Two year Master of Technology (MTech) Degree Program

in

Power and Control Systems (P&CS)

by

Department of Electrical Engineering Department
Indian Institute of Technology Patna
Bihta, Patna-801106

Academic Program: M.Tech. in Power and Control Systems (P&CS)
Program Learning Outcomes:

Program Learning Objectives: (i) Specialized training in the field of Power and Control system. (ii) Develop an orientation towards industrial training on specialized field. (iii) Imparting world class training to develop the foundation for making world class researcher in this field of research. (iv) Work collaboratively in multidisciplinary teams, demonstrating effective teamwork and communication to solve complex engineering problems. (v) Recognize the importance of ongoing professional development, engaging in activities such as certifications, workshops, and conferences to stay updated of industry trends.	**Program Learning Outcomes:** The graduates of this program will have ● strong fundamentals in Power and Control system engineering. ● ability to analyze and synthesize engineering problems including design and conduct experiments, use standard test equipment and interpret experimental data. ● ability to design prototypes for real world problems. ● ability to work in a multidisciplinary team environment. ● ability to appreciate the complexities of professional environments, including taking responsibility for oneself, working effectively and professionally as a team member, and being mindful of ethical, economic, and contemporary concerns. ● ability to continue learning in Power and Control system field. ● ability to independently accomplish engineering tasks related to Power and Control research areas. ● ability to enter industry with the engineering techniques, skills, and tools required to be able to solve real-world problems in Power and Control system engineering.
Program Goal 1: Academic excellence by providing a curriculum that aligns with industry standards and encourages critical thinking in Power and Control system engineering**.**	**Program Learning Outcome 1a:** Highly skilled market ready manpower to serve the emerging electrical and electronic sectors **Program Learning Outcome 1b:** Skilled Human resource to cater the needs of next generation power systems and EV technologies.
Program Goal 2: A culture of research and innovation by promoting faculty and student involvement in innovative projects in Power and Control system technologies.	**Program Learning Outcome 2a:** Trained researchers for implementing research projects in line with national priorities such as Energy, EVs, Smart Grids, Green Technologies. **Program Learning Outcome 2b:** Design and develop innovative smart technologies/products in energy and EVs as per the societal need
Program Goal 3: To design dynamic and flexible course structures for UG and PG programs as per the changing requirement of the industries.	**Program Learning Outcome 3a:** Industry relevant UG, PG, and research programs **Program Learning Outcome 3b:** Trained manpower as per the industry requirement
Program Goal 4: To promote entrepreneurship among the students in the field of Power and Control system engineering	**Program Learning Outcome 4a:** Realization of working prototype towards product development **Program Learning Outcome 4b:** Promotion of in-house technology-based ventures catering societal needs .

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Sl. No.	Subject Code	**SEMESTER I**	**L**	**T**	**P**	**C**
1.	HS51PQ	Technical Writing and Soft Skill	3	0	2	4
2.	EE5101	Computer Aided Power System Analysis	3	0	2	4
3.	EE5102	Advanced Power Electronics Converters	3	0	2	4
4.	EE5103	FACTS and Its Applications	3	0	2	4
5.	EE51PQ/EE61PQ	DE-1	3	0	0	3
6.	EE51PQ/EE61PQ	DE-2	3	0	0	3
7.	XX61PQ	IDE	3	0	0	3
	TOTAL		**18**	**0**	**8**	**25**

Sl. No.	Subject Code	**SEMESTER II**	**L**	**T**	**P**	**C**
1.	EE5201	Power System Dynamics, Control and Protection	3	0	2	4
2.	EE5202	Nonlinear Dynamical Systems	3	0	2	4
3.	EE52PQ/EE62PQ	DE-3	3	0	0	3
4.	EE52PQ/EE62PQ	DE-4	3	0	0	3
5.	EE52PQ/EE62PQ	DE-5	3	0	0	3
6.	RM6201	Research Methodology	3	1	0	4
7.	XX61PQ	IDE	3	0	0	3
	TOTAL		**18**	**1**	**4**	**24**

Sl. No.	Subject Code	**SEMESTER III**	**L**	**T**	**P**	**C**
1	EE6198	Summer internship/Mini Project*	0	0	12	3
2	EE6199	Project I	0	0	30	15
	TOTAL		**6**	**0**	**42**	**18**

Sl. No.	Subject Code	**SEMESTER IV**	**L**	**T**	**P**	**C**
1.	EE6299	Project II	0	0	42	21
	TOTAL		**0**	**0**	**42**	**21**

GRAND TOTAL	**88**

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Elective Courses:

Semester-I

DE-1	**DE-2**
EE5111 Renewable Energy Integration	EE5113 Power System Deregulation
EE6111 Advanced Power System Reliability	EE6113 Advanced Power System Protection
EE6114 Advanced State Estimation and Target Tracking	EE6115 Switched Mode Power Converters
EE6117 Multivariable Control System	EE6116 Advanced Digital Control System
EC6150 CMOS Phase Locked Loops	EC5111 VLSI Architectural Design and Implementation

Semester-II

DE-3	**DE-4**	**DE-5**
EE5213 Recent Trends in Optimization Techniques	EE6218 Power System Optimization	EE6211 Control Techniques in Power Electronics
EE6212 Model Predictive Control	EE6213 Advance Electric Drives	EE6214 Telemetry and SCADA
EE6217 HVDC Transmission Systems	EE6215 Random Signals and Systems	EE5212 Electric Vehicle Technology
EC6270 Advance FPGA Platform and System	EE6216 Quantitative Feedback Theory	EE 6219 Optimal Control

Core Courses:

Course Number	**EE5101**
Course Credit	**L-T-P-C: 3-0-2-4**
Course Title	**Computer Aided Power System Analysis**
Learning Mode	Lectures and Labs
Learning Objectives	Complies with Program Goals 1 and 2
Course Description	The course is designed to meet the requirements of Ph.D. and M. Tech students to get sufficient knowledge on power system analysis of large power systems from programming perspectives.
Course Outline	Load flow for AC systems, fast decoupled load flow, optimal power flow. Fault Analysis, Symmetrical components, Z - matrix for short circuit studies. Introduction to state estimation, Weighted least squares method, LO algorithm, fast decoupled state estimation, DC state estimation, Network observability analysis. Security and contingency studies. Unit Commitment. Load frequency control. Optimal hydro-thermal scheduling. AI applications to Power Systems
Learning Outcomes	Complies with PLOs 1a, 2a, and 3a
Assessment Method	Quizzes/Assignments, Mid Sem, and End Sem
Suggested Readings	**Text/References** 1. O.I.Elgerd, Electric Energy Systems Theory, McGraw Hill, 1971 2. G.W.Stagg and A.H.El-Abiad, Computer Methods in Power System Analysis, McGraw Hill 1968. 3. G.L.Kusic, Computer Aided Power Systems Analysis, Prentice Hall, 1986. 4. I.J.Nagrath, D.P.Kothari, and R K Saket, Modern Power Systems Analysis, Tata McGraw Hill, 1980. 5. A.J.Wood and B.F.Wollenberg, Power Generation, Operation and Control, John Wiley, 1984

Course Number	**EE5102**
Course Credit	**L-T-P-C: 3-0-2-4**
Course Title	**Advanced Power Electronic Converter**
Learning Mode	Lectures and Labs
Learning Objectives	Complies with Program Goals 1 and 2
Course Description	The course is designed to meet the requirements of M. Tech. The course aims at giving a broad overview of advanced power electronic converters. Multilevel inverter, soft switched rectifiers and some special converters are detailed.
Course Outline	Concept of PWM inverters and Multilevel inverters Neutral point-controlled inverters: Concept, Operation, Analysis, Design and control techniques Soft switching converters: Concept of Soft switching: Zero voltage switching, Zero current switching DC-DC resonant link inverters: Concept, Operation, Analysis, Design and control techniques, Hybrid resonant link inverters: Concept, Operation, Analysis, Design and control techniques Quasi resonant link converters: Concept, Operation, Analysis, Design and control techniques

