

# National Center for Assessment in Higher Education (QIYAS)

## Framework for Assessing Learning Outcomes in Engineering

(Electrical Engineering)

*December 2013*

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# 1. INTRODUCTION, BACKGROUND AND FRAMEWORK STRUCTURE

## 1.1 Introduction

The Ministry of Higher Education in Saudi Arabia has recently requested the National Center for Assessment in Higher Education (QIYAS) to launch an ambitious project to develop a comprehensive framework for assessing Learning Outcomes (LOs) in Engineering Education (Phase 1) and to subsequently prepare a unified engineering qualification exam based on the developed framework (Phase 2). The project covered the following areas of engineering education: Chemical, Civil, Computer, Electrical, Industrial, Mechanical, in addition to Architectural Engineering. In the first phase of this project, a multi-disciplinary team composed of university professors and experts from QIYAS was formed to develop the learning outcomes framework. During the work in this phase, the team interacted with many national and international institutions and experts. The team also reviewed available approaches and methodologies related to the development of frameworks for learning outcomes in engineering education. The review covered experiences from various countries worldwide including North America, Europe, Australia, New Zealand, Japan, Singapore, China, Korea, Malaysia and South Africa. The review also covered independent and important projects on learning outcomes such as the Accreditation Board for Engineering and Technology (ABET) in the United States [1], Engineers Australia (EA) [2], European Network for Accreditation of Engineering Education (EUR-ACE) [3], The UK Standard for Professional Engineering Competence (UK-SPEC) [4], Conceiving-Designing-Implementing-Operating (CDIO) initiative [5], Tuning-AHELO framework [6] and the National Architectural Accrediting Board (NAAB) [7]. In addition, two workshops were conducted at the QIYAS Center, to review the outcomes of the study. The first workshop was attended by high ranking officials from the Ministry of Higher Education and by several international experts on engineering education and development of learning outcomes. The second workshop was attended by

representatives of various local universities who presented their detailed comments on the framework.

## 1.2 Background on Learning Outcomes

The current international trends in education are showing a shift from the traditional teacher-centered approach to a student-centered approach. The teacher-centered approach focuses essentially on the teacher's input. Among the criticisms of this type of approach is that it can be difficult to identify precisely what the student has to be able to do in order to pass the course or program [8]. The alternative student-centered (or outcome-based) approach focuses on what the students are expected to be able to do at the end of the course or program [8]. Statements called learning outcomes are used to express what a learner is expected to know, understand and/or be able to demonstrate after completion of a process of learning [9]. Learning outcomes have strong implications on curriculum design, teaching, learning and assessment, as well as quality assurance. Engineering education is in the forefront of areas that should benefit from the student-centered approach. The Engineering education environment is changing as information and communication technologies are having greater impact, and innovation is becoming increasingly essential. The future role of engineering requires that non-technical skills should be added to the technical dimension of engineering education.

Moreover, in today's competitive environment, the assessment of learning outcomes has become a primary focus for engineering education worldwide. Employers as well as academic accreditation entities push for the incorporation of sound assessment techniques into engineering programs. The outcome-driven assessment process, if carefully designed and implemented, can be useful at different levels; (1) It can provide useful information on whether graduates have acquired the knowledge and skills defined by predetermined educational objectives; (2) It can also convey useful information to faculty and administrators on the effectiveness of the design and delivery of the educational program; (3) It can also

develop, in the long term, instruments to obtain comparable information on what students actually learn across different engineering colleges [8 -10].

The assessment of learning outcomes is particularly important to the Kingdom higher educational institutes. The Kingdom has recognized the need to move from a natural resource-based economy to a knowledge-based economy, which puts new priority on the role of universities in general and engineering colleges, in particular. Saudi's young engineering generation will need to acquire new skills and capabilities to meet the current diversification objectives and to be competitive with the best students from anywhere in the world. The proposed assessment framework will ensure that acceptable educational standards are fulfilled by public as well as private universities.

### 1.3 Structure of the Proposed Framework

One of the unique and innovative features of the developed framework is the hierarchy (multi-level) structure used in specifying the learning outcomes as well as the level of comprehensiveness which covers both the discipline and sub-discipline levels. As illustrated in Figure 1, four hierarchy levels are covered in the developed Framework of Engineering Learning Outcomes, namely:

- 1) **General Skills**, which cover learning outcomes for any higher education graduate (engineering or otherwise). General skills or generic skills also referred to as transferable or soft skills, address the basic competencies that all higher education graduates, including engineering graduates, ought to possess upon their graduation.
- 2) **Engineering Skills**, which cover learning outcomes for any engineering graduate regardless of his/her general specialty (discipline).
- 3) **Discipline-level Engineering Skills**, which cover learning outcomes for a given engineering specialty (Chemical Engineering, Civil Engineering, Computer Engineering, Industrial Engineering, Electrical Engineering, Architectural Engineering, and Mechanical Engineering)

- 4) **Sub-discipline-level Engineering Skills**, which cover learning outcomes for a given engineering specific specialty (Electronics Engineering, Materials Science and Engineering, Thermal and Desalination Engineering, Structural Engineering, Manufacturing systems engineering, Computer Networks, etc.)

In setting up the learning outcomes for General Engineering and for specific disciplines, the four key learning areas namely **Basic Sciences & Engineering Fundamentals, Engineering Analysis and Investigation, Engineering Design,** and **Engineering Practice** were considered. The proposed Learning outcomes were formulated using the revised Bloom taxonomy in the cognitive level (Remembering, Understanding, Applying, Analyzing, Evaluating and Creating) given in the Appendix.

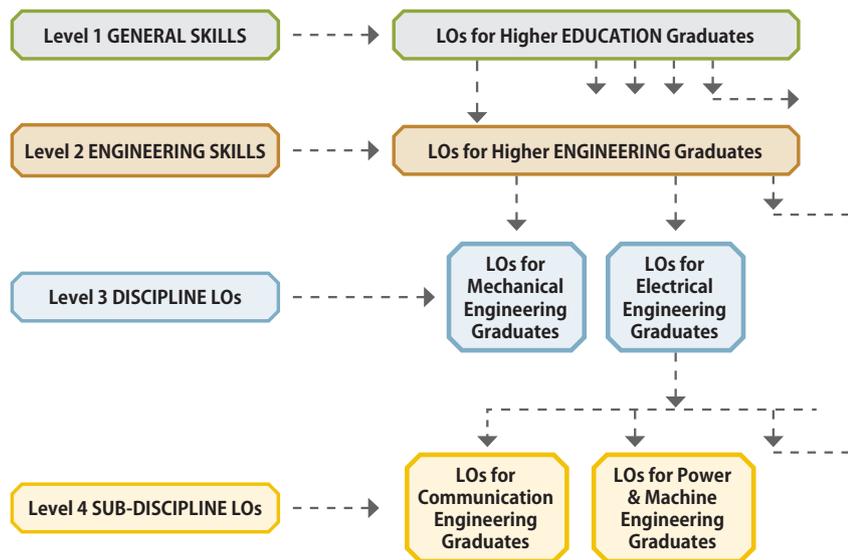


Fig. 1 Hierarchy levels of QIYAS Framework of Engineering Learning Outcomes

## 2. ELECTRICAL ENGINEERING LEARNING OUTCOMES (EE)

### 2.1 Discipline Level Learning Outcomes

Electrical Engineering (**EE**) skills include the knowledge of the fundamentals of various electrical engineering principal areas, namely, electric power and machines, communications and electronics as well as control systems. Electrical engineering graduates should be able to build on their acquired skills pertaining to the basics of engineering sciences as well as engineering design, analysis, investigation and practice skills, and consequently acquire electrical engineering discipline-level skills and demonstrate their knowledge and explain the basic concepts governing various electrical engineering phenomena and the associated design and operating principles. The following is the list of discipline related abilities, denoted by (DEE#) and under each ability there is a set of learning outcomes associated with the ability.

