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Key challenges to expanding renewable energy

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HIGHLIGHTS

- Integration of intermittent renewables with existing power grids.
- Renewable ramping and over production issues.
- Renewable caused system costs.
- Energy poverty circumstances and consequences.

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ABSTRACT

The key advantage of renewables is that they are free of direct pollution and carbon emissions. Given concern over global warming caused by carbon emissions, there are substantial policy efforts to increase renewable penetrations. The purpose of this paper is to outline and evaluate the challenges presented by increasing penetrations of renewable electricity generation. These generation sources primarily include solar and wind which are growing rapidly and are new enough to the grid that the impact of high penetrations is not fully understood. The intrinsic nature of solar and wind power is very likely to present greater system challenges than "conventional" sources. Within limits, those challenges can be overcome, but at a cost. Later sections of the paper will draw on a variety of sources to identify a range of such costs, at least as they are foreseen by researchers helping prepare ambitious plans for grids to obtain high shares (30–50%) of their megawatt hours from primarily solar and wind generation. Energy poverty issues are outlined and related to renewable costs issues.

1. Introduction

The purpose of this section is to outline and evaluate the challenges presented by increasing penetrations of renewable electricity generation. These generation sources primarily include solar and wind, which are growing rapidly and are new enough to the grid that the impact of high penetrations is not fully understood. The challenges associated with solar and wind will be examined qualitatively, and to the extent possible, in terms of the costs that might impact the system over and above the costs associated with deploying and operating electrical generation equipment. Hydropower is generally well integrated into existing operations, but has much less potential for growth. Tidal, wave, run-of-river hydro and geothermal sources are currently much more limited in both quantity and growth (EIA, 2015). Energy efficiency is sometimes considered an energy "source," but is not usually combined with renewables; nonetheless, it is discussed below because the potential for more efficiency would to some extent obviate the need for renewables (or for more nuclear). Special challenges posed in developing countries are presented as well.

The intrinsic nature of solar and wind power is very likely to present greater grid system challenges than "conventional" sources. See "Power System Fundamentals," Section 2 below for explication of the unique challenges presented by renewables. Within limits, those challenges can be overcome, but at a cost. Later sections of the paper will draw on a variety of sources to identify a range of such costs, at least as they are foreseen by researchers helping prepare ambitious plans for grids to obtain high shares (30–50%) of their megawatt hours from primarily solar and wind generation.

Since a primary policy rationale to including renewables in the system is reduction of carbon emissions, prospects for high (30–50%) penetrations of renewable power will be a key focus, even though they may require significant technology improvements such as renewable cost reduction and widely available low cost energy storage. There is hope that areas unusually endowed with renewable resources can achieve these reductions given current trends (Brinkman et al., 2016).

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These issues also raise the question of what role is appropriate for nuclear power (a non-CO2 power source whose capacity can be expanded) in helping integrate renewables into grid operation.

2. Some power system fundamentals

Modern electric power grids are really a technological marvel, even if routine. Electric power, delivered as needed on demand is a priceless resource for industry, commerce and everyday household life. In addition to the simple availability of easy-to-use energy, its value is much increased by the reliability and the "quality" of supply. Power must be supplied to users within voltage tolerance limits, and rigidly maintained frequency (60 Hz in the US).

Power systems are typically very large networks drawing on many generating sources of power and dispatching that power to many loads. This involves large-scale "transmission" of power to nodes and "distribution" of power to users who range from very large industrial complexes to ordinary homeowners and everyone in-between. These systems are extensively thought-out and planned.

The degree of difficulty for maintaining such a system is substantially exacerbated by the fact that power flows are virtually instantaneous and that power storage opportunities are very limited. Thus, any upsets in the system (large power plants or industrial users tripping offline, transmission line breakdowns, etc.) must be offset on the order of seconds. Further, like any mechanical equipment, power plants must be periodically shut down for planned maintenance and reserve power must be available during these periods.

The two most basic measures of electricity are megawatts (MW), which connote the flow rate of power or capacity of generation, and megawatt hours (MWh), which indicate energy usage.

