VOL. 3. NO. 1
ISSN 2581-5849
INDEXED WITH J-GATE

PDPU JOURNAL OF ENERGY AND MANAGEMENT

PANDIT DEENDAYAL PETROLEUM UNIVERSITY • A RESERVOIR OF KNOWLEDGE •

PDPU
PANDIT DEENDAYAL PETROLEUM UNIVERSITY
Gandhinagar, Gujarat, India

PDPU JOURNAL OF ENERGY AND MANAGEMENT

UGC APPROVED JOURNAL: NO. 63922

PDPU Journal of Energy and Management (JEM) is an International referred peer-reviewed journal. PDPU Journal of Energy and Management welcomes original papers from both academicians and practitioners on experimental energy science and technology (conventional and non-conventional), energy sector related management, business, and organizational issues related to energy and research. Papers, based on theoretical or empirical research or experience, should illustrate the practical applicability and/or policy implications of work described.

The bi-annual journal carries many features including perspectives, conceptual research, empirical research, colloquium, management case, and book reviews. Authors are invited to submit their contribution under any feature.

AIM AND SCOPE

The proposed research journal shall report and focus on identifying new opportunities, challenges, best practices and strategies for global economy on various complementing issues like business & techno-managerial Issues, regulatory & policy matters, marketing issues, financial & accounting issues, operational excellence & management, social & human resource management and capacity building in general and energy sector in specific.

PDPU JEM is a peer reviewed journal and follows a 'double blind' review process. All the papers submitted to PDPU JEM go through a preliminary review at the editorial desk and those considered appropriate are sent to an Editor representing a specialized domain. On recommendation of the concerned Editor, the Article may be rejected or assigned to two reviewers.

PUBLICATION INFORMATION

PDPU JEM shall be published biannually.
All editorial correspondence should be addressed to the Chief Editor, C. Gopalkrishnan, School of Petroleum Management, Pandit Deendayal Petroleum University, Gandhinagar, Gujarat - 382007 or sent by mail to *jem.pdpu@pdpu.ac.in* or *jem.pdpu@gmail.com.*

CONTACT DETAILS:
Dr. Ashutosh Muduli, Managing Editor

School of Petroleum Management,
Pandit Deendayal Petroleum University
Gandhinagar, Gujarat - 382007, India.

E-mail: jem.pdpu@pdpu.ac.in
jem.pdpu@gmail.com

PUBLISHER'S DETAILS:
Pandit Deendayal Petroleum University,
Gandhinagar, Gujarat - 382007, India.

Telephone: +91 79-23275101

E-mail: jem.pdpu@pdpu.ac.in
jem.pdpu@gmail.com

Website: https://www.pdpu.ac.in

PDPU JOURNAL OF
ENERGY AND MANAGEMENT

VOL. 3. NO. 1
INDEXED WITH J-GATE

CONTENT

EDITORIAL

We are pleased to present to you the Vth issue of PDPU Journal of Energy and Management. The following are the highlights of the papers presented in the journal.

'Geothermal as Energy Source for Remote Areas' by Dr. P. B. Sarolkar discusses the geothermal energy status in India and suggests measures for development of geothermal resources in India. The paper further examines the prospects of utilization of hot springs in Gujarat. The author observed that in India, geothermal energy sources are mainly located along the Himalayan belt in the north, Son - Narmada - Tapi lineament in central India, West Coast, and Godavari valley. There are isolated hot springs reported from Gujarat, Jharkhand and North Eastern Region, mostly located in interior parts. The hot springs in India range from 30°C at Ladakh to 97°C at Tatapani, Chhattisgarh. The estimated reservoir temperature in geothermal fields in India ranges from 110°C in West Coast to >200°C at Puga, Ladakh. The geothermal resources in these areas are a potential source of energy as a substitute to electricity, as well as for direct heat uses, like spa, hot water baths, space heating, food processing, green house cultivation,and aquaculture concludes Dr. Sarolkar.

In the second paper, Rashmi Singh, Madhu Sharma, and Chandan Banerjee explain 'Performance monitoring of high-efficiency Maxeon™ based SunPower PV plant in the composite climate of India'. The paper presents a case study of long-term performance monitoring of high-efficiency Maxeon™ based SunPower solar plant installed at the National Institute of Solar Energy, Gurugram, India. The paper also focuses on the suitability of high-efficiency SunPower solar technology in the composite climate of India by the analysis of the Performance Ratio (PR) and Thermal normalized PR (PRSTC). The authors also explains estimation of the thermal factor, as well as spectrum factor. The paper found that the average PR and the PRSTC found to be maximum in June and minimum in December months. PR of the SPV system correlates with the four seasons and temperature of the SPV module, as the key feature of assessment. It has been found out that the range of PR is 0.94-0.96 during winter, 1-1.01 during summer, and 0.95-0.98 during the post-monsoon and 0.93-0.98 during Monsoon.

The third paper on 'Solar Distillation System with Nano Particle: A Review' by Ruchir Parikh, and Dr. Umang Patdiwala focuses on different desalination methods and improvements, which are needed to commercialize these methods. The paper also discusses different parameters that affect the performance of the distillation system. From among the different desalination techniques and desalination methods which integrate renewable sources of energy, the authors summarized that solar desalination is a the most effective technique as it does not require external power or any other conventional energy sources. Solar desalination is also effective a the remotely located area, where energy and water are not easily accessible or are costly to meet the requirements of people.

The fourth paper on 'Achieving Inclusive Development through Smart Village' by Anand Singh and Megh Patel discusses the upcoming urban development projects focused on developing smart cities and observes that development of smarter villages have been ignored so far. Cities are being crowded at an unprecedented pace globally, 30% of the world's population was urban in 1950 with a projection of 66% by 2050. Lack of basic amenities and limited economic growth in villages lead toward uncontrolled migration from rural to urban area. Current scenario of urban living shows cities are struggling to cope up with the basic infrastructure like transportation, healthcare, housing and utilities. 30% of urban residents are living in slums. Rural development focusing on development of smarter villages will avoid further migration and can help to bring a balance to the entire ecosystem.

Finally, the paper 'Analysis of the Key Factors Affecting Levelized Cost of Electricity of Solar PV in India' by Nisarg Shah discusses on the recently introduced reverse auction process by the government of India which helps in reducing the tariff of power from Solar PV below Average Power Purchase Cost (APPC). The author commented that although such low tariff has raised doubt about the viability of solar PV project considering the high cost of debt prevailing in India. Further, the recently set target of deployment of 100 GW of Solar PV by the year 2022 in India may lead to around $100Bn investment. Under this condition, it is important to analyse the impact of various sets of factors affecting the levelled cost of electricity. This analysis will be helpful to investors for avoiding the problem of underbidding and/or overbidding. This analysis is also helpful to policy makers for maintaining the competitive nature of markets as well as the sustainability of the market.

Wishing all the readers of the Journal a very Happy 2019.

- C. Gopalkrishnan

1

GEOTHERMAL AS ENERGY SOURCE FOR REMOTE AREAS

Dr. P. B. Sarolkar,
Former Director General, Geological Survey of India

ABSTRACT: The modern development of a country is linked to the availability of energy, in the form of electricity and heat source. The electricity generation is mostly dependent on fossil fuels while the transport sector is controlled petroleum products which are major contributors to the pollution of the atmosphere. Wind, Solar, Biomass and geothermal are the main alternate sources, mostly available in remote areas. Geothermal energy is a non-conventional, environment-friendly energy source, available almost all round the year.

In India, geothermal energy sources are located along the Himalayan belt in the north, Son - Narmada - Tapi lineament in central India, West Coast,and Godavari valley. There are isolated hot springs reported from Gujarat, Jharkhand and North Eastern Region, mostly located in interior parts.The hot springs in India range in temperature from 30°C at Ladakh to 97°C at Tatapani, Chhattisgarh. The estimated reservoir temperature in geothermal fields in India ranges from 110°C in West Coast to >200°C at Puga, Ladakh. The geothermal resources in these areas are a potential source of energy as a substitute to electricity, as well as for direct heat uses, like spa, hot water baths, space heating, food processing, green house cultivation,and aquaculture. The measures for development of geothermal resources in India and prospects of utilization of hot springs in Gujarat are discussed here.

KEYWORDS

Geothermal energy, Tatapani, Unai, Dholera, Gujarat, Spa, Green house

Introduction

The development of modern society is directly linked with energy availability. The ample and regular supply of electricity controls the industrial and agricultural growth of the country, contributing to economic growth and employment opportunities. The energy need of India may be 3,00,000 MW by the year 2030. Presently the installed capacity of power generation is 3,31,118 MW in India, most of which is contributed by fossil fuels.The thermal power capacity in 2017 is 2,19,415 MW, Hydropower is 44,765 MW, nuclear 6780 MW and renewable energy is 60,158 MW. The notion – conventional energy is dominated by Wind and Solar energy, with partial contribution of biogas and biomass. India’s peak demand for power is expected to rise from the current level of 153000 MW to about 690000MW by 2035-36, according to the Draft National Electricity Plan prepared by the Central Electricity Authority (CEA). Such a demand puts heavy pressure on coal production and import of petroleum, ultimately contributing to green house gas emission. Thus, to meet this huge demand for energy, it is essential to switch over to non-conventional sources of energy. Besides wind, solar and biomass, geothermal is an alternate, renewable, environment-friendly source of energy.

Geological Survey of India prepared an inventory of 340 hot springs (Krishnaswamy and Ravishanker, 1982). The hot springs of India are categorized into 10 geographical provinces by Padhi & Pitale (1995). Most of these hot springs are located in remote areas along the Himalayan belt, North East India, Central India and West Coast of India, as given in the table below.

Sr. No.	Geothermal Province	Locality	Temp. Gradient	Heat Flow
I	Himalayan Geothermal Province	i. PugaIsunga Suture Zone ii. Puga Chumthang iii. Parbati Valley, Sutlej Valley, Alaknanda Valley	100°C /m 60±20°C /m 17±5°C /m	200 MW/m^2 130+30 MW/m^2
II	Naga Lusai Province	Naga Lunai Hill range bordering Burma.	Not available	70-100 MW/m^2
III	Andaman Nicobar Islands Province	Barren & Narcondam islands	Not available	100-180 MW/m^2
IV	West Coast Province	West Coast tract in Maharashtra	55±5°C /m	130±10 MW/m^2
V	Cambay Graben Province	Springs in tertiary reactivation area, oil & gas wells	25 to 55°C /m	130±10 MW/m^2
VI	Aravalli Province	Northwest ridges of Aravalli, in Rajasthan and Haryana, Neotectonic activity	41±10°C /m	100±25 MW/m^2
VII	Son Narmada Tapti Province	Tatapani, Salbardi, Anhoni - Samoni Geothermal prospects	40-120°C /m	70-300 MW/m^2
VIII & IX	Godavari and Mahanadi Province	Springs along post - Gondwana faults, e.g. Manuguru, Raigarh	39±10°C /m	80±21 MW/m^2
X	South Indian Cratonic Province	Isolated springs in shield area	30°C /m	60-90 MW/m^2

TABLE 1. Geothermal Provinces of India (Padhi & Pitale 1995)

Geothermal Prospects in India

Puga at Ladakh, Jammu & Kashmir; Tatapani at Chhattisgarh, Tapoban & Manikaran in Himachal Pradesh, Bakreshwar in West Bengal, Anhoni Samoni in Madhya Pradesh, Jakrem in Meghalaya, Garamapani in Assam, Takshing (52°C @ 90 lps) and Chetu Maja (88°C @ 30-60 lps) in Arunachal Pradesh, Surajkund in Bihar, Manuguru in Telangana, Unai and Dholera in Gujarat, are hot springs located in remote areas useful for development geothermal resources for benefit of local population (Fig. 1).

