Topic B

Battery Energy Storage with an Inverter that Mimics Synchronous Generators

Vision

- To develop a grid-connected bi-directional battery energy storage system with an inverter that mimics the functions of synchronous generators
- To reduce the overall cost and volume of energy storage systems
- To offer students a challenging opportunity to integrate their knowledge and skills in power conversion circuit theory, control, battery energy management and power systems

Goals

Design and build a battery energy storage system with an inverter that will:

- Have the basic functions of charging, discharging and protection for the battery;
- Meet the desired power quality to the grid/load;
- Improve power density;
- Realize power conversion between the battery and the gird/load with high efficiency;
- Mimic the function of synchronous generators to autonomously take part in the regulation of system frequency and voltage via controlling the real power and reactive power delivered;
- Achieve seamless transfer between grid-connected and stand-alone modes;
- Reduce manufacturing cost.

Background

Renewable generation is a growing component of electricity grids around the world due to its contributions to energy system decarbonization and long term energy security. Most renewable energy sources are location-dependent and experience intermittency, a combination of non-controllable variability and partial unpredictability. These cause a lot of challenges for generation owners and grid operators in the integration of wind and solar generation. One important solution is to adopt distributed energy storage systems. This could postpone the need of network expansion and can be optimized for different kinds of grid services. Energy storage systems could enhance the reliability of power systems and the security of supply and increase the level of the penetration of renewable energy sources.

Grid-connected storage systems can be installed at different voltage levels, depending on the location and the application scenario. The charging/discharging process of energy storage systems introduces different dynamics into the grid, which may lead to heavy burden to the grid and threaten the system stability. How to integrate energy storage systems into the grid so that they can behave similarly as conventional power plants is very important.

The main objective of Topic B is to develop a grid-connected energy storage system with an inverter that can mimic the functions of synchronous generators. It should be able to autonomously deliver the right amount of real power and reactive power according to the grid frequency and voltage or to regulate the frequency and voltage via changing the real power and reactive power delivered. At the same time, the harmonic components of the generated voltage should be maintained low. Moreover, such inverters should also achieve seamless transition between grid-connected mode and stand-alone mode to facilitate the applications in renewable energy and microgrids.

In order to connect an inverter to the power grid, it often needs a dedicated synchronization unit, e.g., a phase-locked loop (PLL). However, because PLLs are inherently nonlinear and so are the inverter controller and the power system, it is extremely difficult and time-consuming to tune the PLL parameters to achieve satisfactory performance. As a result, how to achieve synchronization quickly and accurately is very challenging. The teams are encouraged to get rid of the dedicated synchronization unit and implement the function of synchronization by the controller itself.

Conventional technical challenges to build a normal inverter should also be fully considered, which include power density, efficiency, electromagnetic compatibility and electromagnetic interference (EMC/EMI), reliability, thermal management, safety and cost etc.

Requirements

The energy storage system will be judged against a set of objectives, requirements and characteristics. The basic functions are listed as follows:

- Having the basic functions of charging, discharging and protection for the battery;

- Meeting the desired power quality to the grid/load;
- Mimicking the function of synchronous generators to autonomously take part in the regulation of system frequency and voltage via controlling the real power and reactive power delivered;
- Achieving seamless transfer between grid-connected and stand-alone modes;
- Encouraging performance beyond requirements and the specifications, especially for the efficiency, prototype dimension, design flexibility and performance;

Specifications

Design Item	*Minimum* Target Requirement
1. Dimensions	Volume less than 1 Litre
2. Weight	Less than 1 kg
3. Manufacturing cost	Less than US$0.5/W
4. Overall energy efficiency	Higher than 95%
5. Input (battery) voltage	48V DC (nominal)
6. Power supplies	Four 12V 40Ah lead-acid batteries will be provided at the competition test site as the only power source to the energy storage system. No auxiliary power supplies will be provided.
7. Output power rating	500 VA continuous
8. Output voltage	AC 230 V (rms) nominal (single phase)
9. Output frequency	50 Hz nominal
10. Frequency regulation	The change of 100% real power corresponds to the change of 1% grid frequency.
11. Voltage regulation	The output voltage should be regulated within ±5% of the nominal voltage, corresponding to ±100% reactive power delivered.
12. Harmonics of the output voltage	Total harmonic distortion (THD) of the output voltage should be less than 5% when supplying a standard nonlinear test load (details to be provided) and the THD of the grid current should be less than 5% at the rated power when connected to

	the grid.
13. User interface	A LED is required to indicate whether the energy storage system is ready for connection to the grid and a switch or button should be provided for grid connection/disconnection.
14. Operation mode	The energy storage system is intended for use as a grid-connected system, which can achieve seamless transition between grid-connected mode (charging/discharging) and stand-alone mode (discharging).
15. Synchronization	Removal of a dedicated synchronisation unit, e.g. PLL, is not required but highly encouraged.
16. EMI	The system is expected to meet the EMI requirement specified by EN55022 (CISPR22) Class B. It is encouraged to include EMI test results in the final report.
17. Protection	The system should shut down if the output current exceeds 5A (instantaneous value). No damage caused by output short circuit and open circuit.
18. Safety	No live electrical elements are to be exposed when the unit is fully configured. The system is intended for safe, routine use by non-technical customers. It is recommended to follow industry safety standards such as UL 1741-2000.
19. Storage temperature range	-20 to 85 °C
20. Operating temperature	-20 to 50 °C The system will be tested at room temperature.
21. Cooling	Natural convection is encouraged.
22. Acoustic noise	No louder than conventional domestic refrigerator. Less than 50 dBA, measured 1.5 m from the unit.
23. Galvanic isolation	Not required but encouraged. A line frequency transformer will be provided to isolate the inverter from the grid during tests.

24. Technical report	It should include the description of the basic principles, design of the system, simulation results, experimental results and cost study for mass production of 1000 units, taking price information of components from RS Components Ltd (http://uk.rs-online.com/).

Final Competition Prototype Testing

The detailed test protocol will be presented to the teams prior to the competition. The test will be carried out at University of Sheffield, UK in six steps: 1) operation in the standalone mode with a local load; 2) synchronization with the grid; 3) operation in the grid-connected mode; 4) Transition between grid-connected and stand-alone modes; 5) battery charge, discharge and protection test; 6) Conversion efficiency test.

Team Composition

For each team, the minimum undergraduate student number is four to qualify for the competition. No graduate students are allowed in the competition. However, up to two graduate students could participate in each team as advisors.

Financial Support

Each team will receive travel support of $1000 for distance less than 5000km and $2000 for distance of 5000km or above. Moreover, each team will receive components from RS Components (worth up to GBP250, ordered online at http://uk.rs-online.com/).

References

[1] D. Pavlov, Lead-Acid Batteries: Science and Technology, *Elsevier Science*, Jun 2011.
[2] C. D. Rahn and C.-Y. Wang, Battery systems engineering. *John Wiley & Sons*, 2013.
[3] Q.-C. Zhong and T. Hornik, Control of power inverters in renewable energy and smart grid integration. *Wiley-IEEE Press*, 2013.
[4] Q.-C. Zhong, P.-L. Nguyen, Z. Ma, and W. Sheng, "Self-synchronised synchronverters: Inverters without a dedicated synchronisation unit," *IEEE Trans. Power Electron.*, vol. 29, no. 2, pp. 617-630, Feb. 2014.