POWER Engineering

High Penetrations of Renewable Energy for Island Grids

Integrating renewable energy sources into islands - geographic or otherwise - can be troublesome. Achieving high penetration is possible...provided integration issues receive careful attention.

By Peter Lilienthal, PhD., Green Island Power

Island grids represent an overlooked opportunity for renewable power. In addition to geographical islands there are also many electrical islands, such as remote locations throughout the world, where interconnections with neighboring grids are not a practical option. Due to transportation issues and the lack of economies of scale, these grids typically rely on liquid fuel derived from petroleum.

No worries, mon. Integrating renewable resources into island grids–geographic or otherwise–can be achieved with proper planning. Larger conventional utilities may learn a thing or two, as well.

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Thanks to policy incentives in a growing number of jurisdictions, wind and photovoltaics have become the two fastest growing energy sources in the world. They are now dominated by global corporations with the resources to support their installations with the reliability demanded by the electric utility industry. To date, most of this growth has been targeted at continent-scale electric grids, where they represent a tiny fraction of the installed capacity. At current penetration levels, continent-scale electric systems can easily absorb the variable output of the wind and solar resource. Output variability becomes a much more important issue at the higher penetration rates that are easily reached on smaller grids. However, the overriding economic and security benefits of displacing petroleum can more than offset the additional integration costs.

Relying on petroleum for electric generation raises three substantial and increasing concerns. First, petroleum is the most costly and risky fossil fuel. The prospect of near term decline in global petroleum production is a very controversial issue. However, electric systems are planned using a horizon of decades over which even the most optimistic projections of oil supply suggest that global production will have difficulty meeting increasing demand.

Second, relative to more diversified utilities, island utilities would face a severe and immediate crisis in the event of a geopolitical incident, even one that disrupted oil supplies for only a few weeks.

Third, islands and certain remote communities such as those in the Arctic are literally on the front line of climate change. Although they are not the predominant cause of the problem, they are at substantially higher risk than their mainland counterparts. Leadership actions they take to reduce carbon emissions will amplify their voice in the climate change debate. In addition, many islands are unusually dependent on the tourism market, which is, in turn, highly dependent on energy-intensive aviation and is showing a rapidly increasing sensitivity to environmental issues.

Project development on islands is more challenging for several reasons. Logistic costs are greater and it is harder for island utilities to take advantage of economies of scale. This is more of an issue for wind power than for photovoltaics. These costs are relatively easy to analyze. The variability of the output of wind and solar represents a more complex analytical challenge. Although variability in output does not create technical challenges at current levels of renewable penetration on continent-scale grids, small island systems can easily reach renewable penetration levels at which utilities need to take special provisions to maintain power quality and system stability.

This article focuses on the issues that arise as island systems install renewable power systems at increasing penetration levels. Mainland utilities should be interested to learn how these issues evolve on smaller systems in anticipation of scaling-up their methods for larger systems in the future.

Defining Renewable Penetration

Four separate metrics define renewable penetration; each can lead to very different numbers. The two simplest metrics are the ratios of the renewable power systems' aggregate capacity either to the peak load or to the system's total installed capacity. The latter ratio gives a smaller value. This is because utilities maintain reserve capacity in excess of their peak load. Small island utilities without external interconnections maintain even larger reserve capacity levels than mainland utilities.

TABLE 1 PENETRATION BY VARIOUS METRICS	WIND	SOLAR
Peak Instantaneous Penetration	25%	~15%
Penetration Based on Peak Load	10%	10%
Penetration Based on System Capacity	6.67%	6.67%
Penetration Based on Energy	5%	3%

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Instantaneous renewable penetration measures the ratio of renewable power to the system load at any given instant. It varies from moment to moment as the renewable resource varies. The peak instantaneous penetration is the highest level that the instantaneous penetration ever reaches, typically in the middle of a windy night. This metric can have a value over twice as great as the previous metrics for the same system. This is also true for solar energy systems, although to a somewhat lesser degree. The peak instantaneous penetration ratio is the relevant measure for much of the integration analysis that looks at the effect renewable power has on power quality and system stability of the overall electric utility system.

The ratio of the renewable power system's energy output to the total energy production of the electric system results in the smallest penetration value for a particular system. This metric can be useful as a rough proxy for a renewable project's effect on carbon emissions or fuel consumption. The actual impact will be somewhat less, depending on the size of the losses associated with the various integration measures discussed below.

