Photovoltaic power station

A photovoltaic power station , also known as a solar park , is a large @-@ scale photovoltaic system (PV system) designed for the supply of merchant power into the electricity grid . They are differentiated from most building @-@ mounted and other decentralised solar power applications because they supply power at the utility level , rather than to a local user or users . They are sometimes also referred to as solar farms or solar ranches , especially when sited in agricultural areas . The generic expression utility @-@ scale solar is sometimes used to describe this type of project .

The solar power source is via photovoltaic modules that convert light directly to electricity . However , this differs from , and should not be confused with concentrated solar power , the other large @-@ scale solar generation technology , which uses heat to drive a variety of conventional generator systems . Both approaches have their own advantages and disadvantages , but to date , for a variety of reasons , photovoltaic technology has seen much wider use in the field . As of 2013 , PV systems outnumber concentrators by about 40 to 1 .

In some countries , the nameplate capacity of a photovoltaic power stations is rated in megawatt @-@ peak (MWp) , which refers to the solar array 's DC power output . However , Canada , Japan , Spain and some parts of the United States often specify using the converted lower nominal power output in MWAC ; a measure directly comparable to other forms of power generation . A third and less common rating is the mega volt @-@ amperes (MVA) . Most solar parks are developed at a scale of at least 1 MWp . As of 2015 , the world 's largest operating photovoltaic power stations have capacities of close to 600 megawatts and projects up to 1 gigawatt are planned . As at the end of 2015 , about 3 @,@ 400 projects with a combined capacity of 60 GWAC were solar farms larger than 4 MW .

Most of the existing large @-@ scale photovoltaic power stations are owned and operated by independent power producers , but the involvement of community- and utility @-@ owned projects is increasing . To date , almost all have been supported at least in part by regulatory incentives such as feed @-@ in tariffs or tax credits , but as levelized costs have fallen significantly in the last decade and grid parity has been reached in an increasing number of markets , it may not be long before external incentives cease to exist .

History

The first 1 MWp solar park was built by Arco Solar at Lugo near Hesperia , California at the end of 1982 , followed in 1984 by a 5 @.@ 2 MWp installation in Carrizo Plain . Both have since been decommissioned , though Carrizo Plain is the site for several large plants now being constructed or planned . The next stage followed the 2004 revisions to the feed @-@ in tariffs in Germany when a substantial volume of solar parks were constructed .

Several hundred installations over 1 MWp have been since been installed in Germany , of which more than 50 are over 10 MWp . With its introduction of feed @-@ in tariffs in 2008 , Spain became briefly the largest market , with some 60 solar parks over 10 MW , but these incentives have since been withdrawn . The USA , China India , France , Canada , and Italy , amongst others , have also become major markets as shown on the list of photovoltaic power stations .

The largest sites under construction have capacities of hundreds of MWp and projects at a scale of 1 GWp are being planned .

Siting and land use

The land area required for a desired power output , varies depending on the location , and on the efficiency of the solar modules , the slope of the site and the type of mounting used . Fixed tilt solar arrays using typical modules of about 15 % efficiency on horizontal sites , need about 1 hectare / MW in the tropics and this figure rises to over 2 hectares in northern Europe .

Because of the longer shadow the array casts when tilted at a steeper angle , this area is typically

about 10 % higher for an adjustable tilt array or a single axis tracker , and 20 % higher for a 2 @-@ axis tracker , though these figures will vary depending on the latitude and topography .
The best locations for solar parks in terms of land use are held to be brown field sites , or where there is no other valuable land use . Even in cultivated areas , a significant proportion of the site of a solar farm can also be devoted to other productive uses , such as crop growing or biodiversity .

= = = Agrivoltaics = = =

Agrivoltaics is co @-@ developing the same area of land for both solar photovoltaic power as well as for conventional agriculture . A recent study found that the value of solar generated electricity coupled to shade @-@ tolerant crop production created an over 30 % increase in economic value from farms deploying agrivoltaic systems instead of conventional agriculture .

= = = Co @-@ location = = =

In some cases several different solar power stations , with separate owners and contractors , are developed on adjacent sites . This can offer the advantage of the projects sharing the cost and risks of project infrastructure such as grid connections and planning approval . Solar farms can also be co @-@ located with wind farms . Sometimes the title ' solar park ' is used , rather than an individual solar power station .
Some examples of such solar clusters are the Charanka Solar Park , where there are 17 different generation projects ; Neuhardenberg , with eleven plants , and the Golmud solar parks with total reported capacity over 500MW . An extreme example is calling all of the solar farms in the Gujarat state of India a single solar park , the Gujarat Solar Park .

