



Power Electronics for Utility Applications

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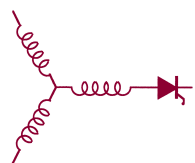
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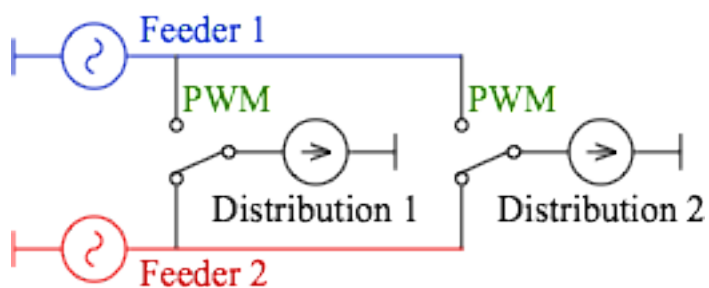
Electrical Power Delivery Systems

- Reliability
- Efficiency
- Economy
- Dynamic capability
 - Variability
 - Multiflow
 - Complexity
 - Enabling power electronics



PWM AC Power Flow Control

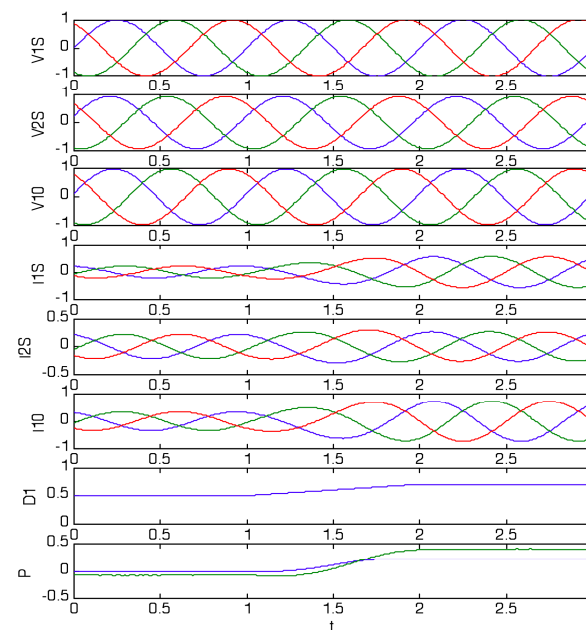
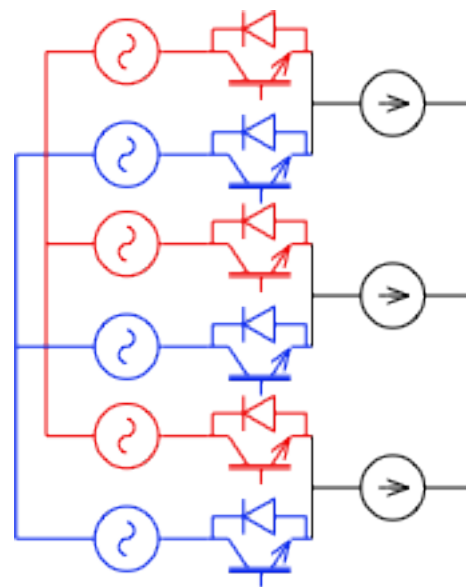
- 2 Feeders in and out at a substation
- Regulate shared power from each feeder

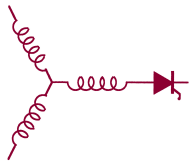


$$\begin{bmatrix} S_{1s} \\ S_{2s} \end{bmatrix} = \begin{bmatrix} .5 & .2 \\ .5 & .8 \end{bmatrix} \cdot \begin{bmatrix} 600 \\ 1039 + j600 \end{bmatrix} = \begin{bmatrix} 508 + j120 \\ 1131 + j480 \end{bmatrix}$$

