ISSN 2250-3153

A Vital Role of Concentrating Solar Power Plants of Rajasthan in Future Electricity Demand of India

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Abstract- The deserts of the world are hottest places, very less rainfall, almost clear skies throughout the year. These deserts receive highest direct normal irradiance which is most suitable for concentrating solar power plants. With the technological developments and their innovations in concentrating solar power, thermal storage and hybridization/ back up, the sunniest countries expects that CSP should be source of bulk power in peak and intermediate loads by 2020, and base load power by 2025 to 2030. By2050, CSP could produce 11.3% of global electricity, with 9.6% from solar Power and 1.7% from back up fuels (fossil fuels or biomass). The Thar Desert of Rajasthan is most suitable site for CSP in India. The purpose of the study is to highlight available solar resource, present technology of CSP, future development in technology and contribution of power generated from CSP plants of Rajasthan and its role in India's electricity demand by 2052[*], under the guidelines of Jawaharlal Nehru Solar mission.

Index Terms- Annual Average DNI, Back up/ hybridization, Base Load, Capacity Factor, Concentrating Solar Power, Direct Normal Irradiance, Intermediate Load, Jawaharlal Nehru Solar Mission(NSM), Peak Load, Satellite data, Solar India

Abbreviations

C-WET	Centre for Wind Energy Technology.
GW	Gigawatt (109 watts)
IEA	International Energy Agency.
MNRE	Ministry of New and Renewable Energy
MoP	Ministry of Power
MWe	Megawatt electrical
NASA	National Aeronautics and Space Administration.
NREL	National Renewable Energy Laboratory
NTPC	National Thermal Power Corporation
NVVN	NTPC Vidyut Vyapar Nigam
PPA	Power Purchase Agreement
R&D	Research and Development.
TWh	Terawatt- hour

I. Main Features of CSP

Concentrating solar power (CSP) technologies use mirrors to reflect and concentrate sunlight onto receivers that collect solar energy and convert it to heat. This thermal energy can then be used to produce electricity via steam turbine or heat engine that drives the generator [(1)]. The sunlight hits the earth's surface both directly and indirectly, through numerous reflections and deviations in the atmosphere. On clear days, the direct irradiance represents 80 to 90 % of solar energy reaching the earth's surface. On a cloudy or foggy day, the direct component is essentially zero. Unlike , photovoltaic cells or flat plate solar collectors, CSP power plant cannot use diffuse part of solar irradiation which result from scattering of direct sun light by clouds, particles, or molecules in the air, because it cannot be concentrated [(2)].

*Year 2052 has been taken i.e. According to five years plan in India

The direct component of solar irradiance is one of the greatest interests to designers of high temperature solar energy systems because it can be concentrated on small areas using mirrors or lenses. Concentrated Solar energy plants require large amount of direct sun light and best constructed in arid or semi arid regions, globally known as sun belt [(3)].

The solar energy that CSP plant use is measured in terms of direct normal irradiance (DNI), which is the energy received on a surface tracked perpendicular to sun's rays. Satellite provides DNI data of whole regions, exact data for particular location can be obtained by measurement at ground. It can be measured with the pyrheliometer [(4)]. The DNI provide the approximation of capacity of a CSP the plant's electrical output potential. The DNI varies and do not remain same throughout the day and also varies season to season. CSP is a proven technology. Parabolic troughs accounts for largest share of current CSP market but other competitive technologies are emerging.

The CSP plants can have thermal storage and can be operated after sunshine. The CSP plants can be hybridized/backup with fossil fuels and biomass. CSP utilizes huge amount of water which is not available in arid and semi arid regions. The desert areas are not the load centers; long high voltage transmission lines are required for utilization of power at load centers from CSP plants. Ample land is available in desert area, which can be utilized for CSP plants.

Technologies for power production

There are five main Configurations of CSP that are commercially available – Parabolic Trough, Linear Fresnel, Fresnel lens, Paraboloidal Dish and Central Receiver Tower [(5)].

