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World's Highest Off-grid Solar PV Potential in India- Search and Penetrate

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Abstract: In this modern age, reliable and affordable electricity is requirement of every human being. 19% of population of the world is without access to electricity. Developed countries are managing to provide reliable and affordable electricity to all, while maintaining energy security. Developing countries are unable to supply the electricity to all, therefore, consuming kerosene for lighting and diesel for agricultural, telecom towers, commercial and miscellaneous activities. In India 300 millions peoples are without access to the electricity, one third of rural population and 6% of urban population [(1)]. Government of India is providing subsidy on kerosene for lighting and diesel for agricultural and other purposes. The Government of India has a vision to electrify 100% villages and households that are not in remote under Rajeev Gandhi Grameen Vidyutikaran Yojana. Such remote villages and households are to be electrified by off- grid solar PV under the guidelines of Jawaharlal Nehru National Solar Mission.

Key Words – Affordable, Demand, Grid parity, Reasonable, Reliable, Solar resource.

Abbreviations BPL – Below Poverty Line, GW- Gigawatt, IEA- International Energy Agency, JNNSM- Jawaharlal Nehru National Solar Mission, KW- Kilowatt, KWh- Kilowatt –hour, MW- Megawatt, RGGVY- Rajiv Gandhi Grameen Vidyutikaran Yojna, SELCO – Solar Electric Light Company.

I. Introduction

Electricity can be generated in any corner of world in the solar resource regions by off-grid solar PV. India has a high solar resource and it is abundantly available in most part of the country. About 70% of population of India lives in villages, large number of village has no access to electricity, villagers are deprived from TV, computer, communication facilities and villagers are dependent on kerosene for illumination. Most of the villages are connected to the grid, villages have not been receiving perennial supply, and rural feeder is cut for several hours and receives poor quality of supply. 400 million grid connected people, the electricity was intermittent and unreliable [(2)]. Therefore, villagers in India are illiterate, socially and economically backward. Electrifying remote villages is not techno-economically feasible, since requires long transmission and distribution lines which involve heavy capital expenditure. Farmers are using diesel pump sets for irrigation, telecom towers are being supplied electricity from the diesel generating sets in un-electrified villages. In totality, there is huge consumption of kerosene and diesel in India. Diesel and kerosene is imported at the international market rates and government of India provide at the subsidized rates in the country. Import of large quantity of kerosene and diesel is challenge to the energy security of the country. Pollution from kerosene indoor lighting causes 64 % of deaths and 81% of disabilities among children under age of five [(2)]. Solar Lantern and Solar Home Lighting System are the best alternative of Kerosene, economical to kerosene. There is need to phase out kerosene by educating the peoples, providing capital subsidy and soft loans to adopt solar lantern and solar home lighting system. The Solar Electric Light Company, India or (SELCO India) is for - profit social enterprise based in Bangalore is actively working and installed 125,000 solar home lighting systems in rural and poor villages of Karnataka. In remote regions, micro grids can serve the requirement of electricity of the villages/cluster of villages 150 to 200 households, cottage industry, schools, dispensary, road lights and community halls. In India 9 million diesel pump sets are used for irrigation out of 21 million pump sets [(3)]. The cost of solar PV has come down and cost of diesel has been regularly increasing. At present the cost of solar PV is very much less to diesel, solar PV cost shall be half of diesel within three to four years, since approaching towards grid parity. 400,000 telecom towers are associated with diesel generating sets having capacity 3 to 5 KW. 60% Telecom towers located in urban and semi urban areas and 100% located in the villages are run by diesel generating sets [(2)]. In fact, off-grid potential is unlimited in India and is about 20 to 25% potential of the world.

II. World Access to Electricity

Developed countries have managed to supply electricity to everyone but millions of people have no access to electricity in Africa, developing Asia, Latin America and Middle East. Table 1, shows that by 2009, 58% of population of Africa, 19% of developing Asia, 7% of Latin America and 11% of middle east had no access to electricity. 25% of Indian peoples had no access to electricity out which 33% in villages and 6% in urban areas. By 2030, 12% of the world population would be without access to electricity.

