EE 374
FUNDAMENTALS OF POWER SYSTEMS AND ELECTRICAL EQUIPMENT

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Course: 3 Credits, Spring 2021, METU Dept. of Electrical and Electronics Engineering

Schedule: Lectures: Monday (15.40-17.30), Wednesday (10.40-11.30)
Recitation: Wednesday (11.40-12.30) (dates will be announced)

Prerequisite: EE 202

References/Textbooks:

1. A. R. Bergen and V. Vittal, Power System Analysis, Prentice-Hall, 2nd Edition, 2000 (Reserve, TK1001 .B44 2000)
2. J. J. Grainger and W. D. Stevenson, Power System Analysis, McGraw-Hill, 1994 (Reserve, TK3001 .G73 1994)
3. N. Nohan, Electric Power Systems – A First Course, Wiley, 2012.
4. Lecture notes.

Teaching Asistants:

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Grading (tentatively):

Three midterm exams, each 14%:	42%
Project:	14%
Homeworks, quizzes, attendance:	12%
Final Exam:	32%

Course Evaluation:

Attendance (to online lectures) is strongly recommended. In order to be admitted to the final examination, a student must have obtained a combined average of at least 30 % out of 100 in midterm examinations. Students not fulfilling both of the above conditions may not be permitted to enter the final examination and will be graded NA at the end of the semester.

Exams are planned as closed book and notes, emphasizing basic concepts and problem solving. Homework assignments will not be accepted late. Each student will be viewed as a future professional in engineering, and thus the highest ethical standards are presumed. <u>It is expected that each student presents his/her own work.</u>

COURSE OUTLINE

Week	Subject	Related Material
1	Introduction - Structure of power systems & Turkish Electric Network - Contemporary issues in power systems engineering	Handouts
2	Power in alternating-current circuits, - Active and reactive power concepts	Lecture Notes
3-4	Balanced three-phase systems and power-factor correction	1/Ch. 2 2/Ch.1
5-6	Review of Transformers and Synchronous Machines - Simplified transformer model - Per-unit normalization - Three-phase transformers (connections) - Transformer types (auto-transformers, tap-changers, phase shifters, three-winding transformers)	1/Ch. 5, 6, 7, 8 2/Ch.2, 3
6	System representation and single-line diagrams	Lecture Notes
7-8	Transmission Line Parameters - Computing the series resistance and inductance - Computing the shunt capacitance	1/Ch. 3 2/Ch.4, 5
9	Transmission Line Modeling	1/Ch. 4 2/Ch.6
10	Power and wiring cables, cable selection	Lecture Notes
11	Symmetrical Three-Phase Faults	1/Ch. 12 2/Ch.10
12	Protection: Relays, Fuses, circuit-breakers, load breakers	Lecture Notes
13	- Conventional energy generation (fossil, hydro, nuclear) - Renewable energy sources (solar, wind, etc.) - Distributed generation, micro grids - Turkish electric network (data, structure)	Lecture Notes
14	Electrical safety and grounding	Lecture Notes

REFERENCES

(1) R.E. Scott, Linear Circuits, Addison-Wesley, 1960 (Chapter 19)
(2) R.M. Kerchner and G.F. Corcoran, Alternating-Current Circuits, John Wiley & Sons, 4th Ed., 1960 (Chapter 8).
(3) J.W. Nilsson, Electric Circuits, Addison Wesley, 1984. (Chapter 11-12).
(4) T. Gönen, Electric Power Distribution Systems, McGraw-Hill, 1985.
(5) A.J. Pansini, Electrical Distribution Engineering, McGraw-Hill, 1983.
(6) T. Schmelcher, Low-voltage Handbook, John Wiley & Sons, 1984.
(7) R. Roeper, Short Circuit Currents in Three-Phase Systems, John Wiley & Sons, 1985.
(8) F.W. Kussy and J.L.Warren, Design Fundamentals for Low-Voltage Distribution and Control, Marcel Dekker, Inc., 1986.

