Capacity factor

The net **capacity factor** of a power plant is the ratio of its actual output over a period of time, to its potential output if it were possible for it to operate at full nameplate capacity indefinitely. To calculate the capacity factor, take the total amount of energy the plant produced during a period of time and divide by the amount of energy the plant would have produced at full capacity. Capacity factors vary greatly depending on the type of fuel that is used and the design of the plant. The capacity factor should not be confused with the availability factor, capacity credit (firm capacity) or with efficiency.

Sample calculations

Baseload power plant

A base load power plant with a capacity of 1,000 megawatts (MW) might produce 648,000 megawatt-hours (MW·h) in a 30-day month. The number of megawatt-hours that would have been produced had the plant been operating at full capacity can be determined by multiplying the plant's maximum capacity by the number of hours in the time period. 1,000 MW × 30 days × 24 hours/day is 720,000 MW·h. The capacity factor is determined by dividing the actual output with the maximum possible output. In this case, the capacity factor is 0.9 (90%).[1]

$$\frac{648,000 \text{ MW·h}}{(30 \text{ days}) \times (24 \text{ hours/day}) \times (1000 \text{ MW})} = 0.9 \approx 90\%$$

Wind farm

The Burton Wold Wind Farm consists of ten Enercon E70-E4 wind turbines @ 2 MW nameplate capacity for a total installed capacity of 20 MW.[] In 2008 the wind farm generated 43,416 MW·h of electricity. (Note 2008 was a leap year.) The capacity factor for this wind farm in 2008 was just under 25%:

$$\frac{43,416 \text{ MW·h}}{(366 \text{ days}) \times (24 \text{ hours/day}) \times (20 \text{ MW})} = 0.2471 \approx 25\%$$

As of April 2011, the Danish wind farm Horns Rev 2[2](the world's largest when it was inaugurated in September 2009[3] comprising 91 Siemens SWT-2.3-93 wind turbines each of 2.3 MW) with a nominal total capacity of 209 MW, has the best capacity factor of any offshore wind farm at 46.7% having produced over 1.5 years 1,278 GW·h.[4] The record for an onshore wind farm is held by Burradale, which reached an annual capacity factor of 57.9% for 2005.[5]

Hydroelectric dam

As of 2010, Three Gorges Dam is the largest power generating station in the world by nameplate capacity. In 2009, not yet fully complete, it had 26 main generator units @ 700 MW and two auxiliary generator units @ 50 MW for a total installed capacity of 18,300 MW. Total generation in 2009 was 79.47 TW·h, for a capacity factor of just under 50%:

$$\frac{79,470,000 \text{ MW·h}}{(365 \text{ days}) \times (24 \text{ hours/day}) \times (18,300 \text{ MW})} = 0.4957 \approx 50\%$$

Hoover Dam has a nameplate capacity of 2080 MW[] and an annual generation averaging 4.2 TW·h.[] (The annual generation has varied between a high of 10.348 TW·h in 1984, and a low of 2.648 TW·h in 1956.[]) Taking the average figure for annual generation gives a capacity factor of:

$$\frac{4,200,000 \text{ MW·h}}{(365 \text{ days}) \times (24 \text{ hours/day}) \times (2,080 \text{ MW})} = 0.23 = 23\%$$

Reasons for reduced capacity factor

There are several reasons why a plant would have a capacity factor lower than 100%. The first reason is that it was out of service or operating at reduced output for part of the time due to equipment failures or routine maintenance. This accounts for most of the unused capacity of base load power plants. Base load plants have the lowest costs per unit of electricity because they are designed for maximum efficiency and are operated continuously at high output. Geothermal plants, nuclear plants, coal plants and bioenergy plants that burn solid material are almost always operated as base load plants.

The second reason that a plant would have a capacity factor lower than 100% is that output is curtailed because the electricity is not needed or because the price of electricity is too low to make production economical. This accounts for most of the unused capacity of peaking power plants. Peaking plants may operate for only a few hours per year or up to several hours per day. Their electricity is relatively expensive. It is uneconomical, even wasteful, to make a peaking power plant as efficient as a base load plant because they do not operate enough to pay for the extra equipment cost, and perhaps not enough to offset the embodied energy of the additional components.

A third reason is a variation on the second: the operators of a hydroelectric dam may uprate its nameplate capacity by adding more generator units. Since the supply of fuel (i.e. water) remains unchanged, the uprated dam obtains a higher peak output in exchange for a lower capacity factor. Because hydro plants are highly dispatchable, they are able to act as load following power plants. Having a higher peak capacity allows a dam's operators to sell more of the annual output of electricity during the hours of highest electricity demand (and thus the highest spot price). In practical terms, uprating a dam allows it to balance a larger amount of variable renewable energy sources on the grid such as wind farms and solar power plants, and to compensate for unscheduled shutdowns of baseload power plants, or brief surges in demand for electricity.