or

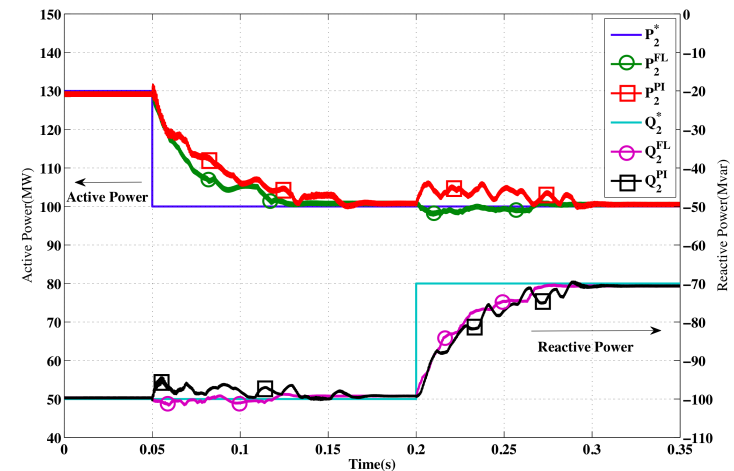
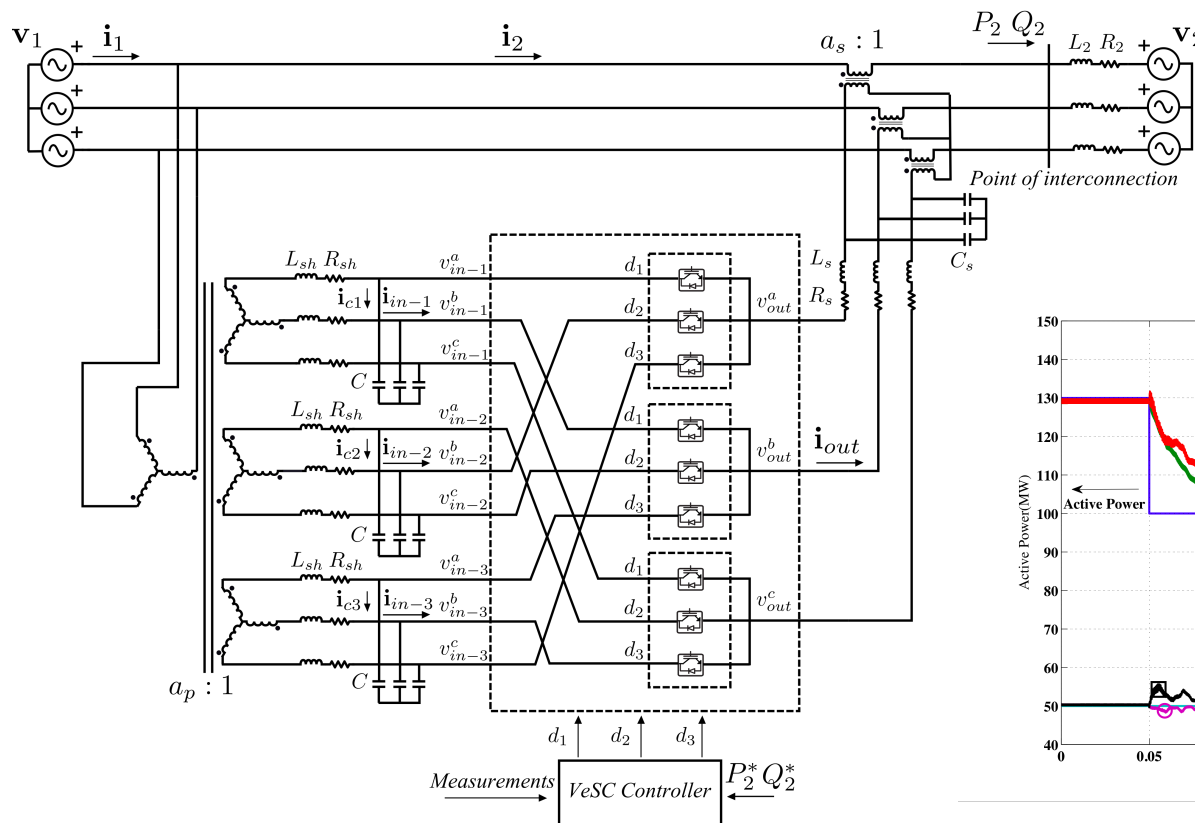
$$\begin{bmatrix} .1 & .7 \\ .9 & .3 \end{bmatrix} \cdot \begin{bmatrix} 600 \\ 1039 + j600 \end{bmatrix} = \begin{bmatrix} 787 + j420 \\ 852 + j180 \end{bmatrix}$$