	Switched mode rectifiers: Concept, Operation, Analysis, Design and control techniques Synchronous link converters: Concept, Operation, Analysis, Design and control techniques Closed loop control of DC-DC, AC-DC, DC-AC converters
Learning Outcomes	Complies with PLOs 1a, 2a, and 3a
Assessment Method	Quizzes/Assignments, Mid Sem, and End Sem
Suggested Reading	**Text/References** 1. Ned Mohan, Tore M, Undelnad, William P, Robbins (3 Edition), Electronics: Converters, Applications and Design; Wiley 2002 2. Rashid, Muhammad H., ed. *Power electronics handbook*. Butterworth-heinemann, 2017. 3. Robert Ericson, Fundamentals of Power Electronics, Chapman & Hall, 2004. 4. Gupta, Krishna Kumar, and Pallavee Bhatnagar. *Multilevel inverters: conventional and emerging topologies and their control*. Academic Press, 2017. 5. B. K Bose, "Power electronics and motor drives: advances and trends." Academic Press Inc. (2020)

Course Number	**EE5103**
Course Credit	**L-T-P-C: 3-0-2-4**
Course Title	**FACTS and its applications**
Learning Mode	Lectures and Labs
Learning Objectives	Complies with Program Objectives 1 and 2.
Course Description	The course is designed to meet the requirements of Ph.D. and M. Tech students to get sufficient knowledge on high voltage AC Transmission.
Course Outline	Basic FACTS controllers: SVC, STATCOM, TCSC, TCPAR, UPFC. Modeling of FACTS Controllers. System static performance improvement with FACTS controllers. System dynamic performance improvement with FACTS controllers.
Learning Outcomes	Complies with PLOs 1a, 2a, and 3a.
Assessment Method	Quizzes/Assignments, Mid Sem, and End Sem
Suggested Readings	**Text/References** 1. Hingorani N. G. “Understanding FACTS Concepts & Technology of FACTS Systems,” IEEE PRESS, 2000. 2. R. M. Mathur and R. K. Varma, Thyristor Based FACTS Controllers for Electric Power Transmission Systems, IEEE Press and Wiley Interscience, New York, 2002

Course Number	**EE5201**
Course Credit	**L-T-P-C: 3-0-2-4**
Course Title	**Power System Dynamics, Control and Protection**
Learning Mode	Lectures and Labs
Learning Objectives	Complies with Program Goals 1 and 2.
Course Description	The course is designed to meet the requirements of Ph.D. and M. Tech students to get sufficient knowledge on power system stability issues and control application for the same.

Course Outline	Basic Concepts of dynamical systems and stability. Modeling of power system components for stability studies: generators, transmission lines, excitation and prime mover controllers, flexible AC transmission (FACTS) controllers. Analysis of single machine and multimachine systems. Small signal angle instability (low frequency oscillations): damping and synchronizing torque analysis, eigenvalue analysis. Mitigation using power system stabilizers and supplementary modulation control of FACTS devices. Small signal angle instability (subsynchronous frequency oscillations): analysis and counter-measures. Transient stability:Analysis using digital simulation and energy function method. Transient stability controllers. Introduction to voltage Instability. Analysis of voltage Instability.
Learning Outcomes	Complies with PLOs 1a, 2a, and 3a.
Assessment Method	Quizzes/Assignments, Mid Sem, and End Sem
Suggested Readings	**Text/References** 1. P.Kundur, Power System Stability and Control, McGraw Hill Inc, New York, 1995. 2. P.Sauer & M.A.Pai, Power System Dynamics & Stability, Prentice Hall, 1997. 3. K. R. Padiyar, "Power System Dynamics: Stability and Control" Anshan Ltd, 2004.

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Course Number	**EE5202**
Course Credit	**L-T-P-C: 3-0-2-4**
Course Title	**Nonlinear Dynamical Systems**
Learning Mode	Lectures
Learning Objectives	Complies with Program goals 1, 2 and 3
Course Description	The course is designed to meet the requirements of Ph.D. and M. Tech students to get sufficient knowledge of nonlinear dynamical systems.
Course Outline	Introduction to nonlinear systems; analysis by phase plane and describing function methods, periodic solutions and limit cycles. Lyapunov stability theory. introduction to stability; equilibrium point; assympototic stability; the Lure problem: Popov's method, circle criterion, direct and indirect methods of stability analysis, stability of non-autonomous systems. Hamiltonian Vector Fields: Symplectic Forms, relationship between Hamilton's equations and the symplectic form, transformation of Hamilton's equations under symplectic transformations, dynamics of completely integrable Hamiltonian systems in action-angle coordinates, stability of elliptic equilibria. Reversible dynamical systems: definition of reversible dynamical systems, examples of reversible dynamical systems, linearization of reversible dynamical systems, additional properties of reversible dynamical systems Introduction to hyperstabilit,.Lagrangian and gradient systems: physical examples and analysis.
Learning Outcomes	Complies with PLO 1a, 2a and 3a
Assessment Method	Quiz, Assignments, and Exams
Suggested Reading	1. V. M. Popov : Hyperstability of control systems. Springer Grundleheren series, 1970. 2. M. Vidyasagar, Nonlinear systems analysis. 2nd Edition. Prentice Hall, 1993. 3. Y. A. Yakubovitch and V. M. Starzhinskii, Linear differential equations with periodic coefficients. Wiley, 1975

Elective Courses:

Course Number	**EE5111**
Course Credit	**L-T-P-C: 3-0-0-3**
Course Title	**Renewable Energy Integration**
Learning Mode	Lecture
Learning Objectives	Complies with Program goals 1, 2 and 3
Course Description	The course is designed to meet the requirements of M. Tech. The course aims at giving a broad overview of renewable energy grid integration with emphasis on the power electronics, policy, regulation and control.
Course Outline	Policy and Regulation, Modeling of Variable energy resources, Variable energy resources in power system, forecasting renewable energy Connecting renewable energy to power grids, System flexibility, demand response and distributed energy resources Variable energy resources in island power system, Solar, Wind, Tidal and Wave energy integration Power Electronics for grid integration: DC-DC converter, DC-AC converter, Filter Design, Parallel Inverter etc. Enabling and disruptive technologies for grid integration DC distribution system and microgrids: Concept of DC distribution, Power electronic, DC distribution standard, grid integration etc.
Learning Outcomes	Complies with PLO 1a, 2a and 3a
Assessment Method	Quizzes/Assignments, Mid Sem, and End Sem
Suggested reading	**Textbooks:** 1. Robert Ericson, Fundamentals of Power Electronics, Chapman & Hall, 2004. 1. Lawerence E Jones, Renewable Energy Integration, Science Direct, 2014. 2. Moreno-Munoz, Antonio. Large scale grid integration of renewable energy sources. No. 137837. IET, 2017. 3. Fox, Brendan. Wind power integration: connection and system operational aspects. Vol. 50. Iet, 2007. 4. Dragicevic, Tomislav, Patrick Wheeler, and Frede Blaabjerg. DC distribution systems and microgrids. Institution of Engineering and Technology, 2018. 5. Jamil, Majid, M. Rizwan, and D. P. Kothari. Grid Integration of Solar Photovoltaic Systems. CRC Press, 2017.