= = Technology = =

Most Solar parks are ground mounted PV systems , also known as free @-@ field solar power plants . They can either be fixed tilt or use a single axis or dual axis solar tracker . While tracking improves the overall performance , it also increases the system 's installation and maintenance cost . A solar inverter converts the array 's power output from DC to AC , and connection to the utility grid is made through a high voltage , three phase step up transformer of typically 10 kV and above .

= = = Solar array arrangements = = =

The solar arrays are the subsystems which convert incoming light into electrical energy . They comprise a multitude of solar modules , mounted on support structures and interconnected to deliver a power output to electronic power conditioning subsystems .
A minority of utility @-@ scale solar parks are configured on buildings and so use building @-@ mounted solar arrays . The majority are ' free field ' systems using ground @-@ mounted structures , usually of one of the following types :

= = = = Fixed arrays = = = =

Many projects use mounting structures where the solar modules are mounted at a fixed inclination calculated to provide the optimum annual output profile . The modules are normally oriented towards the Equator , at a tilt angle slightly less than the latitude of the site . In some cases , depending on local climatic , topographical or electricity pricing regimes , different tilt angles can be used , or the arrays might be offset from the normal East @-@ West axis to favour morning or evening output .
A variant on this design is the use of arrays , whose tilt angle can be adjusted twice or four times annually to optimise seasonal output . They also require more land area to reduce internal shading at the steeper winter tilt angle . Because the increased output is typically only a few percent , it seldom justifies the increased cost and complexity of this design .

Dual axis trackers

To maximise the intensity of incoming direct radiation , solar panels should be orientated normal to the sun 's rays . To achieve this , arrays can be designed using two @-@ axis trackers , capable of tracking the sun in its daily orbit across the sky , and as its elevation changes throughout the year .
These arrays need to be spaced out to reduce inter @-@ shading as the sun moves and the array orientations change , so need more land area . They also require more complex mechanisms to maintain the array surface at the required angle . The increased output can be of the order of 30 % in locations with high levels of direct radiation , but the increase is lower in temperate climates or those with more significant diffuse radiation , due to overcast conditions . For this reason , dual axis trackers are most commonly used in subtropical regions , and were first deployed at utility scale at the Lugo plant .

Single axis trackers

A third approach achieves some of the output benefits of tracking , with a lesser penalty in terms of land area , capital and operating cost . This involves tracking the sun in one dimension ? in its daily journey across the sky ? but not adjusting for the seasons . The angle of the axis is normally horizontal , though some , such as the solar park at Nellis Airforce Base , which have a 20 ° tilt , incline the axis towards the equator in a north @-@ south orientation ? effectively a hybrid between tracking and fixed tilt .
Single axis tracking systems are aligned along axes roughly North @-@ South . Some use linkages between rows so that the same actuator can adjust the angle of several rows at once .

Power conversion

Solar panels produce direct current (DC) electricity , so solar parks need conversion equipment to convert this to alternating current (AC) , which is the form transmitted by the electricity grid . This conversion is done by inverters . To maximise their efficiency , solar power plants also incorporate maximum power point trackers , either within the inverters or as separate units . These devices keep each solar array string close to its peak power point .
There are two primary alternatives for configuring this conversion equipment ; centralised and string inverters , although in some cases individual , or micro @-@ inverters are used . Single inverters allows optimizing the output of each panel , and multiple inverters increases the reliability by limiting the loss of output when an inverter fails .

Centralised inverters

These units have relatively high capacity , typically of the order of 1 MW , so they condition that the output of a substantial block of solar arrays , up to perhaps 2 hectares (4 @.@ 9 acres) in area . Solar parks using centralised inverters are often configured in discrete rectangular blocks , with the related inverter in one corner , or the centre of the block .

String inverters

String inverters are substantially lower in capacity , of the order of 10 kW , and condition the output of a single array string . This is normally a whole , or part of , a row of solar arrays within the overall plant . String inverters can enhance the efficiency of solar parks , where different parts of the array are experiencing different levels of insolation , for example where arranged at different orientations , or closely packed to minimise site area .

Transformers

The system inverters typically provide power output at voltages of the order of 480 VAC . Electricity grids operate at much higher voltages of the order of tens or hundreds of thousands of volts , so transformers are incorporated to deliver the required output to the grid . Due to the long lead time , the Long Island Solar Farm chose to keep a spare transformer onsite , as transformer failure would have kept the solar farm offline for a long period . Transformers typically have a life of 25 to 75 years , and normally do not require replacement during the life of a photovoltaic power station .