Load following power plants

Load following power plants, also called intermediate power plants, are in between these extremes in terms of capacity factor, efficiency and cost per unit of electricity. They produce most of their electricity during the day, when prices and demand are highest. However, the demand and price of electricity is far lower during the night and intermediate plants shutdown or reduce their output to low levels overnight.

Capacity factor and renewable energy

When it comes to several renewable energy sources such as solar power, wind power and hydroelectricity, there is a fourth reason for unused capacity. The plant may be capable of producing electricity, but its "fuel" (wind, sunlight or water) may not be available. A hydroelectric plant's production may also be affected by requirements to keep the water level from getting too high or low and to provide water for fish downstream. However, solar, wind and hydroelectric plants do have high availability factors, so when they have fuel available, they are almost always able to produce electricity.[6]

When hydroelectric plants have water available, they are also useful for load following, because of their high *dispatchability*. A typical hydroelectric plant's operators can bring it from a stopped condition to full power in just a few minutes.

Wind farms are variable, due to the natural variability of the wind. For a wind farm, the capacity factor is mostly determined by the availability of wind. Transmission line capacity and electricity demand also affect the capacity factor.

Solar energy is variable because of the daily rotation of the earth, seasonal changes, and because of cloud cover. However, according to the SolarPACES programme of the International Energy Agency (IEA), solar power plants designed for solar-only generation are well matched to summer noon peak loads in areas with significant cooling demands, such as Spain or the south-western United States,[7] although in some locations solar PV does not reduce the need for generation of network upgrades given that air conditioner peak demand often occurs in the late afternoon or early evening when solar output is zero.[8][9] SolarPACES states that by using thermal energy storage systems the operating periods of solar thermal power (CSP) stations can be extended to become dispatchable (load following).[7] The IEA CSP Technology Roadmap (2010) suggests that "in the sunniest countries, CSP can be expected to become a competitive source of bulk power in peak and intermediate loads by 2020, and of base-load power by 2025 to 2030".[10] A dispatchable source is more valuable than baseload power.[11]

Geothermal has a higher capacity factor than many other power sources, and geothermal resources are available 24 hours a day, 7 days a week. While the carrier medium for geothermal electricity (water) must be properly managed, the source of geothermal energy, the Earth's heat, will be available for the foreseeable future.[12] Geothermal power can be looked at as a nuclear battery where the heat is produced via the decay of radioactive elements in the core and mantle of the earth.

Typical capacity factors

According to the US Energy Information Administration (EIA), in 2009 the capacity factors were as follows:[13]

- Natural Gas Plant–11.4%
- Oil–7.8%
- Hydroelectric–39.8%
- Other renewables (Wind/Solar/Biomass)–33.9%
- Coal–63.8%
- Nuclear–90.3%

However they do tend to vary.

- Wind farms 20-40%.[][]
- Photovoltaic solar in Massachusetts 13-15%.[14]
- Photovoltaic solar in Arizona 19%.[][]
- CSP solar in California 33%. []
- CSP solar with storage in Spain 75%. []
- Hydroelectricity, worldwide average 44%,[15] range of 10% - 99% depending on design (small plant in big river will always have enough water to operate and vice versa), water availability (with or without regulation via storage dam, where a storage dam is designed to store at least enough water to operate the plant at full capacity for around half a year to allow full regulation of the annual flow of the river).
- Nuclear power 70% (1971-2009 average of USA's plants).[]
- Nuclear power 91.2% (2010 average of US's plants).[]

United Kingdom

The following figures were collected by the Department of Energy and Climate Change on the capacity factors for various types of plants:[16][17]

Plant type	2007	2008	2009	2010	2011	2007-2011 average
Combined cycle gas turbine stations	64.7%	71.0%	64.2%	61.6%	47.8%	61.9%
Nuclear power plants	59.6%	49.4%	65.6%	59.3%	66.4%	60.1%
Coal fired power plants	46.7%	45.0%	38.5%	40.2%	40.8%	42.2%
Hydroelectric power stations	38.2%	37.4%	36.7%	25.4%	39.1%	35.4%
Wind power plants	27.7%	27.5%	27.1%	23.7%	29.8%	27.1%
Photovoltaic power stations	9.9%	9.6%	9.3%	7.3%	5.5%	8.3%

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