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EH2741
Communications & Control in Electric Power Systems

Course Memo

6 ECTS credits

Overview

Communication and control of power systems is a wide and comprehensive topic including many different engineering fields ranging from power system instrumentation to power system modelling and control systems theory. To manage and optimise the control and operation of the power system, information and control systems are used throughout the power system. Actually, the information and control systems are so tightly integrated with the physical power system, that together they constitute a *cyber-physical* system.

This introductory course provides a wide perspective on the field of communication and control of electric power systems, opening for continued studies in specialised subjects. It goes beyond traditional analytical control systems or power system courses, and focuses on the practical implementation of systems for communication and control. The course is focused on design, implementation and use of information and control systems for control and operation of the physical power system.

Course Objectives

The objective of this course is to give an overview of technologies and concepts used for communication and control of power systems in a wide sense, including generation, transmission and distribution of electric power. After completing the course, the participants shall be able to:

- Describe the functions of the primary equipment in the power system that is relevant for protection, automation and control
- Analyse substations and simple power systems in terms of reliability protection, automation and control needs.
- Describe the functions and architecture of information and control systems used for protection, automation and control of power systems.
- Describe the importance of information & control systems for the ability to connect large amounts of renewable power sources.
- Analyse and develop basic systems for substation automation and protection.
- Analyse and develop basic communication systems for system-wide control from control rooms, e.g. SCADA systems and EMS applications.
- Describe relevant interoperability standards in the field, such as the IEC 61850
- Construct a state estimator for power systems.
- Describe the threats and risks associated with the use of information & control system for controlling the electric power system, known as Cyber Security.

Prerequisites

The course has no explicit pre-requisites, but it is assumed that course participants have completed a Bachelors degree in Electrical Engineering, or related a topic, e.g. engineering physics, and are eligible for studies on the Master level. It is assumed that the participants have an understanding of data communication fundamentals, such as TCP/IP and networking.

Course Structure

The content of the course is focused on practical implementation aspects of communication and control systems. This means that most of the course content is centered on developing solutions

to practical problems utilising methods and tools from differens fields. The course is divided into three modules:

- Power system control and protection
- SCADA, Energy Management Systems (EMS) and State Estimation
- Power system communication

Each course module corresponds to 2 ECTS credits, the examination for these three modules is described below.

During the course, we will be using the concept of lecturecises, where the first half of the session introduces concepts, and the second half of the session is used for hands-on work with various simulators and tools.

Lectures and exercises

The course constitutes 16 (L1-L10, L12-L13, L15-L18) lecturecises in which theory and practical hands-on work is combined. Participation in the lecturcises series is strongly recommended since the work in the classroom is a key component in reaching the course objectives. For each lecturcise there is recommended reading, either a book chapter excerpt or scientific articles. It is highly recommended that course participants read these texts before the session based on the provided reading guide. Please note that contents from the reading materials is included in the final voluntary test.

During the course, three catch-up combined with Q&A sessions are arranged (L6, L11 & L20) . During these sessions, the students are encouraged to work with their assignments in the classroom and teachers are available to answer questions.

The course also contains to Guest lectures (L14 & L19). The content of the reading material offered for these lectures can be included in the individual test.

Power System Control Assignment (Individual)

The power system control assignment is performed using the ARISTO simulator. The assignment consists of the hands-on exercises handed-out during the first block of lecturecises (L1-L7). Students are free to work on the exercises during, and outside of, classroom time and can work individually, in groups or pairs. The assignment is presented individually at a 15 minute session during which the student is expected to (orally) answer questions on randomly chosen topics from this first block of lecturecises.

State Estimation Assignment (group)

Involves designing a State Estimator, which is the key application for Energy Management Systems (EMS) in electric power control centres. The State Estimation Assignment is conducted in groups of two (2) students per group. The assignment is further described in the assignment text.

Power System Communication Assignment (group)

In the final module of the course students are required to design an information and communication systems architecture for communication within a substation, and between substations and the control centres. This module is also concluded with a practical configuration assignment where the practical communication implementation is studied and analysed. The power system communication assignment is conducted in groups of two (2) students per group. The assignment is further described in the assignment text.

Test (individual)

The course contains **one** voluntary test covering the theoretical concepts covered in the lecturcises, and projects. The test is individual, and voluntary. Participation in the tests is however a pre-requisite for achieving a higher grade than C.

Course Administration

All course materials can be downloaded from the Canvas platform and project assignments must be submitted on Canvas before the corresponding deadlines published therein. Course updates, schedule changes etc. will continually be posted on the KTH canvas, please check regularly.

Literature

The literature for the course consists of the following:

First, excerpts from lecture notes initially prepared by Prof Göran Andersson of KTH and ETHZ, further developed by Prof Gabriella Hug and Andreas Ulbig of the Power systems laboratory at ETHZ. These lecture notes are used with kind permission of the authors, and all credit is due to the authors. The lecture notes are provided in Canvas on relevant lecturcise page. In the course schedule below ***PSDCO*** refers to these lecture notes.

Second, the book "*Power System SCADA and Smart Grids*" by Mini Thomas and John D McDonald (ISBN 978-1-4822-2674-4) is used for the SCADA, EMS and communication part of the course. This book is available online in the KTH library. In the course schedule below ***PSSSG*** refers to this book.

Third, a section from the book "*The Use Case and Smart Grid Architecture Model Approach*" by M. Gottschalk, M. Uslar and C. Delfs (ISBN 978-3-319-49229-2) is used as a guide for the system architecture work in the latter part of the course. This book is available online in the KTH library. In the course schedule below ***SGAM*** refers to this book.

In addition, for some of the lecturcises additional reading is provided on the Canvas pages.

