LEAD CITY UNIVERSITY, IBADAN
FACULTY OF ENGINEERING AND TECHNOLOGY
DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
SEMESTER/SESSION: SECOND SEMESTER, 2024/2025

Course Particulars

Course Code: EEE 534
Coarse Title: Power System Engineering
Course Units: 2
Course Status: Elective

Lecturer's Details

Name: **ADELEYE, Adetunji Oluwaseye**
Qualifications: **B.SC (Computer with Electronics) B.Eng. (Elect and Elect Engr.), M.Sc. (Elect and Elect Engr.) MBA (Business Administration), PhD. (Elect and Elect Engr.) R.Engr. (COREN), R.Engr (NSE) R.Engr (NIEEE).**
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Areas of Specialization
Optimization, modeling, power systems,control, distributed generation and renewable energy.

Course Synopsis
Representation of power systems. Power systems equations and analysis; Power system modeling, static flow equations, classification of system variables, generalized n-bus system, network model formulation, use of network analyzer and digital computer, optimum operating strategies. Load flow studies. Load forecasting. Economic operation of power systems. Symmetrical components; Symmetrical and unsymmetrical faults. System protection; various types of relay used in power systems. Protection systems for power transmission lines. Fault analysis, Principles of fault detection, discrimination and clearance. Elements of power systems stability.

The course objectives are to:

- facilitate the understanding ofvarious models and representations of power system components.
- facilitate the understanding of load flow analysis/studiesand load forecasting models.
- give a good knowledge on optimal operation of generators and economic operation of the power systems.
- understand the concepts ofshort circuit conditions and their calculations during symmetrical and unsymmetrical faults in power systems.
- discuss the power systems stability problems and analyze dynamical systems.

Course Learning Outcomes (CLOs)

At the end of this course, students would be able to:

1. Understand and explain the various models and representations of power system components.
2. Understand and apply load flow methodologies and load forecasting models to solve power system problems.
3. Understand, analyse and solve problems related tooptimal operation of generators and economic operation of the power systems.
4. Understand, analyse and compute short circuit conditions and their calculations to solve symmetrical and unsymmetrical faults problems in power systems.
5. Understand,explainand apply the concepts/elements of power systems stability to analyze dynamics of power systems.

Lecture Delivery Method

- Lecture with interactive sessions

LECTURE PLAN

Course Modules
Module 1: Course overview and representation of power system components.
Module 2: Load flow studies and load forecasting.
Module 3: Optimal operating strategies and economic operation of power systems.
Module 4: Symmetrical fault analysis, symmetrical components and unsymmetrical fault analysis.
Module 5: Elements of power systems stability.

Course Outline
Module 1: Course overview, fundamentals of electrical installations, and concepts of illumination
Number of Lecture Hours: 6

Week	**Lecture Topic**	**Contents**	**Learning Objectives**
1	Introduction and Course Overview	Course outlines, delivery methods, assessments, course materials and recommended text books	Discuss the general overview of the course, rules and regulations for successful achievement in the course.
2	Representation of Power System Components.	Single-line Diagrams and Per Unit Representation of Power Systems.	To facilitate the understanding of the components models and representations used in power systems.

Module 2: Load flow studies and load forecasting.
Number of Lecture Hours: 9

Week	**Lecture Topic**	**Contents**	**Learning Objectives**
3	Load Flow Studies	Introduction. Network model formulation,classification of system variables, generalized n-bus system.	Understand the basic knowledge on network model formulation, and characterization of n-

			bus system.
4	Load Flow Methods and Computation	Various load flow methods. Power systems equations and analysis,static flow equations, use of network analyzer and digital computer solutions.	Understand the principles and methods used for load flow analysis.
5	Load forecasting.	Load forecasting methodology. Estimation of periodic and stochastic components, reactive load forecast, etc.	Understand and develop load forecasting models.