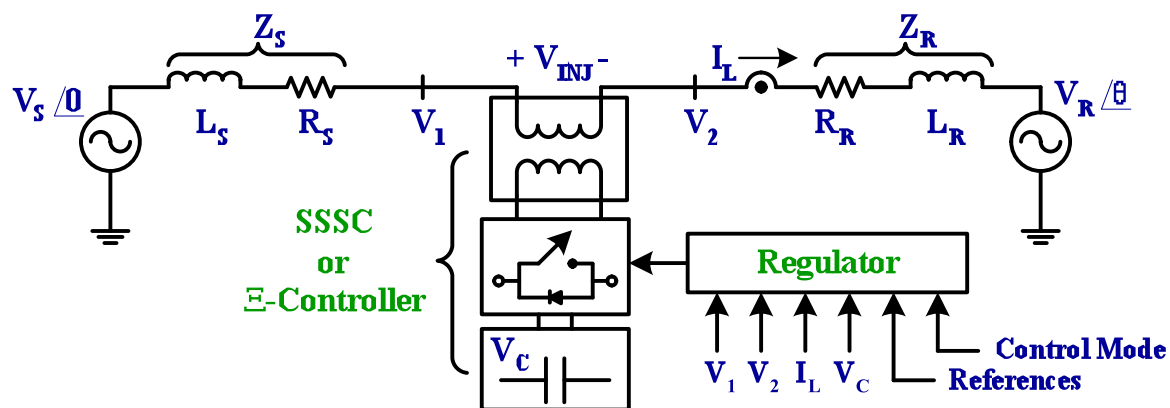


Shunt Series Power Flow Control

- Similar to phase shifter
- Fraction of rating



Series Power Flow Control



System : 110kV/100MVA/60Hz

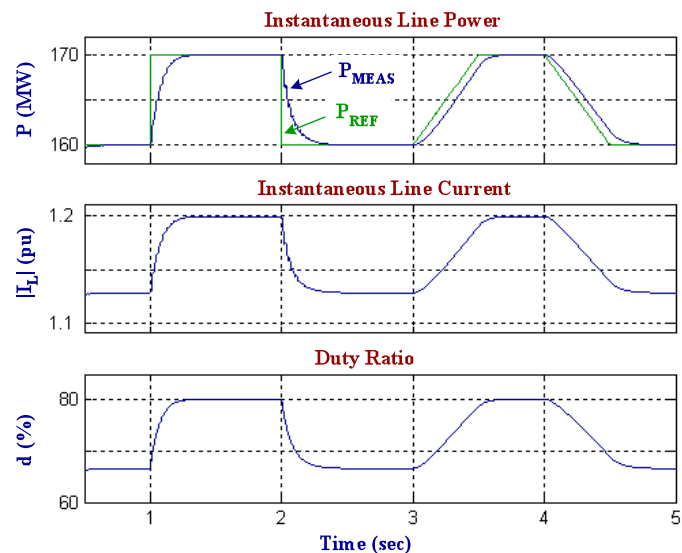
Base Power: $P_L=140\text{MW}$

Max. Compensated Power: $P_L=180\text{MW}$

$V_{INJ}=6.1(\text{kV})$

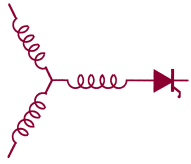
$I_{INJ}=965(\text{A})$

