List of Recorded Lectures
Spring 2008

1) Course organization, Introduction of instructor, importance of the Study Guide, historical introduction to electric power grid, why the power grid has the conventional 60hz, three phase, sinusoidal AC format, review of the phasor concept, identity for product of sine waves, application to calculation of average of a sine product, average equal to 1/2 product of amplitudes times cos ϕ.

2) Average power for sine waves, concept of rms value, calculation of rms value of a sinusoid, use of rms value in phasors, illustration of waveform distortion in dimmer and rectifier (nonlinear) circuits, concept of Fourier series, example of square wave Fourier series, magnitude-angle form of Fourier series, Fourier series graphical examples, average power from Fourier series components, calculation of rms value from Fourier series components, use of concepts of displacement and distortion power factor when only the current is distorted.

3) Calculation of Fourier series coefficients, symmetry properties of Fourier Series, power calculation using phasors, power calculation using current components, introduction of the reactive power concept, additional power loss and voltage drop caused by reactive power, illustration of time domain properties of average power and reactive power, complex power, example of power and reactive power computations, power factor correction, discussion of harmonic response of circuits.

4) Power calculation using impedances, series and parallel circuit models, voltage and current source models, discussion of model selection to represent load behavior, example of harmonic response of circuits, evaluation of total rms in circuits containing harmonics, reactive power in non-sinusoidal systems, control of power and reactive power in large power systems, the power angle curve, discussion of power limits in AC systems,

5) Comments on rms value calculated from harmonics, illustration of waves having identical rms values but very different waveforms, general non-validity of superposition for power calculations, the advantages of polyphase systems, the rotating magnetic field, 50% reduction in power loss with symmetric loads, the three phase Y-Y system, relation between line and phase voltage, omission of neutral wire when system symmetry is assured,

6) Constant instantaneous power as an advantage of three phase systems, relation between line and phase current in a Δ connection, replacing a Δ-connected load with an equivalent Y, example of three phase system calculation, analysis using single line circuit diagrams, power factor correction, power expressed with line voltage and current, power measurement in three phase systems, the two wattmeter method, the readings of the two wattmeters in a symmetric system

7) Example using P an Q for power factor correction, harmonic behavior of three phase systems, special properties (zero sequence) of the triplen harmonics in three phase systems, consequences of the3rd harmonics being in phase, reasons for grounding in AC transmission and distribution systems, grounding in the the single phase, three wire electrical utilization system, purpose of the equipment ground (green wire), use of polarized plugs for added safety, the GFI (Ground Fault Interrupter).

8) Introduction to magnetic field devices, the Bli force as motivation for creating and managing the B field, listing and illustration of magnetic device categories including inductors, transformers, actuators, motors and generators, fundamental magnetic field relationships including Ampere’s Law and the

influence of the material being magnetized, addition of feedback via Faraday's law in AC magnetic devices, illustration of the great difficulty of creating useful levels of B in air, demonstration of how a "good" magnetic material (M43) solves this problem, illustration of magnetic material properties including high permeability, saturation, nonlinearity and flux guiding.

9) Continued illustration of magnetic material properties including hysteresis, permanent magnetism and core loss, DC magnetic calculations including an air gap illustrating saturation of magnetic material, illustration of interchangeability of current and turns with fixed coil I^2R, example using E-I core with air gap, AC excitation and Faraday's law, significance of low circuit resistance in yielding sinusoidal flux when voltage is sinusoidal, waveform of magnetizing current in an AC system using magnetic material.

10) Waveforms of flux and current in AC magnetic systems, influence of hysteresis and eddy currents on current, characterization of exciting current and power in AC magnetic materials using VA/lb and W/lb, example of AC magnetic system calculation with and without an air gap, phasor diagram and equivalent circuit for AC magnetization of magnetic circuit, origin, modeling and mitigation of hysteresis and eddy current losses.