FIGURE 1. Geothermal locations in India

Tatapani Geothermal Field, Balarampur District, Chhattisgarh State

In Central India, hot springs are reported from Salbardi area, Betul district and Amaravati district, AnhoniSamoni in Hoshangabad district, Tatapani-Jhor in Balarampur district, Unkeshwar, Nanded district and parallel to West Coast. Tatapani in Chhattisgarh is the most prominent geothermal field suitable for binary cycle power generation.

Tatapani Geothermal field, Balrampur district, Chhattisgarh State, is located along the Son-Narmada lineament. Thermal manifestations in Tatapani consists of hot springs (50°C - 97°C) in marshy ground, and hydro thermally altered clay zones covering an area of about 0.1 sqkm (Ravishanker, 1987). Tatapani Geothermal field is located 95 km NNE of Ambikapur railway station (Fig.2) and is connected by all weather tar road from Ambikapur.

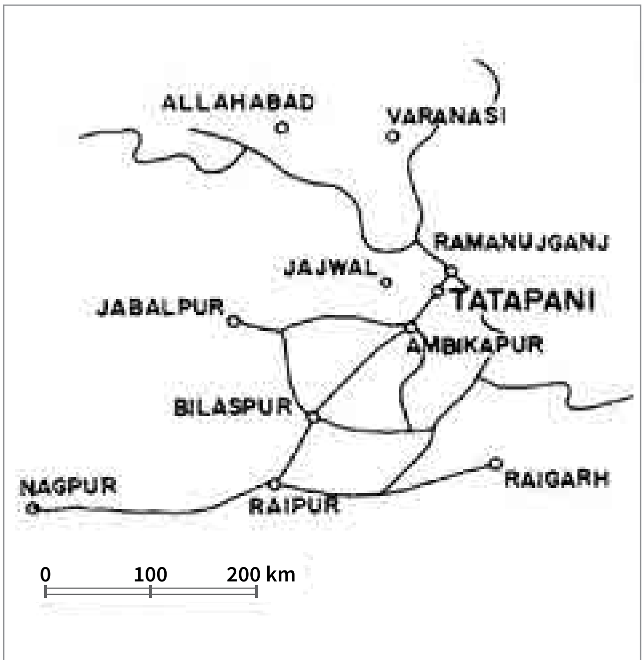

FIGURE 2. Location map of Tatapani

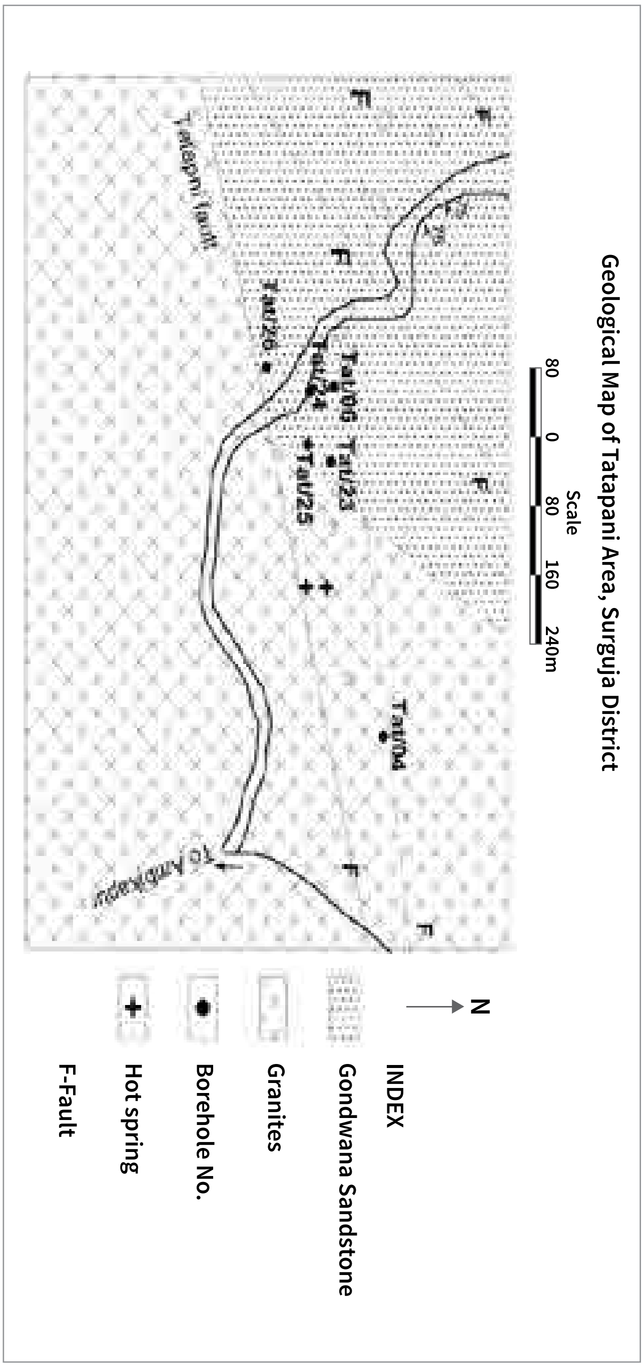

FIGURE 3. Geological map of Tatapani Geothermal Field, Chhattisgarh

Location

Archaean rocks comprising biotite-chlorite schist, biotite gneiss, and few calc-granulite bands cover the area. Precambrian pink porphyritic granite with biotite is exposed south of Tatapani. The pink granite shows the effect of shearing causing alignment of biotite. The fault zone is marked by injections of a quartz vein. The area north-west of Tatapani exposes green shale and siltstone of Talchir Formation, basal conglomerate and feldspathic, coal-bearing Barakar sandstone of Gondwana Supergroup (Fig. 3).

Structure

A fault trending ENE - WSW with sub-vertical dips is noticed near Tatapani village, separating sandstone of Gondwana Supergroup and Archaean/ Precambrian rocks (Patbhaje 2014). The fault is marked by a thick shear zone comprising hard brecciated pink granite and quartz veins. Cross faults trending NE -SW directions are found near village Newadih and Tatapani (Fig 3). The hot springs are mostly confined to this fault system.

Discharge

The hot springs and boreholes at Tatapani were monitored since 1991. The hot springs show temperature varying from 52°C to 97°C. Twenty-six boreholes were drilled, out of which five boreholes GW/tat/6, 23, 24, 25 and 26 discharge water of 104°C (in Tat/25) to 109°C (in Tat/23) on the surface. The discharge of borewells varied from 270 lpm in Tat/6 to 460 lpm in Tat/24. The initial discharge of five bore wells was 1800 lpm, which has reduced to 1125 lpm due to caving and blockage in Tat /24. At Tatapani, the fact that the flow rate is high, that they emerge at near boiling point of water at atmospheric pressure but in association with a gas phase of clear meteoric signature, suggests the presence of a very well developed convective circuit (Misissale and others, 2000).

Chemical analysis

The chemical analysis of water at Chemical Laboratory, GSI Nagpur indicates that thermal water is mostly bicarbonate sodium type with rather high HCO_3 and moderate Cl and SO_4 content. The pH of thermal water ranges from 7.7 to 9.0, chloride content varies from 68 to 140 ppm, TDS from 491 to 545 ppm, SO_4 ranges from 52 to 76 ppm, HCO_3 28 to 169 ppm, sodium varies from 100 to 146 ppm, magnesium, calcium and potassium content is low; SiO_2 varies from 131 to 161 ppm, Boron <1 ppm and fluorine content varies from 10 to 20 ppm (Sarolkar & Mukhopadyay, 1998). The thermal water contains low arsenic and high fluorine.

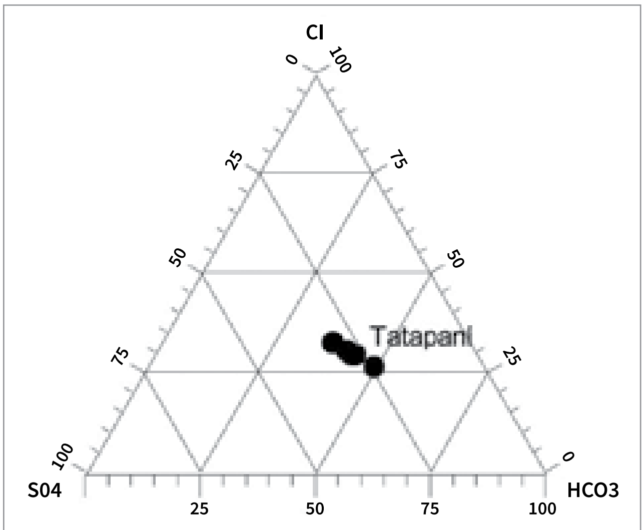

FIGURE 4. Cl-HCO_3-SO_4 ternary diagram, Tatapani

The ternary Cl- SO_4 -HCO_3 diagram (Fig.4) shows that Tatapani thermal water is the mixed chloride-bicarbonate type (Sarolkar 2005). The thermal water falls in the HCO3 field with minor sulphate content. The above observation is supported by Na-K-Mg ternary plot, which shows that the thermal water samples from Tatapani plot in Mg field (Fig.5) suggesting that the thermal water is immature, and may not represent the geothermal water from the deep reservoir (Giggenbach, 1997).

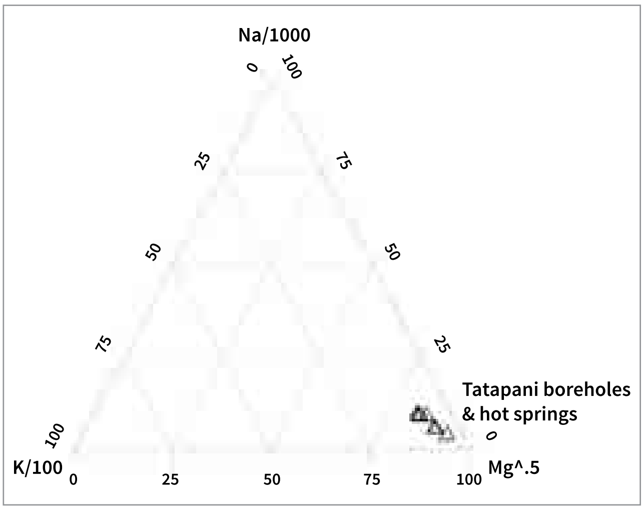

FIGURE 5. Na-K-Mg ternary diagram, Tatapani

This suggests that the Tatapani thermal water is mostly meteoric water heated during percolation to the shallow reservoir and mixed with ground water during ascending to the surface. The deep reservoir geothermal water is still not encountered in the bore wells. Uniform boron content points to the common source of water (Wright 1991).

Isotope Study

The oxygen and deuterium isotope study of Tatapani is depicted in Fig.6. The oxygen isotope study of Tatapani thermal water indicates that the thermal water is mostly meteoric in origin. (Misissale et al., 2000). The thermal water from the bore well Tat/26 shows enrichment in ^{18}O content as compared to the other water samples.

