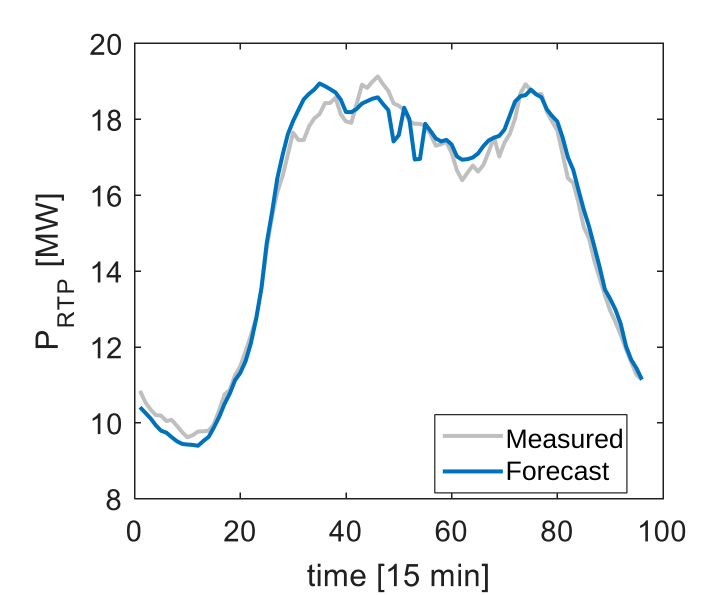
- Main topics of Module 3
  - Traditional distribution network operation
  - Integration and impact of renewables, electric vehicles, storage…
  - Smart grid solutions
- Duration (2 weeks)
  - one week of lectures, tutorial and lab work (each day 9am – 17pm)
  - one week of independent project work
- On-line implementation due to Corona virus situation

Lectures

2. Forecasting



- Definition and use of forecasting
  - The need for forecasting in modern power systems
  - Load, generation, electricity price forecasting
- The concept of forecasting process
- Description of some forecasting methods
  - Statistical methods, AI methods, Knowledge Based Expert Systems, Hybrid techniques
- Description the basis of time-series forecasting (ARIMA)
  - Stationarity, autocorrelation
  - AR, MA, ARMA and ARIMA models
  - Evaluation of forecast accuracy



➢ The students will understand the forecasting process and its importance in electric power systems
  ➢ Basics of time-series forecasting

2. Forecasting - references

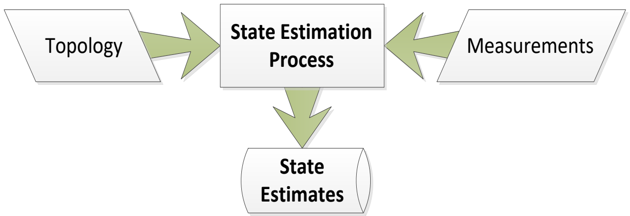
- **G. E. Box, G. M. Jenkins, G. C. Reinsel, and G. M. Ljung, Time series analysis: forecasting and control. John Wiley & Sons, 2015**
- D. C. Montgomery, C. L. Jennings, and M. Kulahci, Introduction to time series analysis and forecasting. John Wiley & Sons, 2015
- R. J. Hyndman and G. Athanasopoulos, Forecasting: principles and practice. OTexts, 2018 https://otexts.com/fpp3/
- https://people.duke.edu/~rnau/411arim.htm
- https://www.mihagrabner.com/blog/categories/forecasting
- D. Upadhaya, R. Thakur, and N. K. Singh, “A systematic review on the methods of short term load forecasting,” in 2019 2nd International Conference on Power Energy, Environment and Intelligent Control (PEEIC), 2019, pp. 6–11. https://ieeexplore.ieee.org/abstract/document/8976518
- K. Zor, O. Timur, and A. Teke, “A state-of-the-art review of artificial intelligence techniques for short-term electric load forecasting,” in 2017 6th International Youth Conference on Energy (IYCE), 2017, pp. 1–7. https://ieeexplore.ieee.org/document/8003734

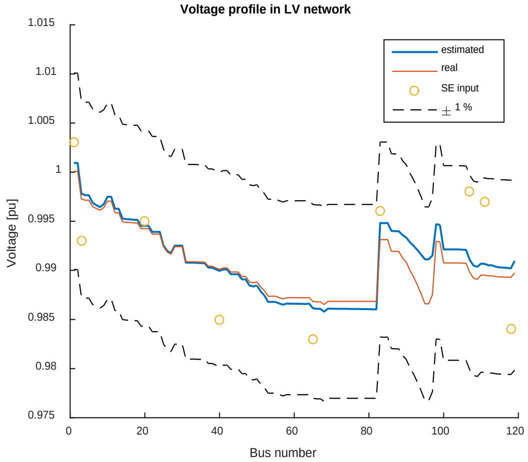
4. State Estimation

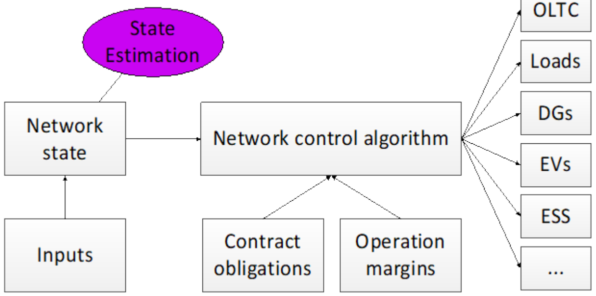
- Overview of distribution network operation
  - Low observability of distribution networks
- Distribution networks of the past and those of the (near) future
- Distribution system State Estimation approaches and techniques
  - Weighted least squares
- Challenges, related to measurements data
  - Robustness, bad data detection

➢ The students will understand:

