EI2452 Reliability Evaluation of Electrical Power Systems (7.5 hp)

Learning Outcomes

The course aims to teach the skills of using reliability analysis as a tool for decision support for planning and operation of electric power systems. After the course completion, the participants are expected to achieve the knowledge and skill to:

1. Describe the fundamental definitions and concepts for reliability assessment.
2. Describe the distribution grid (including the protection system) from a reliability perspective.
3. Analyse a system using the following techniques for reliability assessment:
   a) Network modelling
   b) Component importance techniques
   c) Markov modelling
   d) Lifetime models
4. Conduct reliability calculations with tools such as NEPLAN.
5. Formulate a life cycle cost (LCC) model and conduct investment- and risk evaluations based on the results from reliability and LCC calculations.
6. Describe a reliability-based plan for maintenance control according to a reliability centred maintenance (RCM) strategy and gain knowledge about reliability centred asset management.
7. Describe the potential impact of laws and regulations on different parties within the energy distribution sector from a reliability perspective.

The learning outcomes 1-3 are tested in the exam of the second teaching part. The goals 4 and 5 are fulfilled when successfully participating in the practical laboratory sessions. The learning outcomes 1-3, and 5-6 are also examined in an individual project assignment in the end of the course. Outcome 7 can be part of the final project report. In addition, the students will acquire advice and practice in reporting, reviewing, giving feedback, and doing presentations.

Course outline and activities

The workload of the course corresponds to 5 weeks fulltime studies (200 h – 7.5 hp) during period 4 (March to May) 2017. The teaching is organised in 3 course parts of 3 days each and a final presentation session of 1 day. In particular, the course parts include the following activities:
• **Registration**: The students must register for the course via e-mail to the course responsible ([jhjur@kth.se](mailto:jhjur@kth.se)) until the end of the first course part or sign the enrolment list which is available during the lectures of the first course part.

• **Lectures** present different reliability methods and topics. The teaching focuses on the theoretical background as well as the applicability towards power systems. The lectures include exercise sessions and group discussions are stimulated.

• **Guest lectures** contain an invited speaker with an industry background who talks about the practical viewpoint of reliability analysis. The presenter discusses the experience gained during planning, operation, and maintenance of power systems.

• **Exam** tests the elementary knowledge of the methods presented in the course part 1. A high degree of the answers has to be correctly answered to pass the exam (80% range). A high grade in the exam will positively influence the overall grade of the course, see section examination and grades.

• **Home assignment** is a written examination of knowledge from the second course part. More information can be found in section examination and grades.

• **Laboratories** are practical exercises to apply the methods and tools taught in the course. The participation in these exercises is mandatory and a written report needs to hand in after every session. The sessions are executed in groups of two students.

• **Seminar** includes the oral presentation of the performed projects and their reports of every student. The participation is mandatory, see section examination and grades.

• **Conducting the project assignment**: The project has to be executed individually or in groups of two. The investigated problem should be a concrete and practical case which could related to the students current work from a reliability analysis viewpoint. Where applicable it is recommended that the student select a project from his/her professional background, which could also result in a master thesis project or a scientific publication. The initial project description is formulated before part 2 of the course. The work on the project must be on a continuous basis within the course parts and in-between. The final project work will be presented in a seminar and defended against an opponent. The project report needs to be handed in before the final seminar.

• **Additional tasks (optional)**:
  - **Create exercises**: Every participant has the opportunity to hand in one or more self-created exercises and solutions based on the course material before the 24th of May 2017. Depending on the quality, the participant can gain up to 2 course points extra (affecting grade).
  - **Identifying calculation errors** in the course material and correct solution will add 0.5 course points for each detected error and solution to the total course points.
  - **Maximal 2 course points** can be added to the overall course points from the two aforementioned tasks.

**Course material**

The course is based on the book:

This book and further course material such as lecture and laboratory notes can be bought for 300 SEK during the course part 1 and 2. Other recommended books are presented on page 36 in book 1. Other relevant course books are:
(Remark: These books are not necessary for fulfilling the course requirements.)