Course Number	**EE6111**

Course Credit	**L-T-P-C: 3-0-0-3**
Course Title	**Advanced Power System Reliability**
Learning Mode	Lectures
Learning Objectives	Complies with Program Goals 1 and 2
Course Description	The course is designed to meet the requirements of Ph.D. and M. Tech. The course aims at giving a broad overview of power system reliability at an advanced level.
Course Outline	Basic Probability Theory: Probability concepts, rules for combining probability, probability distributions, random variables, density and distribution functions, mathematical expectations, variance and standard deviation. Basic Reliability Evaluation: General reliability functions, probability distributions in reliability evaluation, network modeling and evaluation of series, parallel, series –parallel, network modeling and evaluation of complex systems, cut-set method, tie-set method, discrete Markov chains, continuous Markov process, frequency and duration technique concepts, application to multi-state problems, approximate system reliability evaluation. Generation System Reliability: Generation system models, capacity outage table, recursive algorithm, loss of load indices, inclusion of scheduled outages, load forecast uncertainty, loss of energy indices, expected energy generation, energy limited systems, Gram-Charlier series and its application to generation system reliability evaluation, generating capacity –frequency and duration method. Interconnected System: Probability array method in two interconnected systems, effect of tie capacity, tie reliability and number of tie lines, equivalent assistance unit method for reliability evaluation of inter-connected system, elementary concepts for reliability evaluation of multi-connected systems. Composite Generation and Transmission System Reliability: Radial configurations, conditional probability approach, network configuration, state selection, system and load point indices. Distribution System Reliability: Basic technique and application to radial systems, customer–oriented indices, load and energy indices, effect of lateral distributor protection, effect of disconnects, effect of protection failures, effect of load transfer, meshed and parallel networks, approximate methods, failure modes and effects analysis, inclusion of scheduled maintenance, temporary and transient failures, inclusion of weather effects.
Learning Outcomes	Complies with PLOs 1a, 2a, and 3a.
Assessment Method	Quizzes/Assignments, Mid Sem, and End Sem
Suggested Readings	**Texts/References:** 1. Reliability Evaluation of Power systems by R. Billinton, R.N.Allan, BS Publications, 2007. 2. Reliability Evaluation of Engineering Systems Concepts and Techniques by R. Billinton, R.N.Allan, Kluwer Academic, 1992 3. Reliability Modeling in Electric Power Systems by J. Endrenyi, John Wiley and Sons, 1978

Course Number	**EE6113**
Course Credit	**L-T-P-C: 3-0-0-3**
Course Title	**Advanced Power System Protection**
Learning Mode	Lectures
Learning Objectives	Complies with Program Objectives 1 and 2.
Course Description	The course is designed to meet the requirements of Ph.D. and M. Tech students to get sufficient knowledge on Digital power system relaying and its applications.

Course Outline	Protective Devices: Philosophy of protection, Methods of earthing and their effect on fault conditions. Different types of relays: attracted armature type, balanced beam type, induction type. Static relays: Generalized theory of phase and magnitude, comparator, realization of different relay characteristics of static devices. Evolution of Power System Protection and the Emergence of Digital Relaying, Digital Signal Processing Basics and Architecture of Numerical Relay: Introduction to Digital Signal Processing, The DSP Signal Processing Chain, Analog to Digital Converters, Anti-aliasing Filter, Algorithms Based on Undistorted Single Frequency Sine Wave, Algorithms Based on Solution of Differential Equation, Algorithms Based on Least Squared Error, Discrete Fourier Transform, FFT and Goertzel Algorithm, Introduction to Digital Filtering, Synchrophasors, Introduction to computer relaying, Relaying applications of traveling waves, Wide area measurement applications.
Learning Outcomes	Complies with PLOs 1a, 2a, and 3a
Assessment Method	Quizzes/Assignments, Mid Sem, and End Sem
Suggested Readings	<u>**Text/References**</u> 1. Arun G. Phadke and James S. Thorp, "Computer Relaying for Power Systems," 2nd Edition, Wiley, 2009. 2. S. R. Bhide, "Digital Power System Protection," PHI Learning Private Limited, 2014.

Course Number	**EE6114**
Course Credit	**L-T-P-C: 3-0-0-3**
Course Title	**Advanced State Estimation and Target Tracking**
Learning Mode	Lectures
Learning Objectives	Complies with Program Objectives 1 and 2.
Course Description	This course will help students learn the theoretical aspects of discrete-time stochastic estimators and filters with target-tracking applications. The interest of the course will cover tracking of a single target as well as multiple targets.

Course Outline	Basic Concept of Estimation: Introduction, maximum likelihood and maximum a posteriori estimation, least square and minimum mean square error estimation, Fisher information matrix, Cramer-Rao lower bounds. State Estimation Methods: Principle of Bayesian estimation, recursive state estimation and filtering, filtering with linear Gaussian systems (the Kalman filter), extended Kalman filter, unscented / sigma point Kalman filtering, cubature Kalman filter, sequential importance sampling, resampling strategy, sampling importance resampling (SIR) filter, particle filtering, Rao–Blackwellization. Tracking a Single Target: Maneuvering models, multiple model filtering techniques, tracking a single target in clutter, probabilistic data association (PDA). Tracking Multiple Targets: Multiple targets in clutter, joint probabilistic data association (JPDA), multiple hypothesis tracking (MHT), track-to-track fusion with and without memory, track-to-track association, covariance intersection. Tracking with Multiple Sensors: multi-sensor tracking of a maneuvering target in clutter, multi-sensor tracking configuration, multi-sensor multi-target data association. A case study: Multi-sensor air traffic surveillance.
Learning Outcomes	Complies with PLOs 1a, 2a, and 3a
Assessment Method	Quizzes/Assignments, Mid Sem, and End Sem
Suggested Readings	**<u>Text/References</u>** 1. B. Ristic, S. Arulumpalam, N. Gordon, Beyond the Kalman Filter: Particle Filters for Tracking Applications, Artech House Radar Library, 2004. 2. Y. B. Shalom, and X. R. Li. Multitarget-multisensor tracking: principles and techniques. Vol. 19, 1995. 3. Bar-Shalom, Yaakov, X. Rong Li, and Thiagalingam Kirubarajan. Estimation with applications to tracking and navigation: theory algorithms and software. John Wiley & Sons, 2004. 4. Shovan Bhaumik and Paresh Date, Nonlinear Estimation: Methods and Applications with Deterministic Sample Points, CRC Press, 2019 5. Jia, Bin, and Ming Xin. Grid-based nonlinear estimation and its applications. CRC Press, 2019.

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Course Number	**EE6115**
Course Credit	**L-T-P-C: 3-0-0-3**
Course Title	**Switched Mode Power Converters**
Learning Mode	Lectures
Learning Objectives	Complies with Program Objectives 1 and 2.
Course Description	The course is designed to meet the requirements of Ph.D. and M. Tech students to get sufficient knowledge on switched mode power converters. Also, it may be useful for B. Tech final year students.

Course Outline	Power Semiconductor Devices and Passive Elements: Power Diode, Power BJT, Power MOSFET and Power IGBT. Discussion on Capacitor and Inductor. Design of Magnetics. Gate Driver and Snubber Circuits: Discussion on gate driver and snubber circuit requirements. Switched Mode DC-DC Converters: Non-isolated Converters (Buck, Boost, Buck-boost, Full-bridge, Cuk, Sepic and Zeta). Design and control of Buck converter. Isolated DC-DC Converters (Half-bridge, Full-bridge, Forward, Flyback and Push-pull). Design and control of Flyback converter. Switched Mode DC-AC Converters: Single-phase and three-phase PWM VSIs. Discussion on AC filters
Learning Outcomes	Complies with PLOs 1a, 2a, and 3a
Assessment Method	Quizzes/Assignments, Mid Sem, and End Sem
Suggested Reading	**Textbooks:** 1. Ned Mohan, Tore M, Undelnad, William P, Robbins (3 Edition), Power Electronics: Converters, Applications and Design; Wiley, 2002 2. Robert Ericson, Fundamentals of Power Electronics, Chapman & Hall, 2004. **References:** 1. Ramanarayanan V.,Switched Mode Power Conversion, 2007. 2. Umanand L., Power Electronics: Essentials and Applications, Wiley, 2009. 3. Jayant Baliga B., Power Semiconductor Devices, PWS, 1996.