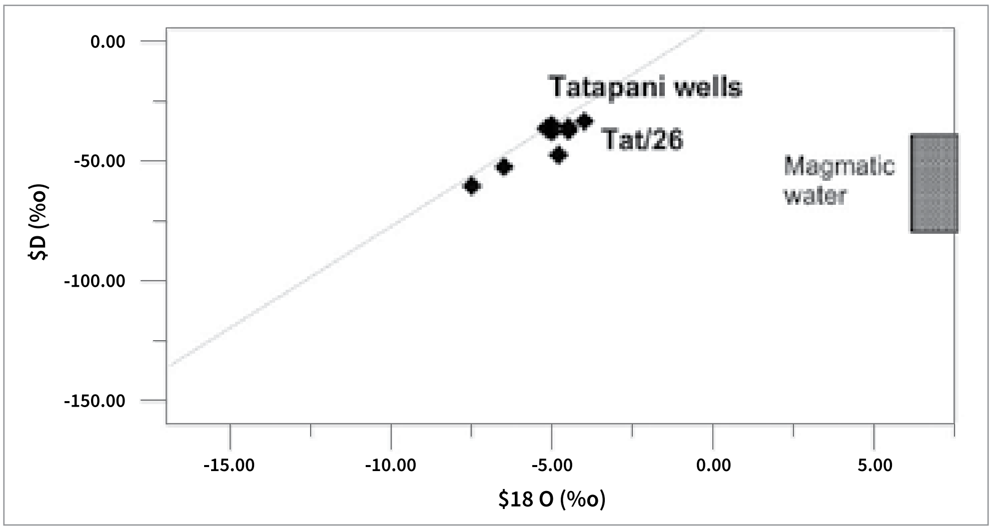

FIGURE 6. Plot of isotope content of thermal water

The bore well Tat/26 has a maximum ^{18}O shift, which may be due to some water-rock interaction (Sharma 1996). The isotope analysis has confirmed the meteoric origin of thermal water at Tatapani. Tritium content in Tatapani water indicates residency period of 30-40 years (Thussu et al. 1987).

Reservoir Temperatures

The indicated reservoir temperatures were calculated by silica and Na/K geothermometers (Table 2). The silica geothermometer shows 137°C to 166°C, while Na/K geothermometer indicates reservoir temperature of 168°C to 237°C. The quartz (Fournier, 1979, 1981) and K-Mg thermometer tends to respond more quickly to sharp cooling gradients and subsequent re-equilibrium (Simmons et al. 1994), which may explain the discrepancy in reservoir temperatures indicated by quartz solubility and Na-K method. The hot water shows mixing at a shallow level, suggesting that temperatures by Na/K method may be more appropriate. Thus, the indicated reservoir temperature at Tatapani is probably > 180°C.

Sl no.	Method	Min. Temp	Max. Temp
1.	Silica, max steam loss	137°C	152°C
2.	Silica, no steam loss	128°C	166°C
3.	Na/ K(F)	168°C	217°C
4.	Na / K(G)	177°C	232°C

TABLE 2. Reservoir temperatures indicated by aqueous geo thermometers

Geophysical Survey

Deep resistivity surveys at Tatapani show the presence of low resistivity zone at the depths of 300 m and 600 m, respectively. The AMT surveys have indicated the zone in the sub surface, close to the hot springs, which may correspond to the hot water formation (Joga Rao et al. 1987). AMT survey at Tatapani has depicted an elongated E-W trending telluric low, suggesting the presence of a conductive zone in this direction. (Harynarayan, 1998). The Tatapani MT anomaly is associated with a narrow conductive fault /fracture zone extending to deeper levels in addition to shallow aquifer with a width of about 3 km (Harinarayan, 1998).

Fluid Inclusion

Fluid inclusion studies on primary and secondary inclusions in quartz vein and calcite / zeolite, in cavity fillings, show Th of 139° to 258°C, during the heating cycle. Nearly 47% fluid inclusions measure Th of >200°C and 38% measure Th of 150°C to 200°C. Rest of the inclusions measure Th of <150°C. Thus, fluid inclusions suggest reservoir temperature around 200°C. The temperature of melting (Tm) of fluid inclusions ranges from -0.3°C to –21.5°C, corresponding to salinities ranging from 0.5%o to 23.3%o with an average of 8.9%o, NaCl equivalent. The low salinity of most of the fluid inclusions suggests a meteoric origin for the geothermal waters.

Hydrothermal alteration

Hydrothermal alteration is controlled by temperature, permeability and pressure conditions in a geothermal reservoir. The hydrothermal minerals at Tatapani are smectite, illite, stilbite, quartz, albite, laumontite, chlorite, calcite and pyrite. Widespread silica sinter observed in the area suggests that the geothermal fluid was alkali chloride type. The smectite-illite, and calcite hydrothermal assemblage in boreholes up to 200 m depth indicate that the geothermal field was in the range of 160°C -180°C. Similarly, the laumontite suggests a maximum temperature of 240°C to 250°C (Liou, 1971). At Tatapani, platy calcite is reported at two levels 60 m and >120 m, indicating that the zone of boiling shifted to greater depths with times. Hydrothermal epidote provides unequivocal evidence of temperature in excess of 250°C during hydrothermal activity (Absar, 1991). Microscopic studies revealed the presence of epidote, suggesting that the TGF had attained a temperature of 250°C, in the past, indicating the possibility of higher temperatures at greater depths.

Sl no.	Method of Survey	Indicated temperature
1.	Geochemical aqueous Geothermometers	160 °C to 190°C
2.	Hydrothermal alteration	180°C to 250°C
3.	Fluid inclusion study	140°C to 250°C
4.	Discharge monitoring	138°C

TABLE 3. Inferred reservoir temperatures

Borehole testing

Pressure and temperature profile survey of the bore wells was carried out in collaboration with the ONGC (Fig.7). The maximum temperature recorded in borehole Tat/23 is 112.5°C, at a depth of >200 m. The bottom borehole pressure ranges from 21 bars in bore well Tat/26 at 210m to 34 bars at 350m depth in Tat/ 23. Static pressure in all the wells is higher than the hydrostatic head, and as a result, all wells are going to flow.

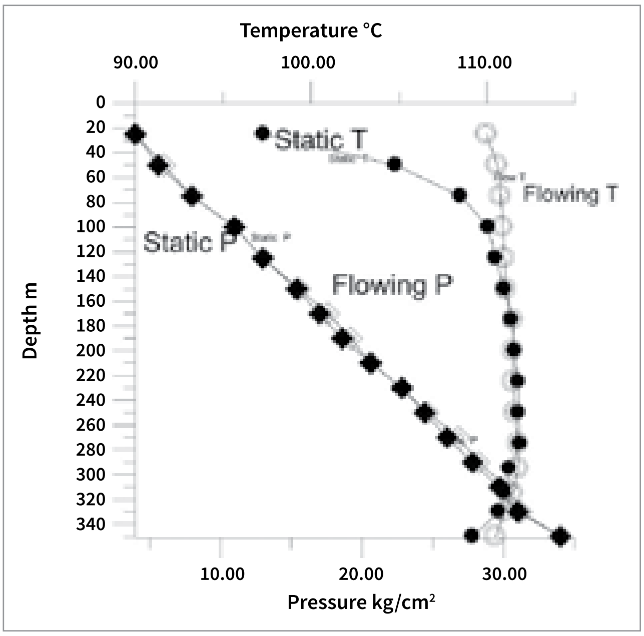

FIGURE 7. P & T profile of bore well Tat/23.

The temperature in the bore well shows a steady increase up to a depth of 250 m below which slight temperature inversion is recorded in boreholes Tat/6, 23 & 25. The permeability is mostly fracture controlled.

The estimated reservoir potential at Tatapaniupto 1500m depth is 11 MW (Sharma & Sud, 2000) to 18 MW (Pitale et al., 1996). The configuration of the geothermal reservoir is elliptical conical in shape (Patbhaje 2014). The binary cycle power potential at a depth of 1500m to 2000m is estimated to be 30 MW, at a temperature of 150°C.

Environment

The thermal water is mostly alkaline with low TDS and low toxicity. The main pollutants are silica, arsenic (2 ppb) and fluorine (10-20 ppm). Monitoring of SiO_2 and F is essential during the production stage to assess pollution effect. Dilution by cold surface water with low fluorine content is low cost, feasible method for control of fluorine toxicity. Gases, H_2S (0.01 mole %) and CO_2 (12.9 mole %) are reported from the geothermal water.

Hot Springs of Gujarat

The main hot springs in Gujarat are Unai (55°), Dholera (42°C to 45°C), Tulsi Shyam (50°C to 60°C), Tuwa (63°C) and Barbara (43.5°). Besides these,numbers of hot springs ranging in temperature from 36° to 42°C are reported from Gujarat (GSI, 2002). Some boreholes drilled for oil exploration in Cambay basin have also reported water and steam.

PDPU is presently working at Dholera hot springs. The

Dholera hot spring contains Silica 12 to 16 ppm, TDS 4844 to 5120 ppm, Na 1107 to 1902 ppm, K 16.6 to 26.7 ppm, Ca 95 to 146ppm, Mg 39 to 72 ppm, Cl 2426 to 4319 ppm, SO4 12 to 56ppm, bicarbonate 40 to 190 ppm, B 3.88 to 4.6 ppm (Shah et al , 2017). Temperatures of 60°C to 75°C is indicated by silica geothermometer and 97°C to 134°Cby Na/K method, for Dholera hot springs. The temperatures estimated from the cross-plots and the Geothermometric analyses show that the springs were a part of the low enthalpy geothermal reservoir system. It is also evident that there is significant mixing of the geothermal waters being produced with the deeply seated circulation system even though the region is located in a sedimentary area (Shah et al., 2017).

Unai hot spring near Surat, reported Silica 16 to 32 ppm, Na 158 to 340 ppm, K 10 to 15 ppm, Cl 345 to 540 ppm, SO4 42 to 108 ppm, HCO3 42 to 126 ppm (Sahajpal et al., 2015). The indicated reservoir temperature is 71°C to 86°C by silica method and 178°C to 217°C by Na/K method. MT survey has suggested that a shallow aquifer body is identified below the hot spring, where a temple exists. It is believed, that if a well is drilled up to 1 km, the same may encounter this shallow reservoir (Sahajpal et al., 2015). The temperatures indicated by silica geothermometer are low suggesting probable mixing of saline water at a shallow level. The water analysis by GSI (2002) and PDPU (Shah et al., 2017, Sahajpal et al., 2015), indicated reservoir temperature as mentioned below.

Sample by	Location	T SiO_2	TSiO_2	T Na/K
GSI, 2002	Tulsi1	137	139	202
	Tulsi2	133	134	187
	Dholera	84	86	118
	Tuwa1	83	84	-
	Tuwa2	122	123	88
PDPU (2015 & 2017)	Unai1	71	72	217
	Unai2	86	87	178
	Unai3	86	87	151
	Dholera 1	55	56	134
	Dholera 2	64	65	97

TABLE 4. Indicated reservoir temperature of hot springs of Gujarat

The reservoir temperature indicated by silica and Na- K method differ much, suggesting that the silica content is modified during ascending to the surface, by conductive cooling or mixing with shallow water. Considering this, a hot water sample from below the ground water level will be useful in getting actual geothermal parameters.

The available data suggest that besides Unai and Dholera geothermal prospects, Tulsi Shyam hot spring area is also a promising area for investigation.

Utilization

Besides power generation, the hot water can be utilized for different low temperature, uses in industry and tourism (Lindal 1979).