$Q_{INJ}=3V_{INJ}I_{INJ}=17.6(\text{MVar})$



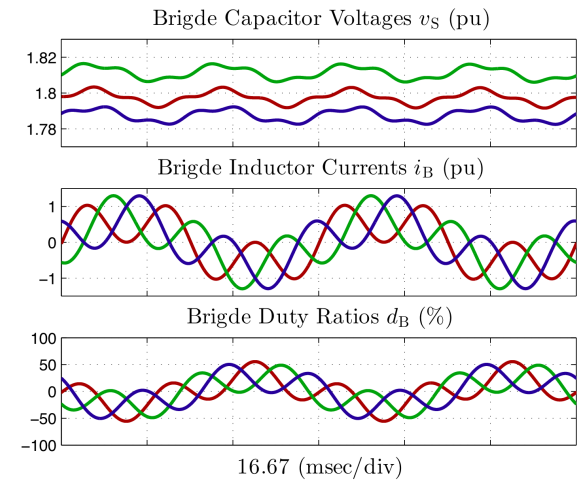
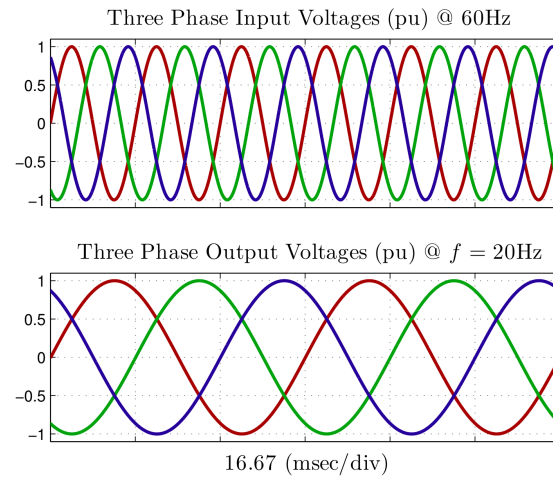
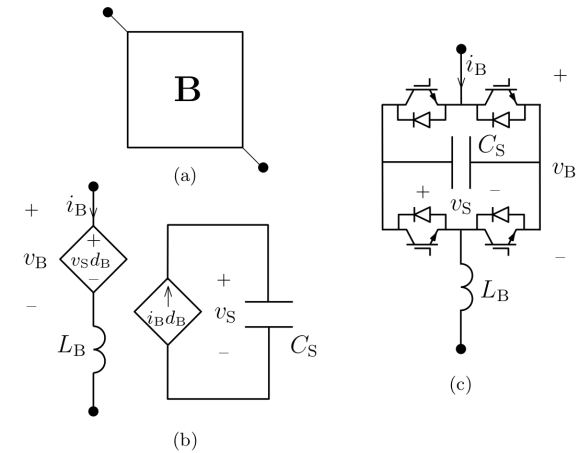
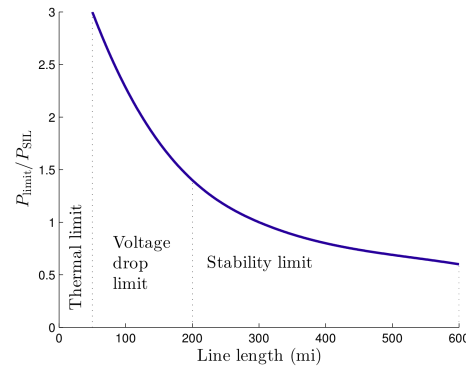
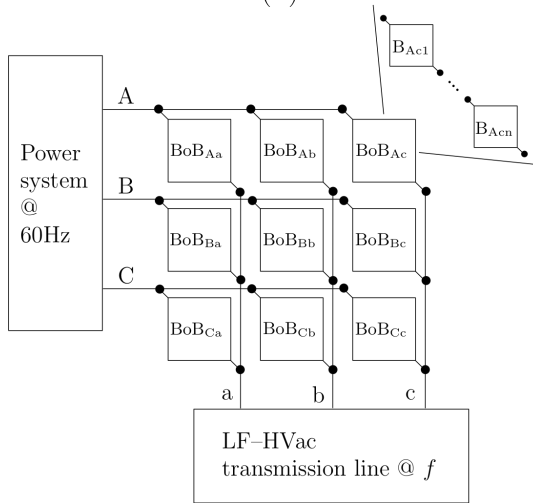
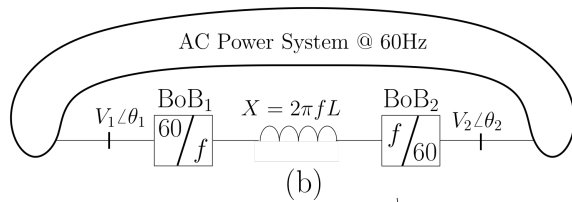
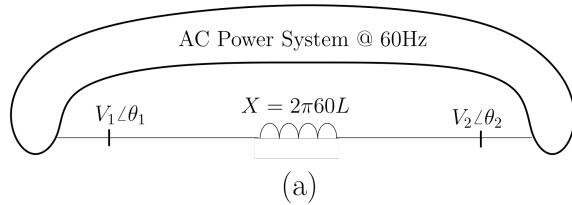
Power circuit cost estimate k\$ (ca. 2007)