  - ➢ Importance of advanced voltage control in modern distribution networks
  - ➢ The role of State Estimation in voltage control
  - ➢ Basic framework of the State Estimation algorithm







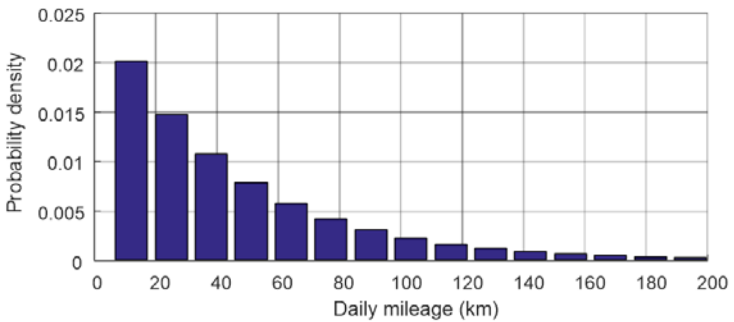
4. State Estimation - references

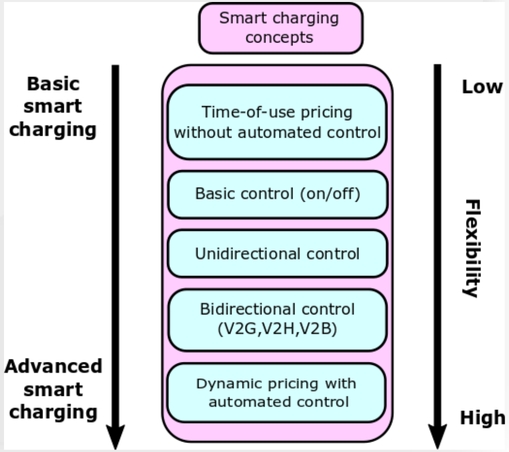
- Abur, Ali, Antonio Gómez Expósito, and Antonio Gómez Expósito. Power System State Estimation : Theory and Implementation. CRC Press, 2004. https://doi.org/10.1201/9780203913673
- Monticelli, A. State Estimation in Electric Power Systems. Boston, MA: Springer US, 1999. https://doi.org/10.1007/978-1-4615-4999-4
- Kersting, William H. Distribution System Modeling and Analysis. CRC press, 2012
- deSouza, J.C.S., M.B. DoCouttoFilho, M. Th.Schilling, and C. deCapdeville. 'Optimal Metering Systems for Monitoring Power Networks Under Multiple Topological Scenarios'. IEEE Transactions on Power Systems 20, no. 4 (November 2005): 1700–1708. https://doi.org/10.1109/TPWRS.2005.857941
- Kuhar, Urban, Gregor Kosec, and Aleš Švigelj. Observability of Power-Distribution Systems: State-Estimation Techniques and Approaches. SpringerBriefs in Applied Sciences and Technology. Cham: Springer International Publishing, 2020. https://doi.org/10.1007/978-3-030-39476-9
- Antončič, Mitja, Igor Papič, and Boštjan Blažič. 'Robust and Fast State Estimation for Poorly-Observable Low Voltage Distribution Networks Based on the Kalman Filter Algorithm'. Energies 12, no. 23 (January 2019): 4457. https://doi.org/10.3390/en12234457
- Baran, Mesut, and T. E. McDermott. 'Distribution System State Estimation Using AMI Data'. In Power Systems Conference and Exposition, 2009. PSCE'09. IEEE/PES, 1–3. IEEE, 2009. http://ieeexplore.ieee.org/abstract/document/4840257/
- Hayes, Barry, and Milan Prodanovic. 'State Estimation Techniques for Electric Power Distribution Systems'. In Modelling Symposium (EMS), 2014 European, 303–308. IEEE, 2014. http://ieeexplore.ieee.org/abstract/document/7154016/

6. Electric vehicles

- Describing electrical vehicle as electrical load:
  - Battery size, SOC, vehicle consumption…
  - User behavior observed trough statistical data
    - travelled distances, start and end of journeys
    - start of charging times…
- Probabilistic analysis of EV-integration
  - Sampling of distributions
  - Monte Carlo approach to definition of EV as a load
- Influence of electric vehicles on network elements and on networks' operation
  - overloading, voltage levels, voltage unbalance…
- Presenting different concepts of smart charging and their advantages

➢ Students will understand the characteristics of EV as electrical load and the impact of EV on distribution grid





6. Electric vehicles - references

1. For introduction and general information about the current use of electric vehicles and deployment of charging infrastructure:
   - https://www.iea.org/reports/global-ev-outlook-2020
   - https://ec.europa.eu/clima/policies/transport/vehicles
   - https://www.eea.europa.eu/
   - https://www.europarl.europa.eu/RegData/etudes/BRIE/2019/637895/EPRS_BRI(2019)637895_EN.pdf
2. Impact on distribution network and smart-charging:

   - M. R. Khalid, M. S. Alam, A. Sarwar, in M. S. Jamil Asghar, „A Comprehensive review on electric vehicles charging infrastructures and their impacts on power-quality of the utility grid“, *eTransportation*, let. 1, str. 100006, avg. 2019, doi: 10.1016/j.etran.2019.100006.
   - P. Kong in G. K. Karagiannidis, „Charging Schemes for Plug-In Hybrid Electric Vehicles in Smart Grid: A Survey“, *IEEE Access*, let. 4, str. 6846–6875, 2016, doi: 10.1109/ACCESS.2016.2614689.
   - N. S. Pearre in H. Ribberink, „Review of research on V2X technologies, strategies, and operations“, *Renewable and Sustainable Energy Reviews*, let. 105, str. 61–70, maj 2019, doi: 10.1016/j.rser.2019.01.047.

