Energy Sector Technology factsheets

Utility-scale Solar PV (flat-plate system)

Defining characteristics	Narrative
General	The photovoltaic (PV) effect[64] was first observed by Edmond Becquerel in the 19th century, but practical applications first became possible with the development of solid-state electronic devices in the 1950s. Propelled by innovations and spinoffs of the US Space Program in the 1970s, solar PV technology debuted in the world energy markets in the 1980s. For field scale applications, solar PV technologies are distinguished into two broad categories: concentrator, and flat-plate systems, the latter being deployed more widely, globally (Green, 1993; Kelly, 1993). Essentially, flat-plate systems are built around monocrystalline or polycrystalline solar cells[65] commonly referred to as modules that transform incident solar radiation into an electrical output. When connected in series, solar cells create an additive voltage to serve as the basis for running a utility-scale power plant (Firor et al., 1993). Compared to distributed solar power generation, utility-scale solar systems (USSSs) produce significantly larger economies of scale, have a high production capacity, and can be built at the optimal geographical location, not necessarily proximal to demand centres (Hernandez et al., 2014). On average, solar panels lose 0.5% of their efficiency a year resulting in a potential loss of 12% of its output performance in 25 years (Green, 1993).
Siting and land use	USSSs are sited in areas known as solar parks. Ideally, solar parks are located in brown field sites, and approval permits informed by environmental and social impact studies. Land area required for solar parks is dependent on the geographical coordinates of the site and its topographic characteristics of the site, type solar tracking configuration, efficiency of the solar modules and rated capacity of the USSS. Field experience suggests that approximately 0.8 to 5.0 hectares of land may be required to generate $1MW_{ac}$ of electricity (IFC, 2015; Pasqualetti and Miller, 1984). With respect to a fixed tilt array system, land requirements could be 10% to 40% higher for a single axis tracker and a 2-axis tracker, respectively (Ong et al. 2013). Other site selection factors include accessibility and availability of grid connections, in consonance with the systems' strategic objectives of generating electricity at competitive costs
Design (components) and Operation	A utility-scale solar system (USSSI integrates the following sub-systems: 1) collection; 2) power conversion; and 3) storage and transmission sub-systems. The collection sub-system is made up of solar modules mounted on frames inclined at an angle slightly less than the latitude of the site and facing the equator. Alternatively, module can be mounted on supports with single axis or dual axis tracking systems[66] capable of boosting modules' efficiency by 20% to 50% (Green, 1993).[67] On exposure to direct or diffuse sunlight, individual modules produce dispatchable electrical energy proportional to incident light intensity.[68] Additive voltages of modules in series strings and parallel strings are connected to the inverters are transmitted with appropriate cablings to a power inverter[69] that converts direct current input voltage into low voltage alternating current[70] at grid frequency (50 – 60 Hz).[71] The power conversion process is

[64] creation of voltage or electric current in a material upon exposure to light

[65] Monocrystalline cells are generally more efficient, but are also more costly

[66] tracking the apparent movement of the sun across the sky throughout the year

[67] Spacing of module arrays and tilt of fixed mounted arrays are important considerations in optimised design (Green, 1993)

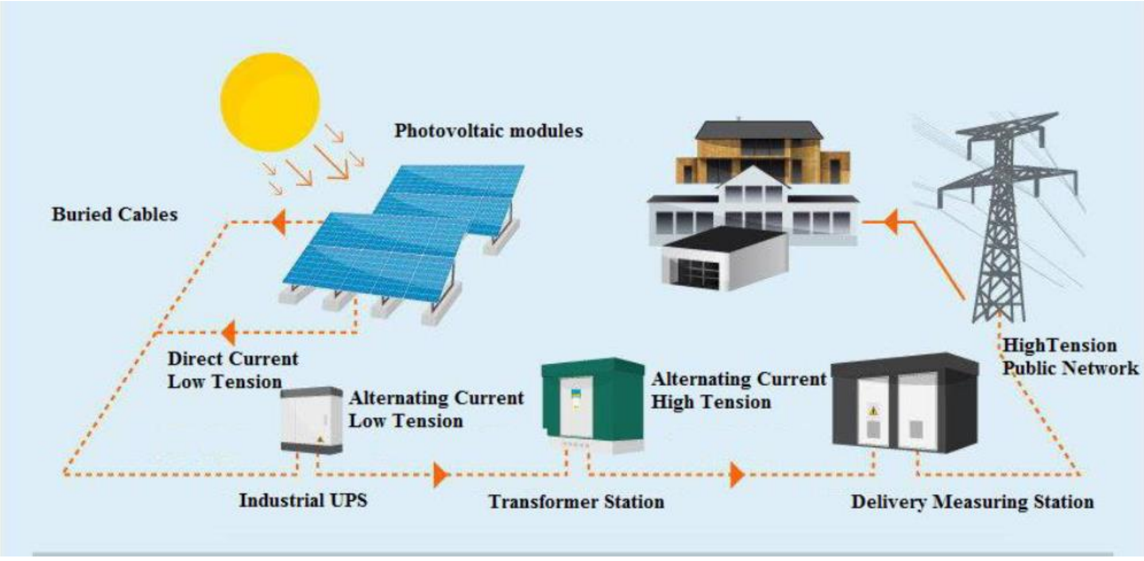
[68] Direct current components are rated to allow for thermal and voltage limits. Technical specifications of modules and guarantees are provided by manufacturers on module datasheets.

