Metric #14: Capacity Factors

M.14.1.0 Introduction and Background

A *capacity factor* is the fraction of energy that is generated by or delivered through a piece of power system equipment during an interval, compared to the amount of energy that could have been generated or delivered had the equipment operated at its design or nameplate capacity. In principle, a capacity factor is readily understood and measured for many types of transmission and distribution equipment, including power generators, transformers, and transmission and distribution lines. Intuitively understood, a capacity factor of zero means that equipment was unused during an interval; a capacity factor of 100% means that the equipment was, on average, used at its rated capacity throughout an interval; and a capacity factor over 100% means that the equipment was overloaded, often an unsustainable or even dangerous condition. A capacity factor may therefore be convenient and useful as an indicator and should serve as a metric of the health and evolution of the smart grid.

Consider some of the traditional approaches to managing capacity factor: if a transmission circuit becomes inadequate, a new circuit is built, or the circuit is reconductored to increase the corridor's design capacity. If electrical load grows, new centralized generating plants are constructed. If you install an on-demand electric water heater in your home, you and your utility must consider whether your home's distribution transformer might require replacement. Indeed, these approaches are effective at managing capacity factors and operational margins.

One thesis of a smart grid is that the power system should be able to defer or eliminate the installation of infrastructure, thus achieving more energy production and transmission using existing equipment. Intelligent controllers might permit us to operate safely close to operational boundaries of installed grid infrastructure. The smart grid should recognize and mitigate stressful conditions on the grid, reacting dynamically to conditions that could overload the grid's infrastructure. Efficient loads can, of course, be supplied more easily than can inefficient ones. These examples are several smart-grid development opportunities that would directly affect, and could be monitored, at least in aggregate, by capacity factors.

The degree with which the nation has recently embraced renewable energy offers another good example with respect to this metric. Renewable generation resources like wind are intermittent. Inclusion of an increasing number of wind generators into a capacity-factor metric will reduce the apparent, aggregate capacity factor of the nation's electricity generators. Because renewable resources are often located far from population centers that would use their energy, growing renewable generation resources with varying output could create fluctuations in available transmission capacity factors as the variation in transmission flows increases either upward or downward (due to fluctuations in generation schedules). Successful implementation of distributed-generation resources, perhaps including renewable ones, near electric loads that they serve could, in principle, reduce the need to transfer much energy over distances. Distributed storage resources could achieve a similar effect. Again, one can see how this metric might be useful for surveying and discussing the effects of renewable resource penetration, even though the metric trends might be simultaneously influenced in both upward and downward directions by attributes of renewable resources.

Consumer trends will also affect capacity factor. Our nation's hunger for plug-load electronics and the possibility that our consumption of fossil fuels will become displaced by plug-in hybrid electric

vehicles both present new challenges—and perhaps opportunities—for the management of capacity factors within our distribution systems.

A smart grid should better use the available capacity of its infrastructure by flattening load profiles. Load profiles that have large diurnal and seasonal peaks stress grid infrastructure and are inefficient with respect to both cost and energy. Conduction losses increase with the square of conducted electrical current. Inefficient, polluting generators are dispatched to meet only the occasional, peak demand. Therefore, not only average capacity factor, but also peak capacity factor should be measured and reported. Of interest are measurements of both yearly peaks and averaged daily peaks.

M.14.2.0 Description of the Metric and Measurable Elements

This section defines specific measurements that will represent capacity factors across the power grid's generation, transmission, and distribution systems, as well as across major types of power-grid equipment, including generators, conductors, and transformers. Three measurements that pair generation with generators, transmission with conductors, and the distribution system with transformers are proposed. Each pairing invites and defines both average and peak capacity-factor measurements.

(Metric 14.a) Yearly average and peak generation capacity factor (%)—the yearly average capacity factor of the nation's entire generator population should be estimated (see Equation 14.a).