ISSN 2250-3153

Table1. Key features and status of five CSP technology categories are summarized below

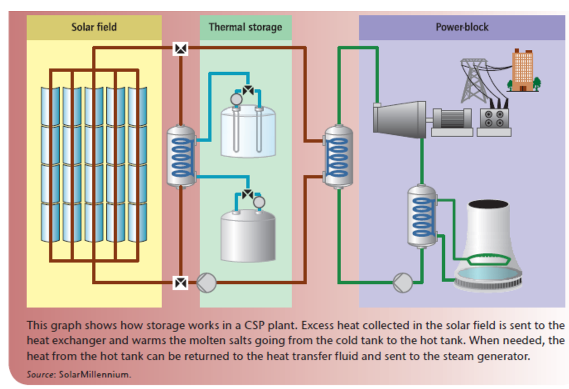
Technology	Annual solar to electricity efficiency	Focus type	Practical Operating temperature of thermal conversion	Power Cycles considered	Commercial maturity	Installed Generating capacity end 2011
Parabolic trough	12-15%	Linear	150 to 400^0 C	Steam Rankine Organic Rankine PV	High	1500 MW_e
Central Receiver Tower	20-30%	Point	300 to 1200^0 C	Steam Rankine Brayton (Gas turbine) PV	Medium	60 MW_e
Linear Fresnel	8-10%	Linear	150 to 400^0 C	Steam Rankine Organic Rankine PV	Medium	38 MW_e
Fresnel lens	12-15%			PV	Medium	15 MW_e
Parabolic Dish	20-30%	Point	300 to 1500^0 C	Sterling EngineSteam RankineBrayton (gas turbine) PV	Low	2MWe 4MWe

Source: Realizing the Potential of Concentrating Solar Power in Australia

Thermal Storage

CSP plant can be equipped with a heat storage system to generate electricity even with cloudy skies or after sunset. For example, during sunny hours, solar heat can be stored in high thermal –capacity fluid and released upon demand (e.g. at night) to produce electricity. The main advantage of CSP technology against other renewable sources as PV and wind power is capability to provide dispatch-able power by storing solar energy through thermal energy storage [6]. If combined with heat storage system, CSP plants can also provide intermediate- and base-load electricity. This increases significantly the dispatch ability of CSP electricity as well as economic competitiveness and the integration in electric grids [7]. To provide the required heat storage capacity, the solar field (i.e. mirrors and heat collectors) of the CSP plant must be oversized with respect to nominal electric supply capacity (MW) of plant. The trades off between the incremental costs associated with thermal storage and increased electricity production. The storage capacity has the advantage, when DNI is high and turbine is unable to absorb the heat, the same can be diverted to the storage tank, operator would have to "defocus" some unneeded solar collectors in the plant without storage. The concept of the storage is very simple as shown in figure 1; the excess heat received throughout the day is diverted to the storage material (e.g. molten salts). When production is required after sun set, the stored heat is released into the steam cycle and plant continuous to produce electricity. CSP can meet different needs by varying storage capacity.

Figure1. Storage system in trough plant



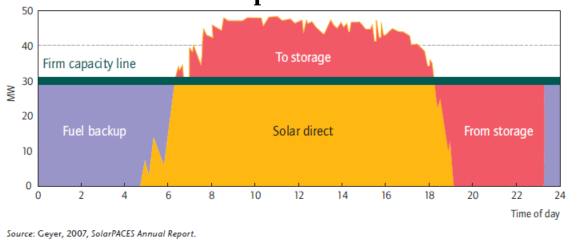
Backup and hybridization

CSP plants can operate with storage or without storage with the fuel power back up system. Fossil back up and/ or storage may be used to extend operation beyond the hours of sunlight and provide firm, dispatchable power [8]. The fuel burners can use fossil fuels, biogas, or eventually solar fuels energy to heat transfer fluids or storage medium, or directly to power blocks. In the area of low DNI, back up is most suitable to produce electricity at a lower cost than the plant could produce electricity with storage and without storage. There is no use storage in less DNI where plant runs on hybrid system, since huge investment is associated in reserve solar fields with Storage capacity.