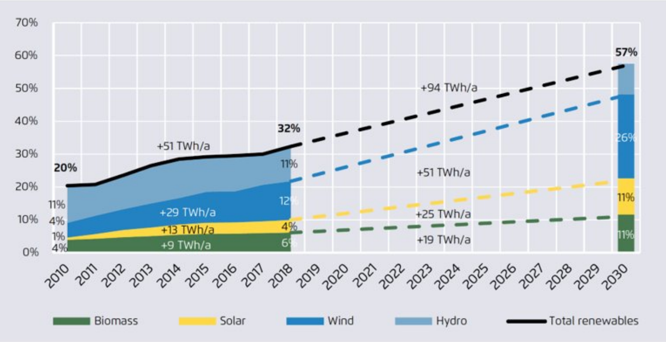
7. Smart Grid Technologies

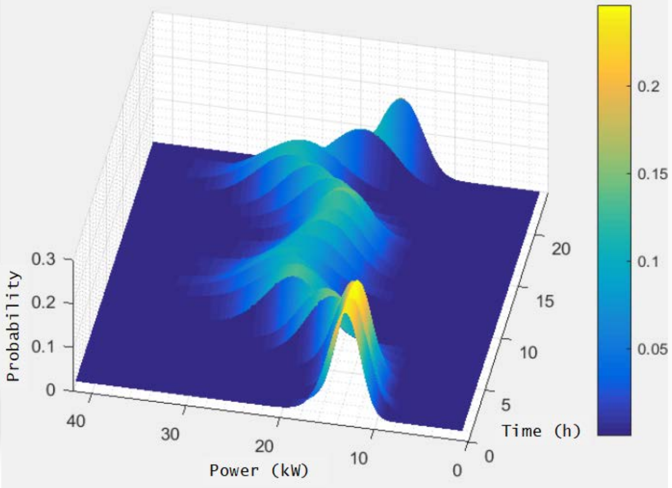
- Overview of EU electricity generation and energy policy
- Challenges of modern power systems
- Traditional distribution network operation
- Presentation of smart grids
  - Upgrade of a traditional grid -> efficient use of existing infrastructure
  - Advanced voltage control, VPP, DR, network services
- A stochastic modelling approach of electric power systems for network planning
  - Monte Carlo simulations approach, confidence interval

➢ The students will understand:

- ➢ The impact of renewables and new loads on distribution networks
- ➢ Basics of traditional distribution network operation
- ➢ The concepts encompassed by smart grids

2030 projection of renewable electricity share in European Commission's Long Term Strategy — Figure 3-8





7. Smart Grid Technologies - references

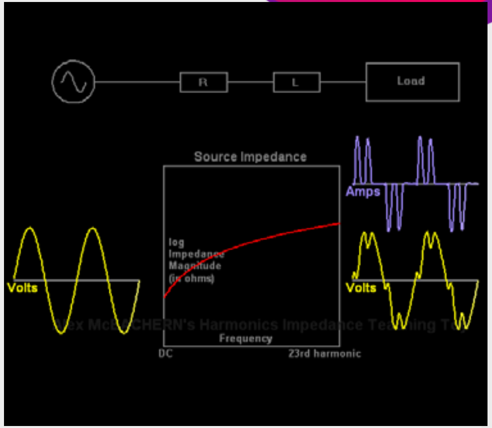
- Q.-C. Zhong, Power Electronics-Enabled Autonomous Power Systems: Next Generation Smart Grids. John Wiley & Sons, 2020.
- A. Keyhani, Design of Smart Power Grid Renewable Energy Systems. John Wiley & Sons, 2016.
- G. Dileep, „A survey on smart grid technologies and applications“, Renewable Energy, let. 146, str. 2589–2625, feb. 2020, doi: 10.1016/j.renene.2019.08.092.
- M. Alilou, B. Tousi, in H. Shayeghi, „Home energy management in a residential smart micro grid under stochastic penetration of solar panels and electric vehicles“, Solar Energy, let. 212, str. 6–18, dec. 2020, doi: 10.1016/j.solener.2020.10.063.
- R. Bayindir, I. Colak, G. Fulli, in K. Demirtas, „Smart grid technologies and applications“, Renewable and Sustainable Energy Reviews, let. 66, str. 499–516, dec. 2016, doi: 10.1016/j.rser.2016.08.002.
- J. B. Ekanayake, N. Jenkins, K. Liyanage, J. Wu, in A. Yokoyama, Smart Grid: Technology and Applications. John Wiley & Sons, 2012.

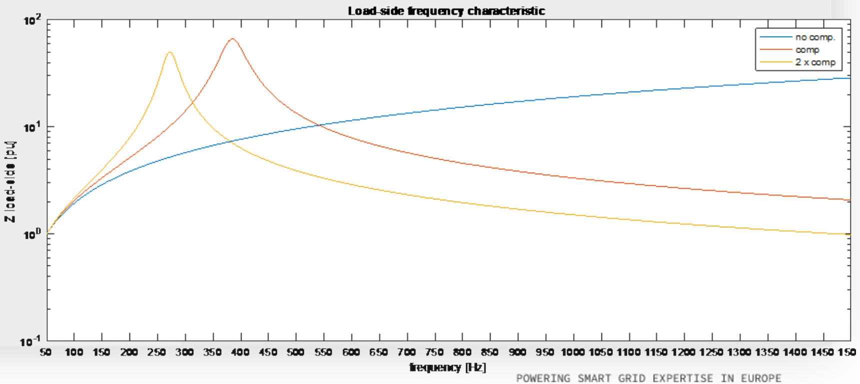
8. Power Quality

- Basic terms and definitions of power quality
  - network operator and customer viewpoints
- Definition of harmonics and their propagation through networks
  - sources, propagation, consequences
  - ➢ harmonic studies, impedance frequency characteristics (resonances)
- Definition of flicker with the description of flicker sources and its consequences in the network
- Definiton of voltage sags, its characteristics and causes