Item	SSSC	E-Controller
Semiconductors	480	160
Transformer	352	352
Capacitors	925	472
Total cost	1757	984

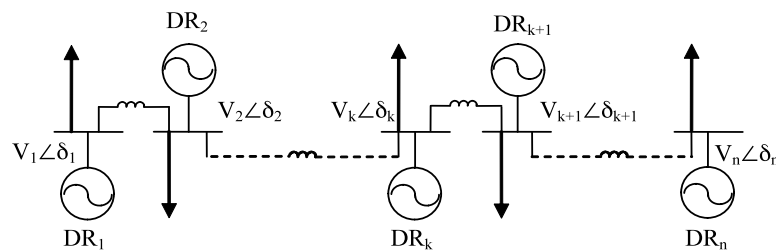


Modular Multilevel Converter

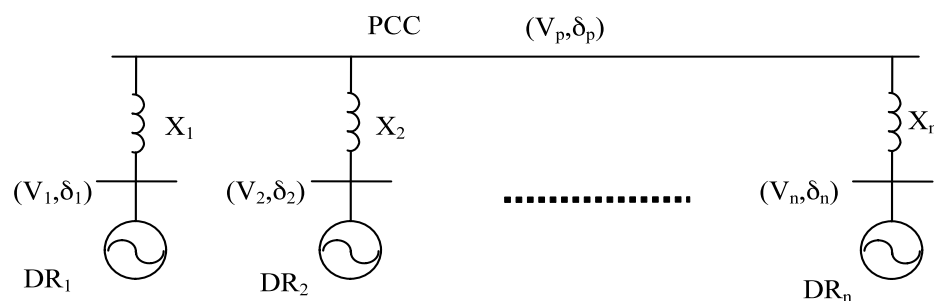
- Low frequency 3 phase transmission



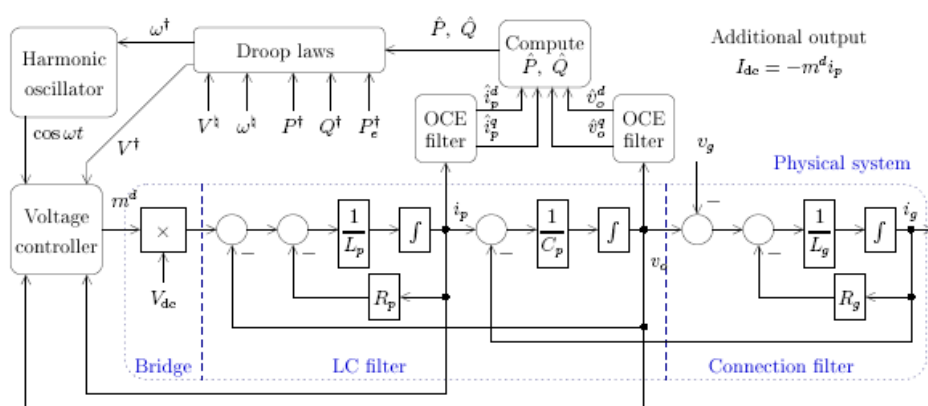
System level interactions



