DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING
M.I.T., MANIPAL
M.Tech. in POWER ELECTRONICS & DRIVES

COURSE STRUCTURE:

YEAR	FIRST SEMESTER						SECOND SEMESTER					
	COURSE CODE	**COURSE NAME**	**L**	**T**	**P**	**C**	**COURSE CODE**	**COURSE NAME**	**L**	**T**	**P**	**C**
I	MAT 5130	COMPUTATIONAL METHODS AND APPLIED LINEAR ALGEBRA	3	1	0	4	ELE 5212	ADVANCED POWER ELECTRONIC CONVERTER	3	1	0	4
	ELE 5112	DESIGN OF CONTROL SYSTEMS	3	1	0	4	ELE 5213	POWER ELECTRONICS IN MODERN POWER SYSTEM	3	1	0	4
	ELE 5113	POWER ELECTRONIC CONVERTERS	3	1	0	4	ELE ****	PROGRAM ELECTIVE I	3	1	0	4
	ELE 5114	POWER SEMICONDUCTOR CONTROL DRIVES	3	1	0	4	ELE ****	PROGRAM ELECTIVE II	3	1	0	4
	ELE 5115	MODELLING OF ELECTRICAL MACHINES	3	1	0	4	ELE ****	PROGRAM ELECTIVE III	3	1	0	4
	HUM 5051	RESEARCH METHODOLOGY & TECHNICAL COMMUNICATION*	1	0	3	-	*** ****	OPEN ELECTIVE	3	0	0	3
	ELE 5141	POWER ELECTRONIC CONVERTERS LAB	0	0	3	1	HUM 5051	RESEARCH METHODOLOGY & TECHNICAL COMMUNICATION*	1	0	3	2
	ELE 5142	MODELLING OF ELECTRICAL MACHINES LAB	0	0	3	1	ELE 5243	ADVANCED POWER ELECTRONIC CONVERTER LAB	0	0	3	1
	ELE 5143	SOLID STATE DRIVES LAB	0	0	3	1	ELE 5244	MODERN POWER SYSTEM LAB	0	0	3	1
	Total					**23**						**27**
	THIRD AND FOURTH SEMESTER											
II	ELE 6091	PROJECT WORK & INDUSTRIAL TRAINING							**0**	**0**	**0**	**25**

*TAUGHT IN BOTH SEMESTERS AND EVALUATED AND CREDITED IN THE SECOND SEMESTER

PROGRAM ELECTIVES		OPEN ELECTIVES	
ELE 5401	DIGITAL SIGNAL PROCESSING AND APPLICATIONS	ELE 5301	INTELLIGENT CONTROL SYSTEMS
ELE 5402	DISTRIBUTED GENERATION SYSTEM		
ELE 5403	ELECTRIC VEHICLE TECHNOLOGY		
ELE 5404	EMBEDDED SYSTEM DESIGN		
ELE 5405	ENERGY ANALYTICS		
ELE 5406	ENERGY STORAGE DEVICES		
ELE 5407	EV COMMUNICATION SYSTEMS		
ELE 5408	EV DATA ANALYTICS		
ELE 5409	EV GRID INTEGRATION		
ELE 5410	EV POLICIES AND REGULATIONS		
ELE 5411	POWER QUALITY ISSUES AND MITIGATION		
ELE 5412	SMART GRID TECHNOLOGY		
ELE 5413	SOLID STATE LIGHTING AND CONTROLS		
ELE 5414	TIME FREQUENCY ANALYSIS		

SEMESTER 1:

MAT 5130: COMPUTATIONAL METHODS & APPLIED LINEAR ALGEBRA [3 1 0 4]

Numerical differentiation and integration, ODE, PDE, Optimization techniques – linear programming, dynamic programming, genetic algorithm, PSO, Linear Algebra - vector space, matrix algebra, simultaneous equations, LU decomposition and matrix inversion, special matrices and Gauss Siedel methods applied in engineering problems, eigen values, characteristic vectors, Cayley-Hamilton theorem, minimal polynomial, polynomial matrices.

References:

1. Steven. C. Chapra and Raymond P. Canale, "*Numerical Methods for Engineers*", Tata McGraw Hill Edition, 2006
2. S. S. Sastry, "*Numerical Analysis for Engineers*" Tata McGraw Hill Edition, 2002
3. Hoffman K and Kunze R, "Linear Algebra", Prentice Hall of India, 2011.

ELE 5112: DESIGN OF CONTROL SYSTEMS [3 1 0 4]

Review of Control system terminology, time response and frequency response, mathematical modelling of geared electromechanical systems – transfer function and state space approach, Robustness and stability concepts - Design and realization of industrial controllers / compensators, Controller digitization – Controller tuning - Motor Control and Converter Control, Controllability, Observability, State Feedback Control, Pole Placement Control, Non-linearity -Lyapunov Stability, Optimal Control, Linear Quadratic Regulator, Linear Quadratic Gaussian control, Sliding Mode Control, Model Predictive control, System Identification.

Self-Directed Learning: Simulation assisted design of Power train control, Motion control.