Course Number	**EE5113**
Course Credit	**L-T-P-C: 3-0-0-3**
Course Title	**Power System Deregulation**
Learning Mode	Lectures
Learning Objectives	Complies with Program Objectives 1 and 2.
Course Description	The course is designed to meet the requirements of Ph.D. and M. Tech students to get sufficient knowledge on Power system restructuring and various business models at different sectors.
Course Outline	Fundamentals of deregulation: Privatization and deregulation, Motivations for Restructuring the Power industry; Restructuring models and Trading Arrangements: Components of restructured systems, Independent System Operator (ISO): Functions and responsibilities, Trading arrangements (Pool, bilateral & multilateral), Open Access Transmission Systems; Different models of deregulation: U K Model, California model, Australian and New Zealand models, Deregulation in Asia including India, Bidding strategies, Forward and Future market; Operation and control: Old vs New, Available Transfer Capability, Congestion management, Ancillary services; Wheeling charges and pricing: Wheeling methodologies, pricing strategies.
Learning Outcomes	Complies with PLOs 1a, 2a, and 3a.
Assessment Method	Quizzes/Assignments: 20 %, Mid Sem: 30 % and End Sem: 50 %
Suggested Readings	**Text/References** 1. Operation of restructured power systems. Kankar Bhattacharya, Jaap E. Daadler, Math H.J. Boolen, Kluwer Academic Pub., 2001. 2. Restructured electrical power systems: operation, trading and volatility Mohammad Shahidehpour, Muwaffaq Alomoush, Marcel Dekker Pub., 2001.

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Course Number	**EE6117**
Course Credit	**L-T-P-C: 3-0-0-3**
Course Title	**Multivariable Control System**
Learning Mode	Lectures
Learning Objectives	Complies with Program goals 1 and 2
Course Description	This course will help students learn the theoretical aspects of dynamical systems in State-Space framework and properties of systems such as Controllability and Observability. Further, State-feedback control, Output feedback control and LQR, Robust Stability will be covered.
Course Outline	State-space dynamic systems (continuous-time): Introduction to LTI state-space models, Four canonical forms for LTI state-space models, One more canonical form, transformations, Time (dynamic) response, Balanced Realization, Diagonalizing the A matrix, The Jordan canonical form; MIMO canonical forms, Zeros of a state-space system, Linear time-varying systems, What about nonlinear systems? The z transform, Working with the z transform, Discrete-time state-space form, More on discrete-time state-space models, Linear time-varying and nonlinear discrete-time systems. Stability: Vector norms and quadratic forms, Matrix gain, Lyapunov stability, Proof of the Lyapunov stability theorem, Discrete-time Lyapunov stability, Stability of locally linearized systems, Input-output stability, LTV case, Input-output stability, LTI case Observability and controllability: Continuous-time observability: Where am I?, Continuous-time controllability: Can I get there from here?, Discrete-time controllability and observability, Cayley-Hamilton theorem, Continuous-time Gramians, Discrete-time Gramians, Computing transformation matrices, Canonical (Kalman) decompositions, PBH controllability/observability tests, Minimal realizations: Why not controllable/observable ? State-feedback control: Bass-Gura pole placement, Ackermann's formula, Reference input, Pole placement, Integral control for continuous-time systems, State feedback for discrete-time systems, MIMO control design Output-feedback control: Open-loop and closed-loop estimators, The observer gain design problem, Discrete-time prediction estimator, Compensation design: Separation principle, The compensator, continuous- and discrete-time, Current estimator/compensator, Compensator design using current estimator, Discrete-time reduced-order estimator, Discrete-time reduced-order prediction compensator, Continuous-time reduced-order estimator, Estimator pole placement Linear quadratic regulator: Introduction to optimal control, Dynamic programming: Bellman's principle of optimality, The discrete-time LQR problem, Infinite-horizon discrete-time LQR, The continuous-time LQR problem, Solving the differential Riccati equation via simulation, Continuous-time systems and Chang-Letov Method. Robust stability and performance analysis for MIMO systems: General control configuration with uncertainty, Representing uncertainty, Obtaining P, N and M, Robust stability of the M -structure, Robust stability for complex unstructured uncertainty, Robust stability with structured uncertainty, Robust Performance
Learning Outcomes	Complies with PLO 1a, 2a, 3a
Assessment Method	Quizzes, Assignments, Exams
Suggested Readings	1. S. Skogestad and I. Postlethwaite, Multivariable Feedback Control: Analysis and Design, John Wiley & Sons, 2nd Edition, 2005 2. J.M. Maciejowski, Multivariable Feedback Design, Addison-Wesley, 1st Edition, 1989 3. J.P. Hespanha, Linear Systems Theory, Princeton University Press, 2nd Edition, 2018 4. L. A. Zadeh and C. A. Desoer, Linear System Theory: The State Space Approach, Springer-Verlag, 2008. 5. W. Rugh, Linear System Theory, Prentice Hall, 2nd Edition, 1995.

Course Number	**EC6150**
Course Credit	**L-T-P-C: 3-0-0-3**
Course Title	**CMOS Phase-Locked Loops**
Learning Mode	Lectures

Learning Objectives	Complies with Program Goals 1 and 2
Course Description	CMOS Phase-Locked Loops (PLLs) involve the design and implementation of frequency synthesis circuits using Complementary Metal-Oxide-Semiconductor (CMOS) technology. The course covers topics such as PLL architecture, phase detection and comparison, loop filter design, voltage-controlled oscillator (VCO) characteristics, and applications in clock generation, frequency synthesis, and communication systems.
Course Outline	Introduction to PLL, Various types of PLL PLL building blocks: Phase detectors, Phase/Frequency detectors, Ring and LC Voltage-controlled Oscillators (VCO), Frequency Dividers Analysis of PLL: Type-I and Type-II 2nd order PLL; Higher-order loop filters and PLL; PLL Stability Designing PLL: a 2nd order PLL Jitter and Phase noise in Oscillators and PLLs, PLL-based frequency synthesizer: Integer-N and Fractional-N synthesizers, $\Delta\sum$ Fractional-N synthesizers All-Digital PLL: Time-to-Digital Conversion, Digital Filters, Digitally Controlled Oscillators, Delay-locked Loops Low jitter frequency synthesizer: Subsampling PLL Architecture and it components
Learning Outcomes	Complies with PLOs 1a, 1b, 2 and 3a
Assessment Method	Quizzes/Assignments, Mid Sem, and End Sem
Suggested Readings	**Text/References** 1. B. Razavi, “Design of CMOS Phase-Locked Loops” Cambridge Univ Press, 2020. 2. William F Egan, “Phase-lock Basics,” IEEE-Wiley 3. Floyd M. Gardner, “Phase Lock Techniques” 3rd Edition, Wiley-inter-science 4. Ronald E Best, “Phase-locked Loop, Design, Simulation and Applications”, 6th edition, McGrawHill 5. Venceslav F Kroupa, “Phase Lock Loops and Frequency Synthesis,” Wiley 6. Shanthi Pavan, Richard Schreier, “Understanding Delta-Sigma Data Converters” IEEE-Wiley

Course Number	**EE6116**
Course Credit	**L-T-P-C: 3-0-0-6**
Course Title	**Advanced Digital Control System**
Learning Mode	Lectures and Tutorials
Learning Objectives	Complies with Program Goals 1 and 2
Course Description	This course will help the students in learning the fundamentals and various components of Digital Control, Digital PID design, discrete state space models, Analyse SISO and MIMO systems and various stability techniques, Deadbeat response and various stability techniques.
Course Outline	Introduction to digital control Introduction -Discrete time system representation –Sample & Hold-Mathematical modeling of sampling process –Data Reconstruction-Design of the hardware and software architecture – Software requirements- Selection of ADC and DAC- Choice of the sampling period –Prefilter/Antialiasing filters - Effects of quantization errors - Phase delay introduced by the ZOH-Sampling period switching- Dual rate control. Modeling discrete-time systems by pulse transfer function -Revisiting Z-transform -Mapping of s-plane to z-plane - Pulse transfer function - Pulse transfer function of closed loop system - Sampled signal flow graph -Stability analysis of discrete time systems -Jury stability test - Stability analysis using bi-linear transformation Design of sampled data control systems Design of PID controller-Filtering the derivative action- Integrator windup- Bumpless transfer between manual and automatic mode - Incremental form-Root locus method - Controller design using root locus - Root locus based controller design using MATLAB - Nyquist stability criteria - Bode plot – Lead compensator design using Bode plot - Lag compensator design using Bode plot - Lag-lead compensator design in frequency domain-Deadbeat response design -Design of digital control systems with deadbeat