The students will understand:

- What is power quality and why it matters
- Harmonic analysis of networks



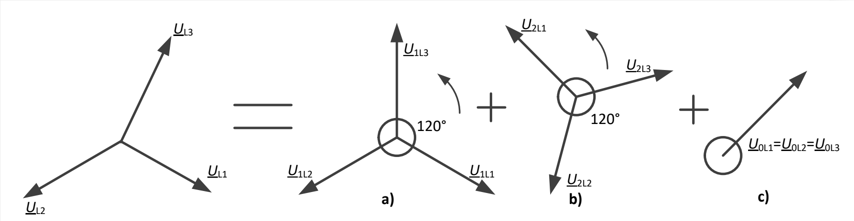


8. Power Quality – references

- Dougan, R.C., McGranaghan, M.F., Wayne Beaty, H., Electrical Power Systems Quality, McGraw-Hill, 1996.
- Blume, D., Schlabbach, J., Stephanblome, T., Spannungsqualität in elektrischen Netzen, VDE-Verlag, 1999.
- Bollen, M.H.J., Understanding Power Quality Problems – Voltage Sags and Interruptions, IEEE, 2000.
- Arrillaga, J., Smith, B.C., Watson, N.R., Wood, A.R., Power System Harmonic Analysis, Wiley, 2000.
- Arrillaga, J., Watson, N.R., Chen, S., Power System Quality Assessment, Wiley, 2001.

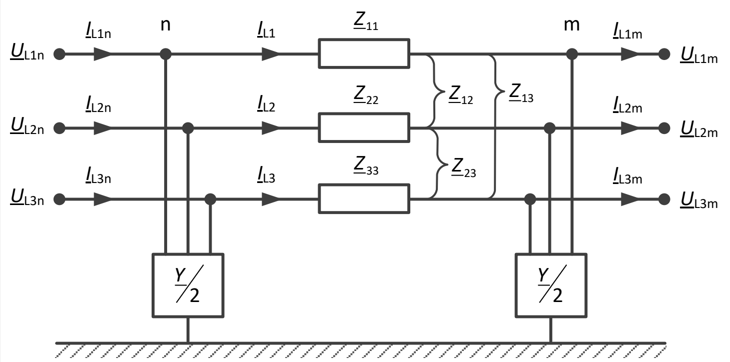
10. Planning of Distributed Network Expansion, part II

- Symmetrical components transformation is derived
    - Description of unbalanced operation
- Models of network elements for load-flow calculations are presented
    - Three-phase power line model, transformer model and load model



The students will understand:

- Reasons for usage of symmetrical components in calculations
- The logic behind the power line model
- Impact of transformer connection and grounding on the zero-sequence component



10. Planning of Distributed Network Expansion - references

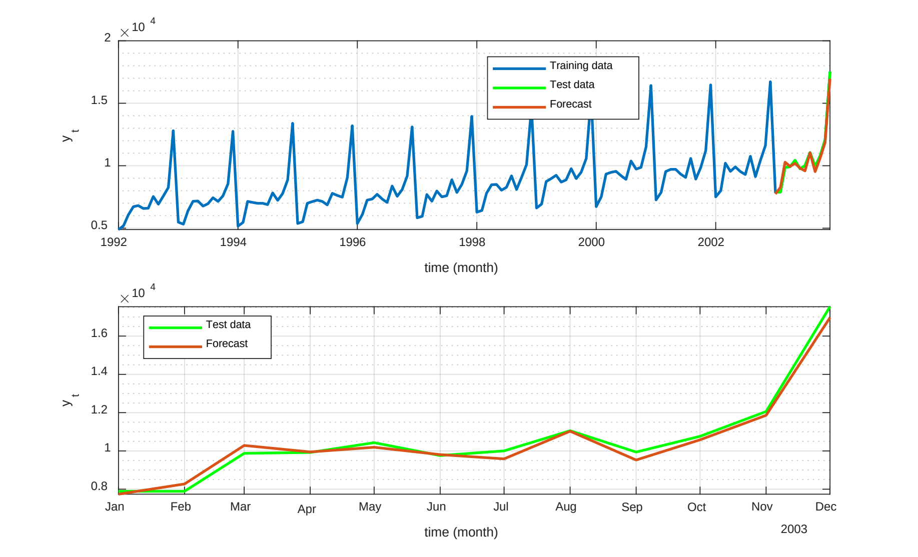
- Kiessling, F., Nefzger P., Nolasco J.F., Kaintzyk U., Overhead Power Lines: Planning, Design, Construction, Springer Verlag, 2003.
- William H. Kersting, Distribution System Modelling and Analysis, CRC Press, 2002.
- Ramasamy Natarajan, Power system capacitors, Taylor & Francis, 2005

Exercise sessions

Exercise session 2 - Forecasting (1h)

Exercise to train students on time series forecasting:

- Determine the components of time series (training data, test data; linear trend, seasonality)
- Identify an appropriate ARIMA model
- Parameter estimation using Matlab, calculate forecast
- Comparison of a forecast and actual data

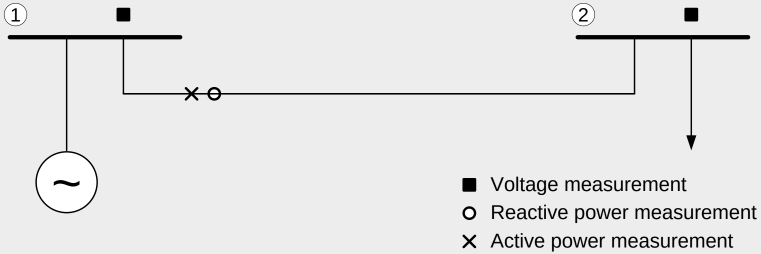


MAPE	RMSE	MSE
2.43 %	308,70	255,78

Exercise session 4 - WLS state estimation (1h)

Exercise supporting the students in the process of understanding the state estimation concept:

- Recognition of the state estimation goal.
- Application of WLS method to the estimation problem.
- Step-by-step state estimation of the simple 2-bus network.