#### 2.1.1 Engineering Sciences

**DEE1.** The ability to identify electrical components and interpret their characteristics and material contents

##### *Learning Outcomes*

Graduates who possess this ability should be able to:

1. Identify characteristics of electrical circuit components and materials, such as resistance, inductance, capacitance, conductors, semiconductors and dielectrics
2. Explain the meaning, symbols and notations associated with various electrical quantities and master the usage of – and conversion between – their units of measurements

3. Demonstrate familiarity with the characteristics and composition of electrical components as well as their behavior under both direct and alternating current (DC, AC) excitations
4. State the principles of electrostatic, electromagnetic and Magneto-static fields, electric potential and current density

**DEE2.** The ability to apply the knowledge of engineering sciences, such as physics and chemistry, to formulate the governing relations and formulas with proper interpretation of the associated physical phenomena which determine the behaviors of such systems

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Describe the basic phenomena and concepts associated with electrical systems, such as magnetic coupling, resonance, losses, power and energy, and stability
2. State the components and functions of basic electric and electronic devices, such as operational amplifiers, rectifiers and filters
3. Demonstrate knowledge of the operating principles of key electronic components and devices, such as PN junctions and field-effect transistors (FETs)
4. Describe the fundamentals of communication systems, such as amplitude and frequency modulation (AM, FM), pulse modulation (amplitude, width and position), sampling, division multiplexing (frequency and time)
5. State the physical meaning and governing phenomena of communication systems processes and components, such as receivers, transmitters and repeaters, and shift keying (amplitude, frequency and phase)

### 2.1.2 Engineering Analysis and Investigation

**DEE3.** The ability to solve, with proper notation, and analyze electrical systems of limited-size using efficient and effective solution and analysis methods

#### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Apply basic laws and formulas of circuit theory, such as Ohm's and Kirchoff's laws as well as circuit theorems (Thevenin and Norton theorems, superposition principle, etc.)
2. Solve electrical circuit equations using fundamental techniques such as nodal and mesh analysis methods
3. Analyze electrical networks (such as two-port and three phase networks) with sinusoidal sources and apply the concept of phasors, complex powers and power factor in circuit analysis
4. Explain and analyze electrical control systems using mathematical techniques, such as state variable, time domain and frequency domain analyses
5. Analyze the performance of electrical control systems using graphical interpretation methods, such as bode plots and root locus
6. Perform transient (time-domain) analysis of first and second order electrical circuits
7. Explain and apply signal processing techniques and algorithms, signal classifications and operations, singularity function, continuous and discrete time signals

**DEE4.** The ability to use computational, simulation and experimental tools to investigate the behavior of various electrical systems under variable operating conditions

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Use computational techniques to obtain and examine frequency response of RLC and selective circuits
2. Employ advanced numerical algorithms to investigate and process complex electrical systems, such as Laplace transform, Fourier Series and z-transform
3. Use analytical and numerical techniques and computerized tools to investigate the behavior of electrical systems via solving Maxwell and wave equations as well as time varying and time harmonic fields
4. Utilize computer-aided packages and tools in reporting the investigation results and assemble specialized electrical engineering reports and graphs
5. Use basic electrical measurement and experimental tools, such as ammeters, oscilloscopes, power supplies and electrical connections

### **2.1.3 Engineering Design**

**DEE5.** The ability to explore and identify the preliminary design features of electrical systems and the underlying principles of assembling such systems

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Describe the basic design features of transformer devices, such as construction, types, equivalent circuit and operation of single-phase, three-phase and auto transformers
2. Outline the operating principles of electromechanical energy conversion devices, such as types, construction, equivalent circuit, basic designs and operation of single-phase and three-phase AC induction machines

3. State the meaning and principles of voltage regulation and efficiency of electrical machines
4. Recognize the basic design and construction features of electrical power, communications and electronic systems, such as power transmission lines, electric insulators, mobile communications and electronic chips
5. Explain preliminary notions of adhering to customer requirements and design specifications in the fabrication and construction of communication devices, electronic boards, power equipment and electrical machines
6. Identify target clients and establish innovative solutions to open-ended electrical engineering problems while dealing with limitations, uncertainties, safety and cost effectiveness factors

**DEE6.** The ability to design conceptual prototypes and laboratory-scale electrical components and sub-systems

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. State the principles of designing, performing and conducting laboratory experiments and field tests on electrical components and systems to meet desired needs
2. Identify relevant design constraints and features of electrical components and systems to meet desired needs, such as economic, environmental, sustainability, operability, ethical, health and safety, and social constraints
3. Use analytic and laboratory experimental tools as well as electrical engineering application software to help in the design process
4. Incorporate basic concepts of probability theory to handle randomness

associated with the design of electrical systems, such as linear regression, random number generator, correlation and spectral density

5. Apply the concepts of logic design, number systems, Boolean algebra, flip-flops and logic gates to investigate the design features and performance of logic circuits
6. Explain the basics of automatic control systems design and the associated representations, such as transfer functions, block diagrams and signal flow graphs
7. Generate and explore several alternative concepts of designing basic electrical circuits, evaluate merits and drawbacks of alternate design scenarios concerning efficiency, losses, voltage-drop, etc.
8. Assess electrical design product compliance with relevant electrical specifications and standards while realizing the impacts on environment, society, and depletion of national resources

#### **2.1.4 Engineering Practice**

**DEE7.** The ability to recognize and distinguish electrical installations, equipment and drawings in both laboratory environment and practical engineering setups, and understand the historical background of electricity development and the associated contemporary issues as well as the main recent advances, innovations and modern developments in electrical engineering

#### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Identify various measuring devices and equipment in electrical circuit laboratory environments, such as voltage and current sources, DC/AC meters, Transducers, sensors, three-phase sources, and AC/DC bridges

2. Demonstrate familiarity with electronic devices in laboratory environments, such as oscilloscopes, amplifiers, CRTs, LCDs, analog and digital electronic circuits, analog to digital converters and spectrum analyzer
3. Recognize electrical installations and equipment in real life situations, such as communication installations, integrated circuits, power lines and towers, industrial motors and electric wiring in buildings
4. Analyze and interpret electrical engineering experimental data and output information from electrical tests and experiments
5. Recognize that the rapid advances in electrical engineering necessitate life-long learning and familiarity with modern electrical engineering tools and technologies as well as associated contemporary technological issues
6. Demonstrate awareness and knowledge of basic electrical engineering safety schemes, such as grounding, shielding, and noise reduction

**DEE8.** The ability to participate in electrical engineering crises teams and think-tank groups charged with solving major electrical system problems, such as electricity interruptions and high-risk exposures, as well as interact and engage in constructive debating dialogues and use problem-solving skills to overcome the obstacles

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Work professionally within a group in various electrical systems areas, such as the design, planning and operation of such systems
2. Recognize and appreciate the multidisciplinary and complex nature of making functional electrical systems in real life via integration of different engineering, economics and management expertise
3. Explain group dynamics and the behaviors required to function on specialized

teams and multi-disciplinary teams charged with solving electrical engineering problems

4. Use oral, visual and written communication skills effectively in debates on electrical engineering matters, discussions and consultations
5. Exercise time-management, negotiation and debating skills to overcome problematic situations

**DEE9.** The ability to recognize - and readiness to apply - ethical values, safety provisions, principles of entrepreneurship and professional conduct when dealing with high-risk and hazardous electricity systems as well sensitivity to environmental issues

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Explain the meaning and implications of professional responsibility regarding product quality and liability as well as codes of ethics applicable to the electrical engineering practices
2. Recognize and use electrical hazards and fire protection equipment as well as explain the steps that should be taken in case of electrical risks and hazardous situations
3. Describe the operation of electrical grounding schemes and shielding mechanisms to ensure workers and public safety
4. Assume accountability for deliverables and results and accept responsibility for mistakes and errors resulting in system malfunction and/or damage to personnel or equipment

## 2.2 Sub-discipline #1: Electrical Power Engineering

Electric Power Engineering skills include the detailed knowledge of the design and construction features as well as the operating and management principles of various electric power engineering equipment, installations and systems. Electrical power engineering graduates should be able to build on their acquired knowledge and skills pertaining to basic discipline-level electrical engineering learning in order to understand, synthesize, analyze and design specialized electric power devices and systems as well as assess their operating performance under different planning and operation scenarios.

