SOLAR POWER

An artist's impression of a 2 MW/12 MWh single PV-Battery block

The right mix of solar energy

Solar energy is a rapidly growing part of energy supply, with various technologies jockeying for primacy. What combination of photovoltaics and concentrating solar power is best for the future in sun-rich regions? *Manfred Engelhard* unpacks a new study.

Large-scale solar power installations currently come in two forms – those made up of arrays of solar photovoltaic (PV) panels, and concentrating solar power thermal plants (CSP) where steam is created to drive a conventional turbine. How will the costs of these technologies develop over time, how does energy storage fit into the picture, and what is the best mix of the two technologies for future grids? A new study, THERMVOLT, looks at how these issues will play out over the next 15 years.

The study, a collaboration between the M+W Group, the DLR Institutes for Solar Research and Technical Thermodynamics, the Lappeenranta University of Technology in Finland and Fichtner GmbH & Co, and with support from the German Federal Ministry for Economic Affairs and Energy (BMWi), looked at power generation costs and conditions at sun-rich locations in Morocco and Saudi Arabia. Among other things, the study, which extrapolates generation costs and conditions for the years 2020 and 2030, finds that PV power plants with battery-based energy storage could become cost-competitive with other large-scale solar production technologies by 2030.

CSP and PV

CSP plants use mirrors to concentrate solar irradiation, which is generally used to power a turbine and generate electricity. These plants produce surplus heat during the day, which is stored in hot molten salt tanks and released during the night to keep producing power after the sun goes down. They can also be easily paired with fossil fuel back-up generators to pick up slack if stored energy is insufficient.

CSP plants are restricted, however, to regions of the world where direct solar radiation is relatively high (and, in many places, population densities are relatively low). The specific structure of the CSP technology also restricts it to large centralised installations, typically above 100 MW electric power output.

PV power systems use the photovoltaic effect to generate electricity directly. They have no inherent energy storage capability, so there are two general mitigation strategies when sunlight is low – either the energy network makes up for the shortfall with other forms of generation, or batteries are used to store power for later use. The cost of battery storage makes it the most expensive of these power generation methods at present.

On the other hand, PV can be implemented at almost any scale and anywhere on the planet (though power production levels will differ). Using 50 blocks of 2 MW PV and battery (PV-B) modules would result in a 100 MW PV installation with the potential for 600 MWh of storage capacity, providing reserve power for six hours at full load or 12 hours at half load. The decentralised nature of PV-B generation and storage is a large advantage for this method.

Study conditions

The THERMVOLT study compared the costs of a variety of PV-based and CSP-based power plant concepts under the same boundary conditions. In the calculations the plants followed a given load profile and it was indicated which methods decreased greenhouse gas emissions at the lowest cost overall.

The study constructed computer models based on simulated 100 MW plants in Ouarzazate, Morocco and Taiba, in the Kingdom of Saudi Arabia. Both of these regions get plenty of sun – around 2,200 kWh/m^2 annual Global Horizontal Irradiation (GHI) in both locations – making both CSP and PV-B viable options. For comparison, London residents can expect an annual GHI of 990 kWh/m^2. A model for fossil fuel use was included in the simulations for situations where power draw exceeded solar production.

The models simulated power requirements on an hour-by-hour basis throughout the year for the locations in Morocco and Saudi Arabia. Both scenarios used profiles for a baseload as well as for a typical day type load curve. The latter load profile shows generally higher energy requirements in the afternoon and evening and reduced (Saudi Arabia) or no (Morocco) energy consumption during the night.

The sizes of the solar fields and

different storage capacities were optimised for each variant when computing the defined cases. The optimisation target was to find the right system component sizing which can reach the lowest levelised cost of energy (LCOE) paired with the lowest possible carbon emission level.

A model based on learning rates and expected growth rates was applied to predict cost development in each of these technologies. All of these inputs were combined to calculate the LCOE for CSP, PV-B and a combination of the two technologies. This standard measure takes initial capital and the discount rate into account, as well as the costs for operation and maintenance.

Researchers then extrapolated the situation to 2020 and 2030 using a baseline growth model, as well as models that assumed high and low growth in various renewables.

Outcomes

The results showed that a number of scenarios are possible. All considered scenarios could reach a very low level of specific system-wide carbon emissions in the future, showing that a high ratio of solar to fossil fuel power is achievable in parallel with the power cost optimum. Specifically, the calculations showed that carbon dioxide output could be reduced from current levels (about 600 g of carbon dioxide per kWh of electricity for a typical energy mix) to lower than 50 g CO_2/kWh in 2030. Increasing energy storage reduces carbon emissions by increasing the carbon-free solar power share.

