II Year II Semester **L T P C**

Code: 20EE4636 **4 0 0 4**

NON-LINEAR CONTROL SYSTEMS

Preamble: Most systems are nonlinear, and therefore, it is of general interest to investigate possible behaviours of nonlinear systems, investigate their stability, and to design control schemes.

Course Objectives: At the end of the course, the students are supposed

1. To introduce the need and concept of nonlinear system.
2. To impart knowledge about different strategies adopted in the analysis of nonlinear systems.
3. To analyse the stability of nonlinear systems using various approaches.
4. To familiarize with the design of different types of nonlinear controllers.

Course Outcomes: At the end of the course, the students can able to

1. demonstrate non-linear system behaviour by phase plane and describing function methods
2. perform the stability analysis nonlinear systems by Lyapunov method
3. analyse the application of Lyapunov function and its control
4. design a controller to the nonlinear system either through direct approach or by linearization of the states.

PO& PSOs	Program Outcomes (POs)												PSOs		
COs	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
CO1	3	2					1						2	3	
CO2	3	2					1						2	3	
CO3	3	2					1						2	3	
CO4		3	2	1									2	3	

*Mapping Strength: **Strong-3; Moderate-2; Low-1**

Unit – I: Introduction and Phase Plane Analysis

Introduction. Linear vs. nonlinear systems and nonlinear phenomena. State-space representation of nonlinear systems, Basic characteristics of nonlinear systems. Second Order Systems (Phase plane analysis): Classification of equilibrium points. Systems with multiple equilibria. Analysis of piecewise linear control systems-Feedback systems in standard form-Classification of nonlinearities.

Unit – II: Describing function analysis
Describing function analysis-The principle of harmonic balance. Describing functions for various nonlinearities. Stability of limit cycles by describing function method. Limit cycle analysis of control systems. Nonlinear differential equations-Existence and uniqueness

Unit – III: Lyapunov Stability Theory
Mathematical preliminaries-Linear vector spaces-Norms and inner products-Normed and inner product spaces. Lyapunov's direct method-Definite functions-Stability and instability theorems. La Salle theorems. Stability of linear systems-Lyapunov equation for time-invariant systems-Stability conditions for time varying systems. Lyapunov's linearization (indirect) method. Region of attraction

Unit – IV: Application of Lyapunov Theory
Input-Output stability-Relationships Between I/O and Lyapunov Stability.Passivity Theorem, The Small-Gain Theorem, Feedback Stability: Absolute Stability (Lure) problem-Circle criterion-Popov's criterion. Passivity-Based control, Control Lyapunov functions.

Unit – V: Nonlinear Control Design and Feedback Linearization
Nonlinear Control Design Methods-Sliding Mode Control-Robust Control of Nonlinear Systems-Backstepping. Feedback Linearization-Lie derivatives and Lie brackets-Input-state linearization of SISO systems-Input-output linearization of SISO systems.

Text Books:

1. H. K. Khalil Nonlinear Systems, Third Edition, Prentice-Hall., 2002
2. S. Sastry, Nonlinear Systems: Analysis, Stability, and Control, Springer 1999.
3. K.M. Hangos, J. Bokor and G. Szederkényi, "Analysis and Control of Nonlinear Process Systems", Springer ISBN 1-85233-600-5

Reference Books:

1. H. J. Marquez, Nonlinear Control Systems: Analysis and Design, JohnWiley Inter science, 2003.
2. J. J. Slotine and W. Li Applied Nonlinear Control, Prentice-Hall, 1991.
3. M. Vidyasagar, Nonlinear Systems Analysis, SIAM, 2002
4. J. E. Gibson Nonlinear Automatic Control, McGraw-Hill, 1963.