Table 1, Number of people without access to electricity by region (million)

S no.	Region/ country	2009			2030		
		Rural	Urban	Share of population	Rural	Urban	Share of population
1	*Africa*	*466*	*121*	*58%*	*539*	*107*	*42%*
	Sub-Saharan Africa	465	121	69%	538	107	49%
2.	*Developing Asia*	*595*	*81*	*19%*	*327*	*49*	*9%*
	China	8	0	1%	0	0	0%
	India	268	21	25%	145	9	10%
	Rest of developing Asia	319	60	36%	181	40	16%
3.	*Latin America*	*26*	*4*	*7%*	*8*	*2*	*2%*
4.	*Middle East*	*19*	*2*	*11%*	*5*	*0*	*2%*
5.	Developing countries	1106	208	25%	879	157	16%
6.	*World*	*1109*	*208*	*19%*	*879*	*157*	*12%*

Source: World Energy Outlook, Energy for all, International Energy Agency, 2011

III. Capacity and PV Market of End –Use Sectors

There are four end- use sectors with distinct market for PV, Residential systems (typically up to 20 KW systems on individual buildings/ dwellings), Commercial Systems (typically up to 1MW systems for commercial office buildings, schools, hospitals, and retail), Utility scale systems (starting at 1MW, mounted on buildings or directly on ground), Off-grid applications (varying sizes) [(4)]. As per table 2, cumulative installed capacity of four end use sectors (residential, commercial, utility and off-grid) is expected to change significantly over time. The residential sector has the highest potential, it has maximum around 60%. After residential sector, utility sector is one of the biggest sectors and followed by off-grid and commercial sectors. The relative shares of PV deployment among the different sectors will vary by country and according to the requirement of individual country. In India, limited land resource restricts the utility scale end-use sector. India has the highest potential of off –grid end use sector in the world, around 20 to 25% potential of world.

Table 2, Cumulative installed PV capacity (GW) by end –use sector (World)

PV capacity (GW)	2010	2020	2030	2040	2050
Residential	17	118	447	957	1380
Commercial	3	22	99	243	404
Utility	5	49	223	551	908
Off-grid	2	21	103	267	463
Total	27	210	872	2019	3155

IEA, Technology Roadmap, Solar Photovoltaic Energy, 2010

IV. Off-grid solar PV

Off-grid solar PV generation means, generation in isolation (no utility grid is available) in solar resource region. The electricity can be generated from few watts to megawatts from off-grid solar PV. It has a great potential in developing countries. Mainly off-grid solar

PV applications are lighting; agricultural pump sets for irrigation and telecommunication towers. Presently, Kerosene is used for lighting purposes and diesel is used for agricultural pump sets and telecommunication towers. Solar lantern, solar home lighting system and micro grids are the best alternative for replacing Kerosene. Solar PV pump sets can replace diesel pump sets. Solar PV application can replace/hybridize with diesel generating sets installed at telecommunication towers. Off- grid solar PV has several advantages and electricity can be generated anywhere in solar resource regions in daytime, while sun shines.

Solar Lantern

Solar lanterns are viable and cost effective for lighting of un- electrified households. Solar lanterns are for poor villagers who cannot afford high amount for illumination. The solar lanterns are available between 0.5 to 5 Watts .These solar lanterns can replace the use of Kerosene, used by poor villagers.

Solar Home Lighting System

Solar home lighting system is also cost effective for lighting and other minimum requirement of house hold. Solar home lighting system is for those who are above below poverty line and can afford for illumination and other minimum requirements. These solar home lighting systems are available between 2.5 to 70 Watts. Solar home lighting system can also replace the use of kerosene.

Solar PV Micro -grid

Solar PV micro grids are able to supply electricity to the villages or cluster of villages. These micro grids are able to meet the demand of lighting loads, drinking water pumps, community buildings, school, and cottage industry and for commercial activities. Solar PV generates electricity during sunshine, therefore, running of cottage industry and commercial activities can take place during sun shine period. Batteries can be charged during sun shine hours for lighting load in night hours. Off-grid solar PV micro- grid can be hybridized with bio-mass or any other source of renewable energy.

Solar PV based Irrigation Pump Sets

A total land mass of 328.73 million hectare in country is used for agricultural and this includes 140.2 million hectare under cultivation [(5)]. Therefore, most of the crops in India depend upon electric/ diesel pump sets for irrigation. The 17th electric power supply survey of India claimed that over the period 2010-2011, agricultural consumption accounted for 21% of total electric consumption of India [(6)]. There are 21 million pump sets in the country, out of which 9 million pumps run by diesel, rest are connected to the grid [(3)]. Off- grid solar PV based pump sets can replace diesel. These solar pumps can run in day hours only (i.e. during sunshine period) and cannot run in night, cloudy days or non availability of sunshine in the day. Mainly, water is required for irrigation in sunny days.