(9) IEEE, Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems, ANSI-IEEE Std.493-1980, Gold Book
(10) IEEE, Recommended Practice for Electric Power Distribution for Industrial Plants, ANSI-IEEE Std. 141-1986, Red Book.
(11) Siemens, Electrical Installations Handbook, Ed. by G.G.Seip, 2nd Ed., 1987.
(12) L. M. Faulkenberry and W. Coffer, Electrical Power Distribution and Transmission, Prentice Hall, 1996.
(13) Fitzgerald, Kingsley and Umans, Electric Machinery, McGraw-Hill, Fourth Ed., 1983.
(14) M. E. El-Hawary, Introduction to Electrical Power Systems, John Wiley & Sons, 2008.
(15) T. Gönen, Modern Power System Analysis, Wiley, 1988.
(16) T. Gönen, Electric Power Transmission System Engineering, Wiley, 1988.
(17) S. A. Nasar, Electric Energy Systems, Prentice Hall, 1996.
(18) H. Saadat, Power System Analysis, McGraw-Hill, 2002
(19) T.K. Nagsarkar and M.S. Sukhija, Power System Analysis, Oxford University Press, 2007.
(20) N. D. Tleis, Power System Modelling and Fault Analysis: Theory and Practice, Newnes, 2008.
(21) J. D. Glover, M.S. Sarma, T.J. Overbye, Power System Analysis and Design, Thomson, 6th Ed., 2016.
(22) L.L. Grigsby, Power System Analysis and Simulation, Boca Raton: CRC Press, LLC, 2001.
(23) J.C. Das, Power System Analysis, Marcel Dekker, 2002.
(24) D.P. Kothari, I.J. Nagrath, Modern Power System Analysis, Tata McGraw Hill, 4th Ed., 2011.

USEFUL WEB LINKS AND OTHER RESOURCES:

Check the web page of the course at METU-CLASS system. Announcements and new course material will be added through the semester: https://metuclass.metu.edu.tr/

LINKS TO SIMILAR COURSES:

1. Florida State University
   EEL 4213 & EEL 5930 Power System Analysis
   EEL 6252 Computational Methods for Power System Analysis
2. Dr. Bruce Mork, Michigan Technological University
   EE 5200 Advanced Methods in Power Systems Analysis
   http://www.ece.mtu.edu/faculty/bamork/ee5200/
   EE 5240 Computer Modeling of Power Systems
   http://www.ece.mtu.edu/faculty/bamork/ee5240/
3. Goran Andersson, EEH - Power Systems Laboratory, ETH Zurich
   http://research.iaun.ac.ir/pd/bahador.fani/pdfs/UploadFile_6990.pdf
4. Video lectures on power system topics: India
   https://freevideolectures.com/course/2353/power-systems-analysis
5. NPTEL, India: http://nptel.ac.in/courses/108104051/ui/TOC.htm

- Useful References, Journals, Publications
  - Research Journals and Transactions
    - IEEE Xplore - online database of all standards, and all articles since 1989 |
    - IEEE Transactions on Power Systems
    - IEEE Transactions on Power Delivery
    - IEEE Transactions on Smart Grid
    - IEEE Transactions on Industrial Applications

        - IEEE Transactions on Power Electronics
        - IEE Proceedings - Generation, Transmission and Distribution
        - IEE Proceedings - Electric Power Applications
    - Magazines on Computer Methods and Engineering Applications
        - IEEE Power and Energy Magazine (Fusion of Computer Applications in Power Systems, CAPS + Power Engineering Review)
        - IEEE Industry Applications Magazine
    - Engineering Applications Magazines
        - Transmission & Distribution World - "T&D Magazine"
        - Power Quality Magazine

