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THE "PRESSURE COOKER" EFFECT OF INTERMITTENT RENEWABLE GENERATION IN POWER SYSTEMS

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Key Points

- Power systems have fundamental needs: load following, flexibility and dynamic response.
- Increasing intermittent renewable generation in a power system has a “pressure cooker” effect and can involve an unaffordably high level of integration costs.
- Every power system is different but, in most systems, the practical upper limit for renewables is around 40% of total electricity generated. This may be exceeded but it is likely to require a greater level of interconnection with adjoining power systems, more energy storage, increased recourse to demand-side management and regulatory changes.
- The scale-up of intermittent renewables not only diminishes the robustness of a particular power system but can also magnify the short and long-term risk of investing in non-renewable generation assets and the power grid itself.

Fundamentals of power system operation

Reliable and competitively priced electricity is the foundation of modern society and the economy. Power systems must balance the total electricity generation with the total customer demand for electricity, otherwise the power system will collapse within seconds, resulting in blackouts with catastrophic consequences. Customers' electricity needs vary continuously over time and are mostly inflexible because of the essential role of electricity. It is critical that the combined generating system can adjust the amount of electricity produced to match total customer needs, which can vary by a factor of three over time.

Breakdowns of large generating units often occur unexpectedly and, to avoid the instantaneous interruption of customers' electricity supplies, the sudden reduction in electricity generation must be immediately replaced by other generators. Power systems mostly operate extra generators at part load that can immediately respond to these unpredictable events.

Need for ramp-up, load following and dynamic response in the overall system

Power systems depend on there being sufficient generators to continuously adjust their electricity generation to follow the varying electricity needs over time; with the flexibility to ramp their output up and down. There is also an essential need for generators to operate at part load so they can immediately replace the reduction in power generation due to unexpected generator breakdowns, or in the case of renewables, sudden reductions in wind or solar energy resources. Intermittent renewable energy sources such as wind power and solar PV cannot perform these additional roles that are essential for a reliable, secure and low-cost electricity supply.

Achieving system reliability through energy storage in conventional generators

These essential functions have traditionally been delivered by conventional generators which store energy in various stages of their generating process so they can respond instantaneously, or within seconds, minutes or hours. Energy stored in dams, coal stockpiles or gas pipelines can be fed into the power plants in minutes to hours' time-frames, enabling generators to follow the variations in total customer load, or a reduction in wind or solar intensity at a renewable energy power station. High-pressure steam stored in boilers, and high pressure water in penstocks, can be regulated in seconds by quickly adjusting valves, enabling shorter-term response. Rotating kinetic energy in heavy turbines and generators is immediately available and is automatically converted into electricity the instant the power system starts to slow down following an unexpected generator breakdown anywhere in the power system. Electrical and magnetic energy from electrical generators is instantaneously released following a fault on the network, playing a critical role, along with rotating inertia, in power system stability and high speed power system protection. Both wind-power and solar PV are technically incapable of storing, controlling and releasing energy in any of these ways, and simply convert the available wind or sunshine into electricity depending on the prevailing weather conditions. It is technically possible to interrupt customer electricity supplies or to release energy stored in batteries to partially meet some of these roles, however these options have limited utility compared with conventional methods.

Research and demonstration of energy storage systems needs therefore to be accelerated. As technology currently stands, electricity cannot be economically stored at scale except as potential energy by large hydro-electric pumped storage projects.

Integration costs of intermittent renewable generation

Small quantities of intermittent renewables can be fed into conventional power systems, with the only cost being the additional life-cycle costs of the energy conversion process as the displacement of conventional power generation capacity is minimal and there are still sufficient conventional generators for the other essential functions. Once renewable penetrations exceed approximately 10%, the costs of renewables integration progressively increase. [Hirth] A ‘pressure cooker’ effect starts, where the strain on the remaining system causes additional costs and may require wasteful curtailment of surplus renewable generation.

The main reasons for the increasing costs are:

(a) lower utilisation of capital-intensive conventional generators increases their average cost;
(b) the more renewables, the more flexibility is needed to compensate for their intermittency;
(c) as conventional generation is displaced, the costs of load following and dynamic response ancillary services increase;
(d) curtailment of surplus renewable generation becomes increasingly necessary at times of high wind and sunshine; and
(e) there is an increased need for additional investment in interconnections, energy storage and more robust transmission and distribution networks.

Despite suffering reduced revenues, which can threaten their viability, many of the remaining generators must remain available to perform the essential functions for the power system listed above.

In summary, the impact of intermittent renewables on power system security and costs varies with the characteristics of the power system, the nature of the intermittent resources, the flexibility of the remaining generation, the extent of interconnection, the availability of energy storage and the regulatory requirements governing the market.

It has been suggested that, as a rule of thumb, the maximum practical penetration of intermittent renewables is similar to the annual capacity factor of the renewable energy resource itself. [Jenkins] However, integration costs increase rapidly and, at high penetration rates of 30-40%, can reach 50% of the levelised cost of the renewable resources. [Hirth]

Conclusions

In any power system, as the rate of penetration of intermittent renewables increases, the impact on the remaining generators increases rapidly. At times of high wind and/or solar generation, the renewables could supply nearly all of the total system demand (for penetrations exceeding 30%), leaving no room for conventional generation unless renewable energy is spilled, exported to neighbouring power systems or stored. Yet, some level of conventional generation must be continuously operated for the other essential functions and its ability to turn down will depend on its flexibility. Renewable generation by its very nature can quickly disappear, placing huge ramping requirements on the remaining conventional generation, particularly at times of total customer peak load.

It may be concluded that, in most power systems, the practical limit for intermittent power generation is around 40% of total electricity generated. Every system is different but, when intermittent power generation exceeds this level, system security requirements almost invariably demand increased operational flexibility from the remaining conventional generators, causing additional costs for them. As well, the costs of back-up from additional interconnection with other systems, energy storage systems and network upgrade costs might be considered unaffordable.

Finally, it might be noted that there can be a flow-on effect for investments in all long-lived energy assets within power systems. The scale-up of intermittent renewables not only diminishes the robustness of a particular power system but can magnify the short and long-term risk of investing in non-renewable generation assets and the power grid itself. This is because the total available revenue must be shared between all asset owners and because all asset owners, as well as consumers, will suffer if the power system collapses.

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Professor Simon Bartlett AM, is Australian Chair in Electricity Transmission at the University of Queensland. He has 40 years' industry experience in power generation and transmission in Australia, Europe and North America, including as Chief Operating Officer of Powerlink Queensland, a Director of ElectraNet South Australia, a member of the AEMC Reliability Panel and the AEMO NEM Operating Committee. He was the Australian Professional Engineer for 2008 and awarded a Member of the Order of Australia in 2012 for services to Australia's power industry.