This metric requires that the total national electricity generation and the total electricity generation nameplate or design capability of the nation's generators should be accurately estimated each time this metric is to be updated. With minor modification of this calculation, one can estimate the yearly or average daily peak generation capacity factor answering, "How close did the nation come last year to exceeding its generation capacity?"

$$CF_{\text{Generation}}(\%) = \frac{\sum_{\textit{All Generators}} \sum_{\text{Year}} \text{Generated Energy (MWh)}}{8760\,(\text{hours}) * \sum_{\textit{All Generators}} \textit{Generator Power Rating}\,(MW)} * 100\,(\%) \qquad (14.a)$$

(Metric 14.b) Yearly average and average peak capacity factor for a typical mile of transmission line (%-mile per mile): capacity factor of the nation's transmission lines should be estimated, the result being weighted to account for transmission line distances (See Equations 14.b1 and 14.b2).

A minor modification of this measurement can be performed to also provide the yearly or daily average *peak* transmission capacity factor on a mile of our nation's transmission lines during the year.

$$CF_{\text{Trans. Line}}(\%) = \frac{\sum_{\text{year}} \text{Transmitted Energy (MWh)}}{8760\,(\text{hours}) * \sum \text{Line Power Rating (MW)}} * 100\,(\%) \qquad (14.b1)$$

$$CF_{\text{Per Mile Trans. Line}}(\%) = \frac{\sum_{\text{All Lines}} \text{Line Distance (miles)} * CF_{\text{Trans. Line}}(\%)}{\sum_{\text{All Lines}} \text{Line Distance (miles)}} \qquad (14.b2)$$

(Metric 14.c) Yearly average and average peak distribution transformer capacity factor (%): estimate of the average capacity factor of the nation's distribution transformers over the year (see Equation 14.c).

This calculation may be modified to further define the yearly or average daily *peak* distribution transformer capacity factor across all distribution transformers.

$$CF_{\text{Dist. Xfmr}}(\%) = \frac{\sum_{\text{All Xfmrs.}} \sum_{\text{year}} \text{Xfmr. Energy (MWh)}}{8760 \text{ (hours)} * \sum_{\text{All Xfmrs.}} \text{Xfmr. Ratings (MW)}} * 100\,(\%) \qquad (14.c)$$

M.14.3.0 Deployment Trends and Projections

Useful data for metric measurement 14.a were found concerning our nation's generation adequacy. Most informative were the data collected and forecast by NERC.[1] These list peak summer demand and summer generation capacity, peak winter demand and winter generation capacity, and yearly energy demand for each major NERC region. Published data included measurements from 1989 through 2006 and projected estimates through 2016. Table M.14.1 summarizes these data and the resulting Metric 14.a capacity factor measurements for two years: 2006, the most recent year for which measured data is provided, and 2008, the present year, for which only projected data are provided. On average, a little less than half of the nation's generation capacity is now used, but less than 20% of the nation's total generation capacity remains unused during summer peaks. Smart grid techniques may be able to increase asset utilization, thus increasing overall capacity factors.

Table M.14.1. Measured and Projected Peak Demands and Generation Capacities for Recent Years in the U.S.[2] and Calculated Capacity Factors

	2006 Measured	**2008 Projected**
Summer peak demand (MW)	789,475	801,209
Summer generation capacity (MW)	954,697	991,402
Capacity factor 14.a, peak summer (%)	82.69	80.82
Winter peak demand (MW)	640,981	663,105
Winter generation capacity (MW)	983,371	1,018,124
Capacity factor 14.a, peak winter (%)	65.18	65.13
Yearly energy consumed by load (GWhr)	3,911,914	4,089,327
Capacity factor 14.a, average (%)[(a)]	46.08	46.46

(a)The average of the NERC (2006) summer and winter capacities was used for this calculation.

Some trends can be observed in these data in Figure M.14.1, which points out the maximum and minimum capacity factors and years for each of the three data sets. According to these NERC data, the U.S. crept closer to its generation limits for at least the ten years preceding 1998-2000, but it sharply reversed that trend during the next 5 years and returned to more conservative generation capacity factors. Relatively constant generation capacity factors are predicted for the next 8 years.