Module 3: Optimal operating strategies and economic operation of power systems.
Number of Lecture Hours: 12

Week	**Lecture Topic**	**Contents**	**Learning Objectives**
6	Optimal Operating Strategies.	Optimal operation of generators in a bus bar: generator operating cost and optimal operation etc.	Understand and solve problems related to the economic dispatch of power, plant scheduling, and unit commitment.
7	Revision and Tutorial		Revise the course contents taught from week 1 to week 6.
8	Mid-Semester Test		Continuous Assessment
9	Economic Operation of Power Systems.	Optimal unit commitment. Reliability consideration. Optimum generator scheduling. Optimal load flow solution.	Understand and solve problems related to the economic dispatch of power, plant scheduling, and unit commitment.

Module 4: Symmetrical fault analysis, symmetrical components and unsymmetrical fault analysis.
Number of Lecture Hours: 12

Week	**Lecture Topic**	**Contents**	**Learning Objectives**
10	Symmetrical Fault Analysis.	Introduction. Transient on a transmission line. Short circuit of a synchronous machine. Selection circuit breakers.	Understand theconcepts of short circuit conditions and principles governing the selection of protective devices in power systems.
11	Symmetrical Components	Introduction. Symmetrical component transformation. Sequence impedance and sequence network of power system. Construction of sequence network of a power system.	Understand the concept of sequence networks and the transformation of symmetrical components.

12	Unsymmetrical Fault Analysis.	Introduction.Shunt type faults:single line-to-ground (LG) fault, line-to-line (LL) fault and double line-to-ground (LLG) fault. Series type faults: open conductor (one or two conductors open) fault.	Understand the principles and concept of unsymmetrical faults, and methods to resolve them.

Module 5: Elements of power systems stability.
Number of Lecture Hours: 9

Week	**Lecture Topic**	**Contents**	**Learning Objectives**
13	Elements of Power Systems Stability.	Introduction. Dynamics of a synchronous machine. Power angle equation. Transient on a transmission line. Steady state stability. Transient stability.	Understand the theoretical concepts of stability in power systems
14	Elements of Power Systems Stability.	Equal area criterion. Fault detection, discrimination and clearance.	Understand and apply the concepts of power systems stability to analyze dynamics of power systems
15	Revision and Tutorial		Revise the course contents taught from week 9 to week 14.

Grading System

This course will be graded as follows:

Attendance:	10%
CA/Assignments:	30%
Examination:	60%
Total:	**100%**

References

Kothari, D.P. and Nagrath, I.J., 2003. Modern power system analysis. Tata McGraw-Hill Publishing Company.

Grainger, J.J.S., 1994. John J Grainger, and William D Stevenson. Power system analysis.McGraw-Hill

EEE 534Tutorial Questions

Question 1 15 marks

a) Write short notes on single-line diagram and impedance or reactance diagram, and per unit representations of a power system.
b) Figure Q1 shows the one-line diagram of asimple power system. The reactance data of the elements are given as:
Generator No. 1: 30 MVA, 10.5kV, X” = 1.6 ohms
Generator No .2: 15 MVA, 6.6k V, X” = 1.2ohms

Generator No. 3: 25 MVA,6.6k V,X” = 0.56ohms
Transformer 1 (3phase): 15MVA,33/11kV,X = 15.2ohmsperphaseon hightensionside
Transformer 1 (3phase): 15MVA, 33/16.2kV, X = 16 ohms per phase on high tension side
Transmission line: 20.5ohms/phase
Load A: 15 MW,11kV,0.9laggingpowerf actor
Load B: 40MW, 6.6kV,0.85lagging powerfactor
Obtain the per unit impedance(reactance)diagram of the power system of Fig.Q1

