Inverter energy

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The Kapaia solar-plus-storage facility, operated by the Kauai Island Utility Cooperative, includes 52 megawatt-hours of energy storage. The storage is based on Tesla"s Powerpack 2 battery system.

It"s late in the afternoon of 2 April 2023 on the island of Kauai. The sun is sinking over this beautiful and peaceful place, when, suddenly, at 4:25 pm, there"s a glitch: The largest generator on the island, a 26-megawatt oil-fired turbine, goes offline.

That April event in Kauai offers a preview of the electrical future, especially for places where utilities are now, or soon will be, relying heavily on solar photovoltaic or wind power. Similar inverters have operated for years within smaller off-grid installations. However, using them in a multimegawatt power grid, such as Kauai"s, is a relatively new idea. And it"s catching on fast: At the time of this writing, at least eight major grid-forming projects are either under construction or in operation in Australia, along with others in Asia, Europe, North America, and the Middle East.

Reaching net-zero-carbon emissions by 2050, as many international organizations now insist is necessary to stave off dire climate consequences, will require a rapid and massive shift in electricity-generating infrastructures. The International Energy Agency has calculated that to have any hope of achieving this goal would require the addition, every year, of 630 gigawatts of solar photovoltaics and 390 GW of wind starting no later than 2030--figures that are around four times as great as than any annual tally so far.

To understand the promise of grid-forming inverters, you must first grasp how our present electrical grid functions, and why it"s inadequate for a future dominated by renewable resources such as solar and wind power.

This characteristic gives rise to a property called system inertia. It arises naturally from those large generators running in synchrony with one another. Over many years, engineers used the inertia characteristics of the grid to determine how fast a power grid will change its frequency when a failure occurs, and then developed mitigation procedures based on that information.

If one or more big generators disconnect from the grid, the sudden imbalance of load to generation creates torque that extracts rotational energy from the remaining synchronous machines, slowing them down and thereby reducing the grid frequency--the frequency is electromechanically linked to the rotational speed of the generators feeding the grid. Fortunately, the kinetic energy stored in all that rotating mass slows this frequency drop and typically allows the remaining generators enough time to ramp up their power output to meet the additional load.

Electricity grids are designed so that even if the network loses its largest generator, running at full output, the other generators can pick up the additional load and the frequency nadir never falls below a specific threshold. In the United States, where nominal grid frequency is 60 hertz, the threshold is generally between 59.3 and 59.5 Hz. As long as the frequency remains above this point, local blackouts are unlikely to occur.

Wind turbines, photovoltaics, and battery-storage systems differ from conventional generators because they all produce direct current (DC) electricity--they don''t have a heartbeat like alternating current does. With the exception of wind turbines, these are not rotating machines. And most modern wind turbines aren''t synchronously rotating machines from a grid standpoint--the frequency of their AC output depends on the wind speed. So that variable-frequency AC is rectified to DC before being converted to an AC waveform that matches the grid''s.

Grid-following inverters operate only if they can "see" an existing voltage and frequency on the grid that they can synchronize to. They rely on controls that sense the frequency of the voltage waveform and lock onto that signal, usually by means of a technology called a phase-locked loop. So if the grid goes down, these inverters will stop injecting power because there is no voltage to follow. A key point here is that grid-following inverters do not deliver any inertia.

Grid-following inverters work fine when inverter-based power sources are relatively scarce. But as the levels of inverter-based resources rise above 60 to 70 percent, things start to get challenging. That''s why system operators around the world are beginning to put the brakes on renewable deployment and curtailing the operation of existing renewable plants. For example, the Electric Reliability Council of Texas (ERCOT) regularly curtails the use of renewables in that state because of stability issues arising from too many grid-following inverters.

It doesn''t have to be this way. When the level of inverter-based power sources on a grid is high, the inverters themselves could support grid-frequency stability. And when the level is very high, they could form the voltage and frequency of the grid. In other words, they could collectively set the pulse, rather than follow it. That''s what grid-forming inverters do.