References:

1. Norman S. Nise, Control Systems Engineering, John Wiley & Sons, Inc, 7^{th} edition, 2014.
2. Ogata K, Modern Control Engineering, Englewood Cliffs, NJ: Prentice Hall, 5^{th} edition 2015.
3. Ogata K, Discrete time Control system, Englewood Cliffs, NJ: Prentice Hall, 2^{nd} edition 2005.
4. Richard C. Dorf, Robert H. Bishop., Modern Control Systems, Pearson, 2011.
5. K.R. Varmah, Modern Control Theory, CBS Publishers & Distributers Pvt. Ltd.,2017
6. https://www.coursera.org/lecture/converter-control/9-5-4-design-example-ouS1u
7. https://www.mathworks.com/learn/training/control-system-design-with-simulink.html
8. NPTEL Material on Advaned Control System (Prof. S. Majhi, IIT Guhavati)

ELE 5113: POWER ELECTRONIC CONVERTERS [3 1 0 4]

Review of power semiconductor devices, series-parallel operation, snubber circuit design, device protection, thermal analysis and Heat sink design. Line-commutated converters, the principles of operations, analysis, power factor improvement methods, pulse width modulated converters, and design. Harmonics and Power Factor Calculations, High Power Factor Converters. Switching Mode Inverter, switching schemes, Multilevel Inverter, Harmonic control, design problems. Choppers: Introduction to DC-DC conversion, various topologies. AC-AC Converters: AC Voltage Controllers, Harmonic analysis. matrix converters. Motor drive applications.

Self-directed learning: Gate and base drive circuits. Remedies for Line-Current Harmonics and Low power factor. Harmonic minimization in inverters and cyclo-converter. Power conditioner and uninterrupted power supplies.

References:

1. Robert W. Erickson, Dragan Maksimovic; Fundamentals of Power Electronics, (2 ed), Springer, 2005.

2. Mohan, Undeland & Robbins; Power Electronics, Converters, Applications and Design, Wiley-2001.
3. Daniel.W. Hart, Introduction to Power Electronics by, PHI-1997 edition.
4. http://nptel.ac.in/courses/108108036/

ELE 5114: POWER SEMICONDUCTOR CONTROLLED DRIVES [3 1 0 4]

Electric drive systems, choice of power modulators and electric drives, speed-torque relations, multi-quadrant operation, components of load torque, rating of converters and motors, control techniques for DC motor – starting, braking, plugging, speed control of DC motors, time and energy loss in transient operation, rectifier control of DC motors: single-phase and three phase fully controlled converter fed separately excited DC drives, motoring and regenerative breaking mode, self-study components: controlled freewheeling with motoring and regeneration mode, dual converter fed DC motor drives, effect of armature current ripples on motor performance; chopper fed DC drives: single and two quadrant chopper fed DC Drives, self-study components: four-quadrant chopper; induction and synchronous motor drives: control methods of induction motors, stator voltage control, static rotor resistance control, self-study components: slip power recovery scheme; frequency control, V/f, E/f and flux weakening schemes, constant torque and power operation, operating characteristics, FOC, DTC, overview of scalar and vector control schemes of PMSM, SRM and wound field motors.

Self-Directed Learning: Brush less DC excitation for wound field machines, stepper motor.

References:

1. Dubey G.K., Fundamentals of Electric Drives, Narosa Publishing House, 2010.
2. Murphy J.M.D. and F. G. Turnbull, Power Electronic Control of AC motors, Oxford Oxfordshire, New York, Pergamon, 1988
3. Dubey G.K., Power Semiconductor Controlled Drives, Prentice Hall, 1988.
4. Dewan S.B., G. R. Slemon and A. Straughen, Power Semiconductor Drives. Wiley, 1984
5. Bose B.K., Modern Power Electronics and AC Drives, Pearson, 2010
6. Krishnan R., Electric Motor Drives: Modeling, Analysis, and Control, Pearson, 2011.

ELE 5115: MODELLING OF ELECTRICAL MACHINES [3 1 0 4]

Modelling of singly and multiple excited systems with liner and cylindrical motion, the inductance of machines with the constant air gap, salient pole, and distributed winding. Dynamic modelling of induction machines: induction machine in the two-phase reference frame, generalized model in an arbitrary reference frame, small signal modelling, introduction to field oriented control, space vector formation, steady state models. Dynamic modelling of DC machines, small signal model. Dynamic modelling of salient pole synchronous machines: the reactance of salient pole synchronous machines, steady state models. Modelling of permanent magnet synchronous machines, Modelling of synchronous reluctance machines.

Self-directed learning: Induction machine modelling in Stator, Rotor and Synchronously rotating reference frames, applications.

References:

1. Paul C. Krause, Oleg Wasynczuk, Scott D. Sudhoff, Analysis of Electric Machinery and Drive Systems (2 ed) Wiley, 2010
2. R. Krishnan, Electric Motor Drives, Modeling, Analysis, and Control, PHI Learning 2013
3. Fitzgerald and Kingsley, Electric Machinery (7 ed) McGraw-Hill Higher Education, 2020
4. Boldea I , Reluctance Electric Machines Design and Control, Taylor & Francis, 2019
5. Modelling and Analysis of Electric Machines, Dr. Krishna Vasudevan, IIT, Madras. https://nptel.ac.in/courses/108106023/

HUM 5051: RESEARCH METHODOLOGY & TECHNICAL COMMUNICATION [1 0 3 2]

Research Methodology: Basic concepts: Types of research, Significance of research, Research framework. Sources of data, Methods of data collection. Research formulation: Components, selection and formulation of a research problem, Objectives of formulation, and Criteria of a good research problem. Research hypothesis: Criterion for hypothesis construction, Nature of hypothesis, Characteristics and Types of hypothesis, Elements of research design, Introduction to various sampling methods Sources of data, Collection of data, Research reports, references styles, Effective Presentation techniques, Research Ethics.

References:

1. Sekaran, U., & Bougie, R. (2016). *Research methods for business: A skill building approach*. John Wiley & Sons.
2. Zikmund, W. G., Babin, B. J., Carr, J. C., & Griffin, M. (2013). *Business research methods*. Cengage Learning.
3. Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage Publications.
4. Donald R Cooper & Pamela S Schindler, *Business Research Methods*, McGraw Hill International, 2018.