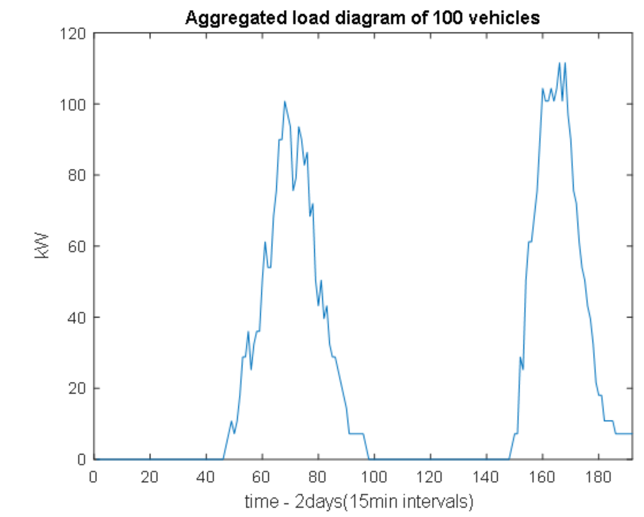


$$\hat{\mathbf{x}} = \begin{bmatrix} \hat{x}_1 \\ \hat{x}_2 \\ \hat{x}_3 \end{bmatrix} = \begin{bmatrix} \hat{\delta}_2 \\ \hat{V}_1 \\ \hat{V}_2 \end{bmatrix} = ?$$

Exercise session 6 - Electric vehicle (1h)

Students have to determine the charging diagram of electric vehicles using MATLAB. Necessary data is provided. To determine simplified EV charging diagram following approaches are required:

- Sampling of data from the provided statistics of the traveled distances
- Calculate vehicle consumption
- Defining probability distribution function for start of charging times
- Determine charging time of electric vehicle



Exercise session 7 - Smart Grid Technologies

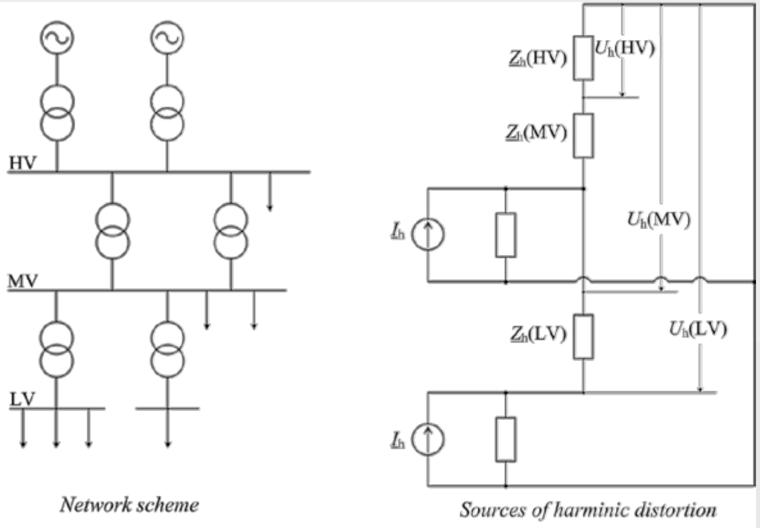
Self-sufficiency – case of a household user with PV and battery storage: students design an algorithm for battery charging and calculate the self-sufficiency index of the system.

- Loading of 1-year PV and consumption data in Matlab
- Define the battery size, power and SOC
- Propose a charging algorithm

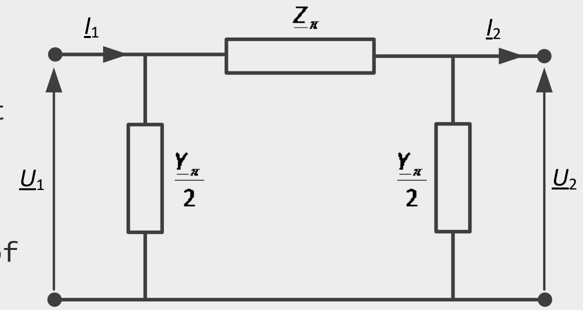
Exercise session 8 – Resonances in power networks (1h)

Exercise giving the students an insight of the process of harmonic study based on the example of a reactive power compensator:

- Calculation of frequency dependant network impedances and equivalent imepdances
- Observations of the impedance resonance problems.



Exercise session 10 – Power line model (1h)



Exercise providing insight in difference between two different line models: equivalent model and nominal model

- Calculation of power and voltages for all elements/nodes of the Pi circuit

- Two examples: heavily loaded and lightly loaded line
- Two lengths: short line and long line

- Comparison of results and discussion of the reasons for differences.

$$\begin{bmatrix} \underline{U}_1 \\ \underline{I}_1 \end{bmatrix} = \begin{bmatrix} 1+\dfrac{\underline{Z}_\pi \underline{Y}_\pi}{2} & \underline{Z}_\pi \\ \underline{Y}_\pi \left(1+\dfrac{\underline{Z}_\pi \underline{Y}_\pi}{4}\right) & 1+\dfrac{\underline{Z}_\pi \underline{Y}_\pi}{2} \end{bmatrix} \cdot \begin{bmatrix} \underline{U}_2 \\ \underline{I}_2 \end{bmatrix}$$

