# ACC2015 Workshop on
# Next Generation Smart Grids: Power Electronics based Power Systems

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## Duration of the Workshop

It is intended to run the workshop for a half day.

## Introduction

Power systems are going through a paradigm change from centralized generation to distributed generation and further onto smart grids. In order to make power systems more secure, more efficient, more resilient to threats and friendlier to the environment, a huge number of heterogeneous players, including renewable energy sources, electric vehicles, and storage systems etc. on the supply side and different types of smart loads on the demand side, are being connected to power systems. Because of the heterogeneous nature and the huge number of players involved, it is a great challenge for control and systems theorists to find a control architecture so that all heterogeneous players could work together to maintain system stability and achieve desired performance.

In this workshop, the fundamental challenge behind the scene during the paradigm change is identified: that is ***future power systems will be power electronics based, instead of electrical machines based, with a huge number of heterogeneous players.*** This makes it less of a power problem but more of a systems problem. Moreover, an autonomous scalable distributed control architecture is presented from the systems perspective. All the heterogeneous players, including new add-ons of generation, such as wind farms, solar farms, EVs, energy storage systems, and the majority of loads, can be controlled to behave like virtual synchronous machines so that all behave homogeneously, in terms of the underlying mathematical models. This unifies the interface of all these players with the grid and facilitates the reduction of large-scale power systems into small-scale models and the analysis of power systems. All the distributed players (agents) communicate with each other through the dynamics of power systems, instead of an extra communication network, to realize the same goal with independent individual actions. Because the low-level control does no longer require the support of an extra communication network, this paradigm is distinct from the current paradigm of smart grids and hence sets the architecture for the next-generation smart grids. It is able to considerably enhance the ***operability, stability, scalability, reliability and security*** of next-generation smart grids.

Two technical routes to implement the architecture will be presented. One is based on the synchronverter technology [1, 2, 3] that takes into account the internal dynamics of synchronous machines and the other is based on the robust droop control strategy [4] that mimics the external function of synchronous machines. Both technical routes embed the synchronisation function into the controller of the power electronic converters and hence the dedicated synchronization unit, e.g. PLL, that is deemed to be a must-have component for grid-tied power electronic converters can be removed [2].

## Target Audience

More and more control engineers are, and will be, moving into this area. At the recent IFAC World Congress held in Cape Town, South Africa, four out of the top six key words are related to power systems and smart grids. This workshop is timely and will attract researchers to explore the challenging problems in this area and fully appreciate the beauty of the integration of control, power electronics and power systems. Most of the artful control strategies to be presented at the workshop will be demonstrated with experimental results and, hence, the workshop will also attract many practitioners in this area to see how advanced control strategies could improve system performance. The workshop also provides an excellent opportunity for PhD students and post-doctoral fellows who work in the area to get familiar with the latest developments.

This workshop is an extended version of the Distinguished Lecture of the IEEE Power Electronics Society on the same topic[1]. A preliminary version of this workshop was delivered as a tutorial at the 2014 ACC in Portland, which was very popular (attracting over 40 people) and will be delivered at the 2014 IEEE IECON in Dallas in Oct. 2014. It is also the continuation of a very popular workshop/tutorial on the control of power inverters for the smart grid delivered at the 2012 ACC in Montreal, 2013 ACC in Washington DC, 2013 IECON in Montreal (attracting ~ 100 people), 2013 IEEE CDC in Hawaii, 2014 IFAC World Congress in Cape Town, 2014 IEEE PEDG in Galway etc.

It is expected that this will be a very popular workshop, with the number of registrants exceeding 15.