ELE 5141: POWER ELECTRONIC CONVERTERS LAB [0 0 3 1]

Device Characteristics (MOSFET, IGBT,SCR).
Simulation exercises on AC-DC converter topologies
DC-AC Converter
AC-AC converter Topology
Hardware realization of AC-DC converter, DC-AC Converter and AC-AC converter.

ELE 5142: MODELLING OF ELECTRICAL MACHINES LAB [0 0 3 1]

Simulation & Analysis of:
Startup transients of DC motor, Regenerative braking.
Startup transients of induction machine, Short circuit performance, re-closure transients, square wave inverter fed induction machine, Transients during plugging
Transients in a short circuit of the alternator with damper, Study of grid-connected alternator
Dynamic performance of Permanent Magnet Synchronous Machines and Synchronous Reluctance Machines.

References:

1. Paul C. Krause, Oleg Wasynczuk, Scott D. Sudhoff, Analysis of Electric Machinery and Drive Systems (2 ed) Wiley, 2010
2. R. Krishnan, Electric Motor Drives, Modeling, Analysis, and Control, PHI Learning 2013
3. Fitzgerald and Kingsley, Electric Machinery (7 ed) McGraw-Hill Higher Education, 2020
4. Boldea I , Reluctance Electric Machines Design and Control, Taylor & Francis, 2019
5. Modelling and Analysis of Electric Machines, Dr. Krishna Vasudevan, IIT, Madras. https://nptel.ac.in/courses/108106023/

ELE5143: SOLID STATE DRIVES LAB [0 0 3 1]

Modelling and Simulation Exercises on DC and AC drives, the study of PMSM drives using wavect, Experiments on drive systems with converter fed dc and ac drives and their control.

References:

1. Murphy J.M.D. and F. G. Turnbull, Power Electronic Control of AC motors, Oxford Oxfordshire, New York, Pergamon, 1988
2. Dubey G.K., Power Semiconductor Controlled Drives, Prentice Hall, 1988.
3. Dewan S.B., G. R. Slemon and A. Straughen, Power Semiconductor Drives. Wiley, 1984

SEMESTER 2:

ELE 5212: ADVANCED POWER ELECTRONIC CONVERTERS [3 1 0 4]

Need for High-Frequency Converters, Specifications and Classifications of converters, Linear and switched mode power supply – comparison, Design, and analysis of non-isolated dc-dc converters - Buck, Boost, Buck-Boost, Cuk, SEPIC, Effect of non-idealities on the performance of converters, Isolated dc-dc converter topologies - Design and analysis of Flyback, Forward, Push-Pull, Half-bridge, and full-bridge configurations, Design of Magnetics - Inductor and transformer design for high-frequency applications, Resonant Converters – Loaded resonant converters, SLRs and PLRs – analysis and design issues, ZCS, ZVS, ZCT, ZVT, Converter dynamics, and control, converter transfer functions, regulator design, current mode control, slope compensation technique, unity power factor converter, Applications – MPPT, Solid State lighting.

Self-Directed Learning: AT and ATX/NLX SMPS. A Type 2 Amplifier Control Loop for a buck Converter. ZCT, ZVT. Current mode control, High-frequency transformer design for Forward converter and Push-pull converter.

References:

1. Robert W. Erickson, Dragan Maksimovic; Fundamentals of Power Electronics, (2 ed), Springer, 2005.
2. Mohan, Undeland & Robbins; Power Electronics, Converters, Applications and Design, Wiley-2001.
3. Daniel.W. Hart, Introduction to Power Electronics by, PHI-1997 edition.
4. Umanand L, Bhat S.R, "Design of magnetic components for switched mode power converters", New age International Limited, 2001.
5. http://nptel.ac.in/courses/108108036/

ELE 5213: POWER ELECTRONICS IN MODERN POWER SYSTEMS [3 1 0 4]

Power flow in an uncompensated AC transmission system, problems of conventional AC transmission, types of FACTS, benefits of FACTS, operating principle of shunt, series FACTS controllers & their control strategies, HVDC transmission & converter control characteristics, power quality problems, operation & control of DSTATCOM, DVR, renewable energy sources, power electronic converters & control for renewable energy systems.

Self-Directed Learning: operating principle & control of UPFC, HVDC Converter Faults, operation & control of UPQC, power electronic converter & control for micro grid & smart grid.

References:

1. N.G. Hingorani & Laszlo Gyugyi, 'Understanding FACTS', IEEE press, Wiley Interscience, 2000.
2. K.R. Padiyar 'FACTS controllers in power transmission and distribution', New Age International Publisher, 2008.
3. Dr. Bhim Singh, Ambrish Chandra & Kamal Al-Haddad, 'Power Quality Problems and Mitigation Techniques', John Wiley & Sons, England, 2015.
4. Ewald F. Fuchs & Mohammad A.S. Masoum, 'Power Quality in Power Systems and Electrical Machines', Elsevier Academic Press 2008.
5. K.R. Padiyar, 'HVDC Power Transmission Systems', New Age International Publisher, 1990.
6. Sudipta Chakraborty, Marcelo G. Simões, William E. Kramer, 'Power Electronics for Renewable and Distributed Energy Systems', Springer 2013.

ELE 5241: ADVANCED POWER ELECTRONIC CONVERTERS LAB [0 0 3 1]

Simulation exercise on isolated and non-isolated converter topologies, Design of high-frequency inductor, Simulation exercise on soft switched converters, hardware realization of non-isolated / isolated converter.

