Engineering Tripos Part IB, 2P5: Electrical Power, 2024-25

Course Leader

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Lecturer

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Timing and Structure

Lent term weeks 1 - 4, 2 lectures per week so 8 lectures in total.

Aims

The aims of the course are to:

- Introduce the student to modern electrical power systems including three-phase circuits, synchronous generators, transmission and distribution of electrical power, and the three-phase induction motor.
- Show how electrical power systems are rapidly evolving in order to meet net zero targets.

Objectives

As specific objectives, by the end of the course students should be able to:

- Understand why three-phase systems are used universally for bulk power transfer.
- Analyse balanced three-phase circuits consisting of passive component loads (resistor, inductor, capacitor).
- Appreciate how the UK generating mix is evolving in order to meet net zero targets, and understand some of the challenges involved in this transition.
- Understand the principles of operation of the synchronous generator and how to use its equivalent circuit to carry out performance calculations.
- Know how output real and reactive power are controlled in synchronous generators.
- Know how three-phase power is transmitted and distributed, and understand the limitations on transmission and distribution lines through calculations.
- Understand how the grid is controlled in order to meet the demand for real and reactive power, and what happens in the event of faults causing loss of generating capacity.
- Understand the principles of operation of the three-phase induction motor, and the derivation of the per-phase equivalent circuit.
- Carry out performance calculations on the induction motor using the per-phase equivalent circuit.
- Understand the factors controlling the shape of the induction motor torque/speed curve.

Content

The functioning of modern industrial society depends heavily upon the ready availability of energy in a form that can be transported cheaply and converted easily into other forms. The advantages of electricity make it the overwhelming choice in many applications. In the transition to net zero these applications are expanding to include electrical vehicles and heating systems based on electrically-powered heat pumps. Thus, the UK grid is undergoing a period of enormous and rapid change. However, many of the fundamentals of electrical power systems remain constant, such as the use of three-phase systems for the generation, transmission and distribution of electrical power, the use of synchronous machines for a significant amount of power generation, whilst three-phase induction motors are still the main consumer of industrial electrical power. Thus this course will cover these basics, but in a forward-looking manner which will reference some of the emerging technologies that will facilitate the transition to net zero, as well as highlighting some of the challenges.

Three-phase systems (1.5L)

- Star and delta-connected loads and sources, and the relationship between line and phase quantities.
- Star-delta transformation.
- Real, reactive and apparent power in terms of line quantities.
- Single phase representation.
- Solution of balanced three-phase circuits including mixed loads.
- Power factor correction.

Generation (2.5L)

- Overview of UK generating mix, and how it is evolving to meet net zero.
- Features of electrical energy and how they impact on the re-engineering of the UK electrical power supply system.
- Physical principles of a.c. generators.
- Comparative utility of single-phase and three-phase and justification of the global use of three-phase systems.
- Production of a rotating magnetic field by a three-phase winding, multi-pole windings and the concept of synchronous speed.
- Standalone and parallel operation of synchronous generators and the concept of the infinite bus.
- Conditions for the steady conversion from input mechanical to output electrical power.
- Development of the synchronous machine equivalent circuit.
- Control of real and reactive power, concept of the load angle.
- Operation of synchronous generators as synchronous compensators.
- Generator construction.
- Generator rating.
- Steady-state analysis of generators using the equivalent circuit and phasor diagrams.

Transmission and Distribution (2L)

- Configuration and implementation of the UK transmission and distribution networks.
- Changes to facilitate the transition to net zero: embedded generation; integration of battery energy storage systems; new technologies such as vehicle to grid; HVDC links and the idea of diversity of supply to combat intermittency of renewables.
- Theory of real and reactive power flow in three-phase transmission lines.
- Application of theory to typical examples.
- Limitations on transfer of real and reactive power.
- System level control of real and reactive power.
- Role of grid inertia in stabilising the grid, and impact of moving to more renewable power sources.
- Grid frequency as a measure of mismatch between supply and demand of real power, and use of the grid reserve capacity and low frequency demand disconnection in the event of sudden major loss of generating capacity.
- Some of the grid-level issues of transitioning to net zero.

Induction Motors (2L)

- Principles of operation.
- Derivation of the equivalent circuit.
- No-load and locked rotor tests to determine the equivalent circuit parameters.
- Construction.
- Performance predictions using the equivalent circuit.
- Torque/speed characteristics and control of rotor resistance to vary them.

Further notes

This course has undergone a major rewrite for the 2024/25 academic year. It has been reduced from 10 to 8 lectures, mainly by reducing the amount of synchronous generator theory and removing material on the synchronous generator operating chart. The material on transmission and distribution has been completely rewritten. The per-unit method of analysis is no longer included (so ignore past Tripos questions on that) with a greater focus on the theory of three-phase transmission lines, and grid-level control of real and reactive power. This change facilitates more material on the re-engineering of the grid as the UK electrical power system transitions to net zero.

Examples papers

There are two examples papers:

5/3 - Three Phase Circuits and Synchronous Machines.

5/4 - Transmission of Power and Induction Motors.

Booklists

Please refer to the Booklist for Part IB Courses for references to this module, this can be found on the associated Moodle course.

Examination Guidelines

Please refer to Form & conduct of the examinations [2].

UK-SPEC

This syllabus contributes to the following areas of the UK-SPEC [3] standard:

Toggle display of UK-SPEC areas.

GT1

Develop transferable skills that will be of value in a wide range of situations. These are exemplified by the Qualifications and Curriculum Authority Higher Level Key Skills and include problem solving, communication, and working with others, as well as the effective use of general IT facilities and information retrieval skills. They also include planning self-learning and improving performance, as the foundation for lifelong learning/CPD.

IA1

Apply appropriate quantitative science and engineering tools to the analysis of problems.

IA3

Comprehend the broad picture and thus work with an appropriate level of detail.

KU1

Demonstrate knowledge and understanding of essential facts, concepts, theories and principles of their engineering discipline, and its underpinning science and mathematics.

KU2

Have an appreciation of the wider multidisciplinary engineering context and its underlying principles.

E1

Ability to use fundamental knowledge to investigate new and emerging technologies.

E2

Ability to extract data pertinent to an unfamiliar problem, and apply its solution using computer based engineering tools when appropriate.

E3

Ability to apply mathematical and computer based models for solving problems in engineering, and the ability to assess the limitations of particular cases.

P1

A thorough understanding of current practice and its limitations and some appreciation of likely new developments.

P3

Understanding of contexts in which engineering knowledge can be applied (e.g. operations and management, technology, development, etc).

US1

A comprehensive understanding of the scientific principles of own specialisation and related disciplines.

US3

An understanding of concepts from a range of areas including some outside engineering, and the ability to apply them effectively in engineering projects.

US4

An awareness of developing technologies related to own specialisation.

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