	response - Practical issues with deadbeat response design - Sampled data control systems with deadbeat response Discrete state space model and state feedback design Introduction to state variable model for SISO systems- Various canonical forms – Characteristic equation, state transition matrix - Solution to discrete state equation- Controllability, observability and stability of discrete state space models -Controllability and observability – Stability Pole placement by state feedback - Set point tracking controller - Full order observer - Reduced order observer-Servo Design- State feedback with Integral Control-Deadbeat Control by state feedback and deadbeat observers - Output feedback design - Output feedback design: Theory - Output feedback design: Examples. Introduction to Multivariable & Multi-input Multi-output (MIMO) Digital Control Systems Nonlinear Digital control systems Discretization of nonlinear systems - Extended linearization by input redefinition - - input and state redefinition - output differentiation - Extended linearization using matching conditions – Nonlinear difference equations - Logarithmic transformation- Equilibrium of nonlinear discrete-time systems - Lyapunov stability theory- Lyapunov functions - Stability theorems -Rate of convergence – Lyapunov stability of linear systems - Lyapunov's linearization method- Instability theorems - Estimation of the domain of attraction - Stability of analog systems with digital control Hybrid Systems - State plane analysis - Discrete-time nonlinear controller design- Controller design using extended linearization- Controller design based on Lyapunov stability theory - Input-output stability and the small gain theorem, Absolute stability
Learning Outcomes	Complies with PLO 1a, 2a, 3a
Assessment Method	Quizzes, Assignments, Exams
Suggested Readings	1. B.C Kuo, 'Digital Control Systems', Oxford University Press, Inc., New York, 2nd Ed, 1995 2. G.F. Franklin, J.D. Powell, and M.L. Workman, 'Digital control of Dynamic Systems', Addison-Wesley Longman, Inc., Menlo Park, CA, 1998. 3. M. Gopal, 'Digital Control and State Variable Methods', 4th Ed, Tata McGraw Hill Publishing Company, 2017. 4. John F. Walkerly, 'Microcomputer architecture and Programs', Tata McGraw Hill Publishing Company, ,John Wiley and Sons Inc., New York, 1981. 5. K. Ogata, 'Discrete Time Control Systems' , 2nd Ed, Prentice Hall India Learning Private Limited, 2005. 6. C. H. Houpis and G.B. Lamont, 'Digital Control Systems', McGraw Hill Book Company, 2nd Ed, 1992. 7. C.L. Philips and H.T Nagle, Jr., 'Digital Control System Analysis and Design', Prentice Hall, Inc., Englewood Cliffs, N. J., 1995 8. M. Sami Fadali Antonio Visioli, 'Digital Control Engineering Analysis and Design', 3rd Ed, Academic Press, 2019

Course Number	**EC5111**
Course Credit	**L-T-P-C: 3-0-0-3**
Course Title	**VLSI Architectural Design and Implementation**
Learning Mode	Lectures
Learning Objectives	Complies with Program Goals 1 and 2

Course Description	VLSI Architectural Design and Implementation covers the principles of designing and implementing efficient VLSI architectures. The course includes topics such as pipeline design, data path optimization, and hardware description languages.
Course Outline	Introduction to VLSI System Design and Implementation; Architectural mapping with case studies: Data path, Control path Synthesis; Control Strategies: Hardware implementation of various control structures; Micro-program control techniques; Design issues: Timing, Area, power analysis; FSM Architecture and Synthesis, HDL design and implementation of VLSI architecture; Semiconductor Memory and Peripheral Architectures; Computer arithmetic architecture design and analysis: Introduction to integer and floating-point arithmetic, Adders, Subtractors, Sequential and Array multipliers & dividers, square root, Absolute Difference Value, CORDIC. Hardware architecture design and performance analysis: Sequential/Folding architectures; bit and word serial architecture; High performance architectures: pipelined, parallel and Systolic Array with examples; Architectural performance Analysis: Throughput and Latency; Low Power VLSI Architectures; Basic Hardware Architectures for Digital Signal processing and machine learning algorithms. Introduction to VLSI Chip testing methods and Architectures: Introduction to Chip Fault Model, DFT Architecture, BIST Architecture.
Learning Outcomes	Complies with PLOs 1a, 1b, 2 and 3a
Assessment Method	Quizzes/Assignments, Mid Sem, and End Sem
Suggested Readings	**Text/References** 1. Peter Pirsch, "Architectures for Digital Signal Processing", John Willy & sons,2nd Edition,2014. 2. K. K. Parhi, " VLSI Digital Signal Processing Systems: Design and Implementation", A Wiley-Interscience publications,2011. 3. Behrooz Parhami, " Computer Arithmetic: Algorithm and Hardware Design", Behrooz Parhami, Oxford University Press, 2nd Edition,2009. 4. A. Bellaouar, M. I. Elmarsny, "Low Power Digital VLSI Design", A. Bellaouar, M. I. Elmarsny, Kluwe academic Publication,1995. 5. DSP Integrated Circuit, L. Wamhammer, Academic Press,1999.

Course Number	**EE6211**
Course Credit	**L-T-P-C: 3-0-0-3**
Course Title	**Control Techniques in Power Electronics**
Learning Mode	Lectures
Learning Objectives	Complies with Program Objectives 1 and 2.
Course Description	The course is designed to meet the requirements of **Ph.D.** and **M. Tech** students to get sufficient knowledge on Control Techniques in Power Electronics. Also, it is useful for **B. Tech final year** students.
Course Outline	State space modelling and simulation of linear systems, Discrete time models, conventional controllers using small signal models, Hysteresis controllers, Output and state feedback switching controllers. Averaged - switch modelling, modelling of dynamics of converters operating in discontinuous conduction mode, input filter design.
Learning Outcomes	Complies with PLOs 1a, 2a, and 3a
Assessment Method	Quizzes/Assignments, Mid Sem, and End Sem

Suggested Reading	**Textbooks:** 1. Muhammad Rashid, Power Electronics Handbook, Academic Press-Elsevier, 2001. 2. B. Wu, High-Power Converters and AC Drives. Wiley-IEEE Press, New Jersey, 2006. 3. Erickson and Maksimovic, Fundamentals of Power Electronics, 2nd ed., Springer Science+Business (2000) **Reference**: 1. Ned Mohan, Tore M, Undelnad, William P, Robbins (3 Edition), Power Electronics: Converters, Applications and Design; Wiley 2002.

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Course Number	**EE6212**
Course Credit	**L-T-P-C: 3-0-0-3**
Course Title	**Model Predictive Control**
Learning Mode	Lectures
Learning Objectives	Complies with Program goals 1 and 2
Course Description	This course will help the students in learning the various Mathematical formulations of MPC, step response, finite impulse response models, Linear MPC and its stability using Lyapunov methods, design, motivations and challenges of Nonlinear MPC and its various formulations with stability analysis
Course Outline	Fundamental Elements of Predictive Control Limitations of classical control - Optimization-based Control - Origins of MPC, Mathematical formulation of MPC: prediction models, objective functions, and constraints - Models for MPC: Finite impulse and step response models, Model prediction, Parameter estimation - Prediction using LTI models, transfer function models, Model analysis and Disturbance Modeling- Receding Horizon, Finite Horizon Approximation, Cost versus Horizon - Infinite Horizon Control. Fundamentals of Convex Optimization: Review of linear programming, quadratic programming, and mixed-integer programming Linear Model Predictive Control Dynamic Matrix Control – MPC based on quadratic programming - constrained MPC - state-space based MPC -Discrete-time MPC Using Laguerre Functions - Generalized predictive control – Event triggered MPC. Stability analysis of MPC: Lyapunov stability, terminal state constraints, and terminal cost function. Design considerations for MPC: prediction and control horizon selection, weighting matrices, and handling constraints - Robustness analysis and mitigation techniques for MPC- computational considerations. Nonlinear Model Predictive Control Introduction to Nonlinear Model Predictive Control (NMPC): motivations and challenges - NMPC formulations: direct and indirect approaches, multiple shooting, and collocation methods - suboptimal MPC - Nonlinear system modeling and prediction for NMPC: AR and MA models, Neural Networks - nonlinear optimization: Gradient and Newton methods - Preconditioning and convergence - Stability analysis and Lyapunov-based control approach for NMPC - Computations: Algorithms and Explicit Control Laws. Real-time implementation of MPC: online model updating, state estimation, and disturbance rejection. Applications of MPC Case studies and applications of MPC in systems, such as chemical processes, robotics, Power Electronics, Applications, Building HVAC Systems, and aerospace systems - Implementing discrete-time controllers in numerical simulation software and toolboxes.
Learning Outcomes	Complies with PLO 1a, 2a, 3a
Assessment Method	Quizzes, Assignments, Exams
Suggested Readings	1. Borrelli, F., Bemporad, A., and Morari, M. Predictive Control for Linear and Hybrid Systems. Cambridge: Cambridge University Press, 2017 2. J.B. Rawlings, D.Q. Mayne and M.M. Diehl, Model Predictive Control: Theory, Computation, and Design, Nobb Hill, 2nd edition, 2018