References:

1. Mohan, Undeland & Robbins; Power Electronics, Converters, Applications and Design, Wiley-2001.
2. Daniel.W. Hart, Introduction to Power Electronics by, PHI-1997 edition..
3. Prof. Umanand and Prof. Ramanarayanan, IISc Bangalore, Switched Mode Power Conversion:

ELE 5242: MODERN POWER SYSTEMS LAB [0 0 3 1]

Simulation exercises on FACTS controllers.
Simulation exercises on Custom Power Devices.
Simulation exercises on converter control for Solar & Wind energy.
Simulation exercise on HVDC.
Mini project.

References

1. K.R. Padiyar 'FACTS controllers in power transmission and distribution', New Age International Publisher, 2008.
2. Dr. Bhim Singh, Ambrish Chandra & Kamal Al-Haddad, 'Power Quality Problems and Mitigation Techniques', John Wiley & Sons, England, 2015.
3. K.R. Padiyar, 'HVDC Power Transmission Systems', New Age International Publisher, 1990.
4. Sudipta Chakraborty, Marcelo G. Simões, William E. Kramer, 'Power Electronics for Renewable and Distributed Energy Systems', Springer 2013.

SEMESTER 3 & 4:

ELE 6091: PROJECT WORK & INDUCTRIAL TRAINING [0 0 0 25]

Students are required to undertake innovative and research oriented projects, which not only reflect their knowledge gained in the previous two semesters but also reflects additional knowledge gained from their own effort. The project work can be carried out in the institution/ industry/ research laboratory or any other competent institutions. The duration of project work should be a minimum of 36 weeks. There will be a mid-term evaluation of the project work done after about 18 weeks. An interim project report is to be submitted to the department during the mid-term evaluation. Each student has to submit to the department a project report in prescribed format after completing the work. The final evaluation and viva-voice will be after submission of the report. Each student has to make a presentation on the work carried out, before the departmental committee for project evaluation. The mid-term & end semester evaluation will be done by the departmental committee including the guides.

PROGRAMME ELECTIVES:

ELE 5401: DIGITAL SIGNAL PROCESSING AND APPLICATIONS [4 0 0 4]

Overview on frequency analysis of discrete time linear time invariant systems, characteristics of practical frequency selective filters, Phase and Magnitude response of system, Minimum phase, maximum phase, Allpass - FIR, IIR filter design - Multirate signal Processing: Interpolation, Decimation, sampling rate conversion, Filterbank design, applications. - Power spectrum estimation: Spectral analysis of deterministic signals, estimation of power spectrum of stationary random signals. - Adaptive Filter theory: Adaptive algorithms - steepest descent algorithm.

Self-Directed learning: Wiener filters, LMS and RLS adaptive filters, Linear Prediction. - Introduction to multi resolution analysis. Application of DSP in Power Electronics Converters and Drives.

References:

1. John G. Proakis, Dimitris G Manolakis, *Digital Signal Processing: Principles, Algorithms, and Applications,* (4e), Pearson, 2007
2. Sanjit K. Mitra, *Digital Signal Processing: A Computer-Based Approach*, (4e), McGraw-Hill, 2011
3. Oppenheim A. V. and R. W. Schafer, Discrete time signal processing, (3e), Pearson, 2014
4. Sozański K. Digital signal processing in power electronics control circuits, (2e), Springer, 2017
5. Vaidyanathan, Parishwad P - Multirate systems and filter banks, Pearson Education India, 2006.
6. Vaidyanathan Palghat P- The theory of linear prediction, Springer, 2008
7. NPTEL Course on Introduction to Adaptive Filters, https://nptel.ac.in/courses/117105075

ELE 5402: DISTRIBUTED GENERATION SYSTEMS [4 0 0 4]

Introduction to Distributed Generation Systems- Principle and Structure of DGS- Features of DGS, Distributed Generation Technologies-Overview, Integrating Distributed Energy Resources with the Grid, Planned/non-planned DG,. DG Technologies DG Technologies: Wind Energy Conversion System, Photovoltaic Systems-PV grid tied systems and different configurations. Micro turbine Generation, Small Hydro Generation Systems, Fuel Cells.Energy Storage Technologies-Different Energy storage technologies-Overview, Design Issues and control of Distributed Generation Systems-General model of DGS, Technical Regulation of DG integration, DG Optimization and Energy Management. Concept of smart grid technology.

Self-Directed Learning: Introduction to microgrids, components, micro-sources, loads, power electronic interface, Overview of protection scheme in microgrid and challenges associated with it.

References:

1. G.B. Gharehpetian and S. Mohammad MousaviAgah, Distributed Generation Systems. Design, Operation and Grid Integration, Butterworth-Heinemann, 2017.
2. Magdi S. Mahmoud, Fouad M. AL-Sunni, Control and Optimization of Distributed Generation Systems, Springer International Publishing, 2015.
3. Bo Zhao, Caisheng Wang, Xuesong Zhang, Grid integrated and standalone photovoltaic distributed generation systems analysis, design and control, Wiley, 2017.

ELE 5403: ELECTRIC VEHICLE TECHNOLOGY [4 0 0 4]

Introduction to Electric Vehicles - History, social and environmental importance, impact of modern drive-trains; Conventional vehicles: Basics of vehicle performance, vehicle power source characterization; Energy storage - Introduction, battery based energy storage, fuel cell based energy storage, Electric drivetrains - Basic concepts, power flow control, power converter topologies; Electric propulsion unit: Introduction, configuration and control of DC motor drives, induction motor drives, permanent magnet synchronous motor drives, switched reluctance motor drives; Sizing the drive system - Sizing the propulsion motor, power electronics, energy storage technology, communications; Supporting subsystems - Energy management strategies, battery management systems, EV standards, charge controllers; Case studies - Design of a battery electric vehicle (BEV).