11) Origin, modeling and mitigation of eddy current losses, demonstration of eddy current effects using permanent magnet and copper and aluminum plates, comments on induction heating as a useful application of eddy currents, illustration of types of magnetic materials used at various frequencies including laminations (up to 100's of hz), cut cores and tape wound cores (up to ≈ 25 khz), powder cores (up to ≈ 300 khz), Ferrite cores (up to ≈ 2000 khz), large and small signal inductances in magnetic systems using magnetic material, importance of air gap in stabilizing inductance,

12) Energy storage with internal and external variables, example calculation of air gap volt-amperes to show consistency with Ampere's Law in AC magnetic systems, AC magnetic device classification and goals for design, outline of the inductor design problem, summary of magnetic system relationships, the magnetic circuit - electric circuit analogy, concept of magnetic reluctance, value of the analogy and when not to use it in computation,

13) Modern permanent magnet materials, ferrite magnets vs rare earth magnets, determination of the operating B level of a PM in a magnetic circuit, linear model of rare earth PM, concept of a load line, equivalent circuit model of a rare earth PM, determination of the optimal operating B level to minimize magnet volume, PM demagnetization by an external source, example of PM calculation to find required magnet size

14) Underlying principals of the transformer (Faraday's and Ampere's laws), leakage flux, exciting current and winding resistance as imperfections in transformer behavior, the ideal n-winding transformer voltage and current relationships, impedance transformation in a two winding ideal transformer, summation of vi as an alternative to Σ Ni = 0, P and Q summation as an alternative to Σ Ni = 0, example - three winding transformer, example - three winding transformer with direct connection between transformer windings (autotransformer), transformer winding voltage and current ratings.

15) transformer volt-ampere rating, example – alternative connections and corresponding VA ratings of a four winding transformer, autotransformer rating compared to two winding rating, the variac as a variable turn ratio autotransformer, the concept of leakage inductance, development of a transformer model including resistance, leakage and exciting current, discussion of "exact" and approximate

equivalent circuits for a two winding transformer, referring impedances to one side to obtain the Req, Xeq transformer model.

16) Comments on (open book) mid term, explanation of relative unimportance of resistance and exciting current compared to leakage flux effects, example of voltage drop, efficiency and short circuit calculations, use of equivalent circuit for autotransformer calculations (proper placement of Req and Xeq), parameters of importance in special transformers e.g., differential current monitor (GFI), current transformers, high leakage transformers, magnetic circuit interpretation of leakage flux, the practical difficulty of separating primary and secondary leakage flux.

17) Discussion of mid-term retake exam and design project, importance of short circuit operating point for evaluation of leakage reactance, illustration using high leakage transformer, concept of scaling laws, tendency toward higher efficiency and increased cooling problems in larger transformers as examples of scaling laws, discussion of inrush currents in resistive, capacitive and inductive circuits, influence of saturation on inductive inrush current.

18) Examples of inrush waveforms, Bli and $B^2/2\mu_0$, as basis for singly excited, linear motion devices, examples of such devices including speakers, linear actuators, fuel injectors and trip devices, description of number of such devices in typical home (77, including 27 circuit breakers or GFI's and 26 in 2 automobiles), first order analysis of current driven and voltage driven $B^2/2\mu_0$ devices, comparison of properties of current vs voltage driven devices, detailed analysis of $B^2/2\mu_0$,device.

19) Energy balance as a global approach to energy conversion and an alternative to Bli and $B^2/2\mu_0$, evaluation of electric energy, mechanical energy and magnetic field energy, graphical interpretation of the energy conversion process in the $\lambda - i$ plane, constant current transition using coenergy, constant flux transition using field energy, general force equations using energy and coenergy, force equations for linear magnetic systems, application of linear magnetic system equations to determination of existence and direction of force in systems with and without magnetic material.

20) Example of application of linear magnetic system force equations to linear motion device, force computation in both x and y directions, extension of force equations to systems with more than one exciting coil, demonstration of repulsion force device, observation that two rings float higher than a single ring, development of a model of the floating ring device, illustration of modeling concepts such as simplification, retaining the physical basis, maintaining units, choosing the source to reduce complexity, use of phasors and averaging of sine products.