	3. E.F. Camacho and C. Bordons, Model Predictive Control, 2nd edition, Springer.2013 4. Wang, Liuping, Model predictive control system design and implementation using MATLAB. Springer Science & Business Media, 2009. 5. Saša V. Raković, William S. Levine, Handbook of Model Predictive Control, Springer-Birkhauser, 2019. 6. Lars Grüne, Jürgen Pannek : Nonlinear Model Predictive Control Theory and Algorithms, Springer International Publishing, 2016

Course Number	**EE6213**
Course Credit	**L-T-P-C: 3-0-0-3**
Course Title	**Advance Electric Drives**
Learning Mode	Lectures
Learning Objectives	Complies with Program goals 1 and 2
Course Description	The course is designed to meet the requirements of Ph.D. and M. Tech to get advance knowledge of modelling and control of DC and AC machines.
Course Outline	Generalized theory and Kron's primitive machine model, Modelling of dc machines Modeling of induction machine, Modeling of synchronous machine Reference frame theory and per unit system Control of Induction Motor Drive Scalar control of induction motor Principle of vector control and field orientation Sensorless control and flux observers' Direct torque and flux control of induction motor Multilevel converter-fed induction motor drive Utility friendly induction motor drive Control of Synchronous Motor Self-controlled synchronous motor Vector control of synchronous motor, Cycloconverter-fed synchronous motor drive Control of synchronous reluctance motor Control of Special Electric Machines Permanent magnet synchronous motor Brushless dc motor Switched reluctance motor Stepper motors and control
Learning Outcomes	Complies with PLOs 1a, 2a, 3a
Assessment Method	Quizzes/Assignments, Mid Sem, and End Sem
Suggested Reading	<u>**Text/References**</u> 1. P.C. Krause, O. Wasynczuk, and S. D. Sudhoff, "Analysis of Electric Machinery", McGraw-Hill Book Company. 2. R. Krishnan, "Electric Motor Drives: Modeling, Analysis and Control", Prentice Hall. 3. P. S. Bhimbra, "Generalized Theory of Electric Machines", Khanna Publication. 4. B. K. Bose, "Modern Power Electronics and AC Drives", Pearson Education.

Course Number	**EE6214**
Course Credit	**L-T-P-C: 3-0-0-3**
Course Title	**Telemetry and SCADA**
Learning Mode	Lectures
Learning Objectives	Complies with Program Objectives 1 and 2
Course Description	The course is designed to meet the requirements of Ph.D. and M. Tech to get advance knowledge of Telemetry and SCADA applications in Power Systems.
Course Outline	Power system automation: Introduction, Evolution of automation systems, SCADA in power systems, Advantages of SCADA in power systems, Power system field, SCADA fundamentals: Introduction, Open system: Need and advantages, Building blocks of SCADA systems, Remote terminal unit (RTU), Intelligent electronic devices (IEDs), Data concentrators and merging units, SCADA communication systems, Master station, Human-machine interface (HMI), Building the SCADA systems, legacy, hybrid, and new systems, Classification of SCADA systems, SCADA implementation: A laboratory model, Case studies in SCADA SCADA communication: Introduction, SCADA communication requirements, Smart grid communication infrastructure, SCADA communication topologies, SCADA data communication techniques, Data communication, SCADA communication protocol architecture, Evolution of SCADA communication protocols, SCADA and smart grid protocols, Media for SCADA and smart grid communication, Guided media, Unguided (wireless) media, Communication media: Utility owned versus leased, Security for SCADA and smart grid communication, Challenges for SCADA and smart grid communication Substation automation (SA): Substation automation: Why? Why now? Conventional substations: Islands of automation, New smart devices for substation automation, The new integrated digital substation, Substation automation: Technical issues, The new digital substation, Substation automation architectures, New versus existing substations, Substation automation (SA) application functions, Data analysis: Benefits of data warehousing, SA practical implementation: Substation automation laboratory Energy management systems (EMS) for control centers: Introduction, Operating states of the power system and sources of grid Vulnerability, Energy control centers, EMS framework, Data acquisition and communication (SCADA systems), Generation operation and management, Transmission operations and management: Real time, Study-mode simulations, Post-event analysis and energy scheduling and accounting, Dispatcher training simulator, Smart transmission, EMS with WAMS Distribution automation and distribution management (DA/DMS) systems: Introduction to distribution automation, Subsystems in a distribution control center, DMS framework: Integration with subsystems, DMS application functions, Advanced real-time DMS applications, Advanced analytical DMS applications, DMS coordination with other systems, Customer automation functions, Social media usage for improved reliability and customer satisfaction
Learning Outcomes	Complies with PLOs 1a, 2a, and 3a.
Assessment Method	Quiz, Assignments, and Exams
Suggested Reading	**<u>Tex/Reference Books:</u>** 1. Mini S. Thomas, John D Mcdonald, "Power systems SCADA and Smart Grids" 2015, CRC Press. 2. Arun G. Phadke and James S. Thorp, "Computer Relaying for Power Systems," 2nd Edition, Wiley, 2009. 3. Arun G. Phadke and James S. Thorp, "Synchronised Phasor Measurement and Their Application" Springer, 2017.

Course Number	**EE6215**
Course Credit	**L-T-P-C: 3-0-0-3**
Course Title	**Random Signals and Systems**
Learning Mode	Lectures
Learning Objectives	Complies with Program Objectives 1 and 2.
Course Description	The course is designed to meet the requirements of Ph.D. and M. Tech students to get sufficient knowledge on random processes and its effects on linear systems.
Course Outline	Probability and statistics of multivariable (a quick revision): Bayes theorem, multiple random variable, discrete random variable, probability mass function and probability density function, a few well known distributions, moments. Random process: Concept of random process, ensemble, mathematical tools for studying random process, correlation function, stationarity, ergodicity, a few known stochastic processes: random walk, Poisson process, Gaussian random process, Markov chains, Brownian motion etc., pseudorandom process, nonlinear transformation of random process. Random process in frequency domain: Peridogram and power sprectral density, Weiner-Khintchine-Einstein Theorem, concept of bandwidth, spectral estimation. Linear system: Discrete time and continuous time LTI system, concept of convolution, system described in frequency domain, state space description of the system. Linear systems with random inputs: Linear system fundamentals, response of a linear system, convolution, mean, autocorrelation and cross correlation function in LTI system, power spectral density in LTI, cross power spectral density in LTI. Processing of random signals: Noise in systems, noise bandwidth, SNR, bandlimited random process, noise reduction, matched filter, Wiener filter. The Kalman filter: Mean square estimation, discrete Kalman filter, innovation, Kalman filter vs Wiener filter,properties of Kalman filter, Kalman Bucy filter, engineering examples.
Learning Outcomes	Complies with PLOs 1a, 2a, and 3a.
Assessment Method	Quizzes/Assignments, Mid Sem, and End Sem
Suggested Readings	**Text** 4. Miller, Scott, and Donald Childers, “probability and random processes: with applications to signal processing and communications”, Academic Press, 2012. 5. Wim C. van Etten, “Introduction to random signals and Noise”, Chichester, England: Wiley, 2005. 6. Peyton Z. Peebles, “Probability, random variables, and random signal principles”. McGraw Hill Book Company, 1987. **References** 1. Geoffrey R. Grimmett, and David Stirzaker, “Probability and random processes”, Oxford university press, 2001. 2. Alberto Leon-Garcia, “Probability, statistics, and random processes for Electrical engineering”, Upper Saddle River, NJ: Pearson/Prentice Hall, 2008. 3. Grewal, Mohinder, and Angus P. Andrews, “Kalman filtering: theory and practice with MATLAB”, John Wiley & Sons, 2014. 4. Alberto Leon-Garcia, “Probability, statistics, and random processes for Electrical engineering”, Upper Saddle River, NJ: Pearson/Prentice Hall, 2008. 5. Kay, Steven M, “Fundamentals of statistical signal processing”, Prentice Hall PTR, 1993. 6. H.L. Van Trees, “Detection, estimation, and modulation theory, part I”, New York, NY: John Wiley & Sons, Inc., 1971.