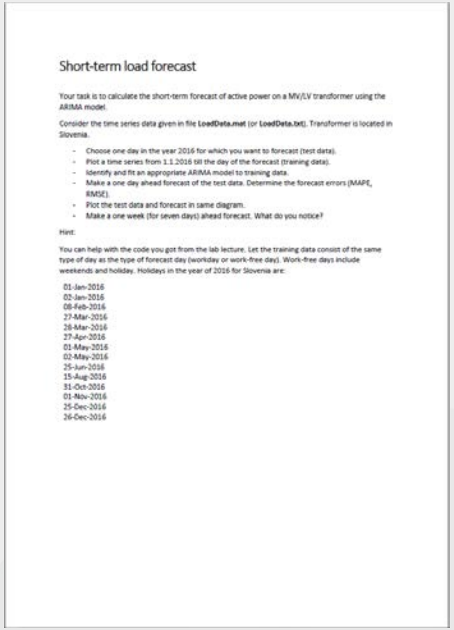
Project work

PW 2: Short-term load forecast

- Time series of a load was given to the students.
- They had to analyse the time series and calculate the short-term forecast of active power on a MV/LV transformer using the ARIMA model

This task had the following objectives:

- To make the students more familiar with the time series forecasting.
- To evaluate the capacity of students to use concepts and tools studied during the lectures and exercises sessions.



Short-term load forecast

Your task is to calculate the short-term forecast of active power on a MV/LV transformer using the ARIMA model.

Consider the time series data given in file **LoadData.mat** (or **LoadData.txt**). Transformer is located in Slovenia.

- Choose one day in the year 2016 for which you want to forecast (test data).
- Plot a time series from 1.1.2016 till the day of the forecast (training data).
- Identify and fit an appropriate ARIMA model to training data.
- Make a one day ahead forecast of the test data. Determine the forecast errors (MAPE, RMSE).
- Plot the test data and forecast in same diagram.
- Make a one week (for seven days) ahead forecast. What do you notice?

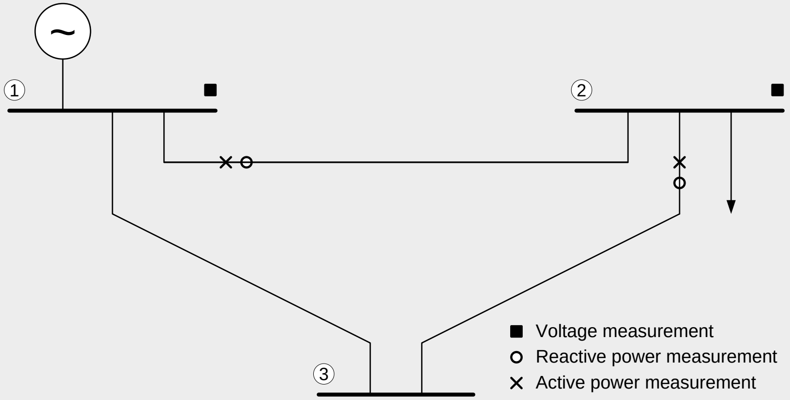
Hint:

You can help with the code you got from the lab lecture. Let the training data consist of the same type of day as the type of forecast day (workday or work-free day). Work-free days include weekends and holiday. Holidays in the year of 2016 for Slovenia are:

01-Jan-2016
02-Jan-2016
08-Feb-2016
27-Mar-2016
28-Mar-2016
27-Apr-2016
01-May-2016
02-May-2016
25-Jun-2016
15-Aug-2016
31-Oct-2016
01-Nov-2016
25-Dec-2016
26-Dec-2016

PW 4: WLS state estimation

- Students were given network topology and some measurements.
- They had to estimate the true network state, based on the given data.
- The objective of this task was to consolidate the knowledge gained in the exercise session and independently estimate the network state.



$$\hat{\mathbf{x}} = \begin{bmatrix} \hat{x}_1 \\ \hat{x}_2 \\ \hat{x}_3 \\ \hat{x}_4 \\ \hat{x}_5 \end{bmatrix} = ?$$

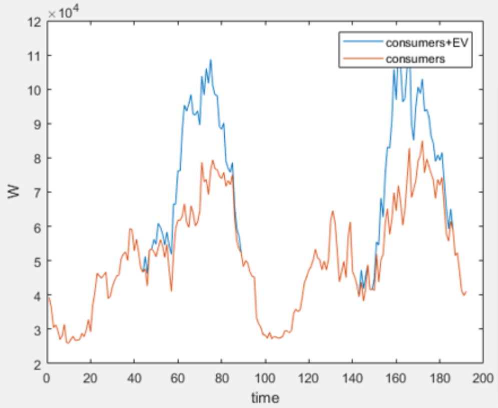
PW 6: Electric vehicle impact on distribution network

Students had to determine charging diagram of electric vehicle fleet using MATLAB. Necessary data was provided. To determine simplified EV charging diagrams following approaches were required:

- Sampling of data from the probability distribution function describing travel distances
- Defining probability distribution function for start of charging times
- Calculate vehicle consumption
- Determine charging times of electric vehicles
- Add the consumption of the whole fleet to the consumption diagram of 100 residential consumers