Off- grid Solar PV for telecom towers

India is the largest and fastest growing telecom market in the world. The number of telecom towers was 400,000 in 2010 and expected to be 800,000 by 2015 [(2)]. Average telecom tower is equipped with 3to 5KW diesel generating sets. 60 % telecom towers in urban / semi urban area and 100% in rural area are dependent on diesel generating sets. The consumption of diesel is around 2. 8 billion liters per annum and emits 6 million tones of CO_2 [(2)].

Cost of Off – grid solar PV

It was only few years ago, PV electricity was four to five times more expensive than the fossil fuels [(7)]. Continuing decreasing cost of solar PV and increasing cost of fossil fuels, grid parity could occur within three to four years in several states of India where high solar resource is available and prevailing high tariff of electricity. The grid parity is expected to be achieved in 2019-20 in the states where moderate solar resource is available and prevailing lower tariff of electricity. Cost of off-grid is higher to utility scale, residential and commercial end use sectors. Cost of off-grid applications increase due to transportation to remote places, since off- applications are in remote regions Battery further increases the cost of the off-grid solar PV system. Still, cost of off -grid solar PV is much less than grid in remote areas.

Advantages of off- grid solar PV

- Solar resource is abundantly and locally available.
- It is distributed form of electricity, need no transmission lines.

- It is clean and renewable, no emission.
- Free from market rates, fluctuating fuel prices and provides energy security.
- The capacity can be added since the system is flexible and scalable.
- It involves minimum maintenance since no moving parts.

Disadvantages of off- grid solar PV

- Off- grid Solar PV system works effectively in solar resource regions.
- It works in day while solar resource is available in day time.
- It does not work in night hours and cloudy days.
- Storage of electricity is costly.
- It requires huge space i.e. 1KW requires 10 m^2.

V. Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY)

Government of India launched Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) in 2005, for electrification of rural India; aim was to provide minimum requirement of electricity to 100% villagers that are not living in remote regions. There is a provision of free electricity connection to all below poverty line (BPL) households. Rural Electrification Corporation (REC) is a nodal agency for rural electrification under RGGVY. Under the schemes for rural electrification, 90% capital subsidy will be financed and balance 10% as a loan assistance on soft terms by REC. Electrification of un-electrified Below Poverty Line (BPL) households will be financed with 100% capital subsidy as per norms of Kutir Jyoti Programme in all rural habitations[8]. RGGVY had a target of electrifying 100,000 villages and providing free electricity connection to 17.5 million households below poverty line by March 2012[1].

Jawaharlal Nehru National Solar Mission

Jawaharlal Nehru National Solar Mission has paid special attention to provide light and power to the peoples living in remote areas with off-grid opportunity (lighting homes), where grid connection is neither feasible nor cost effective. Government of India will deploy 20 million solar lighting systems by 2022. The Solar mission has a target of 1000 MW by 2017 and 2000 MW by 2022 for off-grid applications. Government of India has launched financial incentives and promotional schemes for use of decentralized applications. Government of India has been providing 90% subsidy for the poor people's living remote (tribal area). Government has developed mechanism for banks to offer low cost credit to the peoples of villages which are connected to the grid for promotion of solar lights.

VI. Research and development (R&D)

R&D in the field of off –grid solar PV end-use sector is more important in India. Developed countries have no potential for off- grid solar PV system. Developing countries have total off- grid solar PV potential of the world. India is developed country among the developing countries that have highest off-grid solar PV potential. The off- grid solar PV potential in India is around 20 to 25% of world's potential. Therefore, India needs to concentrate and develop R&D mechanism for off-grid Solar PV system for illuminating the life of poor villagers of India and Developing world.

VII. Potential of off- grid Solar PV Applications in India

Solar Lantern and Solar Home Lighting System

Solar lantern and solar home lighting system are the replacement of kerosene. 75 million households in India are without access to electricity and India has highest subsidy levels for kerosene in the world, the annual expenditure on kerosene in India is USD 2 billion for lighting [9]. In India, rural BPL card owners are 70 millions and without BPL 50-55 millions use Kerosene as per NSSO 2004-05. It is assumed that BPL card holder will adopt solar lantern and without BPL cards will adopt solar home lighting System. Assuming 75% households are located in solar resource region, households in solar resource regions comes to 56 millions. These 56 million households are to be distributed in the ratio 70:55 BPL and non-BPL comes to 32 million and 24 million respectively. Adoption of solar lantern would be 27-37 million and SHS would be 19 -29 million respectively.