[69] In some installation, an industrial UPS serves to stabilise intermittent and rapid changes in the input voltage influenced by shading effects of passing clouds

[70] Inverters may be constructed without in-built transformers for stepping up the voltage. Inverters with transformers provide galvanic isolation but adversely affect efficiency as a result of transformer losses (IFC, 2015)

[71] The maximum number of modules in a string is constrained by the maximum direct input voltage of the inverter to which a string is connected

	completed with the aid of a (three-phase) step up transformer of known rated power that transforms low voltage alternating current (from inverter) to a high voltage output predisposed to transmission over long distances on an electric grid. On a systemic level, earthing is provided as a means to protect against electric shock, fire hazard and lightning. A delivery measuring station, typically located on the property of the electricity network operator/owner houses the required grid interface switchgear such as circuit breakers, and disconnects for protection and isolation of the USSS, as well as metering equipment (IFC, 2015, SRA International, 2008).
Costs	The cost of producing electricity using utility-scale solar PV could be highly variable, even within the same country (Sims et al., 2003). In effect, costs depend on the solar resources at the site, cost of modules and other parts of the system, cost of money, etc. Kelly (1993) and SRA International (2008) reports indicative investment costs in the order of USD0.03 to USD0.17 per kWh for sites across the US. For medium-scale projects, the author also report operation and maintenance (O&M) costs lying between USD0.03 and USD0.07 per kWh. Investment and O&M data compiled by Black and Veatch (2012) show significant economies of scale with increasing size of plant. IFC (2015) presents benchmark cost of USSS components that add up to USD1.74 million/MW_p. Crucially, modules, supporting structure and power inverter account for approximately 75% of total system costs.
Supporting infrastructure	Control room Delivery measuring station Roads Power substation
Advantages	Harvests freely available, domestic carbon-free energy resource Operates for decades with little maintenance (Kelly, 1993) More cost effective than residential scale systems (Tsuchida et al., 2015) Offers additional environmental benefits by using degraded land (Hernandez et al, 2014) Low production of hazardous wastes
Disadvantages /Challenges	Requires significant amounts of equipment and land Power produced by USSSs has fluctuations on both short and long time scales cannot eliminate the need for substantial firm power or dispatchable demand response (Curtright and Apt, 2008)
Abatement potential	Although the operation of a USSS entails no carbon emissions, emissions are non-zero from a life cycle analytical perspective. Depending on PV technologies these fall in the range of 20 - 50 gCO_2 per kWh of electricity. Still, this is far less than the carbon intensity of grid electricity reported as 500 gCO_2 per kWh (Nelson et al., 2014).
Level of penetration	USSS is a completely new technology, but there is a thriving market for solar PV, and considerable experience on small scale sol r in the Gambia



Source: AfDB, 2015. Construction of the Bokhol Solar photovoltaic plant in Senegal. Project Document.

Further readings

Black and Veatch, 2012. Cost and performance data for power generation technologies. Report prepared for the National Renewable Energy Laboratory. 60p + Appendices

Curtright, A.E., Apt, J., 2008. The Character of Power Output from Utility-Scale Photovoltaic Systems. Prog. Photovolt: Res. Appl. 16:241–247.

Firor, K., Vigoth, R., Ianucci, J,J., 1993. Utility field experience with photovoltaic systems in Johanssen, T.B., Kelly, H., Reddy, A.K.N, Williams, R.H. (eds), 1993. Renewable energy: Sources for fuels and electricity. Island Press, Washington DC, pp. 482 – 512.

Green, M.A., 1993. Crystalline and polycrystalline solar cells in Johanssen, T.B., Kelly, H., Reddy, A.K.N, Williams, R.H. (eds), 1993. Renewable energy: Sources for fuels and electricity. Island Press, Washington DC, pp. 337 – 360.

Hernandez, R.R., Easter, S.B., Murphy-Mariscal, M.L., Maestre, F.T., Tavassoli, M., Allen, E.B., Barrows, C.W., Belnap, J., Ochoa-Hueso, R., Ravi, S., Allen, M.F., 2014. Environmental impacts of utility-scale solar energy. Renewable and Sustainable Energy Reviews 29, 766–779

International Finance Corporation (IFC), 2015. Utility-Scale Solar Photovoltaic Power Plants. A Project Developer's Guide. pp58-93, 173-181

Kelly, H., 1993. Introduction to photovoltaic technology in Johanssen, T.B., Kelly, H., Reddy, A.K.N, Williams, R.H. (eds), 1993. Renewable energy: Sources for fuels and electricity. Island Press, Washington DC, pp 297 – 336.

Nelson, J., Gambhir, A., Ekins-Daukes, N.,2014. Solar power for CO_2 mitigation. Grantham Institute for Climate Change, (GICC), Briefing Paper 14. Imperial College, London, 16p.

Ong, S., Campbell, C., Denholm, P., Margolis, R., Heath, G., 2013. Landr-use requirements for solar power plants in the United States. National Renewable Energy Laboratory (NREL) Technical Report. NREL/TP-6A20-56290. Available electronically at http://www.osti.gov/bridge

Pasqualetti. M.J, Miller, B.A.,1984. Land requirements for the solar and coal options. The Geography Journal. Vol.50, 2, 192 – 212.

Sims, R.E.H., Hans-Holger R., Gregory, K., 2003. Carbon emission and mitigation cost comparisons between fossil fuel, nuclear and renewable energy resources for electricity generation. Energy Policy 31, 1315–1326

SRA International, 2008. Solar Power Analysis and Design Specifications. Technical Manual. Environmental Protection Agency’s Brownfields Program. 23p.

Tsuchida, B., Sergici, S., Mudge, B., Gorman, W., Fox-Penner, P., Schoene, J., 2015. Comparative Generation Costs of Utility-Scale and Residential-Scale PV in Xcel Energy Colorado’s Service Area.

Websites

https://en.wikipedia.org/wiki/Photovoltaic_power_station
http://www.businessinsider.com/utility-scale-solar-is-now-comparable-to-natural-gas-2016-7