To illustrate the differences between these four metrics, consider a system with 100 MW peak load and 10 MW of renewable power, as measured by the nameplate rating. If the minimum load for the system is 40 MW, the peak instantaneous penetration would be 25 percent, assuming that the 10 MW was a wind farm that occasionally produced at peak power in the middle of the night. Of course, a 10 MW solar energy system would have a lower peak instantaneous penetration because it does not produce power during low load periods at night. If the system had a reserve capacity of 50 percent, the installed capacity would be 150 MW. The penetration by that metric would be 6.67 percent. Finally, if the wind farm had a capacity factor of 30 percent and the electric system had a load factor of 60 percent the penetration in energy terms would be 5 percent (3MW/60MW). A 10 MW solar project with a 20 percent capacity factor would have a penetration in energy terms of 3 percent.

Time-scales of Output Variations

Milliseconds: At this reference point, transients and harmonics can reduce a system's power quality. Although many island electric systems do not have the latest electronic controls, upgrading those systems will also provide many other system benefits.

Seconds: Variations in output that occur over a time frame measured in seconds can be accommodated by the spinning reserve provided by other dispatchable generators as the renewable power backs off the power delivered from them. This requires that the generators operate at less than their maximum capacity, which increases the operating cost per kilowatt-hour. Therefore, the cost savings is less than proportional to the output reduction. The ability to provide spinning reserve is limited by a generator's minimum load constraint and its ramp rate, which is the rate at which a generator can change its output. A wind farm with multiple modestly-sized turbines will create smaller ramp rates than a single large turbine of comparable size. Generators differ greatly with respect both to their ramp rate and their ability to run with reasonable efficiency at partial load.

Minutes: A substantial amount of fuel is required to keep a generator spinning and synchronized, a function that is completely independent of the electric output. Furthermore, maintenance costs are a function of operating hours regardless of generator output. Much greater savings in fuel and maintenance costs can be achieved by turning off a generator than by merely running it at a reduced load. To capture such savings the system must have sufficient spinning reserves or other methods to accommodate output variations over the time it takes to start up additional generation units. A generator's start-up time can be reduced by keeping it in a hot stand-by (or idling, but unsynchronized) mode.

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Controllable loads that can be automatically turned off for short periods of time can provide a system with much of this kind of flexibility. Many large loads, such as chillers and water pumps, can be controlled if their specific operating constraints are carefully considered. The most flexible controllable load is an electric resistance dump load. This type of load can be switched fast enough to provide frequency control and also energy to thermal loads. The 500 kW TDX Power system in St. Paul, Alaska, operates for weeks at a time in the winter with just the wind turbines but with no diesel power or energy storage. A dump load controller provides all the power quality and frequency control required to maintain system stability. Promising new short-term storage technologies, such as flywheels and ultra-capacitors, can also provide a couple of minutes of power to cover fuel-fired generators' start-up time.

Hours: High-penetration renewable systems will generate large amounts of excess energy during high resource periods. But there always will be periods without any output. Bulk energy storage can absorb the excess energy and discharge it when needed to avoid dispatching fuel-fired generators. Lead-acid batteries are commonly used for this purpose in small systems, such as off-grid homes, remote telecommunication systems and eco-tourism resorts. Unfortunately, they have a limited cycle life and are impractical for larger systems. New, large format flow batteries that can overcome most of the limitations of lead-acid batteries are becoming available. These batteries use a variety of technologies such as vanadium redox, zinc-bromine and sodium-sulfur.

Electric systems with renewable power can be roughly categorized into low, medium and high penetration systems. At low penetrations the variations from renewable power systems are similar to the existing variations in load. This means no need exists for any change to the existing system's operation and control. The penetration level at which power control issues becomes important depends on the existing system, its controls and the quality of the renewable resource. It is certainly no more than 50 percent on a peak instantaneous basis or about 10 percent on an energy basis.

High penetration systems operate for periods without any non-renewable generation. Many examples exist of very small, high penetration systems. St. Paul, Alaska (mentioned earlier) is currently the only relatively large system of this kind. Medium penetration systems represent the huge range in between. There are many examples worldwide, including systems at Coral Bay, Australia, where instantaneous penetration levels of up to 90 percent are enabled by a flywheel.

Low penetration systems are simple to develop, but their economic benefits are limited to modest fuel savings. Without a reduction in operating hours of the existing generators, there is no savings to the non-fuel operation and maintenance costs. The fuel savings are also modest, because a generator's fuel consumption depends only partially on its output level. Renewable energy systems can be developed at higher penetration levels as long as careful attention is given to integration issues. Some of the integration measures described above are inexpensive while others are more expensive, both in terms of capital requirements and operating costs.

Careful technical and economic analysis and careful planning are required to implement many of these measures. Nevertheless, the current price for liquid fuels and their accompanying risks can justify substantial investments in these measures.

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