- Public Domain or Royalty-Free Software
    - **ATP** - Alternative Transients Program (Royalty Free, Licensing Required). It is the most widely used Electromagnetic Transients Program in the world! ATP is a universal program system for digital simulation of transient phenomena of electromagnetic as well as electromechanical nature. http://www.emtp.org/
    - **InterPSS**: is a development project aimed to develop an Internet technology based software system for design, analysis, and simulation of power systems (Public domain). http://sites.google.com/a/interpss.org/interpss/
    - **PowerWorld™ Simulator**: Possible to download free academic version. http://www.powerworld.com/
    - **Other Educational Software** - List of Links Provided by IEEE Power Engineering Education Committee: http://www.ece.mtu.edu/faculty/ljbohman/peec/Dig_Rsor.htm
    - **PCFLOW, PCFLOWH** - Load Flow and Harmonic Load Flow, Univ of Texas Austin, Prof. Mack Grady (Public Domain) http://www.ece.utexas.edu/~grady/PCFLO.html

- Available Commercial Software:
    - **Aspen** - Loadflow, Short-Circuit, Relay Coordination (Academic Version Available) http://www.aspeninc.com/
    - **MatLab with Simulink and Power System Toolbox** - Full spectrum of power system analysis and controls (Academic Versions Available) http://www.mathworks.com/products/simulink/ http://www.eagle.ca/~cherry/pst.htm
    - **PSS/E** - Loadflow, Short-Circuit, Dynamic Stability (Academic Pricing Available) http://www.pti-us.com/pti/software/psse/psse.htm
    - **CAPE** - Loadflow, Short-Circuit, and Relay Coordination (Academic Pricing Available) http://www.electrocon.com/cape/cape.htm
    - **V-Flow, V-Net, V-Pro, V-Harm, V-Cap, etc** . - Power Verdict Series: Suite of programs by Cooper Power Systems. http://www.cooperpower.com/Products/Systems/PowerVerdict/
    - **ETAP PowerStation** - Full suite for power system analysis and design. http://etap.com/
    - **Transmission 2000** - Loadflow, Short Circuit, Dynamic Stability, and Relay Coordination (Academic Version Available). http://www.cai-ngr.com/T2000.htm
    - **EDSA** - Loadflow, Short Circuit, Relaying, AC and DC systems (mostly industrial, auto, shipboard). http://www.edsa.com/
    - **CYME**: http://www.cyme.com/
    - **DIgSILENT PowerFactory**: one of the leading high end power analysis tools. http://www.digsilent.de/ ***(USED IN EE472 course)***

NEW CHALLENGES AND RESEARCH AREAS IN POWER SYSTEMS

A. Smart Grid: Development and application of new technologies (IT, AI), changing trends, environmental concerns: Smart grid, micro grids, plug-in electric vehicles, energy storage, AC versus DC; IoT, big data (cloud tech.), cyber security

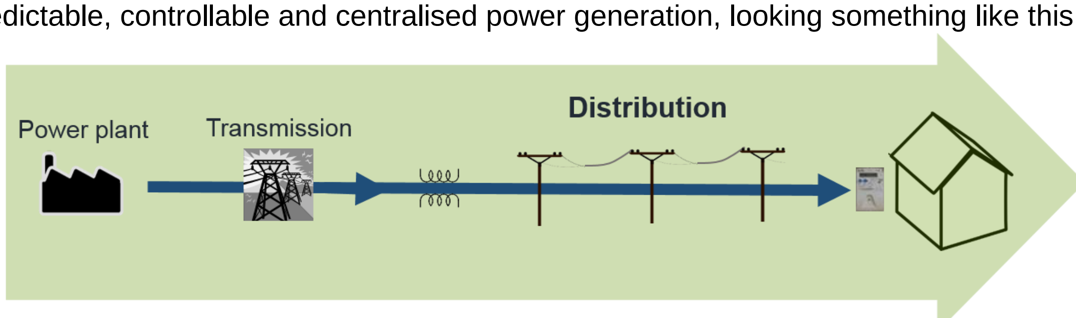
The "**smart grid**" has come to describe a next-generation electrical power system that is typified by the increased use of communications and information technology in the generation, delivery and consumption of electrical energy. "Smart grid" generally refers to a class of technology people are using to bring utility electricity delivery systems into the 21st century, using computer-based remote control and automation. The benefits associated with the Smart Grid include:

- More efficient transmission of electricity
- Quicker restoration of electricity after power disturbances
- Reduced operations and management costs for utilities, and ultimately lower power costs for consumers
- Reduced peak demand, which will also help lower electricity rates
- Increased integration of large-scale renewable energy systems
- Better integration of customer-owner power generation systems, including renewable energy systems
- Improved security.