Hybrid system improves the conversion efficiency of solar heat to electricity by raising working temperature level. As clear from figure 2, that plant runs on the solar direct during the sunshine and after sunshine from storage and from midnight to morning runs on back up/ hybridization.

ISSN 2250-3153

Figure2. Combination of storage and hybridization in a solar plant



Requirement of water

CSP plant require about 3000 L/ MWh for parabolic trough and LFR plants (similar to nuclear reactor) where as in coal based plant the requirement of water is 2000 L/MWh and combined- cycle natural gas plants require 800 L/MWh. Tower CSP plant need less water per MWh than trough plants, depending upon the efficiency of technology. Dishes are cooled by the surroundings air, and need no cooling water. Water is really a great Challenge in desert area (Arid and semi arid regions). Dry cooling system installed on trough plants in hot desert reduces annual electricity production by 7% and increases the cost of produced electricity by about 10% (9). Hybrid wet dry cooling system is an attractive option as to reduce the water consumption. The hybrid system tend to use only dry cooling in winter when cooling needs are lower, then switch to combined wet and dry cooling in summer. For a parabolic CSP plant, this approach could reduce water consumption by 50% with 1% annual drop in electricity.

Requirement of Land

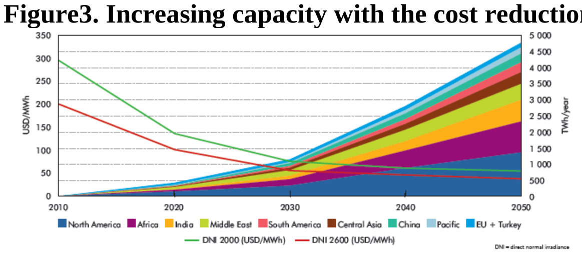
Land required for trough system without storage is 2 hectare/ MW, and for Fresnel with no storage 4 hectare /MW (10). Land required for thermal storage depends upon amount of thermal storage, i.e. operational hours after sunset.

II. Vision of Future Deployment of CSP

Now, the work of investigation for more accurate global solar resource potential is in progress through satellite for obtaining better DNI maps. High quality solar radiation measurement stations have been installed in all the countries and regions for interest of CSP such as India, China, Turkey, Africa, the Middle East and Latin America (11).

The CSP technology will become competitive with coal fired based plants due to decrease cost in solar fields and storage, due to higher temperature technologies (540^{0}C and above). In the sunniest countries, CSP can expected to become a competitive source of bulk power in peak and intermediate loads by 2020, and base- load power by 2025-2030, and by 2050 could provide 11.3% of global electricity, with 9.6% from solar power and 1.7% from back up fuels (fossil fuels or biomass)[12]. As from figure, 3, total global generation of electricity from CSP plant including hybridization shall be 4770 TWh/ annum. The levilised cost of electricity dropping from US$ 200/MWh to $40/MWh from 2010 to 2050.

Figure3. Increasing capacity with the cost reduction



Details of Road maps of IEA

The table 2 shows that India will generate 670 TWh from CSP power plants by 2050 against total generation of the world 4770 TWH, which is 14%. The capacity factor of the CSP plants is increasing due to development of efficient and high technology in thermal storage, capacity factor is expected to be 32% by 2020, 39% by 2030, 45% by 2040 and 50% by 2050.

Table2. Data of Technology Roadmap 2010 and Roadmap 2012of IEA

Sno.	year	Capacity in GW World	Capacity Factor In %	Hours per year	Total generation annually Including Hybridization (in TWh)	CSP share in total generation (in %)	Total generation From CSP plants (in TWh)	Percentage Share global generation From CSP Plants (in %)	Capacity In India (GW)	Total generation including hyberdization In India (in TWh)
1.	2020	148	32	2800	414	82	340	1.3	7	19
2.	2030	337	39	3400	1140	85	970	3.8	33	113
3.	2040	715	45	3900	2790	85	2370	8.3	76	294
4.	2050	1089	50	4380	4770	85	4050	9.6	152	670