21) Review of floating ring analysis, discussion of static stability in a levitation device, explanation for the observed behavior in terms of how rapidly the force changes as a function of the ring resistance, introduction to uniform air gap rotating machines, discussion of widespread use of such machines (over 130 in instructor’s home), comparison of radial flux and axial flux geometry, description of a general BLI machine (all common machines are BLI machines), illustration of how a dc machine maintains the condition for constant force during rotor rotation.

22) Review of BLI concept and dc machine operation via commutator, use of a rotating B-field to produce constant torque by interaction with a dc winding to create a synchronous machine, importance of space phase of current wave (rotor position) in determining torque, use of a rotating B-field to produce constant torque by interaction with a winding moving (slowly) with respect to the B-field to create an induction machine, importance of space phase of current wave (rotor power factor) in

determining torque, discussion of operation with conventional constraints (constant V and f) vs. operation with power electronic constraints (variable f, variable excitation, often current source)

23) Use of slots to reduce effective air gap, slotting also transfers force to slot wall, determination of magnetic field from conductor distribution, influence of winding placement on magnetic field distribution, peak magnetic field proportional to turns per pole, fundamental component representation, the winding factor, magnetic field of AC excited sinusoidally distributed winding as stationary pulsating wave or as forward and backward constant amplitude rotating fields, influence of pole number on rotating field speed, cancellation of backward rotating magnetic field by using two or three phase sinusoidally distributed windings.

24) The two phase rotating field, amplitude of rotating field equal to peak amplitude of one phase, the three phase rotating field, amplitude of rotating field equal to 3/2 times peak amplitude of one phase, influence of harmonics on rotating fields, harmonic field speeds always slower than fundamental because of larger number of poles, illustration of sinusoidal rotating fields, rotating fields with one or two harmonics and a rotating field having a set of harmonics corresponding to concentrated coil windings (rectangular waves).

25) Development of a model for a DC machine, torque in terms of average B and I, torque in terms of flux and I, The back emf in terms average b and I or flux and I, the torque constant and/or back emf constant, the dc machine equivalent circuit, sample calculation and results for a 5 hp, 1750 rpm machine, comparison with results for a 125 hp, 1750 rpm machine, observation that efficiency and speed regulation are much better in large machines, presentation of armature voltage, armature resistance and flux as speed control possibilities with armature voltage having many advantages.

26) Capability curve of a DC machine, illustrations of induction machine construction and basic BLI operation, slip dependence of rotor generated voltage and frequency in induction machines, dependent generator model neglecting stator R, leakage and magnetizing current, reinterpretation with constant rotor frequency and voltage and slip dependent rotor resistance, elimination of dependent generators using ideal transformer, the stator referred model, power and efficiency relations.

27) Power and torque relations, air gap power, small slip behavior, need to add magnetizing reactance to give adequate prediction of current, need to add leakage reactance to predict peak torque, speed for peak torque, approximate expression for peak torque showing peak torque is independent of rotor resistance, addition of stator resistance and core loss to obtain the full stator referred equivalent circuit, sample calculation of motor performance, effect of reduced voltage operation on machine losses.

28) Review of IM model, behavior of model when slip is constant, generic torque vs. slip characteristic, summary of approximate torque relation for rated, peak and starting torques, starting torque and current, need for current limiting using series reactance or transformer motor starters, starting torque improvement via increased rotor resistance, the double cage rotor, speed control by varying voltage, variable frequency speed control, six step inverter waveforms, constant volts hz operation of the IM

29) Development of synchronous motor model from induction motor model, physical interpretation of elements of equivalent circuit, contrast between induction and synchronous machine (SM) properties, principal advantages of SM – adjustable power factor and constant speed, the SM as an isolated generator, frequency control via speed, voltage control via field current, the SM as a grid connected

generator, the power angle curve , adapting to power input changes via changes in δ and power output, adjusting Q via the field current.