Self-Directed Learning: Supercapacitor based energy storage and flywheel based energy storage; charging infrastructure; fleet management systems;

References:

1. Mehrdad Ehsani, Yimin Gao, Sebastien E. Gay, Ali Emadi, *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles – Fundamentals, Theory, and Design*, CRC Press, 2005.
2. James Larminie, John Lowry, *Electric Vehicle Technology Explained*, Wiley, 2012.
3. Iqbal Husain, *Electric and Hybrid Vehicles – Design Fundamentals*, 2 ed., CRC Press, 2016.
4. C. Mi, M.A. Masrur, D.W. Gao, *Hybrid Electric Vehicles*, Wiley, 2011.
5. Allen Fuhs, *Hybrid Vehicles and the Future of Personal Transportation*, CRC Press, 2009.
6. Ashok Jhunjhunwala, Prabhjot Kaur, Kaushal Kumar Jha, L. Kannan, *Fundamentals of Electric vehicles: Technology & Economics*, IIT Madras, 2020: https://nptel.ac.in/courses/108106170
7. Gregory Plett, *Introduction to battery-management systems*, University of Colorado Boulder, www.coursera.org

ELE 5404: EMBEDDED SYSTEM DESIGN [4 0 0 4]

Embedded Systems-Introduction, Embedded hardware, Processor for embedded systems, Processing power and benchmark. PIC16F877 microcontroller, architecture, on chip peripherals, programming. ARM processors, ARM7TDMI processor architecture, processor modes, register bank, instruction set, programming, stack and subroutines, exceptions, 3-stage pipeline. Embedded C programming, ARM CORTEX microcontroller, architecture, programming. Memory for embedded systems, Cache memory. Input and output device interfacing, Parallel and serial communication protocols, Wireless communication protocols. Data converters and timers for embedded systems, interrupts. Current trends in embedded system design. Introduction to Real time systems, task types, task scheduling, Real Time Operating Systems.

Self-Directed Learning: PCI express, Advanced Microcontroller Bus Architecture-AHB and APB, Watchdog timers, Embedded system design- design metrics, issues and challenges, stages, development tools.

References:

1. Frank Vahid and Tony Givargis, Embedded system design, Wiley India, 2012.
2. Ajay V Deshmukh, Microcontrollers, TMH, 2007.
3. Steve Furber, ARM System on chip architecture, Pearson, 2012
4. William Hohl, Christopher Hinds, ARM Assembly Language Fundamentals and Techniques, CRC Press, 2014
5. Jane W.S. Liu, Real time systems, Pearson Education, 2013.
6. https://developer.arm.com/Architectures/AMBA

ELE 5405: ENERGY ANALYTICS [4 0 0 4]

Introduction to Data science and Data analytics. Data Sets and relations. Data Preprocessing. Data Modeling and Visualization. Correlation Analysis. Regression Analysis. Forecasting techniques. Classification and clustering techniques. Electricity and Energy management data: Industrial and household loads, working and maintenance techniques. Demand side management approaches. Applications of data analytics in energy sector.

Self-Directed Learning: case study on application of energy analytics.

References:

1. Thomas A. Runkler, "Data Analytics Models and Algorithms for Intelligent Data Analysis", 2nd Edition, Springer Publications, 2016.

2. John J. McGowan, “Energy and Analytics: Big data and building technology integration”, Fairmont Press, 2015.
3. Seog-Chan Oh, Alfred J. Hildreth “Analytics for Smart Energy Management”, Springer Series in Advanced Manufacturing, 2016.
4. Kornelis Blok, Evert Nieuwlaar, “Introduction to Energy Analysis”, Routledge, 2016.
5. NPTEL course: ‘Data Analytics with Python’. https://nptel.ac.in/courses/106107220

ELE 5406: ENERGY STORAGE DEVICES [4 0 0 4]

Introduction to different energy forms-Need for Energy storage, and performance indices. Mechanical energy storage, Electromagnetic energy storage. Electro-chemical storage-Electro-chemical cell, fuel cells, batteries, Battery Technologies, Fuel cells: History – principle - working - thermodynamics and kinetics of fuel cell process –performance evaluation of fuel cell – comparison on battery Vs fuel cell, Types of fuel cells – AFC, PAFC, SOFC, MCFC, DMFC, PEMFC, Hydrogen storage: Physical and chemical properties, general storage methods, compressed storage-composite cylinders, glass micro sphere storage, zeolites, metal hydride storage, chemical hydride storage, and cryogenic storage, carbon-based materials for hydrogen storage, hydrogen as a storage medium for renewable energy systems, Pumped hydro storage, Energy Storage Systems & applications – utilities, transport, industry, household, total energy system – a hybrid, combined, integrated.

Self-Directed Learning: Hybrid power systems: Differences/interactions between batteries and supercapacitors, solar thermal storage, flywheel energy storage.