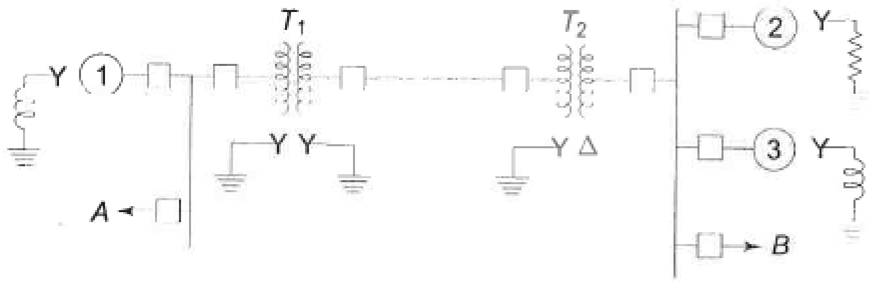


Fig.Q1

Question 2 15 marks

a) Briefly discuss the classification of network buses based on the two variables specified *a priori.*
b) Figure Q2 shows the one-line diagram of a simple four-bus system. Table Q2 gives the line impedances identified by the buses on which these terminate. The shunt admittanceat all the busesis assumednegligible. (i) Find Y_{BUS} assuming that the line shown dotted is not connected. (ii) What modifications need to be carried out inY_{BUS}, if the line shown dotted is connected?

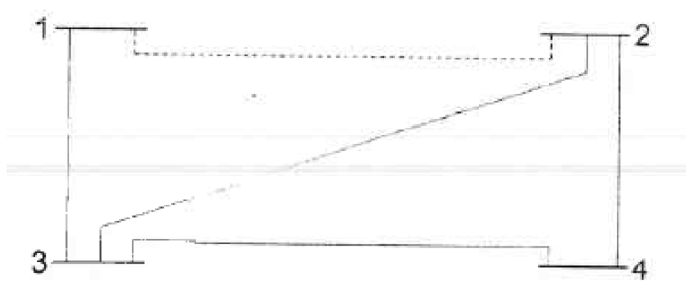


Figure Q2

Table Q2

Line, bus to bus	*R*, pu	*X*, pu
1–2	0.05	0.15
1–3	0.10	0.30
2–3	0.15	0.45
2–4	0.10	0.30
3–4	0.05	0.15

Question 3 15 marks

a) Briefly discuss the equal-area criterion for the transient stability of a power system.
b) Consider the four-bussamplesystem of Fig. Q3 where line reactances are indicated in pu. Line resistancesare considered negligible. The magnitude of all the four bus voltages

are specified to be 1.0 pu. The bus powers are specifiedin the table below. Determine the unknown stateand control variables of the system.

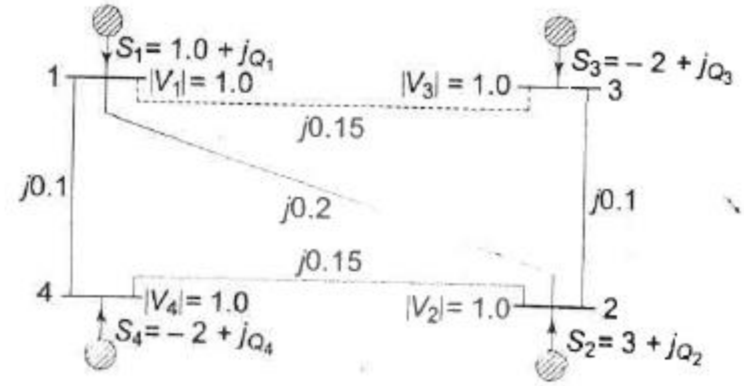


Fig. Q3: Four-buslosslesssamplesystem

Bus	*Real demand*	*Reactive demand*	*Real generation*	*Reactive generation*
1	$P_{D1} = 1.0$	$Q_{D1} = 0.5$	$P_{G1} = ?$	Q_{G1} (unspecified)
2	$P_{D2} = 1.0$	$Q_{D2} = 0.4$	$P_{G2} = 4.0$	Q_{G2} (unspecified)
3	$P_{D3} = 2.0$	$Q_{D3} = 1.0$	$P_{G3} = 0$	Q_{G3} (unspecified)
4	$P_{D4} = 2.0$	$Q_{D4} = 1.0$	$P_{G4} = 0$	Q_{G4} (unspecified)

Question 4 15 marks

a) Briefly explain the importance of d-q transformation in solving power system problems.
b) Incremental fuel costs in rupees per MWh for a plant consisting of two unitsare:

$$\frac{dC_1}{dP_{G1}} = 0.20P_{G1} + 40.0$$

$$\frac{dC_2}{dP_{G2}} = 0.25P_{G2} + 30.0$$

Assume that both units are operating at all times, and total load varies from 40 MW to 250 MW, and the maximum and minimum loads on each unit are to beI25 and 20 MW, respectively. How will the load be shared between the two units as the system load varies over the full range? What are the corresponding values of the plant incremental costs?

