Course title: Grid Integration of Renewable Energy			
Course code: ENR 143	**No. of credits:** 3	**L-T-P:** 38-4-0	**Learning hours:** 42
Pre-requisite course code and title (if any): NA			
Department: Department of Energy and Environment			
Course coordinator: Dr Naqui Anwer	**Course instructor:** Dr Naqui Anwer		
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Course type: Elective	**Course offered in:** Semester 3		

Course description

The characteristics and behaviour of power systems changes when the share of variable energy increase in the total mix. With the increase in penetration from renewable energy sources, the dynamics of the existing electricity infrastructure must be understood. This course provides a platform for strong understanding related to the phenomenon of integrating renewable energy sources. The course is focussed on causes, effects and recovery measures when power from renewable energy sources are injected to the grid.

Course objectives

The objective of this course is to provide:

- A strong understanding of power systems, their operation and control focussed on the issues related to the integration of distributed renewable generation into the network.
- Strong foundation for power system equipments used for integration.
- Detailed knowledge about power quality and its management along with approaches for grid stabilization.
- Deep understanding about integration techniques for RE sources.

Course contents

Module	Topic	L	T	P
1	**Introduction** Various techniques of utilizing power from renewable energy sources, concept of nano/micro/mini grid. Need of integrating large renewable energy sources, issues related to integration of large renewable energy sources, rooftop plants. Concept of VPP.	4	0	0
2	**Power system equipments for grid integration** **Synchronous generator:** synchronization/integration to existing grid, load sharing during parallel operation, stability (swing equation and solution) **Induction Generator:** working principle, classification, stability due to variable speed and counter measures **Power Electronics:** need of power electronic equipments in grid integration, converter, inverter, chopper, ac regulator and cyclo-converters for AC/DC conversion	12	2	0
3	**Power quality and management** THD, voltage sag, voltage swell, frequency change and its effects, network voltage management, frequency management, system protection, grid codes	6	0	0
4	**Grid stabilization** Scheduling and dispatch, Forecasting, reactive power and voltage control, frequency control, operating reserve, storage systems,	6	0	0

	electric vehicles Ancillary services in Indian Electricity Market (regulatory aspect), CERC and CEA orders (technical and safety standards)			
5	**Integration of alternate sources of energy** Introduction, principles of power injection: converting technologies, power flow; instantaneous active and reactive power control approach; integrating multiple renewable energy sources; DC link integration; AC link integration; HFAC link integration; islanding and interconnection	8	0	0
6	**Case studies** Based on synchronous/induction generator for peak demand reduction, grid connected PV system	2	2	
	Total	**38**	**4**	**0**

Evaluation criteria

Test 1: Assignments (after completion of modules 1, and 2) - 10%
Test 2: Written test (after completion of modules 3 and 4) - 20%
Test 3: Written test (after completion of modules 5 and 6) - 20%
Test 4: Written test (at the end of the semester, after completion of all the modules) - 50%

Learning outcomes:

On successful completion of this course, students should be able to:

- Apply advanced knowledge of electrical power system operations and control to analyse the challenges and opportunities for distributed renewable generation in both large interconnected grid and microgrid settings. (Test 1, 2, 3 and 4)
- Assess renewable energy applications and projects in the context of integration into both the physical and economic electricity markets. (Test 1 and 2)
- Describe the principles and requirements of the next generation future power network, incorporating distributed generation and storage and demand management. (Test 2 and 3)
- Understand the principles, power and limitations of complex power networks incorporating distributed generation and storage. (Test 1, 2, 3 and 4)

Pedagogical approach:

A combination of class-room interactions, group discussion and presentations, tutorials, practical and assignments.
Students' interaction with industry experts. Delivery of expert lectures by the professionals working on regulatory bodies and REMCs.

Materials

Reference books

Integration of Alternative sources of Energy, Felix A. Farret and M. Godoy Simoes, IEEE Press – Wiley-Interscience publication, 2006.
Grid integration of solar photovoltaic systems, Majid Jamil, M. Rizwan, D.P.Kothari, CRC Press (Taylor & Francis group), 2017
Renewable Energy Grid Integration, Marco H. Balderas, Nova Science Publishers, New York, 2009.
Wind Power Integration connection and system operational aspects, B. Fox, D. Flynn L. Bryans, N. Jenkins, M. O' Malley, R. Watson and D. Milborrow, IET Power and Energy Series 50 (IET digital library), 2007
Power Generation, Operation, and Control, Allen J. Wood, Bruce F. Wollenberg, Gerald B. Sheblé, John Wiley & Sons, New York, 2013 (3rd edition)

Power Electronics: Circuits, Devices, and Applications. M.H.Rashid, Pearson Education India, 2013

Advanced power system analysis and dynamics, L.P.Singh, New age international publishers, 2017

Suggested readings:

Solar Energy: Principles of Thermal Collection and Storage, S.P. Sukhatme and J. Nayak, Tata McGraw Hill, 2008(3rd edition)

Renewable Energy Engineering and Technology – A Knowledge Compendium, V.V.N. Kishore, TERI Press, 2008.

Analysis of demand response and wind integration in Germany's electricity market, M. Klobasa, IET Renew. Power Generation., Vol. 4, No.1, pp. 55–63 55, 2010.

Impact of wind power on the power system imbalances in Finland, A. Helander1, H. Holttinen, J. Paatero, IET Renew. Power Generation., Vol. 4, No. 1, pp. 75–84, 2010.

Comparative analyses of seven technologies to facilitate the integration of fluctuating renewable energy sources, B.V.Mathiesen H. Lund, IET Renew. Power Generation., Vol. 3, NO. 2, pp. 190–204, 2009.

Advanced grid requirements for the integration of wind farms into the Spanish transmission system, Morales1, X. Robe1, M. Sala, P. Prats, C. Aguerri, E. Torres, IET Renew. Power Generation., Vol. 2, No. 1, pp. 47–59, 2008.

Impact of widespread photovoltaic generation on distribution systems, M. Thomson and D.G. Infield, IET Renew. Power Generation, Vol. 1, No.1, pp. 33–40, 2007.

Teri Mini Grid Project at Gual Pahari.

Additional information (if any): NA

Student responsibilities

Adopt peer learning and knowledge sharing within the class

Attendance, feedback, discipline: as per university rules

Course reviewers:

1. Dr. Sukumar Mishra, Professor, IIT Delhi
2. Dr. Indradip Mitra, Senior technical Advisor, GIZ Gmbh, Germany