### 2.2.1 Engineering Sciences

**DEE\_S1\_1.** The ability to model and simulate electrical power components and systems as well as identify and assess their characteristics and operating performance

#### *Learning Outcomes*

Graduates who possess this ability should be able to:

1. Model and simulate various electrical power components and equipment, such as power transformers, high, medium and low voltage transmission lines and underground cables
2. Use network reduction algorithms to obtain reduced models of large power networks
3. Employ basic electrical power formulations and quantities, such as complex vectors, delta/star transformation, network flow matrices (network topology and incidence matrices) and symmetrical components.
4. Use symbols and notations associated with various electrical power quantities, such as the per-unit system notation and single-line diagrams
5. Describe the characteristics and composition of electrical power components as well as their behavior under both steady-state, transient and cyclic loading
6. State the principles of various phenomena occurring in real-life power systems, such as transient stability, voltage collapse, insulation breakdown, electromagnetic interference.

**DEE\_S1\_2.** The ability to apply the knowledge of advanced engineering sciences as well as the theoretical and analytical basis of electrical power systems, and to formulate the governing equations and formulas with proper interpretation of the underlying physical phenomena, which determine their behaviors

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Explain the basic phenomena, which govern the steady state behavior of power systems, such as power flows, generation input-output characteristics, reactive power supply, and interconnections
2. Describe the concepts, which govern the behavior of power systems under contingency state, such as system faults, frequency deviations, single and multiple contingencies, and dynamic security assessment
3. Recognize various characteristics and practical meaning of demand patterns associated with different consumption categories, such as residential, commercial, industrial, governmental, and agricultural loads
4. Describe the characteristics of various protective relaying components, such as over-current, distance and differential relays, and protective transformers
5. State the operating principles of various protection schemes, such as protection setups for power generators, bus bars, transformers and transmission lines as well as frequency and disturbance monitoring
6. Describe the concepts and implications of availability and forced-outage rates of power facilities as well as the practical significance of electricity customer losses due to degradation in system reliability

### **2.2.2 Engineering Analysis and Investigation**

**DEE\_S1\_3.** The ability to use proper notation and pertinent analytical and computational methods to solve, analyze and assess various types of power systems, namely generation, transmission and distribution systems

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Use numerical techniques to construct power network bus impedance and admittance matrices
2. Apply advanced mathematics to solve power network short-circuit equations and analyze both symmetrical and unsymmetrical type faults
3. Utilize advanced network solution techniques to solve the load-flow equations using both derivative (Newton-Raphson, decoupled and fast-decoupled) and non-derivative (Gauss and Gauss-Seidel) based methods
4. Employ time-domain numerical integration methods to assess the stability of multi-machine power systems
5. Use equal area criterion to assess stability of single-machine system models
6. Estimate demand growth levels in power systems using advanced probabilistic and statistical analysis tools, such as discounted linear regression and artificial intelligence based methods (neural networks)
7. Evaluate the reliability indices of the power system, such as loss-of-load probability, loss-of-load expectation, expected demand not-served and energy index of reliability

**DEE\_S1\_4.** The ability to use computational, simulation and experimental tools to investigate the behavior of electrical power systems under variable loading and operating conditions and to employ logic processing and information technology methods to search, gather, unify and document both the building blocks and the results of such investigation

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Use laboratory experiments and high voltage test techniques to investigate the breakdown phenomena and dielectric strength of different gaseous, liquid, and

- solid insulating materials under DC, AC and impulse voltages
2. Employ high voltage data analysis tools to investigate the impact of corona and weather related factors on the performance of insulators in power systems
  3. Investigate the role and effectiveness of practical problem mitigation methods, such as over-voltage protection and insulation coordination and coordination of protective relays
  4. Employ advanced numerical algorithms and probability distributions to solve and examine state estimation and inspect system measurements, reject bad data and investigate the associated confidence factors
  5. Use analytical and numerical techniques and computerized tools to investigate the performance of the power system and examine its behavior in the presence of unexpected outages and/or load variations

### **2.2.3 Engineering Design**

**DEE\_S1\_5.** The ability to design and plan electrical power systems and to achieve most economical designs while meeting demand growth requirements and other system and environmental constraints

#### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Perform expansion planning of electrical power systems taking into considerations demand growth requirements, site availability and other technical constraints, reliability requirements and economic factors
2. Assess compliance of the arrived-at expansion plan with relevant planning standards as well as its impact on environment, society, and depletion of national resources
3. Design workable protection coordination systems via employing the knowledge of fault analysis, signal transmission and electromechanical operations
4. Determine the rating and performance specifications of protection system components, such as transducers, relays and circuit breakers

5. Use analytic and laboratory experimental tools as well as power engineering application software to help in the design process of complex power system setups, such as multi-zone and stressed power systems
6. Recognize and adhere to electricity consumer needs and requirements, strive for customer satisfaction and welfare
7. Demonstrate responsiveness and sensitivity to consumer's dependence on electricity supply at all times

**DEE\_S1\_6.** The ability to design optimal configurations and operating schemes of electrical power systems and to optimally assemble, configure and schedule available facilities for best operating performance under variable loading conditions

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Perform optimal economic dispatch to optimize the generation pattern in power systems while fulfilling the demand requirements and meeting other physical and operating constraints
2. Use advanced non-linear programming techniques to optimize the performance of power systems via generating alternative scenarios of optimal resource scheduling, improved unit commitment and optimal power flow solutions
3. Assess the merits and drawbacks of each alternate performance improvement scenario in terms of both cost and system security implications
4. Design workable Automatic Generation Control (AGC) schemes to control system frequency and ensure system stability during practical operation while observing transaction agreements and economic constraints
5. Explain the underlying design principles of balancing demand and supply, as well as trading off between economy and security requirements in real-life practical power system design scenarios and operating schemes

### **2.2.4 Engineering Practice**

**DEE\_S1\_7.** The ability to recognize and distinguish electrical power installations, equipment and drawings in both laboratory environment and practical engineering setups, and understand the historical background of power electricity development and the associated contemporary issues as well as the main recent advances, innovations and modern developments in electrical power engineering

#### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Recognize high-voltage and low-voltage power facilities and installations in real life situations, such as fossil and thermal power plants, bulk system equipment, substations, transmission lines and underground cables
2. Explain the functional operation of the supervisory control and data acquisition system (SCADA), energy management system (EMS), and control centers in operating and managing large power systems
3. Recognize and explain schematic drawings of various power system facilities, such as substation layouts, bus configurations, distribution feeder arrangements and routings
4. Appraise the rapid advances in electrical power engineering, which necessitate life-long learning and familiarity with modern electrical power engineering tools
5. Describe the contemporary technological issues and modern topics and technologies, such as load management, energy conservation, electricity markets, environmental emissions, renewable energy and smart grids