Stability DG along radial network



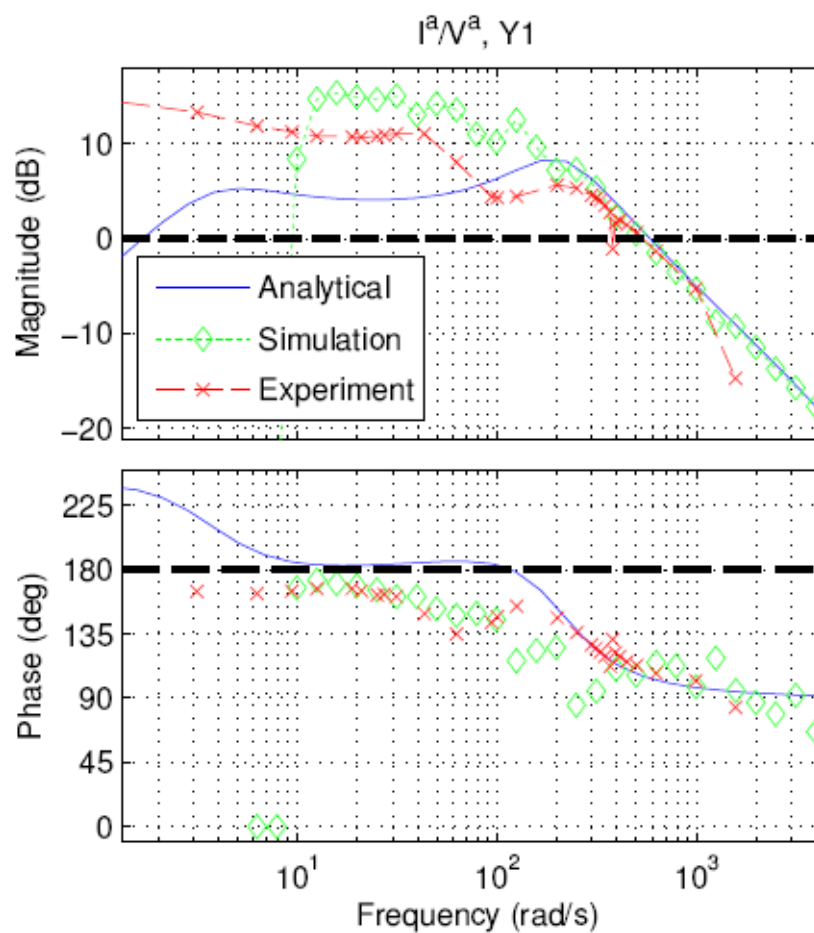
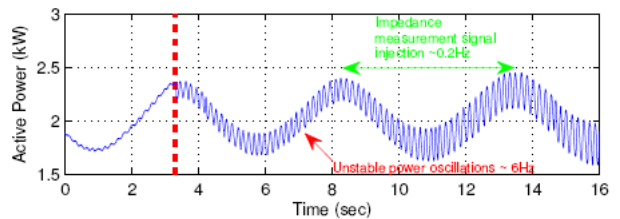
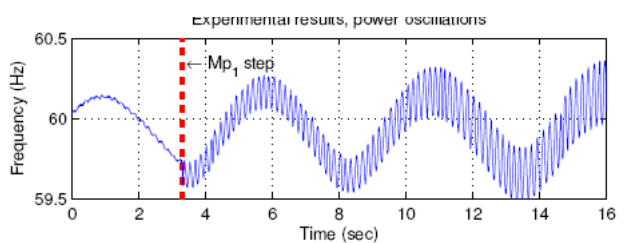
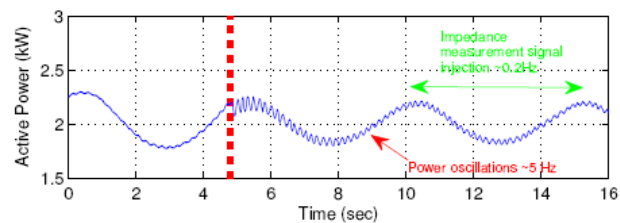
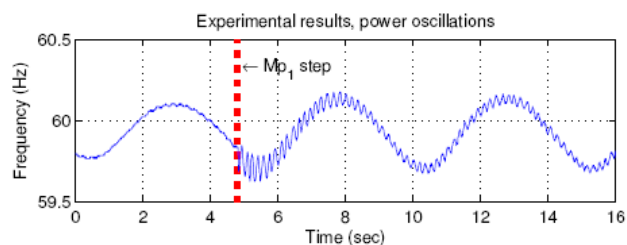
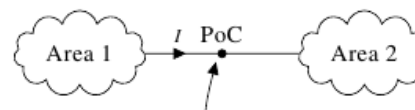
Stability of cluster of feeders containing DG