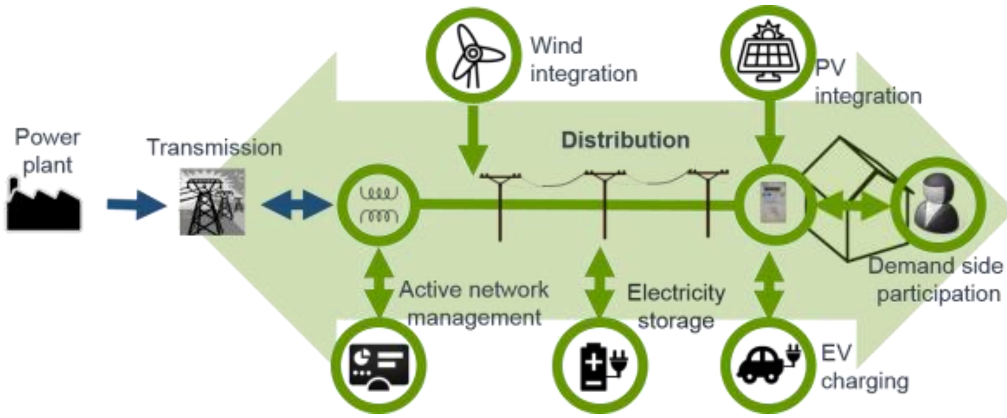
The IEEE PES Technical Report PES TR-66 defines a **microgrid** as follows: "Generally, a microgrid is defined as a group of distributed energy resources (DERs), including Renewable Energy Resources (RES) and Energy Storage Systems (ESS), and loads, that operate together locally as a single controllable entity. Microgrids exist in various sizes and configurations; they can be large and complex networks with various generation resources and storage units serving multiple loads, or small and simple systems supplying a single customer."

IEEE: http://smartgrid.ieee.org/
DOE: http://energy.gov/oe/services/technology-development/smart-grid
DOE: https://www.smartgrid.gov/
EU: http://www.smartgrids.eu/
EDSO: http://www.edsoforsmartgrids.eu/
IEC: http://smartgridstandardsmap.com/

Traditionally, energy systems from power generation to homes are one-directional and based on more predictable, controllable and centralised power generation, looking something like this:



Increasingly, more energy is being generated locally and connected directly to distribution networks, from solar panels on your roof, to small power plants. This is generally referred to by distribution system operators (DSOs) as distributed energy resources (DER) and in the specific case of renewables, distributed renewable energy sources (DRES). Instead of the one-directional system shown above, distribution networks are starting to look more like this:



Also, check the following videos/animation on Smart Grid:
https://energy.gov/eere/education/videos/smart-grid-animation
http://www.whiteboardanimation.com/video/northern-utilities-smart-grid
https://vimeo.com/51192814
https://www.youtube.com/watch?v=zB4-mBQPd7k

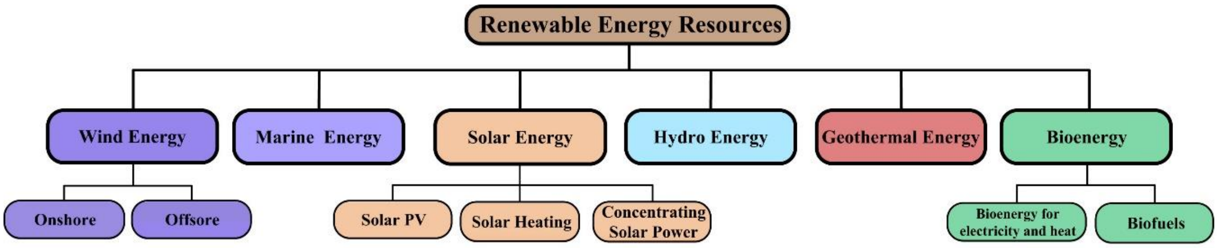
B. Renewable and distributed generation: Developments in technology (solar, wind, fuel cells, micro- turbines, bio energy, etc); environmental concerns; investment cost; their integration to the grid/operational issues; carbon market (international regulations)