**DEE\_S1\_8.** The ability to participate in complex electrical power engineering crises teams and think-tank groups charged with solving major electricity system problems, such as blackouts, facility outages and high-risk exposures, as well as interact and engage in constructive debating dialogues and use problem-solving skills to overcome the obstacles

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Work professionally within a group to debate and tackle various electrical power system planning, operation and control problems
2. Recognize and appreciate the multidisciplinary and complex nature of operating and managing electrical power systems in real life via integration of different engineering, economics and management expertise
3. Describe group dynamics and the behaviors required to function on specialized teams and multi-disciplinary teams working in high-risk and stressful situations while solving emergency power system problems, such as management of blackouts and restoration following major outages
4. Use oral and written communication skills and office automation tools in presentations and debates on power engineering matters, such as system status reports, recommended plans and operating guidelines

**DEE\_S1\_7.** The ability to recognize - and readiness to apply - ethical values, safety provisions, principles of entrepreneurship and professional conduct when dealing with high-risk and hazardous power electricity systems as well sensitivity to environmental issues

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Employ environmental constraints and power plant emissions in the solution of the economic operation of power systems
2. Explain the operation of electrical grounding schemes in power plants, substations and transmission facilities as well as shielding mechanisms to ensure workers and public safety
3. Describe the meaning and implications of professional responsibility in planning and operation of power systems as well as adherence to liability, accountability and codes of ethics for power engineering practices
4. Recognize and prevent high-risk situations in the vicinity of high voltage

- installations and explain the principles of ground current, step and touch potentials and impacts of electric currents on human bodies
5. Use electrical hazards and fire protection equipment and explain the steps that should be taken in case of electrical risks and hazardous situations such as first-aid provisions for electrocution victims
  6. Assume accountability for the delivered plans and instructions, and accept responsibility for mistakes and errors resulting in power system malfunction, outages and/or damage to personnel or equipment

## 2.3 Sub-discipline #2: Electrical Machines Engineering

Electrical Machines Engineering skills include the detailed knowledge of the design and construction features of various electrical machines and the associated testing processes as well as the operating principles and performance assessment of various types of electric machines. Electrical machines engineering graduates should be able to build on their acquired knowledge and skills pertaining to basic discipline-level electrical engineering learning in order to understand, synthesize, analyze and design specialized AC and DC electric machines and transformers as well as assess their operating performance under variable loading and operation scenarios.

### 2.3.1 Engineering Sciences

**DEE\_S2\_1.** The ability to model and simulate electrical machine components and machinery systems as well as identify and assess their characteristics and operating performance

#### *Learning Outcomes*

Graduates who possess this ability should be able to:

1. Model and simulate various electrical machines components, such as equivalent circuits and phasor diagrams of transformers, three-phase and single-phase

- induction motors and synchronous machines
2. Explain the meaning, symbols and notations associated with various electrical machine quantities and parameters, such as use of per-unit system notation and complex vectors
  3. Describe the characteristics and composition of electrical machine components and auxiliary equipment, such as prime-movers, rotors, stators, exciters, governors, etc.
  4. Construct dynamic models of synchronous machines and perform direct / quadrature axis transformations
  5. Use advanced electro-mechanical energy conversion concepts and principles to develop the input-output characteristics of electrical machines

**DEE\_S2\_2.** The ability to apply the knowledge of advanced engineering sciences as well as the theoretical and analytical basis of electrical machines, and to formulate the governing equations and formulas with proper interpretation of the underlying physical phenomena, which determine their behaviors under steady state and transient conditions

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Recognize various characteristics and practical meaning of different electrical machines performance outlines, such as speed-torque characteristics, voltage regulation and swing curves
2. Explain the basic phenomena which govern the behavior of electrical machines, such as electro-mechanical energy conversion principle, electro-magnetic rotating field, synchronizing torque and armature reaction
3. Describe and formulate multi-machine operating characteristics, such as synchronization of parallel electrical machines and out-of-step operating scenarios of alternators connected to large power systems

### **2.3.2 Engineering Analysis and Investigation**

**DEE\_S2\_3.** The ability to use proper technical description, notation and pertinent analytical and computational methods to solve, analyze and assess various types of electrical machines, such as synchronous and induction AC machines as well as transformers and DC machines

#### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Apply advanced mathematics to assess the behavior and performance of electrical machines under both steady state and transient conditions.
2. Use advanced numerical techniques and complex algebra to solve the equivalent circuits and analyze the performance of transformers, DC machines as well as different single-phase and three-phase AC machines
3. Employ time-domain numerical integration methods to solve swing equation and determine the transient performance of synchronous alternators under fault and/or sudden load change conditions
4. Explain and apply the concepts of DC and AC (synchronous and induction) machine dynamics and transients as well as the principles of steady state and transient stability of electrical machines

**DEE\_S2\_4.** The ability to use computational, simulation and experimental tools to determine and investigate the behavior of electrical machines under variable loading and operating conditions and to employ information technology methods to search, gather, unify and document both the building blocks and the results of such investigation

#### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Perform load testing of induction motors
2. Assess performance of DC machines, synchronous motors and alternators

3. Employ advanced control schemes to investigate and coordinate the parallel operation of AC generators
4. Use laboratory experiments, test techniques and data analysis tools to investigate the starting phenomena, mechanisms and requirements of single-phase induction motors as well as DC motors.
5. Investigate problems associated with three-phase connections as well as harmonic related problems

### **2.3.3 Engineering Design**

**DEE\_S2\_5.** The ability to design electrical machines and to achieve most economical machine designs while meeting load requirements and other material, construction and environmental constraints

#### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Construct and apply alternate designs of speed control schemes of DC motors
2. Recognize and adhere to the needs and requirements of electrical machinery users, strive for customer satisfaction and welfare
3. Demonstrate responsiveness and sensitivity to consumer's dependence on continuous and error-free operation of electrical machines at all times
4. Design workable protection systems for electrical machines, and determine the rating and performance specifications of the associated protective devices
5. Perform conceptual designs of electrical DC and AC machines and transformers taking into considerations speed and torque requirements and other technical and performance constraints
6. Apply reliability and efficiency requirements as well as economic factors in electrical machines design, and assess compliance of the arrived-at design with relevant industry standards

**DEE\_S2\_6.** The ability to design optimal and/or improved configurations and operating schemes of electrical machines and to optimally assemble, configure and schedule available facilities for best operating performance under variable loading conditions

***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Use advanced non-linear programming techniques to optimize the design of electric machinery and transformers via generating alternative scenarios and assess the merits and drawbacks of each alternate scenario
2. Perform optimal design of various types of AC and DC electrical machines to optimize their performance while fulfilling the torque and speed requirements and meeting other physical and operating constraints
3. Design workable speed control schemes to control synchronous machine frequency and ensure multi-machine stability during practical real-life operation while observing loading and other operating constraints
4. Describe the underlying design principles and operating concepts of special machines, such as stepper motors, servo motors, universal motors, reluctance and hysteresis motors

**2.3.4 Engineering Practice**

**DEE\_S2\_7.** The ability to recognize and distinguish various types of electrical machines and the associated installations, equipment and drawings in both laboratory environment and practical engineering setups, and understand the historical background of electrical machines development and the associated contemporary issues as well as the main recent advances, innovations and modern developments in electrical machines engineering