References:

1. Johannes Jensen Bent Squrensen, Fundamentals of Energy Storage, John Wiley, NY, 1984.
2. P. Peregrinus, Electrochemical Power Sources: Primary and Secondary Batteries, M. Barak (Editor), IEE, 1980.
3. Baader, W. Dohne, E, Brenndorfer, Bio-gas in Theory and Practice, [Russian translation], Kolos, Moscow, 1982.
4. P.D.Dunn, Renewable Energies, Peter Peregrinus Ltd, London, United Kingdom , 1st Edition, 1986.
5. Sorenson B, Hydrogen and Fuel Cells: Emerging Technologies and Applications, Bent Sorenson, Academic Press (2005).
6. Hordeski MF, Hydrogen and Fuel Cells: Advances in Transportation and Power, The Fairmont Press, Inc. (2009)
7. Busby RL, Hydrogen and Fuel Cells: A Comprehensive Guide, PennWell Books (2005).

ELE 5407: EV COMMUNICATION SYSTEMS [4 0 0 4]

Vehicular Communication and networking - layers of OSI reference model, classification of bus systems. Networks and communication Protocols – Ethernet, TCP, UDP, IP, ARP, RARP. LIN standard, specification, frame transfer, frame types, schedule tables, Task behaviour model, Network management, status management, CAN, message transfer, frame types, error handling, fault confinement, Bit time requirements. Higher Layer Protocol –CAN open, TTCAN, Device net, SAE J1939, Logical device model, protocol basics, MOST protocol- data channels, control channel, synchronous channel, asynchronous channel, , Network section, data transport, blocks, frames, preamble, boundary descriptor. FlexRay Protocol –network topology, ECUs and bus interfaces, controller host interface and protocol operation controls, media access control, frame and symbol processing, coding/decoding unit, FlexRay scheduling. Vehicular communications – Intelligent transportation systems, IEEE 802.11p-ITS-IVC, Inter-Vehicle communications-mobile wireless communications and networks, Architecture, layers, communication regime, V2V communication

Self-Directed Learning: Internet of vehicles, Open communication protocols and standards for electric vehicle charging, V2V-applications and case studies, Simulation of CAN transmission and reception.

References:

1. J. Gabrielleen, "Automotive In-Vehicle Networks", John Wiley & Sons, Limited, 2008.
2. Indra Widjaja, Alberto Leon-Garcia, "Communication Networks: Fundamental Concepts and Key Architectures", McGraw-Hill College; 1st edition, 2000
3. Robert Bosch, "Bosch Automotive Networking", Bentley publishers, 2007
4. Konrad Etschberger, "Controller Area Network, IXXAT Automation", 2001
5. OlafPfeiffer, Andrew Ayre, Christian Keydel, "Embedded Networking with CAN and CANopen", Annabooks / Rtc Books, 2003

ELE 5408: EV DATA ANALYTICS [4 0 0 4]

Data Ecosystem, Analysis Process, Parts of Data Analytics, Data Structure Types, File formats, Extract, Transform, Load Process, Statistical Tools & Techniques, Python Programming, Python Libraries, Data Visualization. Data Sourcing & Cleaning, Feature Selection, Feature Engineering. Univariate / Bivariate Analysis and Derived Metrics, Segmented Univariate & Bivariate Analysis, Random Variables, Gaussian Distribution, Central Limit Theorem, Chebyshev's Inequality, Inferential Statistics, Probability, Bayes' Theorem, Hypothesis Testing. Regression & Classification, SVM, Tree Models, KNN, Occam's Razor, Model Evaluation, Clustering & Association. Deep Learning Neural Network, Vanishing & Exploding Gradient, Dropout & Regularization, Parameters & Hyperparameters Tuning, Convex & Non-Convex Optimization, Cross Validation. Data Analytics on Vehicle Telematics – Big Data, Driving Telematics Sensor Data, Reaction Time, Fuel Consumption, Health & Failure Prediction, Autonomous Vehicular Systems.

Self-Directed Learning: EV Data Mobility, Battery Consumption, Optimized Charging, Travel/Parking/Availability, Decision Support Metering, Python Based Implementation of ML Models, ANN based DL Model, ARIMA, SARIMA, AR, MA Models, LSTM Based ANN Model.

References

1. EMC Education Services, "Data Science & Big Data Analytics: Discovering, Analyzing, Visualizing and Presenting Data", John Wiley & Sons, 2015.
2. Glenn J. Myatt, Wayne P. Johnson, "Making Sense of Data I: A Practical Guide to Exploratory Data Analysis and Data Mining", 2nd Edition, John Wiley & Sons, 2014.
3. Douglas C M, George C R, "Applied Statistics and Probability for Engineers," 5th Edition, John Wiley & Sons, 2011.
4. Coursera Course, "Introduction to Self-Driving Autonomous Vehicles", University of Toronto, Part of Self-Driving Car Specialization, Modules: 1 to 4. *(Self Directed Learning)*

ELE 5409: EV GRID INTEGRATION [4 0 0 4]

History, Definition, and Status of Vehicle-to-Grid (V2G), Benefits, Technical Challenges, Realizing and Problematizing a V2G Future. Influences of EVs on Power System, the Response of EV Charging Load to the Grid Voltage, Analysis on Typical Schemes of the Integration, EV Charging Facility Planning. Grid integration and management, Dispatch of vehicle-to-grid battery storage, renewable energy integrations, Optimal location and charging of electric vehicle, Optimal coordination of vehicle-to-grid batteries and renewable generators. Smart Grid using PEVs, Impact of EV and V2G on the Smart Grid and Renewable Energy Systems, Power Conversion Technology, Power Control and Monitoring, PEV Charging Technologies and V2G on Distributed Systems and Utility Interfaces, Dynamic Programming and Potential Game Approach, Evolutionary Game Theory Approach.

Self-Directed Learning: EV Grid Integration worldwide, EV Charging Facility, Impact of EV and V2G on the Smart Grid and Renewable Energy Systems, Game Theory on Grid Optimal Integration of Electric Vehicles.