Binary cycle power plant (Temperature 140°C to 100°C)- The hot water is used to vapourize a fluid of low boiling point which is used to generate electricity. Useful in hot springs of the Himalayan belt, Tatapani Chhattisgarh, Bakreshwar West Bengal, West Coast and hot springs of Gujarat.

Refrigeration for the preservation of fruits and vegetables (Temperature >100°C): The effluent water from the proposed power plant at Puga, Ladakh, Manikaran, Tapoban Himalayan belt, Tatapani Chhattisgarh, Cambay basin, West Coast, Gujarat, geothermal prospects may be used for refrigeration plant of ammonia absorption type.

Greenhouse (Temperature required, 50°C-80°C): The hot water can be used in space heating and hot bed heating in green hose cultivation. Useful at Puga, chhumthang field in Ladakh, Manikaran, Tapoban, Parbati valley in Himalayan belt, Tatapani in Chhattisgarh, Gujarat, West Coast area.

Food processing - Fruits and see-weed drying, drying of vegetables, onions,and fishes, food processing (Temperature <100°C): Used for the food processing industry. Possible at Tapoban, Parbati valley, Manikaran in Himalayan belt, Arunachal Pradesh, Gujarat, Cambay basin, West Coast.

Industrial uses - cement block curing, timber washing, sericulture (Temperature 80-140°C): The low-temperature hot water is used for sericulture, cement block curing, vegetable cleaning,and small-scale industrial uses. Possible at Puga, Manikaran, Parbati valley, Sohna, Tatapani distt Surguja, West Coast, Bakreshwar, Cambay basin, Surajkund, NE Region.

Aquaculture and agriculture, crocodile farming (Temperature <60°C): The hot water of specific composition and temperature is used for aquaculture. Useful in Manikaran, Tapoban, Parbati valley in Himalaya, Arunachal Pradesh, Gujarat, Tatapani Chhattisgarh, Bakreshwar West Bengal, Puga-Chhumthang in Ladakh, Manuguru in Andhra Pradesh.

Tourism, Spa, Swimming pool (Temperature >40°C): Almost all geothermal localities. Puga-Chhumthang, Parbati valley, Manikaran, Tapoban, Tatapani Chhattisgarh, West Coast, Manuguru in Telangana.

Extraction of rare metals, Mineral water industry (Temperature required, >30°C): separation of borax, sulphur, and helium from hot water at Tatapani, Chhattisgarh (Ag, He). Deposition of silver is recorded in the scaling on discharge pipes of boreholes at Tatapani, Dist. Surguja (Pitale et al. 1995).

Conclusion

The hot springs located at Puga, Manikaran, Tapoban in Himalayan belt, Tatapani in Chhattisgarh, Bakreshwar in West Bengal, Manuguru in Telangana are active geothermal systems in India. The investigation at Tatapani geothermal field indicated reservoir temperature of 180°C to 200°C, which is useful for installation of binary cycle geothermal power plant. Besides, direct heat uses like spa, hot water bath, tourism, sericulture, cold storage,etc., may contribute to developing local industry in remote places. The hot springs at Dholera & Unai Gujarat, show cold water mixing at a shallow level. Investigation to a deeper level is necessary to assess the actual potential of these geothermal prospects.

Acknowledgment

The author is thankful to the editors for providing an opportunity to present this article on the new energy source and to the scrutinizers for making it presentable.

References

Absar A (1991): Hydrothermal epidote- an indicator of temperature and fluid composition, Journal of Geological Society of India, vol. 38, 623-628.

Fournier R. O. (1979): A revised equation for the Na/K geothermometer, Geothermal Resources Council, transactions vol.3, 37-69.

Fournier R.O. (1981): Geothermal systems, principle and case histories, John Wiley, pp109-140

Giggenbach W.F. (1997) The origin and evolution of thermal fluids in magmatic -hydrothermal systems in Geochemistry of hydrothermal ore deposits, editor Barnis H.S,Wiley interscie. pp 737-789

GSI (2002) : Geothermal energy resources of India, Edited by J.L. Thussu, Geological Survey of India, Sp. Pub. No. 69, 152-177.

Harinarayan T & Sarma S.V.S. (1998): Deep electrical conductivity investigations in some geothermal areas of India, Deep electromagnetic exploration, editor Roy K.K., Narosa Publishing House, New Delhi, pp 160-175.

http:/CEA, hindubussinessline.com

Joga Rao M.V., Rao A.P., Midha R.K., Padmanabhan K, Kesavmani (1987) Results of geophysical Surveys in the Tatapani Hot Spring area, Distt. Surguja,M.P., Records GSI, vol.115 pt 6, 66-83.

Krishnaswamy V.S. and Ravishanker (1982): Scope of development, exploration and preliminary assessment of geothermal resources potential of India, Records GSI, Vol. VIII, pt2, -17-40.

Lindal B. (1979): Industrial and other applications of geothermal energy, Geothermal energy edited by H.C.H. Armstead, Earth science vol.12, p-135-148.

Liou J.G.(1971) : P-T stabilities of laumontite, wairakite, lawsonite and related in the system CaAl2Si2O8-SiO2-H2O, Jour.Petrol. vol.12, 379-411

Manan Shah , Anirbid Sircar , Shreya Sahajpal , Prakhar Sarkar , Darshan Sharma , Shivani Garg , Trisha Mishra and Yatharth Shukla (2017): Geochemical Analysis for Understanding Prospectivity of Low Enthalpy Geothermal Reservoirs of Dholera, PROCEEDINGS, 42nd Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, February 13-15, 2017, SGP-TR-212

Misissale A, Vaselli O, Chandrasekharam D, Magro G, Tassi F,and Casiglia A, (2000): Origin and evolution of "intracratonic" thermal fluids from Central –Western peninsular India, Earth and Planetary Science letters, 181, 377-314.

Padhi R.N. and U.L.Pitale (1995): Potential geothermal fields in the context of national scenario on non conventional energy resources development programme in India. Procee. WGC 1995, 525-530.

Patbhaje S. D. (2014): Review of Geothermal investigation at Tatapani, Chhattisgarh, Records GSI, Vol 149, pt 6, 223-225.

Pitale U.L., Sarolkar P.B., Rawat H.S Shukla S.N,(1996) The geothermal reservoir at Tatapani Geothermal Field, Surguja district, Madhya Pradesh , India, 21rst Stan. geoth workshop, 1996, 565-57

Sarolkar P. B. (2005) : Status of investigation at Tatapani geothermal field, Surguja district, chhattisgarh, india and future perspective, proceedings World Geothermal Congress 2005, Antalya, turkey, 24-29 April 2005

Sarolkar P.B and Mukhopadhyay D.K. (1998): Geochemistry of thermal water from production wells, Tatapani geothermal field, India, GRC transcactions, vol.22, 129-135.

Sharma S.K. and Sud V.K. (2000): Technological developments and applications for harnessing geothermal energy, Bulletin of ONGC, Vol.34, No. 2, 81-92.

Sharma Suman, Nair A. R, Kulkarni U.P, Navada S.V., Pitale U.L. (1996): Isotope and geochemical studies in Tattapani Geothermal area, Surguja district, Madhya Pradesh, Geothermal energy in India, GSI Sp .Pub no.45, 223-232.

Shreya Sahajpal, Anirbid Sircar, Anjali Singh, Dwijen Vaidya, Manan Shah, Shubhra Dhale (2015): Geothermal Exploration in Gujarat: Case Study from Unai, www.ijltemas.in Page 38, Volume IV, Issue V, May 2015 IJLTEMAS ISSN 2278 - 2540

Simmons S.F, Stewart M.K, Robinson B.W, Glover R.B.(1994): The chemical and isotopic composition of thermal waters at Waimangu, New Zealand, Geothermics, vol. 23, no.5/6,239-553.

Thussu J.L, Prasad J.M., Saxena R.K., Gyan Prakash, Muthuraman K. 1987: Geothermal energy resources potential of Tatapani hot spring belt , district Surguja, M.P., Geo, Surv. Ind, rec. Vol.115,pt 6, 29-55.

Wright Phillip M 1991: Geochemistry, GHC bulletin, Jan '91, 8-12.

Dr. P. B. Sarolkar
Former Director General,
Geological Survey of India
E-mail: *psarolkar@yahoo.co.in*

2

PERFORMANCE MONITORING OF HIGH-EFFICIENCY MAXEON™ BASED SUNPOWER PV PLANT IN THE COMPOSITE CLIMATE OF INDIA

Rashmi Singh[1,2], Madhu Sharma [2], Chandan Banerjee[1]

[1] National Institute of Solar Energy, Gurugram, India
[2] University of Petroleum and Energy Studies, Dehradun, India

ABSTRACT: The real-time performance monitoring of the photovoltaic system provides useful data to validate performance modeling techniques. This paper presents a case study of long-term performance monitoring of high-efficiency Maxeon™ based SunPower solar plant installed at the National Institute of Solar Energy, Gurugram, India. The paper focuses on the suitability of high-efficiency SunPower solar technology in the composite climate of India by the analysis of the Performance Ratio (PR) and Thermal normalized PR (PR_{STC}). The estimation of the thermal factor, as well as the spectrum factor, is also done in the paper. The average PR and the PR_{STC} found to be maximum in June and minimum in December month. PR of the SPV system correlates with the four seasons and temperature of the SPV module, as the key feature of assessment. It has been found out that the range of PR is 0.94-0.96 during winter, 1-1.01 during summer, and 0.95-0.98 during the post-monsoon and 0.93-0.98 during Monsoon.

KEYWORDS

SunPower, IEC 61724, Seasonal Performance, Performance Ratio, Degradation

Introduction

Many countries in the world deployed solar energy into their daily consumptions as an alternative to conventional energy sources (Kabir et al., 2018). The National Solar Mission (NSM) formerly recognized as Jawaharlal Nehru National Solar Mission (JNNSM) is an ingenuity of the Indian Government and State Governments to increase renewable source utilization, exclusively solar energy in India. The mission under the guidance of Ministry of New and Renewable Energy (MNRE) will approve a 3-phase tactic, first year (up to 2012-13) of the 12th Plan as Phase 1, the Phase 2 as the 12th Plan (2013–17) and Phase 3 is the 13th Plan (2017–22) (Purohit and Purohit, 2018). The original 22GW solar energy target by 2022 under the JNNSM has been recently revised to 100GW, which would require rapid development in solar installations throughout the state in the upcoming age. India increased its cumulative solar power generation (Ground Mounted) capacity by about 21892.42 MW on 31st July 2018 (Purohit and Purohit, 2018), (*https://mnre.gov.in, 2017*). To endure economic growth, to come out of the energy scarcity situation and ensure that energy is usable in every township and village, India must use its huge potential in a sunlight-based generation (Pandey et al., 2016).