***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Recognize and explain schematic drawings of various electrical machines and describe principal components, such as machine windings, air gaps, and field windings
2. Identify and distinguish different practical installations and setups involving electrical machinery, such as electric drives and traction systems
3. Recognize various types, ratings and constructions of synchronous machines, induction machines, DC machines and transformers
4. Follow up with the rapid advances in electrical machines engineering, which necessitate life-long learning and familiarity with modern electrical machine innovations
5. Discuss contemporary technological issues and technologies in electrical machines, such as advanced solid state controllers, small machines for medical applications, and special machines for rapid transit applications
6. Describe the advanced protection and control schemes associated with electrical machines in practical installation setups, such as over-current protection schemes, semi-conductor and power electronics controllers

**DEE\_S2\_8.** The ability to participate in complex machinery operation and investigation teams and think-tank groups charged with solving various electrical machines problems, which require collaborative efforts, such as large machine assembly and installations, complex operation of synchronized machines, and outages of large synchronous alternators, as well as interact and engage in constructive debating dialogues and use problem-solving skills to overcome the obstacles

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Explain group dynamics and behaviors required to function on specialized teams and multi-disciplinary teams working in high-risk and stressful situations involving load interruptions due to outages of major generators
2. Use oral and written communication skills and office automation tools

in presentations on electrical machines, such as explanation of machine performance reports, and machine operating guidelines

3. Recognize and appreciate the multidisciplinary nature of operating and managing group operation and synchronization of electrical machines in real life via integration of various engineering expertise
4. Work professionally within a group to debate and tackle various electrical machine design, operation and control problems

**DEE\_S2\_9.** The ability to recognize - and readiness to apply - ethical values, safety provisions, principles of entrepreneurship and professional conduct when dealing with high-risk and hazardous situations involving electrical machinery as well demonstrate sensitivity to environmental issues

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Explain the meaning and implications of professional responsibility regarding the design, operation and control of electrical machines as well as adherence to liability, accountability and codes of ethics in practice
2. Employ environmental constraints and demonstrate sensitivity to preserving clean environment on issues relating to disposal of used machine cooling oils and discarded spare parts
3. Assume accountability for the delivered operating guidelines and instructions, and accept responsibility for errors resulting in machine malfunction and/or damage to personnel or surrounding equipment
4. Recognize and prevent high-risk situations in the vicinity of large electric machines in motion, and explain the principles of workers and public safety in the surrounding of moving electric drives

## 2.4 Sub-discipline #3: Electronics Engineering

Electronics engineering skills include the detailed knowledge of the design and construction features as well as the operating and manufacturing principles of various electronics engineering equipment, boards and systems. Electronics engineering graduates should be able to build on their acquired knowledge and skills pertaining to basic discipline-level electrical engineering learning in order to understand, synthesize, analyze and design specialized electronic devices and systems as well as assess their operating performance under different environmental and utilization conditions.

### 2.4.1 Engineering Sciences

**DEE\_S3\_1.** The ability to characterize, model and simulate electronic materials, components and systems as well as identify and assess their characteristics and operating performance

#### *Learning Outcomes*

Graduates who possess this ability should be able to:

1. Use computational algorithms and analytical techniques to obtain functional models of large electronic boards and complex electronic equipment
2. Describe the characteristics and composition of electronic components as well as their response and behavior in both steady-state and transient-state, such as light-emitting diodes, photonics semiconductor materials
3. Model various electronic components and equipment, such as clipping circuits, rectification diodes, zener diodes and regulators, linear and nonlinear operational amplifiers, differential amplifiers, and filters
4. Simulate operation and behavior of electronic devices, such as metal-oxide semiconductor field effect transistors and bipolar junction transistors
5. Describe the principles of various phenomena occurring in real-life electronics applications, such as overheating of electronic materials, breakdown,

electromagnetic interference, and optical fiber principles

6. Explain the meaning, symbols and notations associated with various electronics engineering terms and quantities, such as use of per-unit system notation, electronics circuit diagrams, and complex vectors

**DEE\_S3\_2.** The ability to apply the knowledge of advanced engineering sciences as well as the theoretical and analytical basis of electronic systems, and to formulate the governing equations and formulas with proper interpretation of the underlying physical phenomena, which determine their behaviors

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Explain the characteristics and operation of various electronic devices, such as photodetectors, optical amplifiers, analog switches and multipliers, current conveyor, switched capacitor circuits, and microwave devices
2. Express the meaning and outline the principles of dynamic logic, logic gates, transistor digital circuits, transistor logic, laser diodes, crystal oscillators, and automatic gain controllers
3. Describe the phenomena which govern behavior of electronic equipment, such as current flows, integration and difference amplification, current mirroring, optical sources and waveguides, and analog-digital conversion
4. Recognize various characteristics of various electronic devices, such as inverting and non-inverting amplifiers, metal oxide semiconductor inverters and logic gates, transistor logic circuits, and phase-locked loops

### **2.4.2 Engineering Analysis and Investigation**

**DEE\_S3\_3.** The ability to use proper notation and pertinent analytical and computational methods to solve, analyze and assess various types of electronic systems

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Apply advanced electronic circuit solution techniques to solve various electronic system configurations involving mixtures of passive circuit elements, diodes, transistors and other non-linear elements
2. Use numerical techniques to analyze response and performance characteristics of electronic circuits and devices, such as radio frequency tuned amplifiers, power amplifiers and tuned oscillators
3. Employ time-domain numerical solution methods to solve and assess the response of complex electronic circuits and systems
4. Utilize advanced mathematics techniques to solve and analyze very large scale integrated electronic circuits, such as very high speed integrated circuits
5. Evaluate the adequacy, continuity and reliability of electronic systems using adequate performance measure indices

**DEE\_S3\_4.** The ability to use computational, simulation and experimental tools to investigate the behavior of electronic devices and systems under variable loading and operating conditions and to employ logic processing and information technology methods to search, gather, unify and document both the building blocks and the results of such investigation

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Employ advanced simulation packages (PSpice or equivalent) for simulation and analysis of electronic circuits and for examining output responses of the simulated electronic circuits for different input signals
2. Use laboratory experiments and analysis tools to investigate the operating performance of electronic devices, such as operational amplifiers, bridge oscillators, active, low and high pass filters, vibrators and digital circuits

3. Apply analytical and numerical techniques and computerized tools to investigate the performance of electronic systems and examine their behavior in case of component malfunction or loss of excitation signals
4. Investigate the role and effectiveness of practical problem mitigation methods, such as improved computer aided tools for handling the analysis and fabrication of very large integrated circuits

### **2.4.3 Engineering Design**

**DEE\_S3\_5.** The ability to design electronic devices and systems and to achieve most economical designs while meeting performance requirements and other system and environmental constraints

#### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Design workable integrated circuits by employing the knowledge of advanced electronics design principles, such as design rules and layout principles, and basic fabrication sequences
2. Determine the rating and performance specifications of integrated circuit components, such as combinational and sequential circuits, self-aligned gates and gate arrays, memories and registers
3. Perform conceptual designs of electronic systems, such as integrated circuits, taking into considerations performance requirements, material availability and other technical constraints
4. Employ reliability requirements and economic factors in electronic system design, and assess compliance of the arrived-at design with relevant electronic product standards as well as environment and safety regulations
5. Recognize and adhere to consumer needs and requirements of the electronic product users, strive for customer satisfaction and welfare

6. Demonstrate responsiveness and sensitivity to consumer's dependence on electronic equipment at all times
7. Use analytic and laboratory experimental tools and concepts, such as design entry concepts and schematic editors in electronics design process
8. Employ electronics engineering application software, such as functional simulation tools, to help in the design process of low and high level design and implementation of digital electronic circuits