References:

1. Lance Noel, Gerardo Zarazua de Rubens, Johannes Kester, Benjamin K. Sovacool, "Vehicle-to-Grid A Sociotechnical Transition Beyond Electric Mobility", Energy, Climate and the Environment, Springer Nature, 2019.
2. Canbing Li, Yijia Cao, Yonghong Kuang, Bin Zhou, "Influences of Electric Vehicles on Power System and Key Technologies of Vehicle-to-Grid," Power Systems, Science Press & Beijing Springer Nature, 2016.
3. Nand Kishor and Jesús Fraile-Ardanuy, "ICT for Electric Vehicle Integration with the Smart Grid" The Institution of Engineering and Technology, 2019.
4. Junwei Lu and Jahangir Hossain, "Vehicle-to-Grid: Linking Electric Vehicles to the Smart Grid", The Institution of Engineering and Technology, London, United Kingdom 2015.
5. Andrés Ovalle, Ahmad Hably, Seddik Bacha, "Grid Optimal Integration of Electric Vehicles: Examples with Matlab Implementation", Studies in Systems, Decision and Control, Springer Nature, 2018.

ELE 5410: EV POLICIES AND REGULATIONS [4 0 0 4]

EV Prospects, Policy Framework, Policies & Schemes – FAME 1 & FAME 2, NEMMP, PLI, National & State Policies, Regulations, Incentives & Subsidies. GHG Emissions, Transport Energy Mix Diversification, CO_2 Regulations, ZEV & NEV Mandate, Incentives, Fuel Economy & Emission Standards. EV Charging Ecosystem: Regulations & Incentives on EVSE, Interconnected Charging Network, Charge Point Operators & E-Mobility Service Providers, Public EV Charging Demand, Location & Site Planning, Role of DISCOMs, Implementation & Business Models, Public Charging Infrastructures, Batteries Regulations & Directives, Alliance, Use & Recycling Solutions, Second Life Commercialization, Recycle Management, Energy Economics, Infrastructure Upgrades, EV Clustering, Tracking & Billing, Third Party Charging Station, Utility Ownership of EVSE, Sub-Metering, Payment & Billing Models. Barriers in EV, EV Deployment across Public, Commercial & Corporate Fleets, Public Awareness, Education & Skills Training, Industry Incentives, Cost Estimates & Revenue Model.

Self-Directed Learning: Financial, Regulatory & Fleet Management Authorities, CEA, CERC, SERCs, NITI Aayog, MoP, PGCIL, DST, BEE, MoUHA, MoEFCC, MoRTH, DHI, WRI India, ISGF etc.

References

1. Guidelines & Standards for Electric Vehicle Charging Infrastructure, MoUHA, GOI, Feb 2019 & MoP, GOI, Oct 2019.
2. Electric Vehicle Charging Stations Business Models for India, ISGF white Paper, Version-1, Sep 2018.
3. Handbook of Electric Vehicle Charging Infrastructure Implementation, Version1, NITI Aayog, MoP, DST, WRI India – Ross Center.
4. Electric Vehicle Guidebook for Indian States, International Council on Clean Transportation (ICCT), 2019.
5. State Electric Vehicle Policy and State Electric Vehicle Policy Documents. *(Self Directed Learning)*

ELE 5411: POWER QUALITY ISSUES & MITIGATION [4 0 0 4]

Power quality issues: modern power systems, classifications and causes of power quality problems, PQ terminology, effects of power quality problems on customers, PQ standards, PQ

Monitoring, mitigation techniques, passive shunt and series compensators: analysis and design of 1-ph shunt compensators for pf correction and zero voltage regulation, analysis and design of 3ph 3-wire compensators for pf correction, load balancing and zero voltage regulation, 3ph 4-wire compensators for pf correction, load balancing and neutral current mitigation, custom power devices: types, classification of DSTATCOMs and DVRs, operation and applications of 2-wire, 3ph 3-wire and 3ph 4-wire DSTACOMs, control methods of DSTATCOMs: UPF mode of operation and ZVR operation, design of DSTATCOM, capacitor supported DVR operation for the compensation of voltage sag, swell and unbalance, battery supported DVR operation, control techniques for DVRs, design and analysis of unified power quality conditioner (UPQC), rating based classification of UPQC, UPQC-Q, UPQC-P, UPQC-S, control of UPQCs;

Self-Directed Learning: active power filters, design and control algorithm to eliminate voltage and current harmonics, design and performance analysis of simple systems through modelling and simulation studies, PQ improvement in electrical system.

References:

1. Bhim Singh, Ambrish Chandra and Kamal Al Haddad, Power Quality: Problems and Mitigation Techniques, John Wiley & Sons Ltd., U. K, 2015
2. C. Shankaran, Power Quality, CRC Press, 2013.
3. Math H J Bollen, Understanding Power Quality Problems; Voltage Sags and Interruptions, Wiley India, 2011.
4. Roger C Dugan, et.al, Electrical Power Systems Quality, 3rd Edition, TMH, 2012.
5. Arindam Ghosh et.al, Power Quality Enhancement Using Custom Power Devices, Kluwer Academic Publishers, 2002

ELE 5412: SMART GRID TECHNOLOGY [4 0 0 4]

History, Definition, Characteristics and benefits, Basic components of Smart Grid and its technical infrastructure, Impact of EV and V2G on the Smart Grid and Renewable Energy Systems, Power Conversion Technology, Power Control and Monitoring, PEV Charging Technologies and V2G on Distributed Systems and Utility Interfaces. Application of Smart Grid to distribution networks, energy storage systems, Power system protection, Sizing High Speed Micro Generators, Intelligent Multi-agent System, Synchronized Phasor Measurement, Modelling and Control of Fuel Cells, Cyber interoperability standards, Cyber Security, Smart Grid Communications and Measurement Technology, Performance Analysis, Stability Analysis, Smart Grid Design.

