Wide Area Monitoring, Protection, and Control

(Spring Semester, 2024)

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Course Description

Wide-area monitoring, protection, and control (WAMPAC) is an important issue in modern electric power system design and operation; and is becoming more significant today due to the increasing size, changing structure, the introduction of renewable energy sources, distributed smart/microgrids, environmental constraints, and complexity of power systems. The wide-area measurement system (WAMS) with phasor measurement units (PMUs) provides key technologies for monitoring, state estimation, system protection and control of widely spread power systems. A direct, more precise and accurate monitoring can be achieved by the technique of phasor measurements and global positioning system (GPS) time signal. A proper grasp of the present state with flexible wide-area control and smart operation address significant elements to maintain wide-area stability in the complicated grid with the growing penetration of distributed generation and renewable energy sources. In response to the existing challenge of integrating advanced metering, computation, communication, and control into appropriate levels of PSMC, this course provides comprehensive coverage of WAMPAC understanding, analysis, and realization. It presents both theoretical knowledge and a practical foundation for understanding WAPSMC. Different aspects, current challenges and research directions will be examined in detail.

Course Content

1. **Course Description** (Golpira, Bevrani)
2. **Introduction** (Golpira)

   Pre-task: *Document your understanding from the IEEE Taskforce report about power system stability and control.*

   - *IEEE benchmarks, Categorization, Application*
   - *Power system stability and control*
   - *Power system engineering, Control Engineering*

   Project Report 1: *Selecting appropriate IEEE Benchmark and running a simple simulation*

3. **General overview** (Golpira)

Pre-task: *Document your understanding from the IEEE Taskforce report about security, adequacy and main elements of interest.*

- *Power system elements, Power system layers, Phasor and states*
- *Security and adequacy, Stability and categories*
- *Conventional power systems, Modern power systems*
- Infrastructure, Advantages and disadvantages, Roadmap

Project Report 2: *Description of model of elements in the selected test case in Homework 1*

4. **Signal processing and application in power system** (Golpira)
   - *Measurements vs states and variables*
   - *What are measurements? From where? PMU vs RTU*
   - *Denoising,* Why denoising? Advantages and disadvantages, Methods and example
   - *Extracting of features using*, Prony method, Music method, ESPRIT method
   - *Real signal investigation*

   Project Report 3: *Locate PMUs on some buses in the selected test system and denoise the measured signals.*

5. **Simple simulation** (Golpira)
   - *Effect of inertia on power system dynamics, Inertia: good or bad?*
   - *Inertia constant: Synchronous, Virtual, Case studies*
   - *Frequency response model: Parameters, Model derivation*
   - UFLS: *Model-based methods, Measurement-based methods, Case studies*

   Project Report 4: *1-Extrac SFR model for the test system. 2-Shed loads in the test system and discuss the stability assessment*

6. **Simple simulation** (Golpira)
   Pre-task: *Document your understanding from the IEEE Taskforce about transient and small signal stability.*
   - *Effect of PSS and AVR on power system dynamics, PSS is good or bad?*
   - PSS design*: On-line tuning, Off-line tuning, Coordination with AVR*
   - Wide area damping controller*: Model-based methods, Measurement-based methods*
   - *Case studies*

   Project Report 5: *Study effects of PSS and AVR on the test system*

7. **Clustering, Excitation system, and control loops** (Golpira)
   Pre-task: *Document your understanding from the IEEE Taskforce about Excitation system and control loops in power systems.*
   - *Case studies*

   Project Report 6: *implementation of a clustering approach on the test system*

8. **Simple simulation** (Golpira)
    - *Data driven vs model driven, what to be derived? Data driven: good or bad?*
    - *Advanced data-driven control and protection*
    - *Advanced power system modelling, Flexible inertia, Ancillary services*
    - *Practical considerations, Case studies*

    Project Report 7: *Apply a data-driven approach to the test system.*

9. **SCADA and WAMS structure and components** (Bevrani)
    - *SCADA:* Components, Disadvantages, Structure
    - *WAMS:* Concept, Components, Structure, Roadmap

    Homework 1: *Describe a real SCADA and WAMS examples in the world.*

10. **Frequency stability and regulation** (Bevrani)
    Pre-task: *Document your understanding from the IEEE Taskforce about frequency stability.*
    - *Stiff and Low-inertia systems, Comparison*
    - *Local frequencies: Concept, Estimation, Application in power system stability*
    - *Case studies*
    - *Frequency stability indices: Nadir, RoCoF, Delta-frequency deviation*
    - *Parameter estimations: Online, Off-line*

    Project Report 8: *Discuss frequency stability/regulation for the selected test system in response to an applied fault.*

11. **Oscillation mode** (Bevrani)
    Pre-task: *Document your understanding from the IEEE Taskforce about oscillatory stability.*
    - *Definition, Damping, amplitude, Critical mode, Observability*
    - *Mode extraction: Model-based methods, Measurement-based methods, Case studies*
    - *Small-signal stability: Definition, Inertia investigation, Case studies*

    Homework 2: *Use the least squre methode to estimate the parameters of a simple system.*

    Project Report 9: *Discuss the small-signal stability of the selected test system in response to an applied fault.*

12. **Voltage stability** (Bevrani)
    Pre-task: *Document your understanding from the IEEE Taskforce about voltage stability.*
    - *Concept, Instability, Collapse, Sag and swell*
    - *Voltage stability indices: Sensitivity factors, Electrical distance*
    - *Pioneer buses, Control zones*

    Project Report 10: *Discuss the voltage stability of the selected test system in response to an applied fault.*

13. **Dynamic impact of DGs and Microgrids** (Bevrani)
    - *DGs modelling*
    - *Maximum penetration level*
    - *Frequency stability, Small-signal stability, Voltage-stability*

Project Report 11: *Add DGs to test system and do a stability analysis.*

14. **Wide-area protection** (Bevrani)
    - Literature review
    - Advanced protection schemes
    - Wide-area protection backup

Grading

- *Homework*/Pre-task: 20%
- Final Exam: 30%
- **Project Reports and Presentation**: 50%

Homework/Pre-task

The course homework and pre-task will be performed along the semester.

Course Project

The project is organized to be performed on several steps during term-time and covers many topics of the courses. A test system is selected by each student at the beginning of semester. Then, the system must be used to apply learned concepts and methods during the WAMPAC course. Everyone should provide a detailed written report with relevant simulation file in each step. At the end, it may be required to present the project results in a meeting.

Note: Students may discuss the project steps with other students, but are not allowed to share solutions (MATLAB m-files, etc.).

Objectives

Completing the course must give the following knowledge, skills and capabilities to the students who attend all lectures actively:

1- A deep knowledge on the preliminary concepts, frameworks, and components of a WAMPAC system.
2- Learning some methodologies for wide-area power system stability and performance analysis.
3- Learning how to design a data driven based power system controller.

4- Ability to conduct a new research in the relivant areas and complete it.
5- Making an enough strong background for self-learning of other topics and tools in WAMPAC field in a short time.

○ Main References

1- Hêmin Golpîra, Arturo Román-Messina, and Hassan Bevrani. *Renewable Integrated Power System Stability and Control*. Wiley-IEEE Press, 2021.

2- Bevrani, H., Watanabe, M., and Mitani, Y. *Power system monitoring and control*. Wiley-IEEE Press, 2014.

3- Hatziargyriou, N., Milanović, J., Rahmann, C., Ajjarapu, V., Cañizares, C., Erlich, I., ... & Vournas, C. (2020). Stability definitions and characterization of dynamic behavior in systems with high penetration of power electronic interfaced technologies. IEEE PES Technical Report PES-TR77.