The solar module is evaluated under Standard Test Condition (STC), i.e., air mass 1.5 spectral distributions, an irradiance level of $1000W/m^2$ and the temperature of module is 25°C at 00 angles of incidence as per standard IEC 61215 (Wohlgemuth and Kurtz, 2014, IEC 61215). An environmental parameter like wind, humidity, ambient temperature, irradiation, and spectrum constantly changes with time which influences the output of the SPV modules installed in the field (Macalpine et al., 2016). Due to these altered conditions, the performance of SPV modules by standard testing condition may not be accurate and precise. Outdoor real-time performance analysis of the SPV module is important to recognize the viability and usability of the SPV modules in the different climatic conditions (Singh et al., 2018). The impact of the amount of wind flow, temperature variation, and electrical configuration over the functioning of building-integrated (BIPV) and building-applied (BAPV) SPV modules has been examined using experiments based on wind tunnel. The experiment has been done for four air gap thicknesses varying from 0cm (BIPV) to 5.5cm (BAPV) and five freestream approaching wind speeds from 1 to 5 ms^{-1} using with an inclined 3×2 SPV module. In the assessment, the BAPV module with the thickest air gap (5.5cm in this study) has been the optimum performance arrangement (Goossens et al., 2018). Gaglia et. al., 2017 has been presented a relevant data collection, utilizing a multi-crystalline PV array at the real-field experimental facility at the north of Athens. The SPV efficiency has been found out to be approximately 18% lesser than that under standard laboratory test conditions, under similar operating conditions (Gaglia et al., 2017). Balaska et al., 2017 has been done a performance evaluation of mono-crystalline heterojunction with an intrinsic thin layer (HIT), copper indium selenide (CIS), the tandem structure of amorphous silicon, microcrystalline silicon (a-Si_mc-Si), multi-crystalline and mono-crystalline back contact. It has been found out that a-Si_mc-Si and HIT performed much superior than the other SPV technologies. The annual average daily performance ratio of the a-Si_mc-Si module has been found out to be around 1.55% higher in comparison to HIT module and 2.04% in comparison to CIS module (Balaska et al., 2017). Singh et al., 2016 has been estimated the uncertainty in the measurements of power matrix values using indoor test conditions as per IEC 61853-1. During the experiment, it has been found out that the spectrum of the light source is changing with irradiation (Singh et al., 2016). Singh et al., 2015 has been done an analysis of the impact of series resistance on electrical parameters of HIT module. By increasing the series resistance of the modules, there is a decrement in the fill factor, power and Isc (Singh et al., 2015).

From the above literature review, a comprehensive investigation of the performance monitoring of SPV system needed to be done for the forecasting and modeling of solar power plant system. It is also beneficial in the future to improve the power plant scheme development and the demand side management. Dependability analysis of the SPV module enables us to guarantee the commercial feasibility at a specific position. The performance of the SPV system, installed in different climatic zones is a function of the environmental and native conditions. Unless a detailed examination is carried out for the site, it is difficult to foresee the performance and energy production competence. It becomes important to carry out outdoor field test and scientific investigation of the statistics for the site-specific power plant.

The present work demonstrates the real-time performance monitoring of high-efficiency Maxeon™ based SunPower SPV plant in the composite climate of India. The aims are to evaluate the suitability of high-efficiency SPV technologies under Indian climatic conditions. Performance of Maxeon™ based SunPower technology SPV plant in the composite climate zone of India has been analyzed by performance ratio (PR), the spectrum and thermal normalized PR (PR_{STC}). The varying performance based on the monthly data has been also presented in the paper.

Materials & Methods

The 3.2 Kwp SunPower system is installed at the National Institute of Solar Energy, Gurugram, India (Latitude 280 37 N, Longitude 7704 E). The average ground altitude is 217 meters (712 ft) above sea level. Gurugram encounters a monsoon-influenced Composite climate by the Köppen climate classification (Singh et al., 2018).

Materials

To examine the real-time outdoor conditions, an experimental test-bed facility of high-efficiency SunPower array containing 5 SPV modules at NISE, Gurugram is shown in Fig 1.

The test-beds are installed for testing, performance evaluation, and validation of suitable SPV module for a specific climatic situation. The details of the I-V tracer along with the temperature and radiation sensor accuracy is provided in Table 1.

Model	PVPM2450C
Voltage DC (V)	Accuracy ± 2% for voltage
Current DC (A)	Accuracy ± 2% for current
Temperature	-40°C - +120°C with pt1000
Irradiance	Model: SOZ-03, 0-1300 W/m^2

TABLE 1. TI-V tracer along with the temperature and radiation sensor accuracy

FIGURE 1. A testbed of The Maxeon™ based SunPower technology along with I-V curve tracer PVPM

The array consists of five SPV modules connected in series with each other, an I-V tracer for continuous data logging of electrical output, along with a reference cell having same tilt with the tilt of modules to measure in-plane global radiation and a temperature sensor attached to the back of the module to record the module temperature data. Each SPV module comprises 96 cells having single cell area of 156.25 sq.mm. The SPV modules specification are given in Table 2.

Modules Parameter	Specifications
Technology Make	SunPower Technology
No. of solar cells in series	96
Maximum power (W)	327
Maximum voltage (V)	54.7
Maximum current (A)	5.98
Open circuit voltage (V)	64.9
Short circuit current (A)	6.46
Temperature coefficient of voltage	- 176.6 mV/K
Temperature coefficient of current	3.5 mA /K
The temperature coefficient of power	- 0.38 %/K
Cell Efficiency	22.5%

TABLE 2. Technical specification of the Maxeon™ based SunPower SPV module

Electrical and environmental data are recorded at every single 10 second interval of time using four probe connectors. The spectrum data is calculated using The Simple Model of the Atmospheric Radiative Transfer of Sunshine (SMARTS) software provided by the National Renewable Energy Laboratory (NREL). All modules are cleaned regularly to avoid dust deposition or other dirt like the bird dropping effect on the output.

Methods

To analyze the performance monitoring of SPV plant, performance indicators i.e. performance ratios, reference yield, and final yield are calculated as endorsed in IEC 61724 standard (IEC 61724).

Performance monitoring of the SPV system

The International Electro-Technical Commission (IEC) printed the international standards in 1998 which described parameter for the performance monitoring. As well-defined in IEC 61724 the performance ratio specifies the total impact of failures on the PV system rated due to array temperature, inadequate utilization of the radiation and component inadequacies or breakdowns. The final yield of the PV module is expressed as the ratio of the final or actual energy output of the to the total power of the SPV module under STC. The expression of the final yield is expressed as,

$$\text{Final Yield } (Y_f) = \frac{\text{Final Energy Output (kWh)}}{\text{Maximum Power,}_{STC}\text{ (kW)}} \quad (1)$$

The reference yield (Y_r) is described as the ratio of total in-plane irradiance to that of the irradiance in a unit area defined under STC and is expressed with below;

$$\text{Reference Yield } (Y_r) = \frac{\text{Total in-plane Irradiance}\left(\frac{kWh}{m^2}\right)}{1000\left(\frac{kW}{m^2}\right)} \quad (2)$$

The SPV reference irradiance at the STC is equivalent to the 1000 W/m². From the above equation, the reference yield is a site-specific factor. The performance ratio (PR) is defined as the ratio between the final yield of the system (Y_f) to the reference yield (Y_r). PR has been used for the comparative study and performance monitoring of the SPV system in different climatic zones. The expression of the PR is as follows,

$$\text{Performance Ratio (PR)} = \frac{\text{Final Yield } (Y_f) = \dfrac{\text{Final Energy Output (kWh)}}{\text{Maximum Power}_{STC} \text{ (kW)}}}{\text{Reference Yield } (Y_r) = \dfrac{\text{Total in-plane Irradiance} \left(\frac{kWh}{m^2}\right)}{1000 \left(\frac{kW}{m^2}\right)}} \tag{3}$$

For simplification of the understanding, it may be written as,

$$\text{Performance Ratio (PR)} = \frac{\text{Final Yield } (Y_f)}{\text{Reference Yield } (Y_r)} \tag{4}$$

The PR offers the part of the yield of an SPV system in outdoor climatic circumstances concerning the yield at STC normalized input solar radiation. In this manner, the PR has been standardized to PR at STC (PR) with module temperature using the thermal factor (T_f) and spectrum using spectrum factor (S_f).

$$T_f = \frac{1}{1 + \gamma_p (T_m - T_{STC})} \tag{5}$$

Where T_f is a thermal factor, T_m is the temperature of the module, T_{STC} is a standard test condition temperature and γ_p is the temperature coefficient of power at the maximum power point of SPV the module.

$$S_f = \frac{\int \zeta STC(\lambda) . SR(\lambda) \, / \int \zeta(\lambda) . SR(\lambda) d\lambda}{\int \zeta STC(\lambda) . d\lambda \, / \, \zeta(\lambda) d\lambda} \tag{6}$$

Where S_f is spectrum factor, ζSTC is standard spectrum at STC, ζ is the solar spectrum of the place, SR is the relative spectral response of the SPV technology, and λ is the wavelength (nm). The PR_{STC} of SPV module can be determined by

$$PR_{STC} = PR \times T_f \times S_f \tag{7}$$

The methodology followed for the data collection, filtration and for the calculation of the performance ratio and thermal normalized performance ratio is shown in Fig 2.

Results and Discussion

The experimental data have been collected for one complete year. The data have been filtered on the basis of a predetermined factor for the calculations presented in Fig. 2. Based on the experimental data, the performance ratio, thermal factor, spectrum factor and the normalized performance ration has been calculated using IEC 61724.

Using the thermal factor and spectrum factor the normalized performance ratio has been calculated for twelve months. The difference in the PR between the PR_{STC} has been calculated and shown in Fig. 3, and it has been found out that PR_{STC} is higher than the PR due to normalization of the thermal effects occurring over the module surface. The experimental results reveal that the performance of the SunPower modules is stable throughout the year, however, lowest performance has been observed in the may due to the high temperature. The highest performance is observed during the winter season when the surface of the SPV module is low.

From Fig. 3, the year PR of the SunPower is higher than the 0.90 which is quite good for outdoor field-based technology. The most constant PR values are 0.965 on a yearly basis. There is a significant impact of the irradiance and the temperature over the solar PV plant, however, the results presented here were normalized in case of PR_{STC}.

The calculated data has been divided into four seasons, i.e. winter from mid-November to mid-March, summer from mid-March to end-June, and the monsoon from starting-July to mid-September, post-monsoon from mid-September to mid-November. The performance ratio of each season has been shown in Fig. 4.

The performance ratio has been found out that in the range of 0.94-0.96 during winter, 1-1.01 during summer, and 0.95-0.98 during Post-monsoon and 0.93-0.98 during Monsoon. Change in the module temperature gained by the SPV modules in a different season is one of the key reasons for a varying performance over a year.