= = = System performance = = =

The performance of a solar park is a function of the climatic conditions , the equipment used and the system configuration . The primary energy input is the global light irradiance in the plane of the solar arrays , and this in turn is a combination of the direct and the diffuse radiation .
A key determinant of the output of the system is the conversion efficiency of the solar modules , which will depend in particular on the type of solar cell used .
There will be losses between the DC output of the solar modules and the AC power delivered to the grid , due to a wide range of factors such as light absorption losses , mismatch , cable voltage drop , conversion efficiencies , and other parasitic losses . A parameter called the ' performance ratio ' has been developed to evaluate the total value of these losses . The performance ratio gives a measure of the output AC power delivered as a proportion of the total DC power which the solar modules should be able to deliver under the ambient climatic conditions . In modern solar parks the performance ratio should typically be in excess of 80 % .

= = = System degradation = = =

Early photovoltaic systems output decreased as much as 10 % / year , but as of 2010 the median degradation rate was 0 @.@ 5 % / year , with modules made after 2000 having a significantly lower degradation rate , so that a system would lose only 12 % of its output performance in 25 years . A system using modules which degrade 4 % / year will lose 64 % of its output during the same period . Many panel makers offer a performance guarantee , typically 90 % in ten years and 80 % over 25 years . The output of all panels is typically warranteed at plus or minus 3 % during the first year of operation .

= = The business of developing solar parks = =

Solar power plants are developed to deliver merchant electricity into the grid as an alternative to other renewable , fossil or nuclear generating stations .
The plant owner is an electricity generator . Most solar power plants today are owned by independent power producers (IPP 's) , though some are held by investor- or community @-@ owned utilities .
Some of these power producers develop their own portfolio of power plants , but most solar parks are initially designed and constructed by specialist project developers . Typically the developer will plan the project , obtain planning and connection consents , and arrange financing for the capital required . The actual construction work is normally contracted to one or more EPC (engineering , procurement and construction) contractors .
Major milestones in the development of a new photovoltaic power plant are planning consent , grid connection approval , financial close , construction , connection and commissioning . At each stage in the process , the developer will be able to update estimates of the anticipated performance and costs of the plant and the financial returns it should be able to deliver .

= = = Planning approval = = =

Photovoltaic power stations occupy at least one hectare for each megawatt of rated output , so require a substantial land area ; which is subject to planning approval . The chances of obtaining consent , and the related time , cost and conditions , varying from jurisdiction to jurisdiction and location to location . Many planning approvals will also apply conditions on the treatment of the site after the station has been decommissioned in the future . A professional health , safety and environment assessment is usually undertaken during the design of a PV power station in order to ensure the facility is designed and planned in accordance with all HSE regulations .

= = = Grid connection = = =

The availability , locality and capacity of the connection to the grid is a major consideration in planning a new solar park , and can be a significant contributor to the cost .
Most stations are sited within a few kilometres of a suitable grid connection point . This network needs to be capable of absorbing the output of the solar park when operating at its maximum capacity . The project developer will normally have to absorb the cost of providing power lines to this point and making the connection ; in addition often to any costs associated with upgrading the grid , so it can accommodate the output from the plant .

= = = Operation and maintenance = = =

Once the solar park has been commissioned , the owner usually enters into a contract with a suitable counterparty to undertake operation and maintenance (O & M) . In many cases this may be fulfilled by the original EPC contractor .
Solar plants ' reliable solid @-@ state systems require minimal maintenance , compared to rotating machinery for example . A major aspect of the O & M contract will be continuous monitoring of the performance of the plant and all of its primary subsystems , which is normally undertaken remotely . This enables performance to be compared with the anticipated output under the climatic conditions actually experienced . It also provides data to enable the scheduling of both rectification and preventive maintenance . A small number of large solar farms use a separate inverter or maximizer for each solar panel , which provide individual performance data that can be monitored . For other solar farms , thermal imaging is a tool that is used to identify non @-@ performing panels for replacement .

= = = Power delivery = = =

A solar park 's income derives from the sales of electricity to the grid , and so its output is metered in real @-@ time with readings of its energy output provided , typically on a half @-@ hourly basis , for balancing and settlement within the electricity market .
Income is affected by the reliability of equipment within the plant and also by the availability of the grid network to which it is exporting . Some connection contracts allow the transmission system operator to constrain the output of a solar park , for example at times of low demand or high availability of other generators . Some countries make statutory provision for priority access to the grid for renewable generators , such as that under the European Renewable Energy Directive .