Source of data: IEA Technology Roadmap Concentrating Solar Power 2010 and Concentrating Solar Power Roadmap 2012(Abstract prepared from IEA Technology Roadmap Concentrating Solar Power 2010 and Concentrating Solar Power Road map 2012)

III. INDIA'S SOLAR RESOURCE

CSP technologies depend upon Direct Beam radiation for operation. The radiations directly received from the sun, not diffused or deflected by the clouds or other atmospheric factors and can be focused by the mirrors. The data are required in short interval for assessing the potential of site, Direct Normal Irradiance (DNI) is required to measure for several years. For designing a CSP plant, knowledge of seasonal variation in DNI resources is needed to make optimal assessment. The comparison of annual average annual DNI of the best desert sites across the world has shown in table 3.

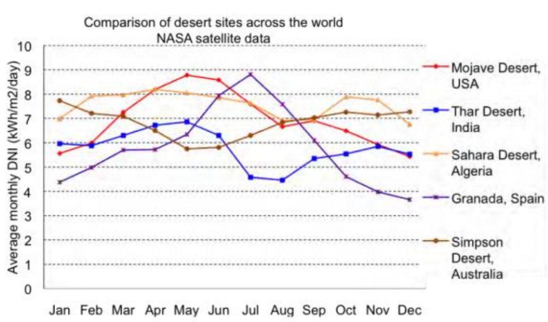
Table 3. Compares of the best desert sites across the world in terms of annual average DNI.

Country	Location	Latitude	Longitude	Annual Average DNI KWh/m^2/day	Annual Average DNI KWh/m^2/year
Saudi Arabia	Rabul Khali (Arabian desert)	20^{0}N	50^{0}E	7.61	2,778
Nigeria	Algadez (Sahara desert)	17^{0}N	8^{0}E	7.57	2,763
USA	Mojave desert (Location of SEGs power plants)	35^{0}N	115^{0}W	6.95	2,537
Australia	Oodnadatta, South Australia (Simpson Desert)	28^{0}S	135^{0}E	6.83	2,493
Spain	Granada (location of Andasol power plants)	37^{0}N	3^{0}W	5.82	2,124
India	Jodhpur, Rajasthan (Thar desert)	26^{0}N	72^{0}E	5.77	2,106

Source- Concentrating Solar Power in India, Australian Government, Departmentof of Climate Chage and Energy Efficiency

As per figure 4, Jodhpur shows dip in the middle of the year coincident with the monsoon. North America deserts have best pssible DNI resource both on annual average and minimum variability basis. Sahara desert have more constient solar resource through out the year, 25% higher than on average than Jodhpur. Jodhpur is comparable to the spanish site Granada(one of the Spanish site) on an annnual average basis.

Figure 4. Comparison of desert sites accrossthe world, NASA Satellite data.



Jawaharlal Solar Mission

Jawaharlal Nehru Solar Mission was launched in January 2010. The objective of mission is to establish India as a global leader in solar energy, by creating the policy conditions for its diffusion across the country as quickly as possible. The objective of solar mission is to create conditions, through rapid scale –up of capacity and technological innovation to drive down the costs towards grid parity. The mission anticipates achieving grid parity by 2022 and parity with coal based thermal plants by 2030, but recognizes this cost trajectory will depend upon the scale of the global deployment and technology and transfer. Above mission adopted three phase approach for targets, the targets for utility grid power including roof top is as under.

i. Phase I 2010-2013
1000-2000MW
ii. Phase-II 2013-2017
4000- 1000MW
iii. Phase-III 2017-2022
20000 MW

Role of NVVN

NTPC has a wholly subsidiary company engaged in business of trading of power –NTPC Vidyut Vyapar Nigam Ltd.(NVVN). NVVN has been designated as nodal agency by Ministry of Power (MoP) for entering into a Power Purchase Agreement (PPA) with the Solar Power Developers. The PPAs shall be signed with the developers who will be setting up solar projects within next three years (i.e. up to March 2013) and are connected to the grid at 33KV and above level. The PPAs will be valid for a period of 25 years. For each MW solar power installed capacity for which PPA is signed by NNVN, MoP will allocate to NVVN an equivalent amount of MW capacity from unallocated quota of NTPC stations. NVVN will bundle this power and sell this bundle power at a fixed rate as per CERC regulations.