Renewable energy is energy that is collected from renewable resources, which are naturally replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat. Renewable energy often provides energy in four important areas: electricity generation, air and water heating/cooling, transportation, and rural (off-grid) energy services. Based on 2016 data, renewables contributed 19.2% to humans' global energy consumption and 23.7% to their generation of electricity in 2014 and 2015, respectively.

Distributed energy is generated or stored by a variety of small, grid-connected devices referred to as distributed energy resources (DER) or distributed energy resource systems. Conventional power stations, such as coal-fired, gas and nuclear powered plants, as well as hydroelectric dams and large-scale solar power stations, are centralized and often require electricity to be transmitted over long distances. By contrast, DER systems are decentralized, modular and more flexible technologies, that are located close to the load they serve, albeit having capacities of only 10 megawatts (MW) or less.

DER systems typically use renewable energy sources, including small hydro, biomass, biogas, solar power, wind power, and geothermal power, and increasingly play an important role for the electric power distribution system. A grid-connected device for electricity storage can also be classified as a DER system, and is often called a distributed energy storage system (DESS). By means of an interface, DER systems can be managed and coordinated within a smart grid. Distributed generation and storage enables collection of energy from many sources and may lower environmental impacts and improve security of supply.

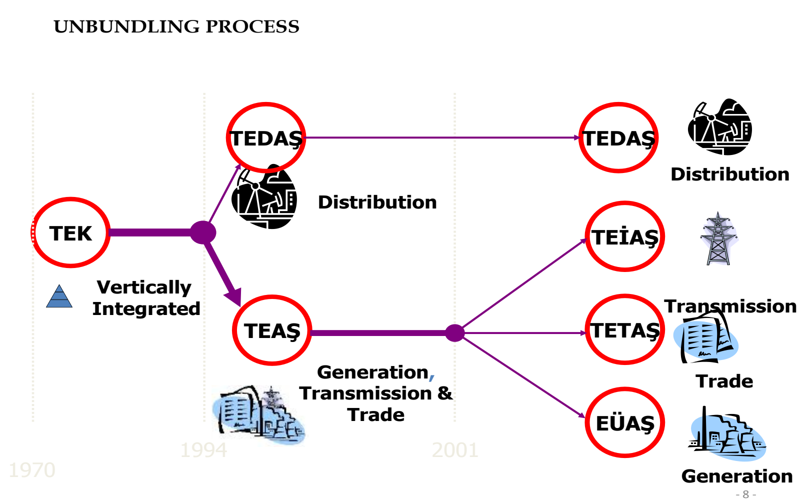
Check: https://en.wikipedia.org/wiki/Renewable_energy,
https://ourworldindata.org/renewable-energy



C. **<u>Deregulation</u>: private investments, competition/market environment, trading/bidding, risk assesment, prosumer concept, carbon market**

Deregulation is the reduction or elimination of government power in a particular industry, usually enacted to create more competition within the industry. The rationale for deregulation is often that fewer and simpler regulations will lead to raised levels of competitiveness, therefore higher productivity, more efficiency and lower prices overall.