= = Economics and Finance = =

In recent years , PV technology has improved its electricity generating efficiency , reduced the installation cost per watt as well as its energy payback time (EPBT) , and has reached grid parity in at least 19 different markets by 2014 . Photovoltaics is increasingly becoming a viable source of mainstream power . However , prices for PV systems show strong regional variations , much more than solar cells and panels , which tend to be global commodities . In 2013 , utility @-@ scale system prices in highly penetrated markets such as China and Germany were significantly lower ($ 1 @.@ 40 / W) than in the United States ($ 3 @.@ 30 / W) . The IEA explains these discrepancies due to differences in " soft costs " , which include customer acquisition , permitting , inspection and interconnection , installation labor and financing costs .

Grid parity

Solar generating stations have become progressively cheaper in recent years , and this trend is expected to continue . Meanwhile , traditional electricity generation is becoming progressively more expensive . These trends are expected to lead to a crossover point when the levelised cost of energy from solar parks , historically more expensive , matches the cost of traditional electricity generation . This point is commonly referred to as grid parity .

For merchant solar power stations , where the electricity is being sold into the electricity transmission network , the levelised cost of solar energy will need to match the wholesale electricity price . This point is sometimes called ' wholesale grid parity ' or ' busbar parity ' .

Some photovoltaic systems , such as rooftop installations , can supply power directly to an electricity user . In these cases , the installation can be competitive when the output cost matches the price at which the user pays for his electricity consumption . This situation is sometimes called ' retail grid parity ' , ' socket parity ' or ' dynamic grid parity ' . Research carried out by UN @-@ Energy in 2012 suggests areas of sunny countries with high electricity prices , such as Italy , Spain and Australia , and areas using diesel generators , have reached retail grid parity .

Incentive mechanisms

Because the point of grid parity has not yet been reached in many parts of the world , solar generating stations need some form of financial incentive to compete for the supply of electricity . Many legislatures around the world have introduced such incentives to support the deployment of solar power stations .

Feed @-@ in tariffs

Feed in tariffs are designated prices which must be paid by utility companies for each kilowatt hour of renewable electricity produced by qualifying generators and fed into the grid . These tariffs normally represent a premium on wholesale electricity prices and offer a guaranteed revenue stream to help the power producer finance the project .

Renewable portfolio standards and supplier obligations

These standards are obligations on utility companies to source a proportion of their electricity from renewable generators . In most cases , they do not prescribe which technology should be used and the utility is free to select the most appropriate renewable sources .

There are some exceptions where solar technologies are allocated a proportion of the RPS in what is sometimes referred to as a ' solar set aside ' .

Loan guarantees and other capital incentives

Some countries and states adopt less targeted financial incentives , available for a wide range of infrastructure investment , such as the US Department of Energy loan guarantee scheme , which stimulated a number of investments in the solar power plant in 2010 and 2011 .

Tax credits and other fiscal incentives

Another form of indirect incentive which has been used to stimulate investment in solar power plant was tax credits available to investors . In some cases the credits were linked to the energy produced by the installations , such as the Production Tax Credits . In other cases the credits were related to the capital investment such as the Investment Tax Credits

International , national and regional programmes

In addition to free market commercial incentives , some countries and regions have specific programs to support the deployment of solar energy installations .

The European Union 's Renewables Directive sets targets for increasing levels of deployment of renewable energy in all member states . Each has been required to develop a National Renewable Energy Action Plan showing how these targets would be met , and many of these have specific support measures for solar energy deployment . The directive also allows states to develop projects outside their national boundaries , and this may lead to bilateral programs such as the Helios project .

The Clean Development Mechanism of the UNFCCC is an international programme under which solar generating stations in certain qualifying countries can be supported .

Additionally many other countries have specific solar energy development programmes . Some examples are India 's JNNSM , the Flagship Program in Australia , and similar projects in South Africa and Israel .

Financial performance

The financial performance of the solar power plant is a function of its income and its costs .

The electrical output of a solar park will be related to the solar radiation , the capacity of the plant and its performance ratio . The income derived from this electrical output will come primarily from the sale of the electricity , and any incentive payments such as those under Feed @-@ in Tariffs or other support mechanisms .

Electricity prices may vary at different times of day , giving a higher price at times of high demand . This may influence the design of the plant to increase its output at such times .