Examination and Grades

Examination

To successfully finish the course, the following requirements must be fulfilled:

- Passing of the project assignment (PRO2) of 4.5 ECTS credits, which includes:
  - A passed written and oral presentation of the assignment.
  - Successful participation in the laboratories and handing in the lab report.
  - Participation at the seminar. This involves opposing another project assignment. Questions have to be prepared before the seminar and a half written page of comments on the project report must be given to the defendant.

- Examination of the course content (TEN2) of 3 ECTS credits.

  The course content is examined in two parts:
  - **Written exam.** The allowed tool during the exam is a calculator. Necessary formulas are given in the exam instructions. Registration for the exam is mandatory and must be done by sending an email to the course responsible jhjur@kth.se. The results are available latest one week after the examination date.
  - **Home exam.** All tools and resources are allowed. All sources and references except course book 1 have to be clearly stated. The support of the teaching staff is limited to the assistance of a normal written examination (e.g. if obvious flaws are identified, guidelines on how to handle these will be given).

  **Remark.** The problems in the home exam must be solved individually. Similar solutions will be investigated. However, it is recommended to have a dialogue with other students. The time to solve the home exams is approximated with two working days.

Grades

The overall grade in the course is a contexture of the grades on the different parts of the course (supposing that all the parts have been passed). Grades are given according on the 7 step scale of the ECTS system (e.g. A-E, pass; Fx not passed but having a possibility to upgrade without taking the re-exam; F failed).

Maximum examination points for each part are:

- **Written examination** 1p
- **Home exam** 2p
- **Project assignment** 3p
- **Optional activities** 2p

The grades are divided into the scale:

- < 1.5 E
- ≥ 1.5 D
- ≥ 2.5 C
- ≥ 4.0 B
- ≥ 5.5 A
- ≥ 7.0 A+ (a letter of recommendation will be offered)
Submission of reports
The submission of reports and home assignments should be done directly or by e-mail to the course responsible or a course assistant. For the submission of the material are the following dates set:

- The project formulation must be formulated under course part 1 and submitted before course part 2 or the latest on 18th of April 2017.
- The reports of the laboratories have to be submitted on 9th of May 2017 for laboratory 1 and latest on 19th of May 2017 for laboratory 2.
- The home assignment must be submitted until 19th of May 2017.
- The project reports must be submitted by 19th of May 2017.
- The final version of the project report must be submitted by 2nd of June 2017.

Deadlines
Material handed in before deadline will be evaluated within a reasonable time. This enables the opportunity for the student to make adjustments based on the given feedback, so that the course can be passed within the same period. Material handed in after the deadline can only achieve a pass with 0 examination points. If a laboratory or project report is handed in after the deadline, it can add -0.5 examination points to the overall student examination score. Moreover, reports handed in after the 2nd of June will not be considered anymore in the given year.

Contact information
KTH
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Osquldas väg 6A
100 44 Stockholm

Examiner and lecturer
Patrik Hilber, telephone 08-790 7772, e-post patrik.hilber@ee.kth.se

Course responsible
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Course assistants
Kateryna Morozovska, kmor@kth.se
Sajeesh Babu, sbabu@kth.se
Ebrahim Shayesteh, ebrahim.shayesteh@ee.kth.se
Per Westerlund, perw@kth.se

Course information
Course webpage: http://www.kth.se/student/kurser/kurs/E12452?l=en

Course Feedback
After the students have successfully conducted the course parts and the project assignment, constructive feedback is welcome. Therefore, short feedback questionnaires are provided after the course. These include questions such as: What parts of the course were well executed and what could be done better (sorry no coffee will be available)? Did you learn new things and could that be applied to your (expected) profession? Suggestions on how to improve the course etc.
Schedule

The schedule for all course parts is presented in the following tables. The tables show the code, the lecture content, lecturer, rooms, time, and day. The code shows the type of session: lectures (F), guest lectures (F), exercise (Ö), laboratories (Lab), exams (TEN), and seminar (SEM). Lecturer names are abbreviated with: Patrik Hilber (PH), Per Westerlund (PW), Sajeesh Babu (SB), Kateryna Morozovska (KM), Jan Henning Jürgensen (JHJ), and Ebrahim Shayesteh (ES). The course rooms are all at the KTH, Main Campus, Stockholm and can be found here:
http://www.kth.se/places

Course part 1:

<table>
<thead>
<tr>
<th>Code</th>
<th>Content</th>
<th>Lecturer</th>
<th>Room</th>
<th>Time</th>
<th>Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1a</td>
<td>Course introduction</td>
<td>JHJ, All</td>
<td>Q24</td>
<td>10-11</td>
<td>Tue 28 March</td>
</tr>
<tr>
<td>F1b</td>
<td>Introduction to the field of reliability analysis</td>
<td>PH</td>
<td>Q24</td>
<td>11-12</td>
<td>Tue 28 March</td>
</tr>
<tr>
<td>F2</td>
<td>Risk and vulnerability analysis</td>
<td>ES</td>
<td>Q24</td>
<td>13-15</td>
<td>Tue 28 March</td>
</tr>
<tr>
<td>F3</td>
<td>Introduction to Markov models</td>
<td>PW</td>
<td>Q24</td>
<td>15-17</td>
<td>Tue 28 March</td>
</tr>
<tr>
<td>F4</td>
<td>Failure models</td>
<td>JHJ</td>
<td>Q24</td>
<td>8-10</td>
<td>Wed 29 March</td>
</tr>
<tr>
<td>F5</td>
<td>Markov models</td>
<td>ES</td>
<td>Q24</td>
<td>10-12</td>
<td>Wed 29 March</td>
</tr>
<tr>
<td>F6</td>
<td>Methods for power system analysis</td>
<td>ES</td>
<td>Q24</td>
<td>13-15</td>
<td>Wed 29 March</td>
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<tr>
<td>O1</td>
<td>Exercise</td>
<td>PW, All</td>
<td>Q24</td>
<td>15-17</td>
<td>Wed 29 March</td>
</tr>
<tr>
<td>F7</td>
<td>Approximative methods for system analysis</td>
<td>PH</td>
<td>V35</td>
<td>8-10</td>
<td>Thu 30 March</td>
</tr>
<tr>
<td>F8</td>
<td>Methods for analysis of the power grid and stations</td>
<td>ES, SB</td>
<td>V35</td>
<td>10-12</td>
<td>Thu 30 March</td>
</tr>
<tr>
<td>Ö2, Lab</td>
<td>Defining and preparing the project and the laboratory</td>
<td>PH, SB, All</td>
<td>V35</td>
<td>14-15</td>
<td>Thu 30 March</td>
</tr>
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</table>

Own work between course part 1 and 2: formulation of the project assignment

Course part 2:

<table>
<thead>
<tr>
<th>Code</th>
<th>Content</th>
<th>Lecturer</th>
<th>Room</th>
<th>Time</th>
<th>Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEN1</td>
<td>Exam</td>
<td>All</td>
<td>Q24</td>
<td>10-12</td>
<td>Tue 18 April</td>
</tr>
<tr>
<td>F9</td>
<td>Guest lecture: Olle Hansson, Ellevio AB</td>
<td>Olle Hansson, KM, All</td>
<td>Q24</td>
<td>13-15</td>
<td>Tue 18 April</td>
</tr>
<tr>
<td>F10</td>
<td>Combined analysis of primary and secondary systems: Overview</td>
<td>SB</td>
<td>Q24</td>
<td>15-17</td>
<td>Tue 18 April</td>
</tr>
<tr>
<td>Dinner</td>
<td>Course dinner</td>
<td>All</td>
<td>To be decided</td>
<td>17-20</td>
<td>Tue 18 April</td>
</tr>
<tr>
<td>F11</td>
<td>Methods for reliability importance</td>
<td>PH</td>
<td>Q24</td>
<td>8-10</td>
<td>Wed 19 April</td>
</tr>
<tr>
<td>F12</td>
<td>Asset Management</td>
<td>KM</td>
<td>Q24</td>
<td>10-12</td>
<td>Wed 19</td>
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### Course part 3:

<table>
<thead>
<tr>
<th>Code</th>
<th>Content</th>
<th>Lecturer</th>
<th>Room</th>
<th>Time</th>
<th>Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ö4</td>
<td>Condition monitoring workshop</td>
<td>PH, All</td>
<td>Q24</td>
<td>10-12</td>
<td>Tue 9 May</td>
</tr>
<tr>
<td>F16</td>
<td>Lifetime analysis</td>
<td>PW</td>
<td>Q24</td>
<td>13-15</td>
<td>Tue 9 May</td>
</tr>
<tr>
<td>Ö4</td>
<td>Theory recap</td>
<td>All</td>
<td>Q24</td>
<td>15-17</td>
<td>Tue 9 May</td>
</tr>
<tr>
<td>F17</td>
<td>Cost- and LCC-analysis</td>
<td>JHJ</td>
<td>Q24</td>
<td>8-10</td>
<td>Wed 10 May</td>
</tr>
<tr>
<td>F18</td>
<td>Guest lecture: Matz Tapper Svensk Energi</td>
<td>Matz Tapper, All</td>
<td>Q24</td>
<td>10-12</td>
<td>Wed 10 May</td>
</tr>
<tr>
<td>Lab2</td>
<td>Laboratory part 2: <em>LCC-analysis for the power grid with an example of an actual case study within RCAM</em></td>
<td>JHJ</td>
<td>Q24</td>
<td>13-17</td>
<td>Wed 10 May</td>
</tr>
<tr>
<td>F19</td>
<td>Introduction to Monte Carlo simulations</td>
<td>ES</td>
<td>Q24</td>
<td>8-10</td>
<td>Thu 11 May</td>
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<tr>
<td>F20</td>
<td>Methods for reliability centred maintenance</td>
<td>PH</td>
<td>Q24</td>
<td>10-12</td>
<td>Thu 11 May</td>
</tr>
<tr>
<td>Ö5</td>
<td>Project Work</td>
<td>Students</td>
<td>Q24</td>
<td>13-15</td>
<td>Thu 11 May</td>
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<tr>
<td>Re-exam</td>
<td>Re-exam – second opportunity to successfully pass the written examination.</td>
<td>All</td>
<td>Q24</td>
<td>13-15</td>
<td>Thu 11 May</td>
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**Own work between course part 2 and 3:** work with project assignment.

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**Course part 3:**

- **Ö4:** Condition monitoring workshop
  - PH, All
  - Room Q24
  - Time 10-12
  - Day Tue 9 May

- **F16:** Lifetime analysis
  - PW
  - Room Q24
  - Time 13-15
  - Day Tue 9 May

- **Ö4:** Theory recap
  - All
  - Room Q24
  - Time 15-17
  - Day Tue 9 May

- **F17:** Cost- and LCC-analysis
  - JHJ
  - Room Q24
  - Time 8-10
  - Day Wed 10 May

- **F18:** Guest lecture: Matz Tapper Svensk Energi
  - Matz Tapper, All
  - Room Q24
  - Time 10-12
  - Day Wed 10 May

- **Lab2:** Laboratory part 2: *LCC-analysis for the power grid with an example of an actual case study within RCAM*
  - JHJ
  - Room Q24
  - Time 13-17
  - Day Wed 10 May

- **F19:** Introduction to Monte Carlo simulations
  - ES
  - Room Q24
  - Time 8-10
  - Day Thu 11 May

- **F20:** Methods for reliability centred maintenance
  - PH
  - Room Q24
  - Time 10-12
  - Day Thu 11 May

- **Ö5:** Project Work
  - Students
  - Room Q24
  - Time 13-15
  - Day Thu 11 May

- **Re-exam:** Re-exam – second opportunity to successfully pass the written examination.
  - All
  - Room Q24
  - Time 13-15
  - Day Thu 11 May
Home assignment: Due on 19th of May 2016

<table>
<thead>
<tr>
<th>Code</th>
<th>Content</th>
<th>Lecturer</th>
<th>Room</th>
<th>Time</th>
<th>Day</th>
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<tbody>
<tr>
<td>TEN2</td>
<td>Home assignment</td>
<td>All</td>
<td>n/a</td>
<td>n/a</td>
<td>Fri 19 May</td>
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Own work before the last seminar: finishing the project report and preparing for the oral presentation and reviewing another students report

Seminar:

<table>
<thead>
<tr>
<th>Code</th>
<th>Content</th>
<th>Lecturer</th>
<th>Room</th>
<th>Time</th>
<th>Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEM</td>
<td>Seminar: oral presentation with questions from the reviewers and others</td>
<td>All</td>
<td>Q24</td>
<td>10-16</td>
<td>Wed 24 May</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>n/a</td>
<td>n/a</td>
<td>Fri 19 May</td>
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