Solar PV Micro- grid

Almost 16% of villages of India are un-electrified, number of such villages are 95,000 [10]. Assuming 75 % of un-electrified villages are in solar resource region; number of un- electrified villages in solar resource region comes to 71,250. 60 % villages/ cluster of villages have 150 to 200 households in un–electrified and solar resource region; number of such villages comes to 42,750. Average 70 KW is required to fulfill the requirement of each village i.e. 1 .5 KWh to 2KWh per day per house hold (minimum requirement of each house hold). Total potential comes to 3000 MW.

Solar PV based Irrigation Pump Sets

9 million pump sets for irrigation run by diesel out 21 million pump sets in India. The average capacity of pump is 3.73 KW (5 HP). Now a days, the rates of diesel has been regularly increasing, the cost solar PV has been drastically decreasing. Solar PV has become very much economical as progressing towards grid parity. The capital cost of solar PV Pump sets is very much higher than diesel pumps. Government support is required for installation of solar PV pump sets, such as capital subsidy and soft loans. Now, there is need to replace diesel pumps with solar PV pumps. Replacement of these diesel pumps depends upon availability of solar resource and land for installation of solar PV system i.e. 10 m^2 for 1 KW (around 40 m^2 for 5 HP pump set). Out of these 9 million diesel pump sets 75% are assumed to be in solar resource region; total number of diesel pump sets in solar resource region comes to 6.75 million. Out of 6.75 million diesel pumps, 70% have land for installation of PV System; total numbers of pump sets in solar resource region and have land for installation of solar PV comes to 4.725 millions. We may take it as 4.5 million (just half of 9 million diesel pumps). The replacement of these 4.5 million pump sets means the potential of 16,785 MW, the replacement of 4.5 million diesel pumps save 223,800 million liter of diesel and 469.98 billion Kg carbon dioxide per annum [11].

Telecom Towers

Telecom towers were 400,000 in 2010. Assuming, 70% telecom towers are powered by diesel generating sets between 3 to 5 KW; telecom towers run on diesel generating sets comes to 280,000. 75% of these towers are located in solar resource region; number of towers using diesel generating sets located in solar resource region comes to 210,000. Assuming, land shall be available to 40% towers; number of towers have land for installation of solar PV in solar resource region using diesel generating sets comes to 84,000. Average generating capacity of diesel generating set is 4KW. Total off-grid potential of solar PV is 336 MW.

VIII. Status of Electricity in Rural India

There has been wide gap between demand and supply of electricity in India. In India, there is deficit of electricity in base load and peak load hours. As per actual power supply conditions during 2011-12, base load requirement was 937,199 (MU) against the availability of 857,886 MU, an 8.5% deficit. During peak loads, the demand was for 130 GW against availability of 116 GW, a 10.6% shortfall [12]. The impact of deficit is visible in urban areas and rural areas, causing load shedding (declared and undeclared power cuts). The rural feeder are under cut in day hours due shortage of supply. Villagers receive electricity in night hours; this electric supply is of poor quality and un- reliable. Poor quality and unreliable supply affects the agricultural production and life of villagers. Villagers needed to be remain in farms during night hours for irrigation of land (since availability of electricity in night hours). The quality way of life of villagers has not been improved due to improper supply in rural India. Most of the works are carried out in day hours, therefore, availability of electricity night hours is not as useful as in day hours.

IX. Future Off- grid Solar PV Potential in India

The future of off-grid solar PV is bright in India. The economic and population growth will give rise to electricity demand in the country at a faster rate. The gap between supply and demand will increase further as the generation resources are very limited in the country. This will ultimately adversely affect the electricity supply in rural areas. The solar PV would achieve grid parity within three to four years; cost of electricity generated from solar PV would be less than grid supply. Million of the farmers in high solar resource regions would replace grid supply by off-grid solar PV for their irrigation pump sets. Now, the market of cell phone would develop at a faster rate in rural areas. Accordingly, new telecom towers shall be installed in rural areas. These telecom towers in rural areas would be associated with solar PV due to low cost. The economic rise in the country would further strengthen the economic conditions of villagers. The demand of electricity in rural areas would further rise, consequently, increase in requirement of solar lanterns, solar home lighting system and micro – grids. The economic and population growth of the country will increase supply and demand gap of electricity, this increasing supply and demand gap would substantially increase in off-grid potential. As per table 2,

IEA, Technology Roadmap, Solar Photovoltaic Energy 2010, off-grid potential of the world will be 463 GW by 2050. India's share would be between 20 to 25%, hence, the potential would be 92 to 115 GW by 2050.