Costs associated with power sources occur at three levels. First, there are the costs of the generation facility itself. These are capital costs for land, equipment and construction, and ongoing operating and maintenance costs. The given facilities must be connected to the grid, and the grid must be capable of carrying sufficient power to desired nodes which gives rise to additional capital and operating costs. Finally, all power systems have substantial infrastructure whose primary purpose is to maintain grid stability and reliability. This need is acute because, at least for now, the possibility of storing electricity is cost-effective only in limited cases.

Solar and wind power are fundamentally different in character from traditional fossil fuel sources, nuclear and hydro. Such "conventional" facilities are normally described by their capacity for power production in terms of MW. That capacity is generally available on a dispatchable basis for the system operator. Fuel (coal, oil, reservoir water, uranium) is stored on site or piped in (natural gas). While breakdowns do occur, they are rare.

Solar and wind are also rated according to capacity. However, these ratings are based on specified conditions: 1 kW/square meter insolation (intensity of sunlight) and 12 m/s wind, for example. However, these conditions are not achieved at the discretion of the operator, but rather are subject to nature.

Consequently, both solar and wind energy present intermittency issues to system operators. These are time of day, seasonal and even idiosyncratic. Solar and wind produce energy from available sunshine and wind. Either of those can change very suddenly. But power demand doesn't fall, so the shortage situation must be dealt with. Wind availability may not correspond to time of day or seasonal power needs. In addition, both solar and wind at utility scale require substantial expanses of land for deployment and good insolation or wind availability. Thus, these sources may require substantial transport of power from locations not convenient to the grid. Conventional sources have similar problems, but face fewer location constraints since their fuel is more transportable or ubiquitously available.

Up to a certain level of penetration, these issues associated with intermittent renewables don't present unique challenges for grid operators. While rare, breakdowns from conventional power generation equipment certainly occur and variations in load occur frequently. Operators have developed a number of tactics for dealing with these. Spinning reserves, for example, can be brought online very quickly to offset power sags or meet load coming onto the system. Power is already transported long distances in particular circumstances.

However, these tactics come at a cost. Currently such costs are often subsumed into aggregate system operation costs. Since renewable sources tend to draw more heavily on these resources, they are in effect subsidized by grid operation. (They can be charged directly for such services, but currently, given their small portion of total supply, this is not often done.) This implicit subsidy is in addition to direct subsidies currently provided renewables (Poser et al., 2014; OECD/NEA, 2012).

As the proportion of solar and wind power to conventional power grows, the operational realities of these issues become clear. To the extent possible, some exemplary costs imposed by renewables will be evaluated. A number of European nations are planning for substantial increases in solar and/or wind shares for their power sources. The California grid currently provides excellent examples, which will be explored. Further, as current energy policy, particularly in California, dictates unprecedented shares of renewable power for future years within utility planning horizons, the ultimate limitations of such power are being investigated and will be examined here and in Chapter Five (OECD/NEA, 2012). See Section 6 "Low Carbon Grid Study" for a counter example of California with relatively well situated resources.

3. System costs versus facility costs

All large power plants require substantial capital investment for site locations, structures and equipment. "Conventional" power plants (coal, oil, natural gas, hydro and nuclear) turn some sort of turbine attached to generation machinery. The capital investments associated with conventional power plants are usually expressed in terms of dollars per MW. These generators produce alternating current power. That power must be conditioned and transferred to the grid. Critically, all of these spinning generators must be synchronized, i.e., spin at the same speed.

Except for hydro, conventional plants have fuel costs. All have operating costs similar to what would occur in any factory and require significant periodic maintenance.

3.1. Connection

Solar and wind power installations require high capital expenditure per MW of rated power which as mentioned above does not have the same connotation as conventional plants. Solar photovoltaic (PV) power requires specific equipment to "condition" produced power to convert direct current to AC, increase voltage and maintain grid synchronization. Additional steps are required to ensure solar PV installations meet grid requirements for upset conditions. On the demand side, grid operators prefer that wind farms install additional equipment to support grid interaction, providing, for example, the ability to curtail wind output.

3.2. Transmission

Large scale power facilities transmit produced power to the grid for ultimate delivery to system nodes and then distribution

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