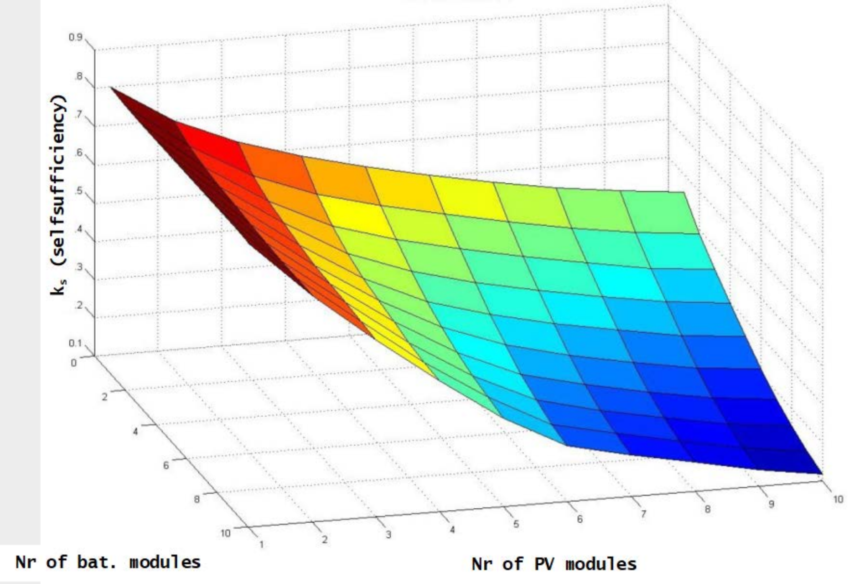
This task had the following objectives:

- To teach students to define simple charging diagrams of EVs
- To observe how much a fleet of electric vehicles can contribute to the loading of the MV/LV transformer at evening peak



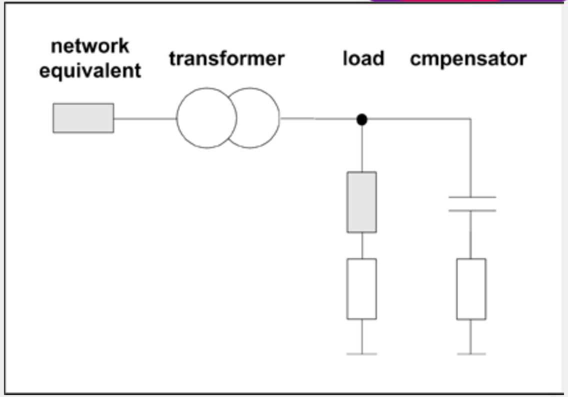
PW 8: *Self-sufficiency*

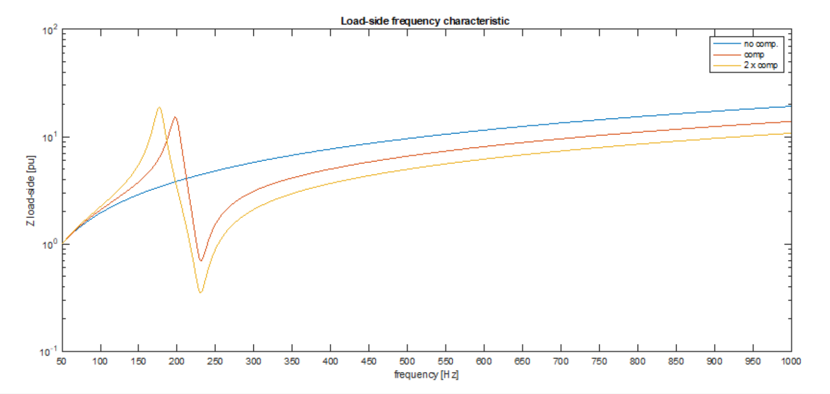
- Students had to analyse the electricity consumption of a household consumer and a PV power plant by designing their own algorithm for battery charging. They had to calculate the self-sufficiency index of the system. The results of the simulation were asked to be shown for a group of household consumers.
- Students could choose the battery and maximum power.
- The objective of this task was to understand how much of electricity need can be covered in a household using PV panels and a battery .



PW 10: Tuning the reactive power compensator

- Students were given network topology and the amplitudes of the harmonic currents.
- Case study 1: calculating the frequency impedance characteristics of the network and evaluting the impact of
  - number of compensators (one, two or three compensators) and
  - Transformer change (one or two transformers)
- Next task was calculation of the harmonic voltage and the voltage THD.
- Case study 2: tuning the reactive power compensator to two tuning frequencies (230 Hz and 330 Hz) and then do the calculations od case study 1 again.
- The objectives of the task were the selection of the appropriate tuning frequency and comparation of all results.