## The Instructor

Qing-Chang Zhong holds the McGraw Endowed Chair Professor in Energy and Power Engineering and Management at Illinois Institute of Technology and is a Specialist in smart grid integration recognised by the State Grid Corporation of China (SGCC). He previously held the Chair Professor in Control and Systems Engineering at University of Sheffield and the Chair Professor in Control Engineering at Loughborough University. He is a Distinguished Lecturer of IEEE Power Electronics Society and the UK Representative to European Control Association. He also serves on the Scientific Advisory Board of US NSF FREEDM Systems Center at North Carolina State University and the Rolls-Royce UTP Board in Power Electronics Systems. He obtained a PhD degree in 2000 from Shanghai Jiao-Tong University and another PhD degree in 2004 from Imperial College London (awarded the Best Doctoral Thesis Prize). He (co-)authored three research monographs, including *Robust Control of Time-delay Systems* (Springer, 2006) [5] and a No 7 Amazon Best Seller *Control of Power Inverters in Renewable Energy and Smart Grid Integration* (Wiley-IEEE Press, 2013) [6]. He proposed the architecture for next-generation smart grids, which is now widely reported on Smartgrid.IEEE.org, Spectrum.IEEE.org, SmartGridNews.com and the US Science News Radio Network. He is an Associate Editor for *IEEE Trans. on Automatic Control*, *IEEE Trans on Control Systems Technology*, *IEEE Trans. on Power Electronics*, *IEEE Trans. on Industrial Electronics*, *IEEE Journal of Emerging and Selected Topics in Power Electronics*, *IEEE Access* and *European Journal of Control*. His research focuses on power electronics, advanced control theory and the integration of both, together with applications in renewable energy, microgrids, smart grid integration etc. He is a Fellow of IET and was a Senior Research Fellow of Royal Academy of Engineering.

Dr Zhong has been working in control theory and applications for more than 25 years. He has made significant contributions to the robust control of time-delay systems and has entered into the area of investigating time-delay systems using the theory of general infinite-dimensional systems. He established links between some fundamental concepts, e.g. sampling-hold and numerical integration, $J$-spectral factorisation and similarity transformation, and algebraic Riccati equations and block diagrams. He proposed the UDE(uncertainty and disturbance estimator)-based robust control strategy for uncertain systems and extended it to time-delay systems, nonlinear systems etc.

He has also established himself in the area of power engineering, with 15 years of working experiences. Together with his collaborator, he proposed and implemented a concept to operate inverters to mimic synchronous generators. Such inverters are called synchronverters [1] and they have the internal dynamics and external functions of synchronous generators. This has considerably facilitated the grid connection of renewable energy and electrical vehicles etc. Another significant contribution is that he has proposed a robust droop controller [4] so that parallel-operated inverters can share both real power and reactive power accurately even if there are numerical errors, noises, disturbances, parameter drifts and component mismatches etc. These forms the foundation of two technical routes for next-generation smart grids to achieve autonomous and scalable operation.

[1] http://www.ieee-pels.org/chapters/distinguished-lecturers.

## Tentative Schedule

- Architecture and Technical Route I (1.5h)
  - Power systems challenges
  - Synchronverters: Inverters that mimic synchronous generators [1]
  - Self-synchronised synchronverters [2]: No more PLLs
  - Self-synchronised PWM rectifiers [7]
  - Architecture for next-generation smart grids
- ***Break (0.5h)***
- Power Quality Control (0.5h)
  - Power quality issues
  - Degradation mechanisms of voltage quality
  - Output impedance control [8]
  - Bypassing harmonic currents [9]
- Technical Route II (1h)
  - Limitations of conventional droop controller
  - Robust droop controller [4]
  - Universal droop controller [10]
  - Harmonic droop controller [11]
  - Droop control is intrinsically an EPLL (enhanced phase-locked loop) [12]
- Summary and Discussions (0.5h)

## References


[1] Q.-C. Zhong and G. Weiss, "Synchronverters: Inverters that mimic synchronous generators," *IEEE Trans. Ind. Electron.*, vol. 58, no. 4, pp. 1259–1267, Apr. 2011.

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[12] Q.-C. Zhong and D. Boroyevich, "A droop controller is intrinsically a phase-locked loop," in *Proc. of the 39th Annual Conference of the IEEE Industrial Electronics Society, IECON 2013*, Vienna, Austria, Nov. 2013, pp. 5916–5921.