**DEE\_S3\_6.** The ability to design optimal layouts and operating schemes of large-scale and complex electronic systems and to optimally assemble and configure various components for best operating performance under variable operating conditions

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Use advanced computer-aided design tools and low power integrated circuit design concepts to optimize the performance of electronic systems via generating alternative scenarios of optimal response
2. Assess the merits and drawbacks of each arrived-at alternate design scenario of electronics devices and schemes in terms of both cost and product quality implications
3. Employ advanced large-scale design languages, such as hardware description languages, to design very large scale integrated circuits and to assess their performance while fulfilling physical and operating constraints
4. Explain the underlying design principles of balancing cost and quality requirements in real-life practical electronic system design scenarios and operating schemes
5. Design workable very high speed integrated circuits and employ proper schemes to control their performance and ensure their operating sustainability and stability during practical real-life operation

#### **2.4.4 Engineering Practice**

**DEE\_S3\_7.** The ability to recognize and distinguish electronic installations, equipment and drawings in both laboratory environment and practical engineering setups, and understand the historical background of electronics engineering development and the associated contemporary issues as well as the main recent advances, innovations and modern developments in electronics engineering

##### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Describe and explain schematic drawings of various electronic equipment and systems, such as computer generated electronic layouts, and integrated circuit configurations
2. Recognize electronic equipment, boards and installations in real life situations, such as radio frequency electronic devices and large integrated circuits
3. Follow up with the rapid advances in electronics engineering, which necessitate life-long learning and familiarity with modern electronics engineering tools
4. Discuss contemporary technological issues and modern topics in electronics engineering, such as high speed integrated circuits, improved electronic system design languages and nano-based electronics
5. Explain the functional operation of complex electronic systems and assemblies, such as optical networking, and state the principles involved in fabricating, operating and managing large electronic systems

**DEE\_S3\_8.** The ability to participate in complex electronics engineering problem solving teams and think-tank groups charged with solving major electronic system problems, such as design and manufacturing of complex electronic systems, as well as interact and engage in constructive debating dialogues and use problem-solving skills to overcome the obstacles

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Employ oral and written communication skills in presentations on electronics engineering matters, such as electronic system performance status reports, recommended design alterations and operating guidelines
2. Recognize and appreciate the multidisciplinary and complex nature of operating and managing electronic systems in real life via integration of different engineering, manufacturing and economics expertise
3. Work professionally within a group to debate and tackle various electronic equipment and system design, fabrication, operation and control problems
4. Recognize group dynamics and behaviors required to function on specialized multi-disciplinary teams solving urgent problems, such as failures of electronic boards and systems serving large installations

**DEE\_S3\_9.** The ability to recognize - and readiness to apply - ethical values, safety provisions, principles of entrepreneurship and professional conduct when dealing with high-risk and hazardous electronic equipment and system related situations as well sensitivity to environmental issues

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Recognize and prevent high-risk situations in the vicinity of electronic equipment, such as microwave devices, and explain the principles of electronic emissions and impacts of harmful emissions on human bodies
2. Recognize professional responsibility in design, fabrication and operation of electronic devices, boards and systems, and adherence to liability, accountability and codes of ethics applicable to electronics engineering

3. Use hazards preventive measures and fire protection equipment and explain the steps that should be taken in case of injuries and hazardous situations such as first-aid provisions for affected victims
4. Assume accountability for the delivered designs and instructions, and accept responsibility for mistakes resulting in electronic device and system malfunction, outages and/or damage to personnel or equipment

## 2.5 Sub-discipline #4: Communications Engineering

Communications engineering skills include the detailed knowledge of the design and construction features as well as the operating and manufacturing principles of various communications engineering equipment, devices and systems. Communications engineering graduates should be able to build on their acquired knowledge and skills pertaining to basic discipline-level electrical engineering learning in order to understand, synthesize, analyze and design specialized communication devices and systems as well as assess their operating performance under different environmental and utilization conditions.

### 2.5.1 Engineering Sciences

**DEE\_S4\_1.** The ability to model and simulate communication components, boards and systems as well as identify and assess their characteristics and operating performance

#### *Learning Outcomes*

Graduates who possess this ability should be able to:

1. Use computational algorithms and analytical techniques to obtain functional models and simulate complex communication systems, such as antenna arrays, radio transmission systems, and cellular mobile systems
2. Recognize the symbols and notations associated with communications

engineering terms, such as probabilistic notation, eye patterns, Nyquist criteria, communications circuit symbols, diagrams and complex vectors

3. Model and simulate various communication components and equipment, such as matched filters, antennas and modulation schemes
4. Explain the principles of various phenomena occurring in real-life communications applications, such as overheating, breakdown, electromagnetic interference, propagation, and signal distortion
5. Describe the characteristics and composition of communications components as well as their response and behavior in different low to ultra high frequency ranges

**DEE\_S4\_2.** The ability to apply the knowledge of advanced engineering sciences as well as the theoretical and analytical basis of communication systems, and to formulate the governing equations and formulas with proper interpretation of the underlying physical phenomena, which determine their behaviors

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Describe the physical meaning of communications terms, such as orthogonal modulation, bandwidth efficiency, binary and quaternary modulation schemes and power spectra
2. Recognize various characteristics of communications principles, such as coherent and non-coherent amplitude, frequency and pulse shift keying, and reflector antennas
3. Explain basic phenomena, which govern the behavior of communication systems, such as baseband pulse transmission, digital pass band transmission,

equalization, signal filtering, modulation, and multiplexing

4. Utilize information theory and data processing in communications systems, such as mutual information and channel capacity, error control coding, source coding, wireless local loops and digital subscriber
5. Describe the characteristics and operating principles of various advanced communication equipment and systems, such as fixed and mobile satellite communication systems
6. Describe the basic terminology and concepts of communication networks, such as multiplexing and switching principles, teletraffics, packet switching, connectionless network, open system interconnection protocols
7. Explain the characteristics and operating principles of complex communication networks, such as local area and wide area networks, internet and intranet principles, transmission control and internet protocols

### **2.5.2. Engineering Analysis and Investigation**

**DEE\_S4\_3.** The ability to use proper notation and pertinent analytical and computational methods to solve, analyze and assess various types of communication systems

#### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Apply advanced probabilistic and statistical models to solve various communications problems involving randomness and data uncertainties
2. Use numerical techniques to solve and analyze wave propagation communications problems, such as ground, sky and space wave propagations
3. Estimate wave propagation and antenna parameters in communication systems using advanced probabilistic and statistical analysis tools, such as statistical

models, diversity principles and neural networks

4. Apply advanced signal processing techniques to solve and analyze complex communication transmission systems, such as radio relay systems, microwave, satellite and cellular mobile communication systems

**DEE\_S4\_4.** The ability to use computational, simulation and experimental tools to investigate the behavior of communication devices and systems under variable loading and operating conditions and to employ logic processing and information technology methods to search, gather, unify and document both the building blocks and the results of such investigation

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Employ analytical and computerized tools, such as teletraffic analysis of circuit and packet switching, to investigate the performance of communication networks and examine their operating behavior
2. Use laboratory experiments, test techniques and data analysis tools to investigate the performance of various communications systems
3. Describe the underlying techniques and methods used in communications engineering, such as amplitude and frequency modulation and detection, pulse-code and delta modulation, bit error rate measurements, time and frequency-division multiplexing, amplitude and frequency shift keying
4. Explain the basic concepts employed in communications engineering, such as impedance measurements and matching, optical fiber parameter measurements, basic propagation and antenna measurements
5. Investigate the role and effectiveness of practical problem mitigation methods, such as interruption of communication signals and loss of information