Course Schedule

Date, Time		Description	Reading	
Wednesday 15 January 15-17 **L51**	L 1	Course Introduction • Power System Control and Comm. *Hands-on:* • ARISTO Power system simulator	***PSDCO*** *Sec 1.1* *Ch 2*	LN
Thursday 16 January 15-17 **Ivar Herlitz**	L 2	Power System Control and Protection I • Substations & Topologies *Hands-on:* • ARISTO: The NORDIC 32 grid	***PSDCO*** *Sec 1.2*	LN
Friday 17 January 10-12 **L52**	L 3	Power System Control and Protection II • Frequency Dynamics *Hands-on:* • ARISTO: Frequency dynamics	***PSDCO*** *Ch 5*	LN

Monday 20 January 15-17 **L52**	L 4	Power System Control and Protection III • Frequency Control *Hands-on:* • ARISTO: Frequency Control	***PSDCO*** *Ch 6*	LN
Wednesday 22 January 13-15 **V34**	L 5	Power System Control and Protection IV • Voltage Control *Hands-on:* • ARISTO: Voltage Control	***PSDCO*** *Ch 10*	LN
Friday 24 January 15-17 **L51**	L 6	Power System Control and Protection V • Protection Principles *Hands-on:* • ARISTO: Faults and protection	***PSDCO*** *Sec 4.3*	LN
Monday 27 January 15-17 **L51**	L 7	SCADA, EMS & State estimation I • SCADA/EMS Systems *Hands-on:* • ARISTO: Catching-up	***PSSSG*** *Ch 2* *Ch 5 (to page 187)*	LN
Wednesday 29 January 13-15 **L52**	L 8	SCADA, EMS & State estimation II • Load Frequency Control *Hands-on:* • ARISTO Load Frequency Control	***PSDCO*** *Ch 8*	LN
Friday 31 January 13-15 **U31**	L 9	SCADA, EMS & State estimation III • Power System State Estimation • Bad data detection • Observability analysis	***PSDCO*** *Sec 3.1*	LN
Monday 3 February 15-17 **L52**	L 10	SCADA, EMS & State estimation IV • Exercise – SE example • Introduction to assignment	***PSDCO*** *Sec 3.1*	TR
Monday 3 February 23.59		**Hand-in Power System Control and Protection Assignment**		
Thursday 6 February 08-10 **TBD**		*This timeslot is used for oral presentations of the Power System Control and Protection Assignment*		
Friday 7 February 13-15 **L51**	L 11	SCADA, EMS & State estimation V • PMU based systems • State Estimation with PMUs	***PSSSG*** *Sec 5.11* *Sec 5.12*	LN
Monday 10 February 15-17 **L51**	L 12	Power System Communication I • Control system architecture *Hands-on:* • SGAM: Architecture modelling	***SGAM*** *Sec 3.1*	LN
Wednesday 12 February 10-12	L 13	Power System Communication II • Substation Automation Systems • Intro to IEC 61850	***PSSSG*** *Sec 3.9.6*	LN

L52		*Hands-on:* • SGAM: SAS Architecture modeling		
Friday 14 February 15-17 **L52**	L 14	Power System Communication III • *Guest lecture:* Substation Automation using IEC 61850	-	AB
Monday 17 February 15-17 **L51**	L 15	Power System Communication IV • Intra-Substation Communication *Hands-on:* • Wireshark: Substation Comms	***PSSSG*** *Sec 3.9.6*	FH
Monday 17 February 23.59		**Hand-in State Estimation Assignment**		
Wednesday 19 February 08-10 **L51**	L 16	Power System Communication V • SCADA & WAMS Architecture *Hands-on:* • SGAM: SCADA/WAMS modeling	***PSSSG*** *Sec 2.4 to Sec 2.8*	LN
Friday 21 February 15-17 **L51**	L 17	Power System Communication VI • SCADA & WAMS Communication *Hands-on:* • Wireshark: SCADA & WAMS Com.	***PSSSG*** *Sec 3.8* *Sec 3.9.2 to Sec 3.9.4* *Sec 3.9.7*	FH
Monday 24 February 13-15 **L51**	L 18	Power System Communication VII • Time synchronization & Performance metrics *Hands-on:* • Wireshark: Time synchronization		FH
Wednesday 26 February 10-12 **L51**	L 19	Power System Communication VIII • *Guest lecture:* Cybersecurity	-	PJ
Friday 28 February 13 – 15 **Q31**	L 20	Power System Communication IX • Repeating and catching up *Hands-on:* • SGAM & Wireshark: Catching up	-	FH
Monday 2 March 08 – 10 **D34, E31, E32**	Test	**Voluntary Test**		LN
Monday 16 March 23.59		**Hand-in Power System Communication Assignment**		

Assessment & Grades

The grading of the course is based on the student achievements in the assignments and on the individual tests.

- The Power System Control Assignment is graded as Fail, Pass or Pass with bonus (0, 3 or 6 course points) depending on the achievement during the (mandatory) oral presentation.
- The State Estimation Assignment is graded as *Fail*, *Pass* (6 course points) and *Pass with bonus* (7-10 course points).
- The Power System Communication Assignment is graded as *Fail*, *Pass* (6 course points) and *Pass with bonus* (7-10 course points).
- The individual test, participation which is on a voluntary basis, can provide an additional 12 course points.

Course grades are only granted to students who pass all mandatory assignments. Grading of the course is based on the collected course points.

Grade	**Course Points**
E	15-19
D	20-24
C	25-29
B	30-34
A	35-38

Course Staff

The following persons are active during the course

Lars Nordström (LN)	Course Examiner & Lecturer Course responsible
Fabian Hohn (FH)	Course Assistant Power System Communication Assignment
Tin Rabuzin (TR)	Course Assistant State Estimation Assignment