	7. Brown, Robert Grover, and Patrick YC Hwang., "Introduction to random signals and applied Kalman filtering", New York: Wiley, 1992. 8. Shovan Bhaumik, and Paresh Date, "Nonlinear estimation: methods and applications with deterministic Sample Points", CRC Press, 2019. 9. Steven Key, "Intuitive probability and random processes using MATLAB®", Springer Science & Business Media, 2006. 10. D. J. Gordana, "Random signals and processes primer with MATLAB", Springer Science & Business Media, 2012

Course Number	**EE6216**
Course Credit	**L-T-P-C: 3-0-0-3**
Course Title	**QUANTITATIVE FEEDBACK THOERY**
Learning Mode	Lectures
Learning Objectives	Complies with Program goals 1, 2 and 3
Course Description	This course will help the students in learning the systematic loop shaping procedures for uncertain, unstable, non-minimum phase systems to satisfy the designer specifications such as tracking specifications, input/output disturbance rejection specifications and robust stability specifications.
Course Outline	Fundamentals Principle and purpose of feedback- Stability of linear time invariant (LTI) Feedback systems: Asymptotic stability and internal stability- Single input single output (SISO) Degrees of freedom (DOF) feedback structures: one and two DOF – Review of classical control concepts: Nyquist stability criterion- Nichols Chart- Uncertain systems- Description of Uncertainties: Parametric and Non-parametric uncertainty- Need for Robust control- Overview of robust control design methods. Quantitative feedback theory (QFT) Preliminaries System(Plant) modelling- Types of robust control problem- Robust performance: disturbance rejection and tracking problem– Robust Stability- Guidelines to select the specifications- Zero Exclusion principle- Loop transmission function and its importance- Concept of loop shaping Sensitivity function and Complementary sensitivity function- Water Bed effect- Benefits and Cost of feedback QFT Synthesis of SISO LTI Uncertain Feedback Systems QFT Design Procedure for SISO LTI system: QFT Templates/ Value set generation- QFT Bound generation methods: Template manipulation and Quadratic Inequality (QI) approach Derivation of QIs for different design specifications- QFT Controller design using Loop shaping approach- Optimal shaping of nominal loop transfer function- Shaping of QFT Prefilter- Design Examples. QFT Synthesis of SISO Unstable and Non-Minimum Phase system Fundamental limitations on Loop transmission function: Unstable pole and right half plane (RHP) zero- Nyquist Stability criterion in the Nichols Chart- Guidelines to Design Controllers QFT Synthesis of Unstable Systems – Synthesis of NMP System: QFT Bound adjustment step All pass system- Robust Design of Smith Predictor- Design Examples. QFT Synthesis for special control structures Cascade Control of SISO Uncertain System: Inner- Outer loop design, Outer-Inner loop design – QFT based Feedforward Controller design - Digital QFT Control design- QFT design for Model matching problem- Introduction to Multi-input Multi output (MIMO) QFT design: Sequential and Non Sequential approaches – Design Examples.
Learning Outcomes	Complies with PLO 1a, 2a and 3a
Assessment Method	Quiz, Assignments, and Exams
Suggested Readings	1. Quantitative Feedback Theory: Fundamentals and Applications, C. H. Houpis, S.J. Rasmussen, Mario Garcia-Sanz, 2nd Edition, CRC Press, 2018. 2. Robust Control Engineering: Practical QFT Solution, Mario Garcia-Sanz, 1st Edition, CRC Press, 2017.

	3. Quantitative feedback design of Linear and Nonlinear Control Systems, Oded Yaniv, 1st Edition, Springer, 1999. 4. Design of Robust Control Systems: From Classical to Modern Practical Approaches, Marcel J. Sidi, 1st Edition, Krieger Publishing Company, 2001. 5. Quantitative Feedback Design Theory (QFT), Horowitz, 1st Edition, QFT Publishers, Denver, CO. 1993. 6. Synthesis of feedback systems, Horowitz, 1st Edition, Academic Press, 1963. 7. Robust control: Theory and Applications, K-Z. Liu, Y. Yao, 1st Edition, 2016.

Course Number	**EE6219**
Course Credit	**L-T-P-C: 3-0-0-3**
Course Title	**Optimal Control**
Learning Mode	Lectures
Learning Objectives	Complies with Program Goals 1, 2, and 3
Course Description	This course will help the students in learning the various fundamentals and formulations of various Optimal Control Settings, Continuous and Discrete Linear-Quadratic Regulators (LQR) and Linear-Quadratic Tracking (LQT) concepts, Constrained Optimal Control, Dynamic Programming, Riccati equations
Course Outline	Non-Linear Optimization: Unconstrained, Constrained, Lagrange Multipliers, Quadratic Programming. Examples of Optimal Control Problems, Formulation of Continuous-Time Optimal Control Problems, Formulation of Discrete-Time Optimal Control Problems, Extrema of functional. Calculus of Variation approach to optimal control problems: Necessary and Sufficient conditions, Optimal control problems with different boundary conditions – final time (fixed, free) and final state (fixed, free), Linear-Quadratic Regulation (LQR) Problems, Frequency Domain Interpretation of LQR - Linear Time Invariant System, LQR with specified degree of stability, Linear-Quadratic Tracking (LQT) Problems, Constrained Optimal Control: Pontryagins Minimum Principle, Min Time, Min Energy, Min Fuel Problems. Dynamic Programming: Principle of Optimality, Computation of Optimal Control using Dynamic Programming, Hamilton-Jacobi-Bellman Equation. Discrete-Time Optimal Control Problems via variational approach, Discrete LQR, Discrete LQT.
Learning Outcomes	Complies with PLO 1a, 21, 3a
Assessment Method	Quizzes, Assignments, Exams
Suggested Readings	1. D.E.Kirk, Optimal Control Theory, Prentice-Hall. 1970. 2. A.P.Sage and C.C.White II, Optimum Systems Control, 2nd ED., Prentice-Hall, 1977. 3. D.Tabak and B.C.Kuo, Optimal Control by Mathematical Programming, Prentice-Hall, 1971. 4. B.D.O. Anderson and J.B.Moore, Linear Optimal Control, Prentice-Hall, 1971. 5. Naidu Desineni Subbaram, Optimal Control Systems, CRC Press, Boca Raton London New York, Washington, D.C, 2002

Course Number	**EE5212**
Course Credit	**L-T-P-C: 3-0-0-3**
Course Title	**Electric Vehicle Technology**