[1]North American Electric Reliability Corporation (NERC). 2007. *Electricity Supply & Demand (ES&D): Frequently Requested Reports. 2007 Reports (with 2006 actuals)*. Accessed October 12, 2008 at http://www.nerc.com/page.php?cid=4|38|41.
[2] NERC 2007.

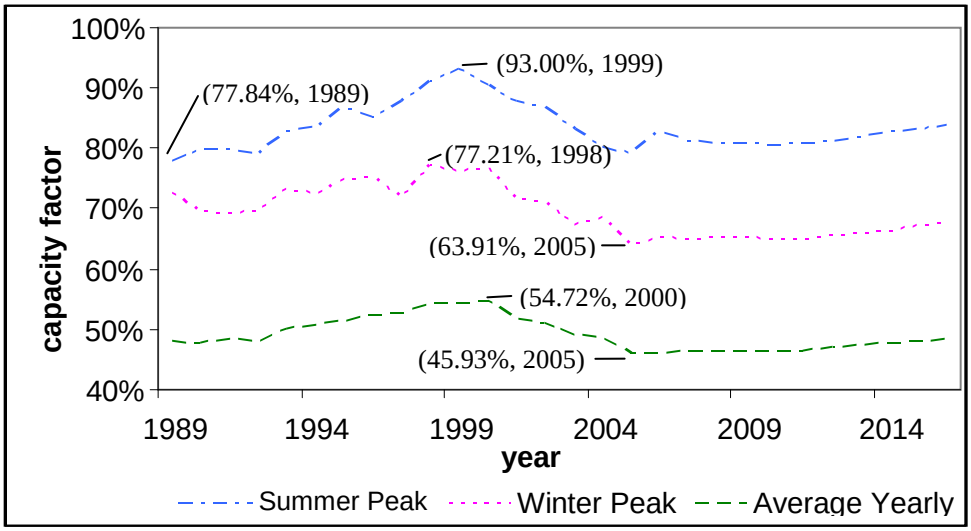

Figure M.14.1. Measured and Predicted Peak Summer, Peak Winter, and Yearly Average Generation Capacity Factors in the U.S.[3]

Data of this quality were not found for the other two recommended measurements, 14.b and 14.c, concerning capacity factors that would indicate the status of our transmission and distribution systems.

The set of APQC interviews (Annex B) conducted during this assessment listed ranges of capacity factors to collect responses into a few bins. The chosen ranges in the interview did not provide meaningful information about capacity factors from the responding utilities' distribution equipment.

M.14.3.1 Stakeholder Influences

Our nation's electrical transmission and distribution system is regulated mostly on a federal and state-by-state basis and involves the participation of a very large number of stakeholders. More specifically,

- Policy advocates: this metric should provide evidence of clear trends for policy advocates. The metric should especially help advocates verify claims that the power grid is adequate or inadequate for the anticipated growth of electricity usage. These trends could also help support smart-grid policies that would flatten load profiles or would allow operation with smaller operational margins.
- Reliability coordinators including NERC: the three measurements of this metric measure generation, transmission and distribution margins. Capacity margin information is important for reliability coordinators and system planners to monitor.
- Generation and demand wholesale electricity traders/brokers: understanding the capacity margin within a marketplace is important for rational participation by market players. Because better knowledge can provide a competitive edge, detailed information is often now protected.
- Balancing authorities: the ability to balance load and generation is affected by the availability of generation resources and may be limited by transmission constraints that are have some reflection in the capacity metric.

[3]NERC 2007.

- Transmission providers: through Equation 14.b, this metric provides a benchmark for transmission providers concerning their relative practices for loading transmission lines.
- Distribution service providers: through Equation 14.c, this metric provides distribution-service providers a benchmark concerning their practices of loading provided distribution equipment - transformers, in this case.
- Electric service retailers: this metric provides general information over time about the effects of changes in customer energy usage. Plug-in electric vehicles, for example, are a technology that threatens to drastically change the way we use our existing electric distribution system and may have ramifications on the way retailers can supply such electrical load.
- End users: end users should benefit indirectly from improved reliability that could result from our improved understanding of the adequacy and operational margins built into our grid infrastructure.