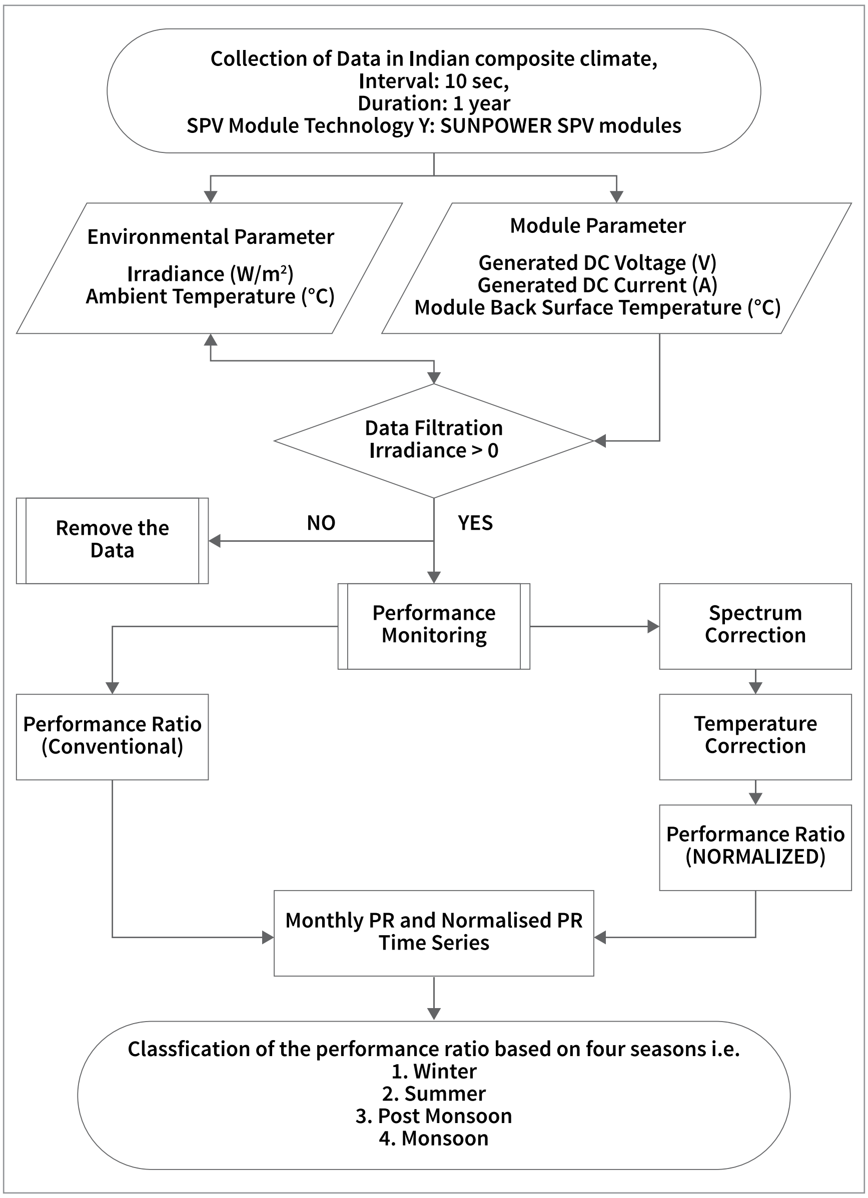

FIGURE 2. Flow-chart of the procedure followed for the performance monitoring

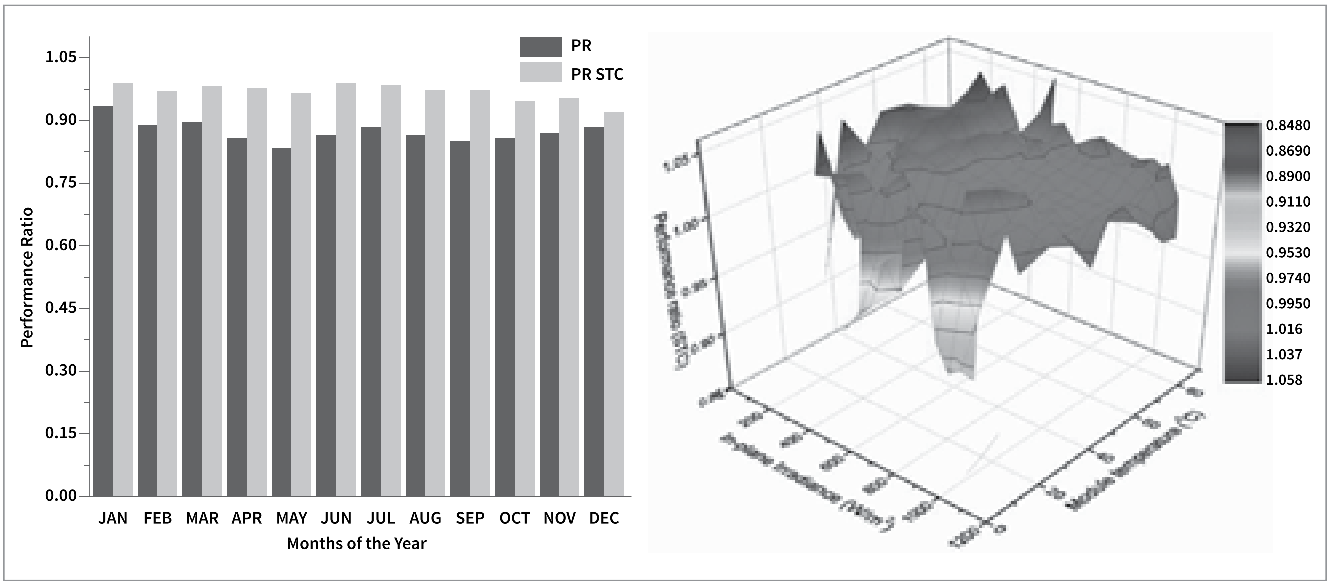

FIGURE 3. (a) Monthly average daily performance ratio and (b) Yearly performance ratiomonitoring

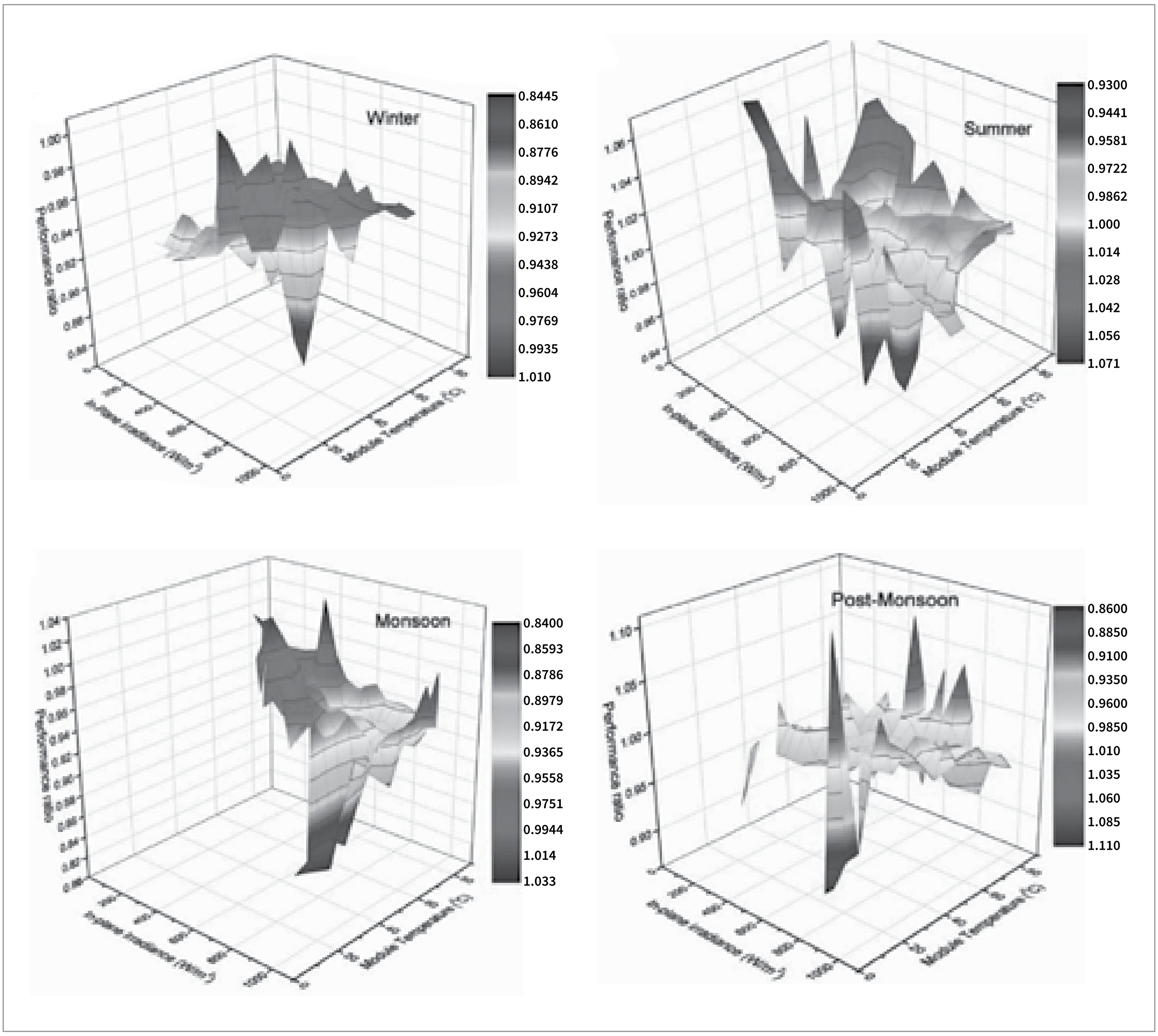

FIGURE 4. Seasonal variations in the performance ratio of the SunPower SPV Plant

Conclusion

Energy generation and utilization of the renewable sources, mainly SPV system would result in a positive impact on the environment. The paper focuses on the suitability of high-efficiency SunPower solar technology in the composite climate of India based on the Performance Ratio (PR), Thermally normalized PR (PR_{STC}). The high efficiency of the plant has been observed in the higher range of irradiance. The SunPower technology is well suited to the climatic zone having normal to high irradiance and temperature.

The analysis of the SPV performance under outdoor field conditions takes into account an ideal evaluation and forecasting the energy output. The proposed associations take into account the seasonal variation of irradiance and temperature that can be used to estimate the performance of SPV power plant under composite climate, thus reducing the probability of over or under sizing the plant design.

References

Balaska, A., Tahri, A., Tahri, F., Stambouli, A.B., 2017. Performance assessment of five different photovoltaic module technologies under outdoor conditions in Algeria. Renew. Energy 107, 53–60. https://doi.org/10.1016/j.renene.2017.01.057.

Gaglia, A.G., Lykoudis, S., Argiriou, A.A., Balaras, C.A., Dialynas, E., 2017. Energy efficiency of PV panels under real outdoor conditions–An experimental assessment in Athens, Greece. Renew. Energy 101, 236–243. https://doi.org/10.1016/j.renene.2016.08.051.

Goossens, D., Goverde, H., Catthoor, F., 2018. Effect of wind on temperature patterns, electrical characteristics, and performance of building-integrated and building-applied inclined photovoltaic modules. Sol. Energy 170, 64–75. *https://doi.org/10.1016/j.solener.2018.05.043 https://mnre.gov.in/(physical achievements).*

IEC 61215: Crystalline silicon terrestrial photovoltaic (PV) modules Design qualification and type approval.

IEC 61724: Photovoltaic system performance monitoring - Guidelines for measurement, data exchange and analysis.

Kabir, E., Kumar, P., Kumar, S., Adelodun, A.A., Kim, K.H., 2018. Solar energy: Potential and future prospects. Renew. Sustain. Energy Rev. 82, 894–900. https://doi.org/10.1016/j.rser.2017.09.094

Macalpine, S., Deceglie, M., Kurtz, S., Bora, B., Sastry, O.S., Singh, Y.K., Singh, R., Rai, S., 2016. Analysis of a Single Year of Performance Data for Thin Film Modules Deployed at NREL and NISE.