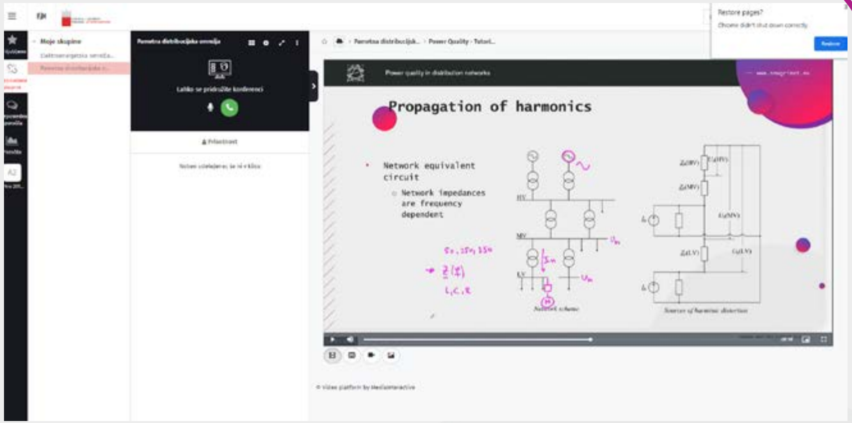




Teaching methods

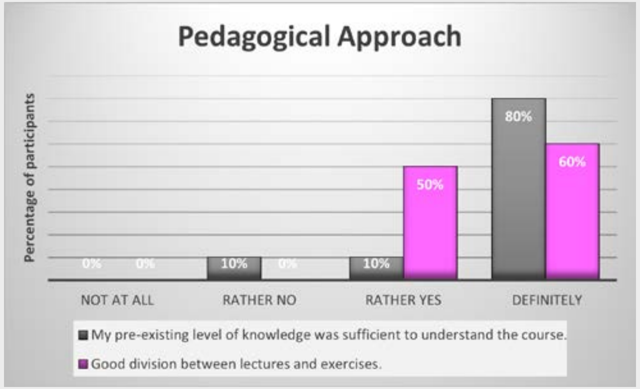
Teaching methods

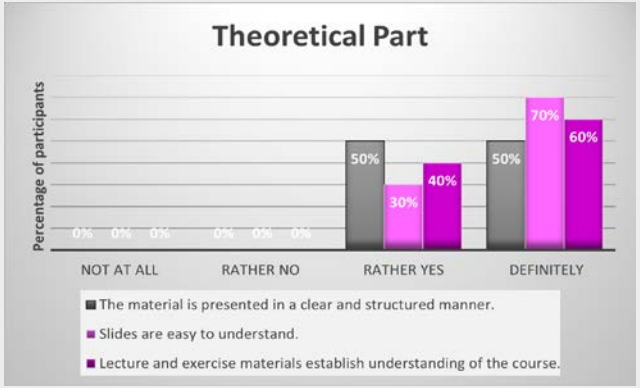
- Lectures:
  - On-line sessions
  - 2-3 hours each topic
- Tutorial and Lab Work
  - On-line sessions
  - 1-2 hours each
  - Students calculation of exercises given with guidance of the teacher
- Independent student work
  - Project assignments were assigned to students
  - With the evaluation of project the course was finished

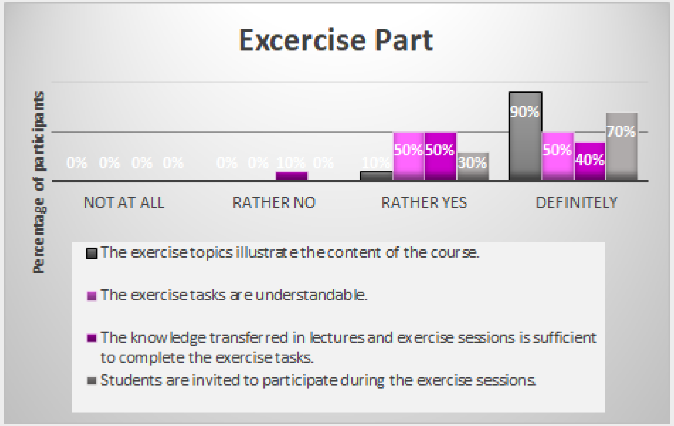


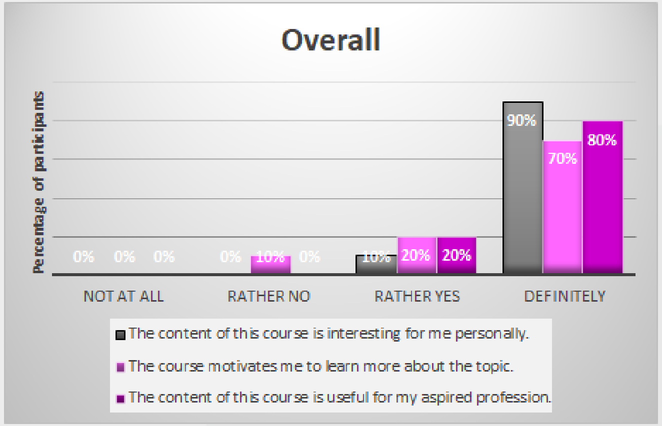
University of Ljubljana's teaching video platform used.

Students feedback


Pedagogical Approach
Percentage of participants
0%
0%
10%
0%
10%
50%
80%
60%
NOT AT ALL
RATHER NO
RATHER YES
DEFINITELY
My pre-existing level of knowledge was sufficient to understand the course.
Good division between lectures and exercises.


Theoretical Part
Percentage of participants
0% 0% 0%
0% 0% 0%
50%
30%
40%
50%
70%
60%
NOT AT ALL
RATHER NO
RATHER YES
DEFINITELY
The material is presented in a clear and structured manner.
Slides are easy to understand.
Lecture and exercise materials establish understanding of the course.


Excercise Part
Percentage of participants
0% 0% 0% 0%
0% 0% 10% 0%
10% 50% 50% 30%
90% 50% 40% 70%
NOT AT ALL
RATHER NO
RATHER YES
DEFINITELY
The exercise topics illustrate the content of the course.
The exercise tasks are understandable.
The knowledge transferred in lectures and exercise sessions is sufficient to complete the exercise tasks.
Students are invited to participate during the exercise sessions.


Overall
Percentage of participants
0% 0% 0%
0% 10% 0%
10% 20% 20%
90% 70% 80%
NOT AT ALL
RATHER NO
RATHER YES
DEFINITELY
The content of this course is interesting for me personally.
The course motivates me to learn more about the topic.
The content of this course is useful for my aspired profession.

- Strong elements of the course:
  - collaboration with foreign university (TUB)
  - well prepared presenters
  - knowledge from lectures applied in excercises and project
  - a popular, unique and interesting subject for engineers
- Weak elements of the course:
  - too much details at some of the lectures
  - the sequence of the course content
  - online execution of the course (hard to follow all the lectures – tiredness, less communication between lecturers and participants)
- Areas for improvement:
  - rescheduling the content of the course
  - more exercises
  - implementation in person

Thank you for your attention

ESTONIA
www.ttu.ee

SLOVENIA
www.fe.uni-lj.si

GERMANY
www.tu-dresden.de

PORTUGAL
www.loba.cx

ESTONIA
www.civitta.com

LITHUANIA
www.ktu.edu

GERMANY
www.sense.tu-berlin.de

ESTONIA
www.elektriliit.ee

FRANCE
www.welcome.univ-lorraine.fr

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