The dominant costs of solar power plants are the capital cost , and therefore any associated financing and depreciation . Though operating costs are typically relatively low , especially as no fuel is required , most operators will want to ensure that adequate operation and maintenance cover is available to maximise the availability of the plant and thereby optimise the income to cost ratio .

Geography

The first places to reach grid parity were those with high traditional electricity prices and high levels of solar radiation . Currently , more capacity is being installed in the rooftop than in the utility @-@ scale segment . However , the worldwide distribution of solar parks is expected to change as different regions achieve grid parity . This transition also includes a shift from rooftop towards utility @-@ scale plants , since the focus of new PV deployment has changed from Europe towards the Sunbelt markets where ground @-@ mounted PV systems are favored .

Because of the economic background , large @-@ scale systems are presently distributed where the support regimes have been the most consistent , or the most advantageous . Total capacity of worldwide PV plants above 4 MWAC was assessed by Wiki @-@ Solar as 36 GW in c . 2 @,@ 300 installations at the end of 2014 and represents about 25 percent of total global PV capacity of 139 GW . The countries which had the most capacity , in descending order , were the United States , China , Germany , India , United Kingdom , Spain , Italy , Canada and South Africa . Activities in the key markets are reviewed individually below .

China

China was reported in early 2013 to have overtaken Germany as the nation with the most utility @-@ scale solar capacity . Much of this has been supported by the Clean Development Mechanism . The distribution of power plants around the country is quite broad , with the highest concentration in the Gobi desert and connected to the Northwest China Power Grid .

= = = Germany = = =

The first multi @-@ megawatt plant in Europe was the 4 @.@ 2 MW community @-@ owned project at Hemau , commissioned in 2003 . But it was the revisions to the German feed @-@ in tariffs in 2004 , which gave the strongest impetus to the establishment of utility @-@ scale solar power plants . The first to be completed under this programme was the Leipziger Land solar park developed by Geosol . Several dozen plants were built between 2004 and 2011 , several of which were at the time the largest in the world . The EEG , the law which establishes Germany ? s feed @-@ in tariffs , provides the legislative basis not just for the compensation levels , but other regulatory factors , such as priority access to the grid . The law was amended in 2010 to restrict the use of agricultural land , since which time most solar parks have been built on so @-@ called ? development land ? , such as former military sites . Partly for this reason , the geographic distribution of photovoltaic power plants in Germany is biased towards the former Eastern Germany . As of February 2012 , Germany had 1 @.@ 1 million photovoltaic power plants (most are small kW roof mounted) .

= = = India = = =

India has been rising up the leading nations for the installation of utility @-@ scale solar capacity . The Charanka Solar Park in Gujarat was opened officially in April 2012 and was at the time the largest group of solar power plants in the world . Geographically the majority of the stations are located in Gujarat and Maharashtra . Rajasthan has successfully been attempting to attract solar development . It and Gujarat share the Thar Desert , along with Pakistan .

= = = Italy = = =

Italy has a very large number of photovoltaic power plants , the largest of which is the 84 MW Montalto di Castro project .

= = = Spain = = =

The majority of the deployment of solar power stations in Spain to date occurred during the boom market of 2007 @-@ 8 . The stations are well distributed around the country , with some concentration in Extremadura , Castile @-@ La Mancha and Murcia .

= = = United Kingdom = = =

The introduction of Feed @-@ in tariffs in the United Kingdom in 2010 stimulated the first wave of utility @-@ scale projects , with c . 20 plants being completed before tariffs were reduced on 1 August 2011 following the ' Fast Track Review ' . A second wave of installations was undertaken under the UK 's Renewables Obligation , with the total number of plants connected by the end of March 2013 reaching 86 . This is reported to have made the UK Europe 's best market in the first quarter of 2013 .

UK projects were originally concentrated in the South West , but have more recently spread across the South of England and into East Anglia and the Midlands . The first solar park in Wales came on stream in 2011 at Rhosygilwen , north Pembrokeshire . As of June 2014 there were 18 schemes generating more than 5 MW and 34 in planning or construction in Wales .

= = = United States = = =

The US deployment of photovoltaic power stations is largely concentrated in southwestern states . The Renewable Portfolio Standards in California and surrounding states provide a particular incentive . The volume of projects under construction in early 2013 has led to the forecast that the US will become the leading market .

Noteworthy solar parks

The following solar parks were , at the time they became operational , the largest in the world or their continent , or are notable for the reasons given :
Solar power plants under development are not included here , but may be on this list .