Pandey, A.K., Tyagi, V.V., Selvaraj, J.A., Rahim, N.A., Tyagi, S.K., 2016. Recent advances in solar photovoltaic systems for emerging trends and advanced applications. Renew. Sustain. Energy Rev. 53, 859–884. *https://doi.org/10.1016/j.rser.2015.09.043*

Purohit, I., Purohit, P., 2018. Performance assessment of grid-interactive solar photovoltaic projects under India's national solar mission. Appl. Energy 222, 25–41. *https://doi.org/10.1016/j.apenergy.2018.03.135*

Singh, R., Bora, B., Sastry, O.S., Rai, S., Bangar, M., 2016. Uncertainty analysis in the power rating measurement of the solar cell as per IEC 61853-1 Uncertainty analysis in the power rating measurement of the solar cell as per IEC 61853-1.

Singh, R., Bora, B., Yadav, K., Sastry, O.S., Kumar, M., Kumar, A., Renu, Bangar, M., Rai, S., Kumar, A., 2015. Effect of series resistance on the degradation of Isc, power output and fill factor of HIT technology. 2015 IEEE 42nd Photovolt. Spec. Conf. PVSC 2015 1–5. *https://doi.org/10.1109/PVSC.2015.7356032*

Singh, R., Sharma, M., Os, S., 2018. Non-destructive in-situ performance monitoring of high-efficiency SPV modules using infrared thermography in a composite climate of India 2, 54–60. *https://doi.org/10.15406/mojsp.2018.02.00024*

Wohlgemuth, J., Kurtz, S., 2014. Photovoltaic Module Qualification Plus Testing. 2014 IEEE 40th Photovolt. Spec. Conf. PVSC 2014 3589–3594. *https://doi.org/10.1109/PVSC.2014.6924883*

Rashmi Singh
National Institute of Solar Energy, Gurugram, India
University of Petroleum and Energy Studies, Dehradun, India
E-mail: *rashmi.sees2012@gmail.com*

Madhu Sharma
University of Petroleum and Energy Studies, Dehradun, India

Chandan Banerjee
National Institute of Solar Energy, Gurugram, India

3

SOLAR DISTILLATION SYSTEM WITH NANO PARTICLE: A REVIEW

Ruchir Parikh[1], Dr. Umang Patdiwala[2]

[1]Ph.D. Research Scholar, Indus Institute of Technology, Indus University
[2]Assistant Professor, Indus Institute of Technology, Indus University

ABSTRACT: For all living entities water is the basic requirement. Ponds, lakes, rivers and underground water are major resources for fresh water. We know that availability of fresh water on the earth is very limited. Due to overpopulation and industrialization, the requirement of fresh water increases day by day. The ocean water has high saline content, hence it needs to be desaline first (Panchal & Patel, 2017). In this present review, we have discussed different desalination methods and improvements, which are needed to commercialize these methods. Also, we have discussed different parameters that affect the performance of distillation system. From different desalination techniques and desalination method which integrates with renewable sources, we can summarize that solar desalination is most effective technique as it does not require external power or any other conventional energy sources. Solar desalination is also effective at remotely located area, where energy and water are not easily accessible or costly to meet the requirements of people. A lot of investigations and research have been carried out and much more are ongoing. In solar distillation system, the major disadvantage is that it has low productivity; so optimization of certain parameters is required to enhance the productivity of the system. The recent researches are based on the concept of Nanotechnology. Few researchers have studied the effect of Nano fluid on the productivity and they found that it shows positive effects on the output of the distilled water.

KEYWORDS

Solar Distillation, Passive Solar Still, Nano Fluid

Introduction

Potable water is the basic need of every human being for their daily livelihood. A person living in remote areas or islands, where fresh water supply by transport is expensive, faces the problem of water shortage every day. Many methods are used to purify the dirty water but all such methods require a significant amount of energy. The energy resources such as oil, natural gas and electricity used in water purification process, have both high cost and environmentally hazardous. The modern studies carried out in recent years, focused on increase the use of renewable energy resources as an energy source for purification of water. Desalination is one of the methods for water purification.

Water Salinity based on dissolved salts			
Fresh Water	Brackish Water	Saline Water	Brine
<0.05%	0.05 - 3%	3 - 5%	>5%

TABLE 1. Level of Water salinity in different water solution (Gupta, Mandraha, Edla, Pandya, 2013)

Different types of desalination techniques are used to purify water. It can be classified according to the source of energy used like; thermal, mechanical, electrical and chemical energy and various processes like evaporation, condensation, crystallization, and filtration techniques. Few of the desalination technologies are still under development like a solar chimney, greenhouse, membrane distillation, membrane bioreactor (MBR), forward osmosis (FO) and ion exchange resin (IXR). Largely implemented distillation technologies are the reverse osmosis (RO) method followed by multistage flashing (MSF) and multi-effects desalination (MED) systems. Along with the productivity of system, it is important to know the amount of conventional energy required by the desalination processes to understand why we need to move toward the renewable and sustainable energy resources. In the global warming phenomenon, the contribution of the conventional desalination systems can be assessed by estimating the amount of the fossil fuel needed to be burned to produce a certain amount of fresh water. In the average, producing 1000 cubic meters of freshwater by desalination technology consumes about 5 tons of crude oil which produces about 10 tons of carbon dioxide or about 5000 cubic meters of greenhouse gases. The total global desalination capacity has witnessed a severe increase within the last few years, from 66.48 million cubic meters per day in 2011 to 86.6 million cubic meters per day in 2015. Therefore, important forward steps toward integrating the desalination systems with the renewable and sustainable energy technologies are required to mitigate the negative effects of the desalination systems. (Alkaisi, Mossad & Sharifian-Barforoush, 2017).

Solar Still (SS) presents certain advantages due to its like easy construction, minimum skills for operation and maintenance of equipment as well as environment-friendly make it more acceptable to be used in these areas. The clean free energy and environment-friendly are two major advantages which strengthen the use of solar stills. The low yield of freshwater is the crucial disadvantage of SS in comparison with the other desalination systems. The average production capacity for a simple type solar still is only between 2–5 l/m²/day. This makes the SS uneconomical compared to the other conventional desalination systems (Velmurugana & Srithar, 2011).

The basic principle of solar water distillation is very simple, yet effective, as distillation replicates the way nature makes rain. The sun's energy heats water to the evaporation temperature. As the water evaporates, water vapor generates. That vaporises and condenses on the glass surface for collection. This process removes impurities, such as salts and heavy metals, and eliminates microbiological organisms.

In the latest research, we find the application of Nanoparticle to enhance the productivity of SS. Nano-fluid has energy-absorbing properties due to which night productivity in both the cases of SS increased, due to the fact that at the time of high radiation, it absorbs energy and when it is needed, released it to the system (Velmurugan, Gopalakrishnan, Raghu & Srithar, 2008).

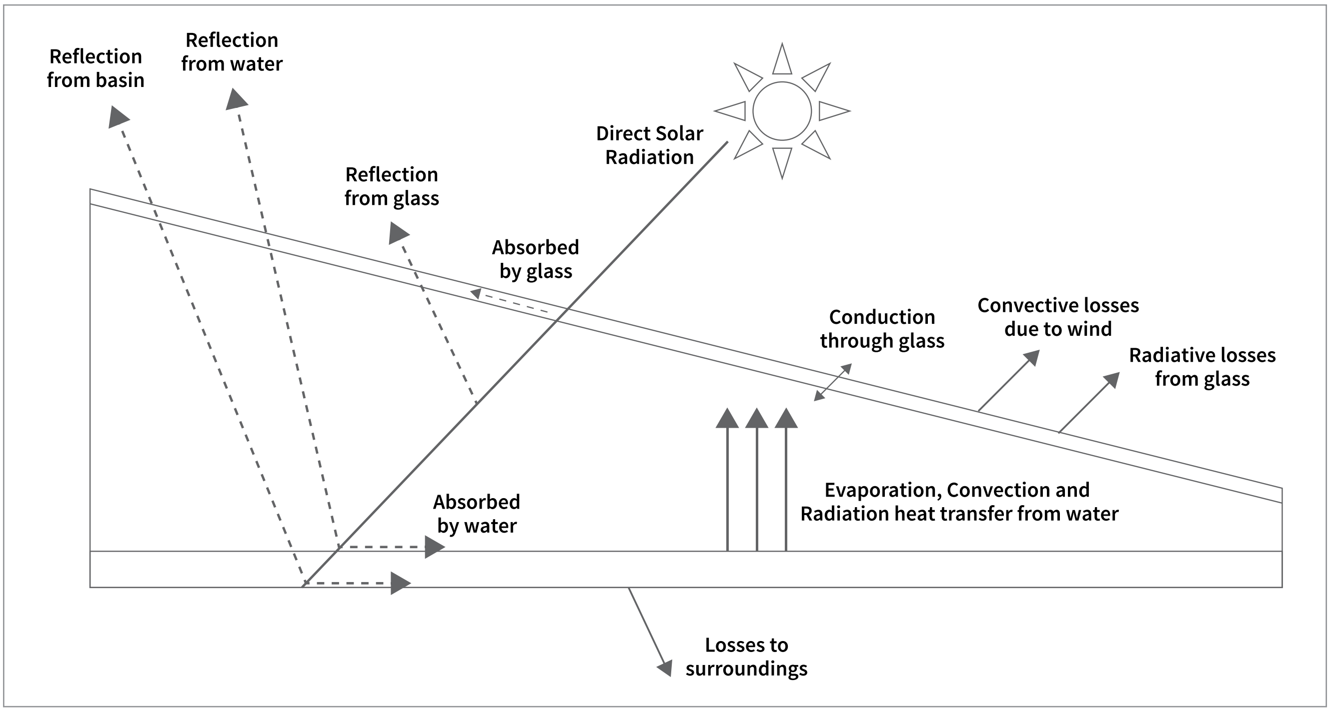

FIGURE 1. Simple solar water distillation process

No.	Name of the author	Enhancement method	% increase in production
1	El-Sebaii, Aboul-Enein & El-Bialy (2000)	Baffle suspended absorber	20%
2.	Nafey, Abdelkader, Abdelmotalip & Mabrouk (2001)	Black rubber with black gravel	20%
3.	Nafey, Abdelkader, Abdelmotalip & Mabrouk (2002)	Floating perforated plate	40%
4.	Hijileh Bassam & Rababa (2003)	Addition of Sponge	18%
5.	Badran Ali, Al-Hallaq Ahmad, Eyal & Odat (2005)	Solar still meshed with flat plate collector	52%
6.	Velmurugan et al. (2008)	Attachment of Fin	45.50%

TABLE 2. Percentage increase in production for various modifications

Several researchers have reviewed thoroughly on the recent work of solar stills such as classification of solar stills, design of solar stills, improvement techniques of solar stills, passive solar stills, active solar stills, inclined solar stills, stepped solar stills, wick type solar stills, and condensers with solar stills (Omara, Kabeel & Abdullah, 2017). The comparison of the performance of previous researcher's works is depicted in table 2 with reference to simple solar still.

Comprehensive reviews of different researchers on the development of Solar Still (SS)

Tanaka & Iishi (2017) researched on a single-effect diffusion still, instead of a multiple-effect diffusion still, combined with a tilted wick still was investigated experimentally. He was found that the single-effect still can be heated by vapor from the tilted wick still and solar radiation absorbed on the single-effect still. Thakur, Khandelwal & Sharma (2018) had been studied different methods of enhancing the productivity of solar still. Comparison of productivity of simple solar still having a water depth of 0.01 m has been done with solar still having nano fluid Al_2O_3 used in water basin and phase changing material in water basin for same depth. It was observed that productivity of SS reaches a maximum when nano fluid Al_2O_3 is used in water basin as compared to both cases. Due to heat storage capacity of nano fluid, the convective rate of heat transfer improves and finally productivity increases. Mahian, Kianifar, Heris, Wen, Sahin & Wongwises (2017) had analyzed the performance of a SS equipped with a heat exchanger using nano fluids both experimentally and theoretically through three key parameters, freshwater yield, energy efficiency and exergy efficiency. To discover the effects of nano fluids, a mathematical model is developed and validated by experimental data at different weather conditions.