### **2.5.3 Engineering Design**

**DEE\_S4\_5.** The ability to design and plan communication boards and systems and to

achieve most economical designs while meeting performance requirements and other system and environmental constraints

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Design workable antenna devices and assemblies operating in different frequency ranges, and determine the response and performance specifications of the associated components
2. Perform conceptual designs of communication equipment taking into considerations performance requirements, material availability and other technical constraints
3. Apply reliability requirements and economic factors in the design of communication systems, and assess compliance of the arrived-at design with relevant communication product standards
4. Recognize and adhere to consumer needs and requirements of the communication product users, strive for customer satisfaction and welfare
5. Demonstrate responsiveness and sensitivity to consumer's dependence on communication equipment at all times
6. Employ application software and laboratory experimental tools, such as error rate measurements, propagation and antenna measurements in the design process of communication systems

**DEE\_S4\_6.** The ability to design optimal configurations and operating schemes of communication systems and to optimally assemble and configure various components for best operating performance under operating conditions

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Design workable communication systems and associated control schemes to ensure communication device and system stability during practical real-life operation while observing functional and performance constraints

2. Perform optimal designs of antennas to optimize their performance while fulfilling functional requirements and meeting other physical and operating constraints
3. Explain the underlying design principles of balancing cost and quality requirements in real-life practical communication system design scenarios and operating schemes
4. Use advanced mathematics and linear/non-linear programming techniques to optimize the performance of complex communication systems, such as linear and planar antenna arrays
5. Generate alternative design scenarios of communication systems and assess the merits and drawbacks of each alternate scenario in terms of both cost and product quality implications

#### **2.5.4. Engineering Practice**

**DEE\_S4\_7.** The ability to recognize and distinguish communication installations, equipment and drawings in both laboratory environment and practical engineering setups, and understand the historical background of communications engineering development and the associated contemporary issues as well as the main recent advances, innovations and modern developments in communications engineering

#### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Explain the propagation models and functional operation of complex communications system installations, such as antenna arrays, and mobile radio systems
2. Recognize practical communication equipment and installations in real life situations, such as microwave towers, and antennas
3. Follow up with the rapid advances in communications engineering, which necessitate life-long learning and familiarity with modern communications engineering tools

4. Discuss contemporary technological issues in communications engineering such as use of modern artificial intelligence tools, electromagnetic compatibility, spectrum management and frequency planning
5. Appraise modern topics and technologies in communications engineering such as cryptography, information Security, speech, image processing and high speed networks
6. Describe schematic drawings of various communication equipment layouts and communication systems maps and diagrams

**DEE\_S4\_8.** The ability to participate in complex communications engineering problem solving teams and think-tank groups charged with solving major communication system problems, such as design and performance assessment of complex communication systems, as well as interact and engage in constructive debating dialogues and use problem-solving skills to overcome the obstacles

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Recognize and appreciate the multidisciplinary and complex nature of operating and managing communication systems in real life via integration of different engineering, manufacturing, economics and management expertise
2. Work professionally within a group to debate and tackle various communication equipment and system design, fabrication, operation and control problems
3. Use oral and written communication skills and employ computer-aided packages and office automation tools in presentations on communications engineering matters, such as interpretation of communication system performance reports
4. Employ computer-aided packages and office automation tools effectively in reporting and debating communications engineering issues, such as presentation of recommended design alterations and operating guidelines
5. Recognize group dynamics and the behaviors required to function on specialized multi-disciplinary teams working in stressful situations while solving urgent problems, such as major communication equipment outages and loss of signals

**DEE\_S4\_9.** The ability to recognize - and readiness to apply - ethical values, safety provisions, principles of entrepreneurship and professional conduct when dealing with high-risk and hazardous communication equipment and system related situations as well sensitivity to environmental issues

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Recognize and prevent high-risk situations in the vicinity of communication systems with high electromagnetic emission, and explain the principles of tolerable emissions and impacts on human bodies
2. Employ environmental constraints in the design and construction of communication systems
3. Recognize the meaning and implications of professional responsibility regarding design and operation of communication systems as well as adherence to accountability and codes of ethics on communications engineering practices
4. Assume accountability for the delivered designs and instructions, and accept responsibility for mistakes and errors resulting in communication device and system malfunction, outages and/or damage to personnel or equipment
5. Use hazards preventive measures and fire protection equipment and explain the steps that should be taken in case of injuries and hazardous situations such as first-aid provisions for affected victims

## **2.6 Sub-discipline #5: Control Systems Engineering**

Control systems engineering skills include the detailed knowledge of the selection, design and assembling features as well as the operating and manufacturing principles of various control systems engineering equipment, boards and systems. Control systems engineering graduates should be able to build on their acquired knowledge and skills pertaining to basic discipline-level electrical engineering learning in order

to understand, synthesize, analyze and design specialized control system devices and systems as well as assess their operating performance under different environmental and utilization conditions.

### **2.6.1 Engineering Sciences**

**DEE\_S5\_1.** The ability to represent, model and simulate control system components, boards and systems as well as identify and assess their characteristics and operating performance

#### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Obtain functional models of engineering control systems using generic components and devices such as transducers, actuators and timers
2. Explain the meaning, symbols and notations associated with various control systems engineering terms and quantities, such as use of block diagrams, bode and Nyquist plots, and control systems circuit diagrams
3. Describe the meaning and characteristics of micro processing components of control systems, such as serial communications interface, serial port interface, and parallel input-output interface
4. Explain the operating characteristics of universal asynchronous receiver/transmitter, and digital to analog and analog to digital converters as well as their response and behavior in operational control systems
5. State the principles of various phenomena occurring in real-life control systems applications, such as overheating, breakdown, and electromagnetic interference
6. Model and simulate various control system components and equipment based on physical processes, such as control of temperature, electrical supply parameters, light intensity, and water levels

**DEE\_S5\_2.** The ability to apply the knowledge of advanced engineering sciences as well as the theoretical and analytical basis of control systems, and to formulate the

governing equations and formulas with proper interpretation of the underlying physical phenomena, which determine their behaviors

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Explain the characteristics and operating principles of various control system components, such as microprocessors, servo motors, memory devices, and digital control components
2. Recognize various characteristics and practical meaning of memory management, such as erasable programmable read only memory, random access memory, and direct memory access
3. Explain the basic phenomena and concepts, which govern the behavior of control system devices and systems, such as two-position, proportional and proportional-integral-derivative control principles
4. Discuss the meaning and operating principles of control loops and feedback mechanisms, time variant and time invariant systems, continuous and discrete time simulations
5. Describe the concepts of interrupt systems, assembly language programming, input/output devices, timing control, programmable input-output interfaces, and proportional-integral-derivative controllers
6. Describe and apply the concepts of stability, controllability and observability of control schemes, such as discrete control systems

### **2.6.2 Engineering Analysis and Investigation**

**DEE\_S5\_3.** The ability to use proper symbols, notation and pertinent analytical and computational methods to solve, analyze and assess various types of control systems

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Solve and analyze complex control systems, such as fast Fourier transform implementation using the digital signal processing chips, digital control

- sampling, Z-transform algorithms, and difference equations
2. Employ time-domain processing techniques and system dynamic simulation methods to assess the performance of engineering control systems
  3. Analyze control systems using digital signal processing techniques, such as discrete time Fourier transform, discrete time signals and systems, Z-transform, fast Fourier transform, decimation and interpolation
  4. Evaluate the performance adequacy and reliability of control systems and components, such as microprocessors, filters and controllers
  5. Apply advanced mathematics to solve and examine control systems responses, such as finite impulse response, and infinite-impulse response
  6. Estimate responses of control systems using advanced probabilistic and statistical analysis tools, such as random number generators and Monte Carlo simulation method