Question 5 15 marks

a) What are the two distinct components of the fault current in each phase during a three phase short circuits at the terminal of a synchronous machine.
b) A two-bus system is shown in Fig. Q5. If 100 MW is transmitted from plant1 to the load, a transmission loss of 10 MW is incurred. Find the required generation for each plant and the power received by load when the system λ is \$25/MWh.The incremental fuel costs of the two plants are given below:

$$\frac{dC_1}{dP_{G1}} = 0.02P_{G1} + 16.0 \text{ Rs/MWh}$$

$$\frac{dC_2}{dP_{G2}} = 0.04P_{G2} + 20.0 \text{ Rs/MWh}$$

Fig. Q5

Question 6 15 marks

a) List and explain the procedures for computing the steady state values of synchronous machine variables as a function of specified terminal quantities.
b) For the radial network shown in Fig. Q6, a three-phasefault occurs at F. Determine the fault current and the line voltage at 11kV bus under faultconditions.

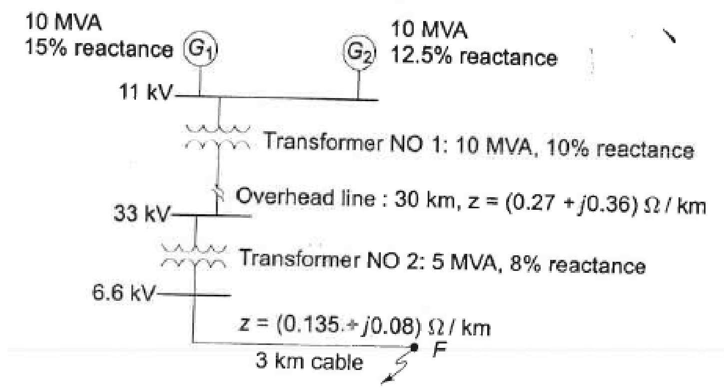


Fig. Q6

Question 7 15 marks

a) Briefly explain the reactive compensation of transmission lines. What is the benefits of shunt compensation?
b) A dc source of 120 V with negligible resistance is connected through a switch S to a lossless transmission line having Z_c = 30 Ω. The line is terminated in a resistance of 90 Ω. If the switch closes at t = 0, draw the lattice diagram and plot V_R versus time until t = 5T, where T is the time for a voltage wave to travel the length of the line. The circuit is shown in Figure Q7.

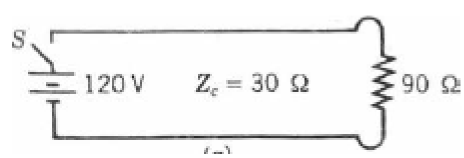


Figure Q7

Question 8 15 marks

a) Explain the classification of overhead transmission line based on the capacitance of the line without loss of accuracy.
b) In a balanced three-phase circuit the voltage V_{ab} *is* $173.2\underline{/0^\circ}$V. Determine all the voltages and the currents in a Y-connected load having $Z_L = 10\underline{/20^\circ}\Omega$. Assume that the phase sequence is abc.

