Approval: 9th Senate Meeting

Course Name:	Nonlinear Stability and Control
Course Number:	EE 515
Credits:	4-0-0-4 (L-T-P-C)
Prerequisites:	EE 301 Control Systems, EE 509 Linear Dynamical Systems or teachers consent
Intended for:	U.G./P.G.
Distribution:	Elective
Semester:	Even

Course Preamble:

Most systems are nonlinear, and therefore, it is of general interest to investi-gate possible behaviours of nonlinear systems, investigate their stability, and to design control schemes. For example, there are many situations in Power systems where linear controllers are used. For these one would like to investigate behaviour under "large sig-nal conditions" when nonlinearities cannot be ignored. And there are areas like Robotics where designs based on linear models do not work well.

Lyapunov's stability theory is a successful and well developed body of work suited for investigating and sometimes guaranteeing desired stability properties. This will be the bedrock of this course. Nonlinear systems exhibit interesting oscillatory behaviours, and indeed unexpected phenomena like Chaos. We will take a peek at the basic phenomena of Limit cycles, Bifurcations, Chaos etc. This is useful in the fields of Control systems, Dynamical systems of applied mathematics, and also in specialized Analog electronic circuits.

Simple and heuristic nonlinear models such as the relay, backlash, and deadband elements find use all across electrical engineering, and the method of Describing functions has inspired adhoc schemes. We will study the effects of these schemes, and see what kind of guarantees can be given. Over the last 50 years, research workers have developed some constructive and effec-tive techniques for synthesizing nonlinear controllers. We will study Backstepping control which is a successful scheme that is relatively easy to design, and has a solid theoretical underpinning.

Controllability of nonlinear systems has interesting differences from its linear counter-part. Its elucidation is a milestone in the Geometric theory of nonlinear control. We will make a short trip into this territory.

This course will be a core requirement for all postgraduate students in Control. This will probably be a highly useful acquirement for postgraduate students in Power Systems, in Robotics, and in Differential equations.

Course Outline: The intended learning outcomes are:

1. Get a feel for the qualitatively different trajectories possible in nonlinear systems.
1. Understand when and how linearized models can be useful for studying behaviour around equilibrium points, and near limit cycles.
2. Master Lyapunov's stability theory and its modern control theoretic extensions.

3. Know how to investigate stability for linear systems with static, sector-contained non-linearities.
4. Know when the method of describing functions works, and when it fails.
5. Understand and gain facility in designing controllers using Passivity, and, Back-stepping.
6. Be aware of basic ideas in Geometric control of nonlinear systems.
7. Be aware of Bifurcations, and Chaos.

Course Modules: The topics to be covered are:

Linear and nonlinear system behaviours (10 hours) Quick recapitulation of linear dif-ferential equations, and their solutions. Qualitative properties of nonlinear systems. Existence and uniqueness of solutions to Ordinary differential equations. Lineariza-tions. Hartman-Grobman theorem. Volterra's functional expansions.

Lyapunov's stability theory (16 hours) Notions of stability. Lyapunov's stability theo-rem. Lasalle's invariance principle. Circle criterion, Popov criterion. Lyapunov-Krasovskii functionals.

Limit cycles, Bifurcations, Chaos (7 hours) Poincaré-Bendixson theorem. Center mani-fold theory. Simple examples of Bifurcations, and, Chaos.

Describing functions (6 hours) The describing function method, Computing amplitude

and frequency of oscillations.

Nonlinear geometric control (3 hours) Lie brackets and controllability. Examples.

Passivity and Backstepping control (8 hours) From Absolute stability to Passivity. Pas-sivity based design. Zero dynamics. Lg V control. Control Lyapunov functions. Recursive designs. Examples.

Lab exercises (10 hours) Experiments on Describing functions, Backstepping controllers etc. for Pendulum and cart system, DC to DC converter, Four tank water level control system etc.

Note: This is mainly a theoretical course. There is a small experimental component need-ing about 10 hours of lab work. This is included to give some practical demonstration

of techniques taught, and also because some of our students (especially future M.Tech.

students) would be heading to industry after their studies.

Textbooks:

1. Nonlinear Systems, H. Khalil, 3rd edition, 2014, Pearson
2. Stability and Stabilization, W. J. Terrell, 2009, Princeton University press
3. Constructive Nonlinear Control, R. Sepulchre et al., 1996, Springer
4. Nonlinear and Adaptive Control Design, M. Krstic et al., 1995, Wiley-Blackwell

Additional References:

1. Nonlinear Systems: Analysis, Stability, and Control, S. Sastry, 1999, Springer
2. Stability of Motion, W. Hahn, 1968, Springer
3. Dynamics of feedback systems, A. Mees, 1981, Wiley-Blackwell
4. Nonlinear Control Systems, volumes 1, 2, A. Isidori, 1995 and 1999, Springer
5. Nonlinear System Analysis, A. Blaquiere, 1966, Academic press
6. Nonlinear Dynamical Systems and Control, W. Haddad, and V. Chellaboina, 2008, Princeton University press
7. Stability Of Stationary Sets In Control Systems With Discontinuous Nonlinearities, V. A.
8. Yakubovich, G. A. Leonov, and, A. Kh. Gelig, 2004, World-scientific