AES Battery Backed Inverter Grid Frequency and Voltage Response

Introduction

AES has developed an intelligent and modular energy storage system that includes bidirectional inverters as part of the power controls system. These are designed to be used used in a variety of power system scenarios.

The AES energy storage product meets both European and US requirements for frequency response and Low Voltage Ride Through (LVRT). Furthermore, as discussed in this paper, inverter based systems provide some added advantages for grid stability relative to traditional sources of thermal generation.

Speed of Response to Frequency Excursions

A traditional synchronous turbine-generator design, whether steam driven, reciprocating engine driven, or gas-fired has mechanical inertia because of the mass of the generator rotors or drive shaft, generator, and exciter.

When generation is lost elsewhere on the grid, the grid frequency falls initially in a linear slope according to the summation of mechanical inertia of all the synchronous generators on the grid (See Figure 1.A). The falling grid frequency slows down the synchronous generator shaft rotation. This linear change in shaft rotational speed is proportional to a cubic change in power required to turn the generator shaft. The lower grid frequency angular velocity is "easier" for the turbine to produce so each synchronous generator on the grid temporarily produces more electrical power from the same mechanical power being delivered to its turbine (Figure 1.B). This additional power is not sustained and will drop quickly to a point where the mechanical power provided to each synchronous generator catches back up to the electrical power with respect to any grid load reduction due to the lower grid frequency

Individually, a synchronous generator will provide an inertial frequency response based on its own characteristics. The larger the machine, the flatter the slope will be, generally aiding in grid stability until the governor response begins.

Inertial response has the advantages of being available and immediate. The disadvantage of inertial response is that it is not controllable or tunable as needed by the power system operator.

If reserve mechanical capability is available, the synchronous generator can also begin to respond in approximately 3-10 seconds (Figure 1.C) with a governor response (more steam, more fuel, etc.) to help stabilize the grid frequency (Figure 1.D).

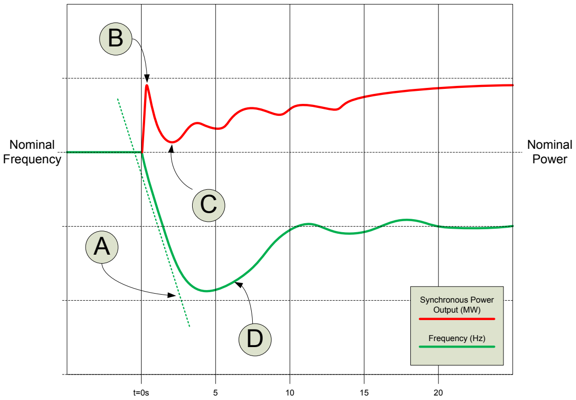

Figure 1: Synchronous Generator Disturbance Response

The synchronous generator governor response can operate faster than load shedding to stabilize grid frequency. However the governor response is relatively slow compared to the inertial response (3-10 seconds after the grid disturbance initiates), it must be tuned to work correctly, and the generator must be capable of increased output if it is to aid in the grid governor response.

Inertial and governor response in combination leave a power "gap" in the recovery period between the immediate inertial response and full governor response (if available) to contribute frequency and power correction.

Inverters, like the excitation systems of traditional generators, are constantly sensing the connected grid with a Phase Locked Loop control system and make adjustments to the output frequency accordingly. Commercial IGBT based inverters, like those used in the AES Energy Storage system, have already demonstrated grid interconnect capability, complying with European and North American frequency response requirements (e.g. BDEW: Technical Guideline "Generating plants connected to the medium voltage network", and NERC PRC-024-1 Attachment 1). While battery and inverter combinations cannot provide mechanical inertia, the inverter's programmed automatic controls can respond within 50 ms (2.5 cycles in 50 Hz nominal electrical systems; 3 cycles in 60 Hz nominal electrical systems).

This time is approximately broken down as follows:

- < 1 cycle to sense frequency
- 20-30 ms to fine tune the Phase-Locked Loop
- 15-20 ms for active power regulator settling

Figure 2 illustrates the response of an IGBT inverter system to the same event illustrated in Figure 1 (Note: inverter response overlaid on Figure 1; magnitude not to scale). When operating at nominal dispatched power level (Figure 2.E) The inverter can sense the grid frequency drop, and respond, after 50 ms, with a power increase (Figure 2.F) that is based on desired parameters and not limited by physical machine design. This "synthetic inertia" is of particular importance between dissipation of the inertial response and the generator governor response.

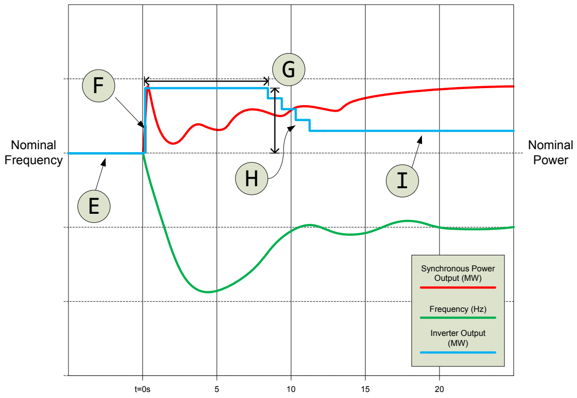

Figure 2: Inverter Grid Disturbance Response

This power increase may continue according to battery capacity (Figure 2.G) until the inverter senses a positive frequency rate of change. Once frequency recovery is sensed, the inverter output power ramps down in as many discrete steps as is practical or desired (Figure 2.H) and eventually settles at the new dispatched power (Figure 2.I).

Additionally, the inverters used by AES have an "overrate capability" (not shown) where, for a finite period of time, the inverter will provide an additional 10% of power output above its nameplate rating in response to frequency excursions in cases where its nominal output was already 100% in the moment before the excursion.

This "overrate" capability is a distinct difference from the governor response of a synchronous generator, where a sustained increase in power output may only be achieved if the machine has the mechanical capability.

System Support During a Transmission Fault

Support of the transmission system during a grid fault is another important attribute of connected generation. During the fault clearing time, typically 100 to 150 ms depending on the location of the fault and the nearest protective elements, generators on the grid are expected to ride through the fault. During the fault period, generators must be able to accommodate increased reactive power, phase imbalances, and frequency fluctuations.

Interconnected grids have established standards for LVRT capabilities for grid fault conditions. While the curve shapes vary from region to region, the typical requirement is for generators to stay connected at any voltage level for up to 150 ms, then various steps or a linear curve upward to 90% of nominal. The inverter portion of the AES Energy Storage System is configurable to meet European and North American standards for voltage ride through, such as the examples provided below.

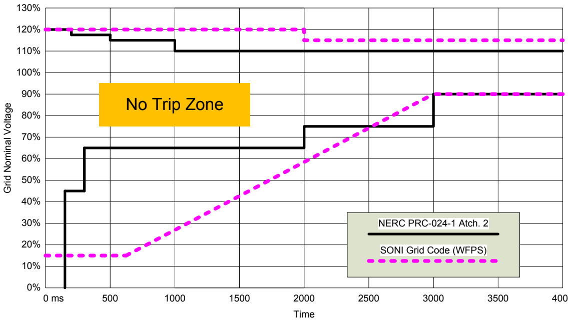

Figure 3: LVRT Grid Connection Requirements

Conclusion

Battery storage and inverters enhance the outcome of grid frequency disturbances by filling the inertia and governor gap of synchronous generators and replicate the performance of synchronous generators in LVRT scenarios. These characteristics improve overall grid stability and reliability.