Estimating the future capacity and cost of the subsystems formed the basis of the scenarios. The base case assumed that CSP capacity would rise from 5 GW worldwide in 2015 to around 80 GW in 2030. The low and high growth conditions calculated this capacity to increase to 28 and 131 GW by 2030 respectively. The CSP CAPEX cost is thus expected to reduce from today's £4,600/kW to about £2,400–2,900/kW in 2030.

Significantly higher capacity figures are expected for PV. The base case was projected to increase from 230 GW worldwide today to 1,960 GW by 2030. The low and high growth conditions here calculated a range between 730 and 3,725 GW in 2030. The PV CAPEX cost is also expected to reduce from £1,000/kW today (single axis tracking) to about £425–680/kW in 2030.

Battery energy storage cost has a good likelihood to reduce from a specific cost of £350/kWh in 2015 (battery rack level) to £125/kWh in 2030.

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Manfred Engelhard, M+W Group

Under current conditions, a combination of CSP and PV plants is more cost-effective than one or the other. The power cost at both baseload and typical day levels was less for the CSP combined with PV scenario at all load levels in both Morocco (about 12p/kWh) and Saudi Arabia (about 9.5p/kWh). This was generally followed closely by the cost per kWh for CSP power, with PV-B costs estimated at generally several cents higher than the other two.

For the future scenarios in 2030, PV-B systems have the potential to be more attractive due to the visible expected cost reduction for battery energy storage and a further cost reduction for PV. The results found that PV-B can become the most cost-optimised solution for load curves following a typical day with a lower load at night such as in Morocco. PV-B (costing around 7.5p/kWh) would represent the favoured system in Morocco over a CSP and PV-B combination (which would provide electricity at around 8.5p/kWh). All systems for Saudi Arabia with its higher night demand show very close results (around 7p/kWh) with a slight advantage for PV-B. The results showed that the LCOE is nearly the same in 2030 for all Saudi Arabia scenarios requiring power at night.

In a nutshell

To put all this in plain English: the results show that the switch to solar energy should be a lot less painful than the casual observer may currently believe. Over the next fifteen years, the cost of solar energy technology will fall to the point where it directly competes with fossil fuels. These falling costs will lead directly to increases in energy security, making it less necessary to fall back on carbon-heavy electricity production modes. And most exciting of all, these trends will cause a more than six-fold reduction in carbon dioxide output by electricity producers in sun-rich areas – again due to solar plants becoming more self-sufficient over time.

The results do come with a couple of caveats. First, the boundary conditions of the analysis, which consist of a fixed load curve that needs to be fulfilled at all times. Second, the results assume a certain market growth in each technology. Both CSP and battery storage will only reduce in cost to the desired levels if the assumed capacity is installed by 2030.

Future outlook

Whereas CSP has the lowest overall cost per kWh in 2015, photovoltaic plus battery systems should approach or surpass CSP in value for money by 2030. However, there are a couple of other factors to consider when comparing the two technologies.

CSP projects are only practical in certain areas and also require large investments in the range of several hundred million pounds per installation. A typical-sized CSP plant with 160 MW power output would require an investment of over £740mn today. Operating a CSP plant poses significant challenges in terms of technical operation (with the molten salt and steam turbine cycle operation), and demands a significant amount of water for mirror cleaning and turbine operation. These technical risk factors pose a challenge in finding investors to line up behind them.

PV-B systems, on the other hand, can be built in a much more decentralised fashion with relatively simple operational challenges demanding little or no water for module cleaning. For comparison, a single PV-B unit comprises a 2 MW output with six hours of energy storage under full load. Building up PV-B capacity is much more flexible than CSP systems and is considered to be 'bankable'.

Prices for solar panels have fallen significantly in recent years – by over 25% in the years from 2010 to 2015 – and are expected to fall further. Battery prices are also expected to fall in the coming years, with large investments in battery technology by the electric car industry and others. Drops in CSP prices are expected to fall more slowly.

Regardless of the preferred mode of solar power production, the results of the THERMVOLT study are clear in two regards. If power producers are to play a significant role in combating climate change, they should start sooner rather than later in building up solar capacity. And if they do so, consumers will benefit from lower prices without having to give up much at all. ●

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A summary of the THERMVOLT study can be accessed at **bit.ly/2ig0ZOE**