Question 9 15 marks

a) What is surge impedance in electric power system?Define wavelength λ of a transmission line.

b) A 300 MVA 20 kV three-phase generator has a subtransient reactance of 20%. The generator supplies a number of synchronous motors over a 64km transmission line having transformers at both ends, as shown on the one-line diagram of Figure Q9. The motors, all rated 13.2 kV, are represented by just two equivalent motors. The neutral of one motor M_1 is grounded through reactance. The neutral of the second motor M_2 is not connected to ground (an unusual condition). Rated inputs to the motors are 200 MVA and 100 kVA for M_1 and M_2, respectively. For both motors X" = 20%. The three-phase transformer T_1 is rated 350 MVA, 230/20 kV with leakage reactance of 10%. Transformer T_2 is composed of three single-phase transformers, each rated 127/13.2 kV, 100 MVA with leakage reactance of 10%. Series reactance of the transmission line is 0.5 Ω/km. Draw the reactance diagram with all reactances marked in per unit. Select the generator rating as base in the generator circuit.

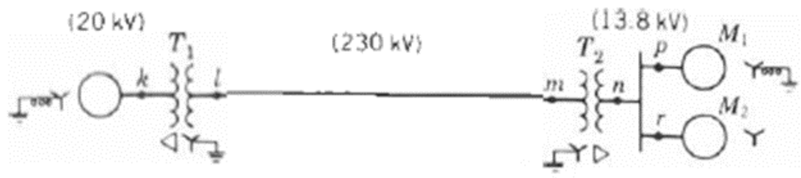


Figure Q9

Question 10 15 marks

a) What are the advantages and disadvantages of DC transmission system?

b) Using the Newton-Raphson method, solve for x_1 and x_2 of the nonlinear equations

$$g_1(x_1,x_2,u) - h_1(x_1,x_2,u) - b_1 = 4ux_2 sinx_1 + 0.6$$

$$g_2(x_1,x_2,u) - h_2(x_1,x_2,u) - b_2 = 4x_2^2 - 4ux_2 cosx_1 + 0.3$$

Treat the parameter u as a fixed number equal to 1.0, and choose the initial conditions $x_1^{(0)} = 0\ rad$ and $x_2^{(0)} = 1.0$. The precision index e is 10^{-5}.

Question 11 15 marks

a) Define transients on transmission systems. Explain the causes and protection of transient over-voltages in transmission lines.

b) An 18-km, 60-Hz, single-circuit, three-phase line is composed of Partridge conductors equilaterally spaced with 1.6 m between centers. The line delivers 2500 kW at 11 kV to a balanced load. Assume a wire temperature of 5°C.

   i) Determine the per-phase series impedance of the line.
   ii) What must be the sending-end voltage when the power factor is
      i. 80% lagging,
      ii. unity,
      iii. 90% leading?
   iii) Determine the percent regulation of the line at the above power factors.
   iv) Draw phasor diagrams depicting the operation of the line in each case.

Question12 15 marks

a) What are the assumptions used in calculating the subtransient fault current for a three-phase short circuit in a power system.

b) Draw the protective zones for the power system shown in Figure Q12. Which circuit breakers should open for a fault at P_1 and at P_2?