Interactions between DG control and system

System interactions

Impedance matching





Summary

- Rich converter topological potential beyond 2 or 3 level VSI are on the horizon
- Redundancy, fault tolerance and prognostics will enable reliability levels
- Multistage/multistep will enable efficiency targets
- Modularity will enable economy targets
- Co-evolution of power systems and power conversion engineering is essential for success

To probe more

1. P. M. Araya, G. Venkataramanan, "Stability analysis of AC Microgrids using incremental phasor impedance matching", *Electric Power Components and Systems*, Volume 43, Issue 4, February 2015, pages 473-484, Taylor and Francis, 2015.
2. S. Bala, G. Venkataramanan, "On the choice of voltage regulators for droop-controlled VSCs in microgrids to ensure stability", *Proceedings of the IEEE ECCE 2010, Atlanta, GA*.
3. Barragán-Villarejo, Manuel ; Venkataramanan, Giri ; Mancilla-David, Fernando ; Maza-Ortega, José María ; Gómez-Expósito, Antonio, "Dynamic modelling and control of a shunt-series power flow controller based on AC-link", *Institution of Engineering and Technology Journal of Generation, Transmission & Distribution*, Volume: 6, Issue: 8, 2012 , Page(s): 792-802.
4. Miguel Carrasco, Fernando Mancilla-David, Giri Venkataramanan, Justin Reed, "Low Frequency HVac Transmission to Increase Power Transfer Capacity", *Proceedings of the IEEE Power Engineering Society Transmission and Distribution Expo and Conference, Chicago, Apr 2014*
5. F. Mancilla-David, G. Venkataramanan, "Realization of an AC Link Unified Power Flow Controller", *Institution of Engineering and Technology Journal of Generation, Transmission & Distribution*, Volume: 6, Issue: 4, 2012, Page(s): 294-302.
6. D. Ludois, G. Venkataramanan, "An Examination of AC/HVDC Power Circuits for Interconnecting Bulk Wind Generation with the Electric Grid" *Energies* 2010, 3(6), Special Issue on Wind Energy, 1263-1289.
7. M. Illindala, G. Venkataramanan, "Small Signal Stability of a Microgrid with Parallel Connected Distributed Generation", *Special Issue on Smartgrids: Microgrid Systems, International Journal of Intelligent Automation & Soft Computing*, Vol. 16, No. 2, 2010. **Invited paper.**
8. F. Mancilla-David, S. Bhattacharya, G. Venkataramanan, "A Comparative Evaluation of Series Power Flow Controllers Using DC and AC Link Converters." *IEEE Transactions on Power Delivery*, vol. 22, April 2008, Page(s):985 – 996
9. G. Venkataramanan, "Three-phase vector switching converters for power flow control," *IEE Proceedings-Electric Power Applications*, vol. 151, pp. 321-333, May 2004.
10. B. K. Johnson and G. Venkataramanan, "A hybrid solid state phase shifter using PWM ac converters," *IEEE Transactions on Power Delivery*, vol. 13, pp. 1316-1321, Oct 1998.
11. G. Venkataramanan, F. Mancilla-David, T. Jimichi, T. Nwachukwu, P. Mendoza-Araya, S. Gupta, "Advanced Power Electronics Controllers for Substations, Challenges and Solutions ", EPRI, Technical Report, Palo Alto, CA and the University of Wisconsin-Madison, Madison, WI: 2008. EPRI TR-1015948.
12. G. Venkataramanan, S. Srinivasan, "Scope of PWM AC-AC Converters for Custom Power Applications", EPRI, Palo Alto, CA and the Montana State University-Bozeman, MT: 1996. EPRI TR-105601.