X. Discussions and Conclusions

In India, 75 million households have no access to the electricity, use kerosene for lighting which is dangerous from health point of view. Annual expenditure on kerosene for lighting in India is approximately USD 2 billion, USD 1.8 billion in rural areas. Need to develop mechanism for making rural India free of kerosene by transfer of kerosene subsidy to solar lantern and solar home lighting System. Approximately 27-37 million solar lanterns and 19-29 million solar home lighting systems shall be required for making India free of kerosene.

About 16% of villages are un-electrified, approximately 95,000 villages. These villages of India are deprived from modern equipment such as TV, computers and mobiles. Therefore, these villages are socially and economically backward. Solar PV micro- grids can be set up in the villages for betterment of lives of rural India in solar resource regions. 42,750 villages may be electrified having 150- 200 households. The potential is around 3000 MW.

9 million diesel pump sets have been deployed by farmers for irrigation in India. Out of these 9 million pump sets, 4.5 million diesel pump sets are located in solar resource regions and have the land for installation Solar PV system. Average capacity of pump is 3.73 KW, and total potential of these pumps comes to 16,785 MW.

400,000 telecommunication towers are installed in India, out of which 84,000 telecom towers powered by diesel generating sets are located in solar resource regions and having land for installation of solar PV. Average capacity of diesel generating set is 4KW; the total potential comes to 336 MW.

Off-grid solar PV has a bright future in India. Mainly, three factors will collectively work and increase off- grid potential several times in India. First factor- limited land resource in India restricts utility scale solar PV end –use sector, Second factor- electrifying remote villages is not techno-economically feasible, since requires long transmission and distribution lines which involve heavy capital expenditure, and third factor - economic and population growth of the country will increase supply and demand gap of electricity, this increasing supply and demand gap would substantially increase in off-grid potential. As per IEA, Technology Roadmap, Solar Photovoltaic Energy 2010, off- grid solar PV potential of the world would be 463 GW by 2050, India would have potential of 20 to 25%, 92 GW to 115 GW by 2050.

The world's highest off-grid potential is in India, therefore, there is need to develop strong R&D on off –grid solar PV to enable to provide minimum requirement of electricity to the rural peoples at reasonable and affordable rates. Government of India and the State Governments need to encourage off-grid solar PV system in India, by providing capital subsidy and soft loans to phase out Kerosene and diesel from the Indian scene. NGO (Non-governmental organization) should come forward to phase out kerosene and diesel from rural India.

References

1. World Energy outlook, Energy for all, IEA, 2011.www.iea.org/papers/2011/weo2011_energy_for_all.pdf

2. Off- Grid Solar Power in Rural India, ESTAP meeting, December 10, 2012. www.iea-etsap.org/.../PB_Off-grid%20solar% 20Power% 20in%20Rural%...

3. Solar Semiconductor; Potential of Solar PV for Distributed Power Generation in Rural & Urban India, 2009, htpp://www.cea.nic.in/planning/conclave%2018-f

4. Technology Roadmap, Solar photovoltaic energy, 2010, www.iea.org/publications/freepublications/ publication/PV_Roadmap.pd

5. State of Indian Agriculture 2012-13, Government of India, Ministry of Agriculture & Cooperation, New Delhi. 164.100.47.132/…/AGRICULTURE/State/%20of%20Indian%20Agriculture, 7 February 2013

6. "Report on 17th electric power survey of India". Central Electricity Authority, Ministry of Power. 2007. http://powermin.nic.in/generation/pdf/17th%20EPS.pdf..

7. IRENA, Renewable Energy Technologies : Cost Analysis Series, Volume 1: Power Sector issue 4/5, Solar Photovoltaic, June 2012, www.irena.org/.../RE_Technologies_Cost_Analysis-Solar_PV.pdf

8. Transmission and Distribution in India , World Energy Council, 2012. www.indiaworldenergy.org/pdf/T&D%20Report_PGCIL.pdf

9. Lighting Asia; Solar Off-grid Lighting, 3, February 2012.

intellecap.com/…/Updated%20Final%20Lighting%20Asia%20Off%20Gr

10. Ministry of Power, Progress Report of Village Electrification as on 31-05-2010, Government of India, 2010.

11. Shuba V. Raghvan, Anshu Bharawaj, Anupam A. Thatte, Santosh Harish, Kaveri K. Iychettira, Rajalaxmi Perumal, Ganesh Nayak ; Harnessing Solar Energy : Options for India, December,2010,

12. Load Generation Balance Report 2012-13, Government of India - Central Electricity Authority, September 2012, www,cea.nic.in/reports/yearly/lgbr _report. pdf

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