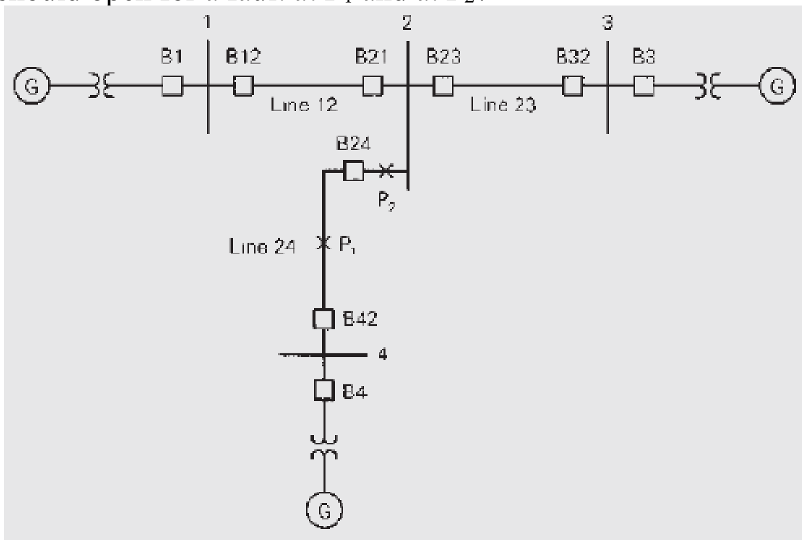
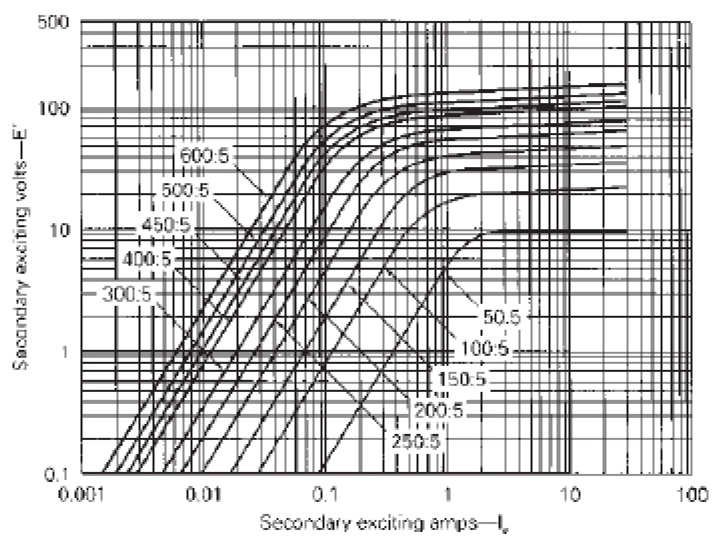


Figure Q12

Question 13 15 marks

a) Briefly explain the design methods for improving power system transient stability.
b) Evaluate the performance of the multiratio CT in Figure Q13 with a 100:5 CT ratio, for the following secondary output currents and burdens:
   i. $I' = 5A$ and $Z_B = 0.5\Omega$;
   ii. $I' = 8A$ and $Z_B = 0.8\Omega$; and
   iii. $I' = 15A$ and $Z_B = 1.5\Omega$.
   iv. Also, compute the CT error for each output current.



CT ratio	Secondary resistance Ω
50:5	0.061
100:5	0.082
150:5	0.104
200:5	0.125
250:5	0.146
300:5	0.168
400:5	0.211
450:5	0.230
500:5	0.242
600:5	0.296

Figure Q13

Question 14 15 marks

a) Briefly discuss the three basic components of a protection system in electrical power systems. 6
b) A 500-MVA, 20-kV, 60-Hz synchronous generator with reactances $X_d'' = 0.15$, $X_d'' = 0.24$, and $X_d = 1.1$ per unit and time constants $X_d'' = 0.035$, $X_d' = 20$, $T_A = 0.2$s is connected to a circuit

breaker. The generator is operating at 5% above rated voltage and at no-load when a bolted three-phase short circuit occurs on the load side of the breaker. The breaker interrupts the fault three cycles after fault inception. Determine:

i. the subtransient fault current in per-unit and kA rms;
ii. maximum dc offset as a function of time; and
iii. rms asymmetrical fault current, which the breaker interrupts, assuming maximum dc offset..

Question 15 15 marks

a) Briefly discuss automatic circuit reclosers.
b) A balanced, positive-sequence, Y-connected voltage source with $E_{ab} = 480\angle 0°$ volts is applied to a balanced-Δ load with $Z_\Delta = 30\angle 30°$ V. The line impedance between the source and load is $Z_L = 1\angle 85°$ V for each phase. A Y-connected voltage source with the following unbalanced voltage is applied to the balanced line and load described above.

$$\begin{bmatrix} V_{ag} \\ V_{bg} \\ V_{cg} \end{bmatrix} = \begin{bmatrix} 277\angle 0° \\ 260\angle -120° \\ 295\angle +115° \end{bmatrix} \text{ volts}$$

The source neutral is solidly grounded. Using the method of symmetrical components, calculate the source currents I_a, I_b, and I_c.