Learning Mode	Lectures
Learning Objectives	Complies with Program Objectives 1 and 2.
Course Description	The course is designed to meet the requirements of M. Tech and UG students to get detail knowledge of components involved and their design in the electric vehicle.
Course Outline	Basics of electro mobility (Pure EV, Hybrid, Plug-In Hybrid), EV and IC engine- pros & cons, EV powertrain architecture, Vehicle Performance such as Maximum Speed of a Vehicle, Grade ability, Acceleration Performance, Steering system and dynamics, Suspension system and dynamics, Thermal management, Gear and transmission Systems, Braking systems, Chassis design, Turbulence, Design against vibration, Wheel and tyre dynamics, Sensor interfaces Electronics for EV testing, Infotainment system, Vehicle to vehicle communication system, Electronic Control unit Motor ratings, EV/HEV motor requirement, Types of Electric Motors: IM, PMSM, SyRM, PMBLDC, SRM, Torque and speed control: IM, PMSM, & SyRM, Torque and speed control: SRM, PMBLDC, Motor drives and Advanced converters used in EVs Battery modeling advantages and Disadvantages, Characteristics of battery cell, Battery sizing, Introduction, and objective of BMS, Charging and discharging control, Understanding of SOC, Cell balancing, BMS topologies, SoC estimation, Protection, and battery management system logic Development Battery Charging methods, EV supply equipment (EVSE), EV battery chargers' components, Charging infrastructure challenges, Classification based on charging levels (region-wise), modes, plug types, Standards related to: connectors, communication protocols, supply equipment, Converters used in EV chargers, Communication protocol/procedures for BHARAT DC001, Communication protocol/procedures for CCS2 charger
Learning Outcomes	Complies with PLO 1a, 2a, 3a
Assessment Method	Quizzes/Assignments: 20 %, Mid Sem: 30 % and End Sem: 50 %
Suggested Reading	**Textbooks:** 1. Ned Mohan, Tore M, Undelnad, William P, Robbins (3 Edition), Power Electronics: Converters, Applications and Design; Wiley 2002 2. Robert Ericson, Fundamentals of Power Electronics, Chapman & Hall, 2004. 3. Mehrdad Eshani, Yimin Gao, Sebastien E Gay, Ali Emadi, Modern electric, hybrid electric and fuel cell vehicles, Fundamentals, Theory, and Design. Boca Raton, FL: CRC (2005) 4. Fernando A. Silva; Marian P. Kazmierkowski, Energy Storage Systems for Electric Vehicles, MDPI, 2021 5. Enge, Per, Nick Enge, and Stephen Zoepf. 2021. Electric Vehicle Engineering. 1st ed. New York: McGraw Hill. **References:** 4. Singh, Sanjeev, Sanjay Gairola, and Sanjeet Kumar Dwivedi, eds. Electric Vehicle Components and Charging Technologies: Design, Modeling, Simulation and Control. Institution of Engineering and Technology, 2023. 5. Chau, Kwok Tong. Energy systems for electric and hybrid vehicles. The Institution of Engineering and Technology (IET), 2016

Course Number	**EE6217**
Course Credit	**L-T-P-C: 3-0-0-3**
Course Title	**HVDC Transmission Systems**
Learning Mode	Lectures
Learning Objectives	Complies with Program Objectives 1 and 2.
Course Description	The course is designed to meet the requirements of Ph.D. and M. Tech students to get sufficient knowledge on high voltage DC Transmission.

Course Outline	General aspects of DC transmission. Converter circuits and their analysis. DC link controls. Faults and abnormal operation and protection. Mechanism of active and reactive power flow control. Multi Terminal DC Systems Filters for reducing harmonics and their design.
Learning Outcomes	Complies with PLOs 1a, 2a, and 3a.
Assessment Method	Quizzes/Assignments, Mid Sem, and End Sem
Suggested Readings	**Text/References** 1. K.R. Padiyar, HVDC Power Transmission Systems, Wiley eastern Ltd. 1990. 2. E. W. Kimbark, "*Direct CurrentTransmission*", Wiley-Inderscience, NewYork.

Course Number	**EC6270**
Course Credit	**L-T-P-C: 3-0-0-3**
Course Title	**Advance FPGA Platform and System**
Learning Mode	Lectures
Learning Objectives	Complies with Program Goals 1 and 2
Course Description	Advance FPGA platform and system focuses on the methods of design, development and implementation of complex digital systems using advanced Field-Programmable Gate Arrays (FPGAs) fabrics platform. The course covers topics such as advance FPGA architecture, design methodologies, IP core integration, and implementation of Digital signal processing, control and communication Systems. It also highlights the methods and tools for implementation of Machine learning algorithms.
Course Outline	Introduction to reconfigurable and FPGA based system Design; Basic and Advanced FPGA Fabrics; Combinational and Sequential logic realization on FPGA; Issues on FPGA based system Design: Area, Timing and Power; Design; Behavioral /high level Design and implementation methodologies: HDL, IP Core, System Generator; Processor and memory cores; Timing analysis; Clock distribution and management systems; Large scale System Design: Platform FPGA, Multi-FPGA System; Busses and I/O communication system; DSP system Design and Implementation using FPGA; FPGA based Embedded system platform: Design and implementation methods. Introduction to Implementation methods and tools for machine learning algorithms. Advance FPGA for real time application: A Case Studies on signal processing, Communication and control systems.
Learning Outcomes	Complies with PLOs 1a, 1b, 2 and 3a
Assessment Method	Quizzes/Assignments, Mid Sem, and End Sem
Suggested Readings	**Text/References** 1. Steve Kilts, "Advanced FPGA design – Architecture, Implementation and Optimization", Wiley publications,2007.7. Samir Palnitkar, "Verilog HDL: A Guide to Digital Design and Synthesis", Second Edition, Prentice Hall PTR, 2003. 2. Wayne Wolf, "FPGA-Based System Design", Prentice Hall Modern Semiconductor Design Series, 2004. 3. Ron Sass and Andrew G. Schmidt, Morgan Kaufmann (MK), "Embedded System design with Platform FPGAs", Elsevier,2010.

Course Number	**EE6218**
Course Credit	**L-T-P-C: 3-0-0-3**

Course Title	**Power System Optimization**
Learning Mode	Lectures
Learning Objectives	Complies with Program goals 1 and 2
Course Description	The course is designed to meet the requirements of Ph.D. and M. Tech students to get sufficient knowledge on optimization and its application to power systems.
Course Outline	Introduction to optimization, optimality conditions for unconstrained optimization, KKT conditions, convex and non-convex optimization, Linear and Non-linear programming, Quadratic programming, Least Squares Overview of power systems and power system optimization. Economic Dispatch and its solution using Gradient Methods, Newton's Method Unit Commitment and its solution using Dynamic Programming Optimal Power flow and its solution using Gradient Methods, Newton Method Introduction to optimization tools – MatLab Optimization Toolbox, GAMS, GUROBI, CPLEX
Learning Outcomes	Complies with PLO 1a, 2a, and 3a
Assessment Method	Quizzes, Assignments, Exams
Suggested Readings	1. Stephen P. Boyd, Lieven Vandenberghe, Convex Optimization, Cambridge University Press, 2004. 2. A. Ravindran, K. M. Ragsdell and G. V. Reklaitis, Engineering Optimization Methods and Applications, John Wiley & Sons, New York, 2006. 3. Allen J. Wood and Bruce F. Wollenberg, Power Generation Operation and Control, John Wiley and Sons, New York, 1984. 4. James Momoh, "Electric Power Systems Applications of Optimization", CRC press, 2015.

Course Number	**EE5213**
Course Credit	**L-T-P-C: 3-0-0-3**
Course Title	**Recent Trends in Optimization Techniques**
Learning Mode	Lectures
Learning Objectives	Complies with Program goals 1 and 2
Course Description	The course is designed to meet the requirements of Ph.D. and M. Tech students to get sufficient knowledge on optimization and its application to different fields of engineering.
Course Outline	Motivation. mathematical review , matrix factorizations, sets and sequences, convex sets and functions. Linear programming and simplex method, Weierstrass' theorem, Karush Kuhn Tucker optimality conditions, algorithms, convergence, unconstrained optimization, Line search methods, method of multidimensional search, steepest descent methods, Newton's method, modifications to Newton's method , trust region methods, conjugate gradient methods, quasi-Newton's methods. Constrained optimization, penalty and barrier function methods, augmented Lagrangian methods, polynomial time algorithm for linear programming, successive linear programming, successive quadratic programming.
Learning Outcomes	Complies with PLO 1a, 2a, and 3a
Assessment Method	Quizzes/Assignments, Mid Sem, and End Sem

Suggested Readings	**Text/References** 1. R. Fletcher Practical Optimization (2nd Edition) John Wiley & Sons, New York, 1987. 2. M.S.Bazaraa , H.D.Sherali and C.Shetty , Nonlinear Programming, Theory and Algorithms, John Wiley and Sons, New York, 1993.