**DEE\_S5\_4.** The ability to use computational, simulation and experimental tools to investigate the behavior of control system devices and systems under variable loading and operating conditions and to employ logic processing and information technology methods to search, gather, unify and document both the building blocks and the results of such investigation

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Solve and examine discrete control systems using advanced simulation and solution techniques, such as discretization methods, and state space representations
2. Describe microprocessor architecture as well as microprocessor C and assembly programming languages and machine code generation
3. Use laboratory experiments, test techniques and data analysis tools to investigate different types of control systems and setups, such as proportional control and proportional-integral-derivative control schemes

4. Analyze and investigate advanced engineering control systems using artificial intelligence methods, such as fuzzy logic, neural networks, expert systems and genetic algorithms
5. Investigate the role and effectiveness of practical problem mitigation methods, such as detecting and solving potential loss-of-control situations of engineering systems
6. Use analytical and numerical techniques and computerized simulation tools, such as Matlab software (or equivalent), to investigate the performance of control systems and examine their operating behavior

### **2.6.3 Engineering Design**

**DEE\_S5\_5.** The ability to assemble, design, realize and configure control system boards and systems and to achieve most economical designs while meeting various operating performance requirements and other system and environmental constraints

#### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Design workable microprocessors as part of control system devices and systems and determine the rating and performance specifications of the associated components
2. Employ the knowledge of microprocessors architecture and assembly language programming in control system design, and apply the concepts of instruction sets, system interrupts and memory management
3. Perform modeling and conceptual designs of physical experimental control equipment and systems taking into considerations output response requirements, material availability and other technical constraints
4. Recognize reliability requirements and economic factors in the design of control systems, and assess compliance of the arrived-at design with relevant control system product standards
5. Explain and adhere to consumer needs and requirements of the control system

- product users, strive for customer satisfaction and welfare
6. Demonstrate responsiveness and sensitivity to consumer's dependence on control system equipment at all times
  7. Use analytic and laboratory experimental tools as well as control systems engineering application software to help in the design process of complex control system components and setups, such as design and realization of recursive and non-recursive digital filters design
  8. Employ advanced computer-aided tools in the design process of complex control schemes, such as design of digital signal processors for communications applications

**DEE\_S5\_6.** The ability to design optimal or near-optimal configurations and operating schemes of control systems and to optimally assemble and configure various components for best operating performance under variable operating conditions

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Use advanced mathematics to optimize the performance of control systems, such as complex controllers, via generating alternative scenarios and improved solutions
2. Generating alternative design scenarios of control schemes and assess the merits and drawbacks of each alternate scenario in terms of both cost and product quality implications
3. Use the digital signal processing chips in implementing efficient numerical processing algorithms, such as fast Fourier transform
4. Perform optimal design of control systems components, such as proportional-integral-derivative controllers, finite impulse response and infinite impulse response filters while complying with design constraints
5. Explain the underlying design principles of balancing cost and quality requirements in real-life practical control system design scenarios and operating

schemes

6. Design workable control schemes in engineering systems and ensure control system device and system stability during practical real-life operation while observing system performance and operating constraints

#### **2.6.4 Engineering Practice**

**DEE\_S5\_7.** The ability to recognize and distinguish control system installations, equipment and drawings in both laboratory environment and practical engineering setups, and understand the historical background of control systems engineering development and the associated contemporary issues as well as the main recent advances, innovations and modern developments in control systems engineering

##### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Explain the fabrication technologies and functional operation of microprocessors in real-life control system devices and systems
2. Recognize and explain schematic drawings of various control system equipment and systems, such as block diagrams and signal flow diagrams
3. Follow up with the rapid advances in control systems engineering, which necessitate life-long learning and familiarity with modern control systems engineering tools
4. Discuss contemporary technological issues and modern topics in control systems engineering such as future trends in microprocessors, use of artificial intelligence methods in control systems, and robotics
5. Recognize control system equipment, boards and installations in real life situations, such as analog and digital control systems, proportional integral derivative controllers, computer controlled systems

**DEE\_S5\_8.** The ability to participate in complex control systems engineering problem solving teams and think-tank groups charged with solving major control system

problems, such as design and assessment of complex engineering control systems, as well as interact and engage in constructive debating dialogues and use problem-solving skills to overcome the obstacles

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Explain group dynamics and the behaviors required to function on specialized teams and multi-disciplinary teams working in stressful real-life situations, such as loss of control and outage of vital controller parts
2. Work professionally within a group to debate and tackle various control system equipment and system design, fabrication, operation and control problems, such as digital signal processing chips, and real time controllers
3. Use oral, visual and written communication skills and employ computer-aided packages and office automation tools effectively in presentations and debates on control systems engineering matters
4. Recognize and appreciate the multidisciplinary and complex nature of operating and managing control systems in real life via integration of different engineering, manufacturing and economics expertise

**DEE\_S5\_9.** The ability to recognize - and readiness to apply - ethical values, safety provisions, principles of entrepreneurship and professional conduct when dealing with high-risk and hazardous control equipment and system related situations as well sensitivity to environmental issues

### ***Learning Outcomes***

Graduates who possess this ability should be able to:

1. Recognize and prevent high-risk situations in the vicinity of special control systems operating with high radiation and/or harmful electromagnetic emissions
2. Explain the meaning and implications of professional responsibility regarding

design, fabrication and operation of engineering control systems as well as adherence to liability, accountability and codes of ethics

3. Assume accountability for the delivered designs and instructions, and accept responsibility for mistakes and errors resulting in control scheme malfunction, system outages and/or damage to personnel or equipment
4. Use hazards preventive measures and fire protection equipment as well as explain the steps that should be taken in case of injuries and hazardous situations such as first-aid provisions for affected victims

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## Appendix: Revised Bloom's Taxonomy [11]

Categories	Cognitive Process	Sample Verbs Commonly used for Stating Specific Learning Outcomes
Remembering	Retrieve relevant knowledge from long-term memory Recognizing Recalling	Collect, Define, Describe, Examine, Identify, Label, List, Name, Quote, Show, Tabulate, Tell
Understanding	Construct meaning from instructional messages, including oral, written, and graphic communication Interpreting Exemplifying Classifying Summarizing Inferring Comparing Explaining	Associate, Contrast, Describe, Differentiate, Discuss, Distinguish, Estimate, Extend, Interpret, Predict, Summarize
Applying	Carry out or use a procedure in a given situation Executing Implementing	Apply, Calculate, Change, Classify, Complete, Demonstrate, Discover, Examine, Experiment, Illustrate, Modify, Relate, Show, Solve

Analyzing	<p>Break material into its constituent parts and determine how the parts relate to one another and to an overall structure or purpose</p> <p>Differentiating Organizing Attributing</p>	Analyze, Arrange, Classify, Compare, Connect, Divide, Explain, Infer, Order, Select, Separate
Evaluating	<p>Make judgments based on criteria and standards</p> <p>Checking Critiquing</p>	Assess, Compare, Conclude, Convince, Decide, Discriminate, Explain, Grade, Judge, Measure, Rank, Recommend, Select, Summarize, Support, Test
Creating	<p>Put elements together to form a coherent or functional whole; reorganize elements into a new pattern or structure</p> <p>Generating Planning Producing</p>	Combine, Compose, Design, Formulate, Generalize, Integrate, Invent, Modify, Plan, Create, Prepare, Rearrange, Rewrite, Substitute

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