Self-Directing Learning: Smart Grids worldwide, Smart Grid with EVs, Smart Grid application; Smart Grid standards, Cyber Security, Challenges in Smart Grid Implementation; Design and Analysis of SMART GRID.

References:

1. S.K. Salman - Introduction to the Smart Grid_ Concepts, Technologies and Evolution-The Institution of Engineering and Technology (2017).
2. Hossain, Jahangir_ Lu, Junwei - Vehicle-to-grid_ linking electric vehicles to the smart grid-Institution of Engineering and Technology (2015).
3. James Momoh - Smart Grid_ Fundamentals of Design and Analysis-Wiley-IEEE Press (2012).
4. Ali Keyhani, Muhammad Marwali, Smart Power Grids, Springer-Verlag Berlin Heidelberg (2011).
5. Takuro Sato, Daniel M. Kammen, Bin Duan, et al. - Smart Grid Standards_ Specifications, Requirements, and Technologies-Wiley (2015)
6. https://archive.nptel.ac.in/courses/108/107/108107113/

ELE 5413: SOLID STATE LIGHTING & CONTROLS [4 0 0 4]

Fundamentals of illumination technology, Introduction to solid state lighting, principle of light generation. Types of LEDs and their photometric and colorimetric characteristics. Colour tunability and white light generation. LED driver considerations and power supply design. LED dimming and control strategies. Thermal management in LED luminaires. Testing standards, Reliability, and performance analysis of LED luminaires. Applications of solid-state lighting.

Self-Directed Learning: Characteristics of different coloured LEDs and colour mixing of LEDs, Junction temperature measurement, Effect of drive current and temperature on performance of LEDs.

References:

1. E. Fred Schubert, "Light-Emitting Diodes (3rd Edition)", Cambridge University Press, 2018
2. W.D. van Driel, Xuejun Fan., "Solid State Lighting Reliability: Components to Systems", Solid State Lighting Technology and Application Series, Springer Publications, 2013. (DOI: 10.1007/978-1-4614-3067-4.)
3. Robert Karlicek, Ching-Cherng Sun, Georges Zissis, Ruiqing Ma., "Handbook of Advanced Lighting Technology", Springer International Publishing, 2017. (DOI: https://doi.org/10.1007/978-3-319-00176-0)
4. Clemens J.M. Lasance, András Poppe., "Thermal Management for LED Applications", Solid State Lighting Technology and Application Series, Springer Publications, 2014. (DOI: 10.1007/978-1-4614-5091-7.)
5. NPTEL: Introduction to DC-DC converter. https://nptel.ac.in/courses/108108036

ELE 5414: TIME FREQUENCY ANALYSIS [4 0 0 4]

The time and frequency description of signals, bandwidth equation, AM and FM contributions to the bandwidth, Fourier transform of the time and frequency densities, non-additivity of spectral properties, uncertainty principle. Instantaneous frequency and the complex signal, analytic signal, quadrature approximation, instantaneous frequency, density of instantaneous frequency, one dimensional densities, two dimensional densities, local quantities, negative densities, Time-Frequency Distributions - global averages, local average, time and frequency shift invariance, linear scaling, weak and strong finite support, uncertainty principle and joint distributions, short-time Fourier transform and spectrogram, global quantities, local averages, optimal window. Wavelet bases for discrete and continuous variables, The Haar basis, Differentiable wavelet bases, Compact wavelet bases, Multiresolution analysis.

Self-Directed learning: Heisenberg uncertainty principle. Applications of short-time Fourier transform. Spectrogram and its use in signal processing. Applications of wavelet transforms.

References:

1. L. Cohen, Time-Frequency Analysis. Prentice Hall, 1995.
2. S. Mallat, A Wavelet Tour of Signal Processing - The Sparse Way. Elsevier, Third Edition, 2009.
3. M. Vetterli, J. Kovacevic, and V. K. Goyal, Fourier and Wavelet Signal Processing. Book site: http://fourierandwavelets.org/terms.php

OPEN ELECTIVE:

ELE 5301: INTELLIGENT CONTROL SYSTEMS [3 0 0 3]

Fundamentals of Artificial Neural Networks - Feed forward and feedback networks, learning rules, Single layer feed forward networks, Multilayer feed forward networks, Linearly non-separable pattern classification, generalized delta learning rule, error back propagation training algorithms, Single layer feedback network - Energy function, Application of neural networks, Introduction to Fuzzy control, Inference rules, Fuzzy knowledge based controllers, Fuzzification, membership function evaluation, Defuzzification methods, Application of fuzzy logic to control systems, fuzzy-neural systems, Introduction to Genetic Algorithms.

References:

1. J. S. T Jang, C.T Sun and E. Mitzutani, *Neuro-Fuzzy and Soft Computing*, Prentice Hall International, Inc, 2011.
2. Chin-Teng Lin, C.S.George Lee, *Neural Fuzzy Systems*, Prentice – Hall International, Inc.1996.
3. S. Haykin, *Neural Networks - A Comprehensive Foundation - 2nd Edition*, Prentice Hall, 2005.
4. T. J. Ross, *Fuzzy Logic with Engineering Applications*, McGraw-Hill, Inc., 2014
5. Jacek M. Zurada, *Introduction to Artificial Neural Networks*, Jaico, 2016