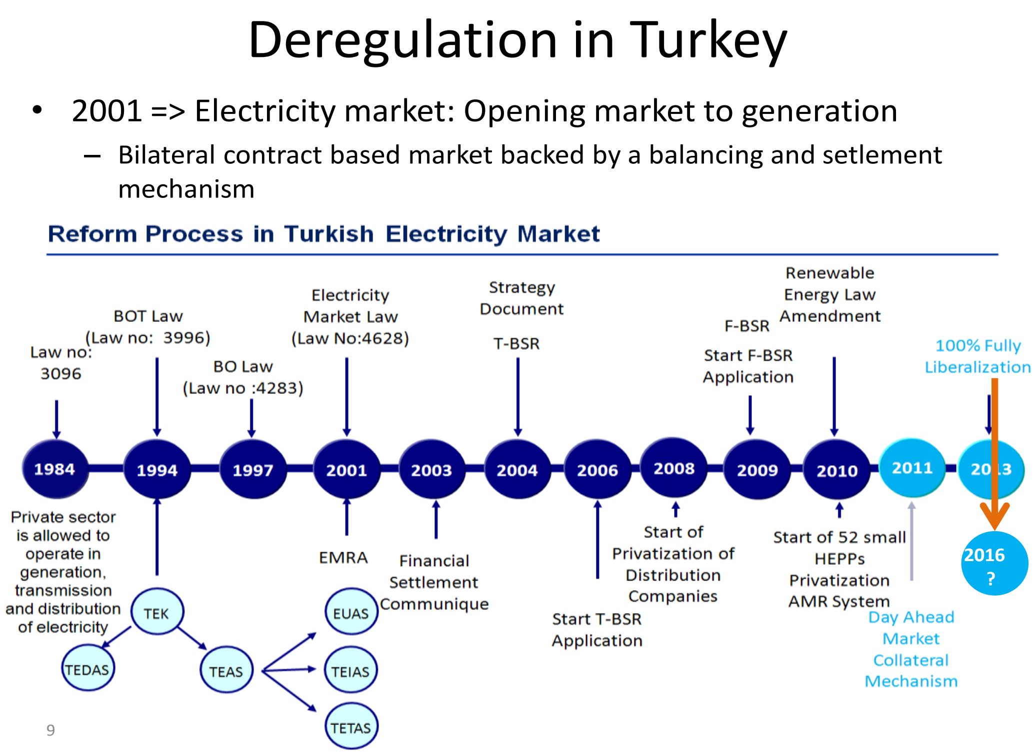
The electric power industry is also undergoing the most profound changes in its history (since 1990s). The disintegration of the vertically integrated industry structure is resulting in the unbundling of products and services and the advent of new players and structures. The cooperative and collegial environment of the past in which the obligation to serve was of paramount importance is rapidly being replaced by a fiercely competitive atmosphere of contracts and markets. The significant and wide-ranging legislative and regulatory developments in many countries serve to spur on these developments at an even more frantic pace. The engineering, planning, operations and control that evolved in the vertically integrated industry structure are themselves changing to reflect the new realities of the emerging regime.



<u>Enerji Piyasası Düzenleme Kurumu (EPDK)</u>: The Electricity Market Regulatory Authority (EMRA) had been established as per Law no. 4628 in Turkey and it was later renamed as **Energy Market** Regulatory Authority.
http://www.epdk.gov.tr/english/default.asp (In Turkish: http://www.epdk.gov.tr)

<u>Türkiye Elektrik İletim A.Ş. (TEİAŞ)</u>: Turkish Electricity Transmission Company
http://www.teias.gov.tr/eng/

Enerji Piyasaları İşletme Anonim Şirketi (EPİAŞ): Energy Market operator, founded in 2015
In addition to operational Day Ahead, Ancillary Services and Balancing Markets, Intraday Market will give participants the opportunity to almost real-time trading and balance their portfolios in short term.
https://www.epias.com.tr/



General Resources on Electricity Restructuring:

Prepared by: Dr. Leigh Tesfatsion (Iowa State University)
http://www.econ.iastate.edu/tesfatsi/epres.htm

You can also check the web page of Dr. Bruce Mork (Michigan Technological University) for the links of useful web pages: http://www.ece.mtu.edu/faculty/bamork/ee5200/

From USA:
PJM Homepage: https://www.pjm.com/
NY-ISO: New York ISO Homepage: http://www.nyiso.com/public/index.jsp
CAL-ISO: California ISO Homepage: http://www.caiso.com/Pages/default.aspx

In addition:
http://en.wikipedia.org/wiki/Electricity_market
http://en.wikipedia.org/wiki/Independent_System_Operator
http://en.wikipedia.org/wiki/European_Transmission_System_Operators