M.14.3.2 Regional Influences

NERC[4] data for regions within the U.S. show some interesting trends. The eastern regions (SPP, SERC) and Texas (ERCOT) are presently expected to achieve the lowest summer regional peak capacity factors in the nation by 2016. These regions appear to be among those that most aggressively addressed the diminished generation-capacity margins observed in 1999-2001. Region MRO in the Midwest is presently projected to progressively become an energy importer, unable to supply its own summer peak generation by 2009. Figure M.14.2 demonstrates that projected performance of regions varies much more among them than their past performance. However, as would be expected, regions appear to alter their strategies and investments to meet their own challenges and bring their performance more in line with that of their neighbors over time.

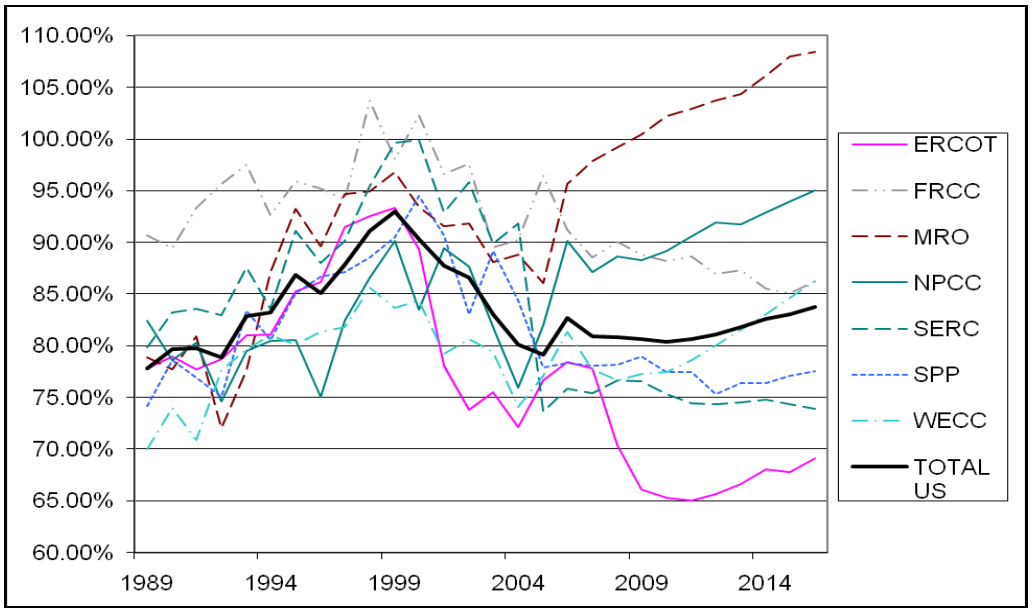

Figure M.14.2. Measured and Projected Summer Peak Capacity Factor by U.S. Region[5]

[4]NERC 2007.
[5]NERC 2007.

M.14.4.0 Challenges

Many technical, business, and policy challenges potentially hinder the use of capacity factor as a metric of smart grid evolution.

M.14.4.1 Technical Challenges

Capacity factors are not typically shared among utilities and regions. The large quantities of equipment at the generation, transmission, and distribution levels will make this metric difficult to track without accepting a statistical-sampling approach for the recommended measurements. Because changes in power-grid infrastructure occur relatively slowly, it will be challenging to obtain useful measurements with an accuracy that supports a meaningful monitoring of system trends over time using capacity-factor measurements.

M.14.4.2 Business and Financial Challenges

Because the grid spans multiple regions, industries, and functions, it is challenging to obtain the necessary information on the state of the grid. In addition, it can be hard to identify those responsible for coordinating and sharing responsibility for making enhancements. This leads to challenges in creating incentives to invest in smart-grid technology that can better manage capacity factors.

M.14.5.0 Metric Recommendations

Data were not readily found for measurements using Equations 14.b and 14.c concerning our nation's transmission and distribution infrastructure. It is recommended that samplings be performed to estimate these metric measurements.

If future interviews of electricity providers are conducted, they should develop questions that more precisely address these metric measures.