Allotment of CSP projects

In phase –I, 50:50 split allocations was made between CSP and PV technologies, on a megawatt capacity, against reverse auction process by NVVN. MNRE selected 7 projects totaling to

ISSN 2250-3153

470 MW. MNRE also "migrated" three existing projects of 10 MW each into the NSM with a combined total of 500 MW. The CSP projects weighted average bid price was Rs. 11.48/KWh as compared to average electricity price of Rs. 4.70/KWh [13].

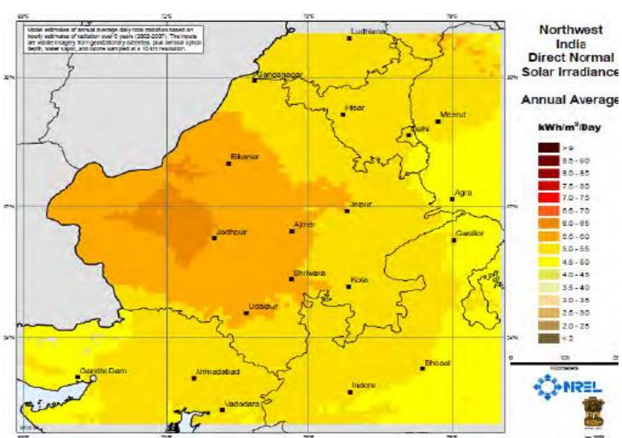
IV. Future CSP Projections for Rajasthan

There has been increasing trend of CSP in worldwide to utilize abundant sunlight available in the deserts. In other words CSP has become the power industry of deserts. The governments of sunniest countries are taking initiatives to provide energy security with the development of CSP in their country. Jawaharlal Nehru Solar mission of government of India is a big step towards making "Solar India". Rajasthan Solar Energy Policy, 2011 of government of Rajasthan to develop Rajasthan as the global hub of solar power in the country. The main objective of this policy is to utilize waste land of desert to meet energy needs of Rajasthan and neighboring states. The future of CSP in Rajasthan is bright and will have major role in electricity demand of India by 2052, if follows the international standards and as per the road map given by IEA 2012.

Solar Resource in Rajasthan

As from the figure.5, the annual average DNI for north –west India, the Thar desert region , with Jodhpur at its border, has the highest DNI . Annual average DNI is 5.89 KWh/m^2/day in the regions of Thar Desert of Rajasthan. The average annual DNI in Rajasthan remains around between 5.42 to 5.89 KWh/m^2/day. These data are based on the satellite data, provides the information about overall area, but does not provide accurate data of particular location; they also do not provide temperature and humidity of particular location. Reliable long term DNI data collected at high frequency is needed to predict system output accurately, mainly as an input to investment decisions. The accurate data can be accessed by ground site data.

Figure5. DNI map of north-west India (NREL, 2009)



DNI map of North West India, (NREL,2009)

MNRE Collection of DNI Data

MNRE has taken step to improve assessments of DNI. The Centre for Wind Energy Technology (C-WET), an autonomous research and development (R&D) institutions established by MNRE, implemented 51 solar radiation resource assessment stations across the country between May to September 2011[14]. These MNRE C-WET stations collect high –quality solar irradiance data at 10 minutes intervals and data from newly installed station's first year operation are available to project developers for a fee[15]. Additional 60 stations will be installed in future, increasing DNI data available as the mission enters phase-II.

Competitive advantage of Rajasthan

Thar desert of Rajasthan is one of the best sites in the world for installation of CSP plants. Rajasthan has about 2,08,110Km^2 of desert land, which is 60% of total area of state[16]. The Indira Gandhi canal flows to meet the requirement of water for CSP plants in desert area. Average annual DNI in desert area of Rajasthan is about 5.89 KWh/m^2/day. As the area has low rainfall, days have good sun shine in a year[17], and western area in Tthar desert it may be extended up to 345-355 days as rain occur only for 10.4 -20.5 days in a year [18]. There is ample desert land is available for CSP plants. Already there is strong transmission lines network in desert for transmitting the power from CSP plants to load centers.