PROPERTIES OF POWER SYSTEMS:

- **LARGE SCALE SYSTEM** (Modeling/Analysis difficult, big data)
- **DYNAMIC NATURE** (Daily load curve, seasonal variations, intermittent nature of renewables)
- **INHERENT NON-LINEARITY**
- **STRONG ECONOMIC ASPECT** (Cost, Deregulation/Market Operation, international trade through interconnections)

STRONG INTERACTION WITH OTHER AREAS OF EE:

- Electronics/Measurement/Hardware (sensors, digital relays, RTUs, smart meters)
- Computers and networks (Smart Grid concept)
- Main frame or PCs
- Networking (WAN, IoT, Big data, cyber security)
- Numerical analysis/techniques, data structures
- Communication networks, data transfer (SCADA applications, Smart Grid, IoT, cloud)
- Control (Exciters, governors, AGC), Optimization techniques
- Power Electronics (Power Quality, SVC, STATCOM, HVDC transmission)
- Waves (Travelling waves of switching and lightning overvoltages)
- Properties of insulation. measurement techniques (High Voltage)

CAREER PATHS AFTER GRADUATION

- DESIGN AND MANUFACTURING OF EQUIPMENT
  (National electro-mechanical industry; LV, MV or HV: Transformers, cable/conductors, switching devices, generators, relays, measuring/monitoring devices, etc. Or export/import/marketing)
  Based on: International standards, tests

- DESIGN AND IMPLEMENTATION OF ANALYSIS SOFTWARE
  (National and international corparations)

- DESIGN AND PLANNING OF THE SYSTEM/NETWORK
  (TEIAŞ, Distribution companies, consulting firms)
  Based on: Heavy use of computer simulations

- BUILDING/CONSTRUCTION
  (Power stations, transmission lines, substations, wind farms, etc)

- OPERATING THE SYSTEM/NETWORK
  (TEIAŞ, Distribution companies, factories/plants)

- MARKET OPERATIONS
  (Analytical approaches/financial operations/ Forecasting load or prices, bidding strategies, etc: Generation or distribution companies, TEİAŞ, EPİAŞ

POWER SYSTEMS OPTION: METU EEE Undergraduate Program Requirements

Core Courses: (EE361, EE374), EE 471, EE 472, EE 474
Technical Electives: Any three of the following:
EE 475, EE 476, EE 478
EE 462, EE 463, EE 464,
EE 441, EE 443, EE444, EE 447,
EE 402, EE 404**,** EE407, EE 430, EE496, EE498

Other power systems courses at METU:

Undergraduate courses:
EE 471 POWER SYSTEM ANALYSIS I
EE 472 POWER SYSTEM ANALYSIS II
EE 474 DISTRIBUTION SYSTEMS
EE 475 HIGH VOLTAGE TECHNIQUES I
EE 476 HIGH VOLTAGE TECHNIQUES II
EE 478 POWER SYSTEM PROTECTION

Graduate Courses: (Note: EE471 and EE472 are "must courses" in the graduate program)
EE 571 WAVE PROPAGATION IN POWER SYSTEMS
EE 572 INSULATION COORDINATION
EE 573 POWER SYSTEM STABILITY AND DYNAMICS
EE 574 POWER SYSTEM REAL-TIME MONITORING & CONTROL
EE 575 ADVANCED HIGH VOLTAGE TECHNIQUES
EE 576 HIGH VOLTAGE MEASUREMENT TECHNIQUES
EE 577 ADVANCED POWER SYSTEM PROTECTION
EE 578 POWER SYSTEM PLANNING
EE 579 ECONOMIC OPERATION OF POWER SYSTEMS
EE 671 MODERN POWER SYSTEM OPERATION & CONTROL TECHNIQUES
EE 674 COMPUTATIONAL TECHNIQUES IN POWER SYSTEM ANALYSIS
EE 710 ELECTRICITY TRADING
EE 786 ELECTRICAL POWER QUALITY, MONITORING AND IMPROVEMENT