Complete Rajasthan is suitable for CSP plants, average annual DNI in Rajasthan ranges between 5.42 to 5.89 KWh/m^2/day (as per record of Rajasthan Renewable Energy Corporation) . High DNI areas are suitable for CSP plants with or without thermal storage and comparatively less DNI areas are suitable for backup/ hybridization. There are two perennial rivers in Rajasthan Chambal and Mahi for meeting the requirement of water for CSP plants.

Under phase-I, total seven numbers of CSP projects for 470 MW were allotted by NVVN to the solar developers after reverse bidding process. Out of 470 MW projects, five projects having capacity 400 MW were allotted to Rajasthan. Solar developers preferred Rajasthan due to climatic and geographical advantage, infrastructure, facilities, policy of government of Rajasthan and good investment opportunities in present and future.

Rajasthan Government is fully committed to promotion of solar energy. Rajasthan Government believe that implementation of Rajasthan Solar Energy Policy will help Rajasthan as a global hub for solar power for 10000-12000MW capacity over next 10 to 12 years to meet energy requirements of Rajasthan and other states of India [19].

CSP capacity and generation

The implementation of Jawaharlal Nehru Solar mission, with its ambitious target of 20 GW of installed solar energy plants by 2022, half is expected to CSP. Therefore, total 10 GW CSP plants shall be commissioned in India 10 GW by 2022, approximately 5GW shall be commissioned in Rajasthan by 2022. If Rajasthan follows the Road map of IEA-2012, given for India, the capacity of Rajasthan would be 23 GW by 2032, 52 GW by 2042 and 104 GW by 2052. Rajasthan will be able to generate 456 TWh per year by 2052 by solar energy including back up/ hybridization.

Table.4 Capacity and generation from CSP plants of Rajasthan

Sno.	By the end the year	Capacity in GW	Generation in TWh/year
1.	2022	5	14
2.	2032	23	78
3.	2042	52	202
4.	2052	104	456

Derived from IEA Roadmap-2012

V. Electricity Demand of India by 2052

The demand of electricity depends upon the population of the country and per capita requirement of electricity. The projected population o India is around 1600 million by 2050 (20). We may take the same population in 2052 as in 2050, since stabilization of population growth starts before 2050 or negligible increase in population. The per capita consumption of electricity shall be 3400 KWh, this per capita consumption is very much less as compared to the current level per capita consumption of leading economics in the world (e.g. for 2001, per capita consumption in Canada was 18212 KWh and in US was13241). Taking per capita consumption of electricity 3400 KWh, therefore, total requirement of electricity shall be 5440 TWh per annum by 2050 (21). The same population will use electricity by 2052 as in 2050, consumption of electricity in 2052 shall remain almost same as in 2050. Therefore, total consumption of electricity shall be 5440 TWh in the year 2052 in India.

VI. Discussions and Conclusions

Here are three important findings (1) The requirement of electricity in India by 2052 will be 5440 Twh per annum which is more than 6 .7 times of generation of 811 TWh in 2010-2011 (22). (2) Thar desert of Rajasthan will be able to produce electricity 456 TWh/ year by 2052 by CSP plants, 8.4% of electricity consumption of India in 2052. (3) The generation 456 TWh from the CSP plants by 2052 is more than half of generation of 811 TWh in the year 2010-11. The generation from CSP plant of Rajasthan can be more than 456 TWh/year by 2052, with the rapid development and innovation of higher temperature technologies than anticipated. Government of India is to concentrate to develop R&D, financing mechanism, grid integration, legal and regulatory frame work, public engagement and international collaboration. The state governments have vital role for development of CSP plant, timely arrange land, water, transmission of power generated from CSP plants and timely provide other infrastructure facilities to the solar plant developers for making mission successful.

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" Challenges Among the Management of Solar Energy Sector in Western Rajasthan"., Mobile No. 91- 7742979229