To improve the performance of solar still Sharshir, Peng, Wu, Yang, Essa, Elsheikh, Mohamede & Kabeel, (2016) had experimentally investigated the use of graphite and copper oxide micro-flakes with different concentrations, different basin water depths, and different film cooling flow rates in an attempt. Gnanaraj, Ramachandran & Christopher (2017) had attempted to improve the performance of the SS. Instead of conventional solar still, a double slope single basin SS was fabricated. Pebbles were speeded at the bottom for internal modification. An External mirror was fitted for external. Internal modification enhanced the production marginally. They achieved outstanding improvement in production when both internal and external modifications were attempted. Deshmukh & Thombre (2017) used sand and servotherm medium oil (heat transfer oil) as passive storage material beneath the basin liner in their experimentally and theoretically investigation of the performance of a single slope single basin SS. The effect of varying depth of storage material for a given quantity of basin water is investigated and compared with the conventional SS for same parameters. El-Sebaii & El-Naggar (2016) investigated the thermal performance of a finned single basin SS experimentally and theoretically, using finned basin liner made of different materials such as aluminum, iron, copper, glass, stainless steel, mica, and brass. They used copper finned basin liner to validate their theoretical model experimentally. The year-round performance of the still in terms of the monthly average of daily productivity and efficiency was performed. Kumar, Esakkimuthu & Murugavel (2016) had proposed a new concept to overcome a major drawback of its low productivity of solar still. Improved evaporation and condensation rate will increase the productivity of the still. A conventional and a modified single basin single slope solar stills were used for experimental analysis. Two single basin single slope solar still of same dimensions were fabricated. One of the still was attached with a provision to give agitation effect and external condensation. Agitation effect was given by a shaft coupled with a DC motor and an exhaust fan was used to extract the vapor from still to an external condenser. Metha, Vyas, Bodar & Lathiya (2011) investigated the single basin single slope SS, they observed the optimum angle is 30° which is near to the latitude of the site.

Hashim & Alramdhan (2010) experimented different types of stills i.e. single slope, double slope, pyramid type etc are investigated by varying different parameters like inclination angle of the glass cover and different basin area, and they concluded that double slope solar still has the highest productivity. They also found that as we increase the inclination angle, productivity increases and while area is increasing, productivity reduced. Kumar & Shantharaman (2015) investigated single slope solar still and found that it shows that the performance of blackened surface of still is more efficient than having normal surface still. Panchal (2015) has done an investigation on single slope double basin solar still with vacuum tubes and with black granite gravel. He observed that the overall productivity of double basin SS with vacuum tube and vacuum tube with black granite gravel is increased to 56% and 65% as compare to alone double basin solar still. Black granite gravel not only worked as an energy absorbing material but it also releases this energy in no-sun shine conditions. Panchal, Patel, Patel & Thakkar (2015) investigated single slope single basin SS with the use of sandstones and marble pieces and concluded that energy absorbing material has the high impact on productivity, even in sunshine hours. We can get high productivity by using sandstones as compare to marble pieces. Velmurugan et al. (2008) used fin to enhance the productivity of solar still. In their works, to augment evaporation of the still basin water, fins were integrated into the basin of the still. Thus production rate accelerated. Also, for further increase in exposure area sponges were used. They found that 29.6% productivity increased, when wick type solar still was used, 15.3% productivity increased when sponges were used and 45.5% increased when fins were used.

Modification	Date	Average solar radiation in W/m^2	Production rate in kg/m^2 /day	
			Experimental	Theoretical
Still only	16.08.06	545	1.88	2.07
Still with sponge	13.08.06	527	2.26	2.4
Still with wick	06.04.06	620	4.07	4.5
Still with fin	28.08.06	533	2.81	3.09

TABLE 3. Effect of modification in SS productivity (Velmurugan et al. 2008)

References, location	Modification	Max. enhancement in productivity
Sharshir et al. (2016) China	- Highest productivity occurs at concentrations of graphite and copper oxide micro flakes, ranged from 0.125% to 2% to get the ideal concentration. - The flow rate of the glass cooling water is changed from 1 kg/h to 12 kg/h to get the best cooling film rate with micro-flakes. - Brine depths ranged from 0.25cm to 3cm are investigated to get the optimum depth with micro-flakes. - Single slope.	47.80% and 37.02%, using copper oxide with and without film cooling, respectively. 57.60% and 43.10%, using graphite with and without film cooling, respectively.
Nijmeh et al. (2005) Jordan	- Using potassium permanganate: (KMnO4) and potassium dichromate (K2Cr2O7). - Single slope.	26% using $KMnO_4$. 17% using $K_2Cr_2O_7$.
Elango et al. (2015) Tamil Nadu, India	- Using Aluminum Oxide (Al2O3), Iron Oxide (Fe2O3), and Zinc Oxide (ZnO) nanoparticles. - Single slope.	29.95% using Aluminum Oxide. 18.63% using Iron Oxide. 12.67% using Zinc Oxide.

References, location	Modification	Max. enhancement in productivity
Kabeel et al. (2014) Egypt	- Using the cuprous oxide and aluminum oxide nanoparticles with providing vacuum. - Single slope.	133.64% using cuprous oxide with a vacuum. 125.0% using aluminum oxide with a vacuum.
Kabeel et al. (2014) Egypt	- Using aluminum-oxide nanoparticles and external condenser. - Single slope.	116% using aluminum-oxide with external condenser.
Madani & Zaki (1995)	- Investigated the productivity of a still with porous basins. - An average productivity of 2.5–4 kg/m^2/day was obtained when carbon powder. - Single slope.	Not Given.
Sahota & Tiwari (2016) India	- Using aluminum-oxide nanoparticles. - Double slope.	12.2% using aluminum oxide.

TABLE 4. Comparison between different research works about SS with nano fluids

In last decade researcher are more interested towards the use of Nano Fluid. Because it has many special properties compared to its base liquid, like high thermal Conductivity and high solar intensity absorptivity, which will help to enhance the still productivity. Recently some researchers studied the influence of different types of Nano fluids on the yield of solar still. Elango, Kannan & Murugavel (2015) used Nano fluids; Aluminum Oxide (Al_2O_3), Tin Oxide (SnO_2) and Zinc Oxide (ZnO) to intensify the output of the still. Nano fluids have 29.95%, 18.63%, and 12.67% higher productivity, respectively compared with the still without Nano fluid. The efficiency of solar still was increased by 29% when the violet dye was used. (Nijmeh, Odeh & Akash, 2005). Summary of research on that topic is shown in above table.

Conclusion

It can be concluded that the most effective method of water refinement in the contemporary time is solar desalination. The standards of safe drinkable water can be measured by distillate water. Optimization of various constraints can fetch high productivity of the system.

In this works review, the possible research work can have thought for the ground of improving the productivity of solar still.

- The leaning position is one of the significant aspect in the improvement of productivity. It should be adjacent to the latitude of the site.
- By purveying insulation, the heat transfer can be decreased. Therefore, insulation is purveyed to the bottom and side wall of the solar still to lessen the heat loss from the basin.
- The output can also be affected by both the external and internal modification. As a result, for the cause of external modification, mirrors can be sited on the side wall to exploit the use of radiation that is communicated on the solar still.
- Besides this, using energy absorbing materials that can increase the productivity and efficiency of the system can create a healthy balance by providing energy in the non-sun shining hours.
- In the case, when high wind speed decreases the temperature of glass cover which, in turn, increases the temperature difference between glass cover and water. Likewise, it too increases the concentration rate of evaporation. This outcome is significantly attained by usage of Nano fluid. It demonstrations the great impact on the yield of the still. Nano fluid has provided the prospect to develop the productivity and effectiveness, by taking benefits of belongings of Nano fluid and several investigators have exposed the same.

Thus, it can be concluded from the examination taken above that getting the highest yielding of distilled water is quite difficult which increases the cost and time duration. Therefore, additional researchers are required in this ground to improve the productivity and as a result, it could be channelized to market place. In this field of research, at last, the manipulation of Nanotechnology is one of the inordinate advancement.

References

Alkaisi, A., Mossad, R., and Sharifian-Barforoush, A. (2017) “A Review of the Water Desalination Systems Integrated with Renewable Energy”, Energy Procedia, vol. 110, pp. 268–274.

Badran, A. A., Al-Hallaq, A. A., Eyal, S. I. A., Odat, M. Z. (2005) "A solar still augmented with a flat plate collector", Desalination 172, pp-227–234.

Deshmukh, H., Thombre, S. (2017) “Solar distillation with single basin solar still using sensible heat storage materials”, Desalination 410, pp-91–98.

Elango, T., Kannan, A., Murugavel, K. (2015) “Performance study on single basin single slope solar still with different water nanofluids”, Desalination, 360, pp-45-51.

El-Sebaii, A. A., Aboul-Enein, S., El-Bialy, E. (2000) "Single basin solar still with baffle suspended absorber", Energy Convers Manage 41, pp-661–675.

El-Sebaii, A. A., El-Naggar, M. (2016) "Year round performance and cost analysis of a finned single basin solar still", Applied Thermal Engineering.

Gnanaraj, S., Ramachandran, S. Christopher, D. S. (2017) "Enhancing the productivity of Double Slope Single Basin Solar Still with Internal and External modification", International Journal of Ambient Energy

Gupta, B., Mandraha, T., Edla, P., Pandya, M. (2013) " Thermal Modeling and Efficiency of Solar Water Distillation: A Review", American Journal of Engineering Research Volume-02, Issue-12, pp-203-213.

Hashim, A. Y. & Alramdhan, W. T. (2010) “An attempt to solar still productivity optimization; solar still shape, glass cover inclination and inner surface area of a single basin solar still, optimization,” Basrah J. Science, vol. 28, no. 1, pp-39–48.

Hijileh Bassam, A. K. & Rababa, H. M. (2003) "Experimental study of a solar still with sponge cubes in basin", Energy Convers Manage 44, 1411–1418.

Kabeel, A., Omara, Z., Essa, F. (2014) "Enhancement of modified solar still integrated with external condenser using nano fluids: An experimental approach", Energy Conversion and Management 78, pp-493-498.

Kabeel, A., Omara, Z., Essa, F. (2014) "Improving the performance of solar still by using nano fluids and providing vacuum", Energy Conversion and Management 86, pp- 268-274.

Kumar, R., Esakkimuthu, G., Murugavel, K. (2016) “Performance enhancement of a single basin single slope solar still using agitation effect and external condenser” Desalination 399, pp- 198–202.

Kumar, S. N. & Shantharaman, P. (2015) “Fabrication of Solar Water Distillation System”, Int. J. Core Eng. Manag., vol. 2, no. 1, pp. 179–186.

Madani, A. A., Zaki, G. M. (1995) "Yield of solar stills with porous basins", Appl. Energy 52, pp-273–281.

Mahian, O., Kianifar, A., Heris, S. Z., Wen, D., Sahin, A. Z. , Wongwises, S. (2017) “Nanofluids Effects on the Evaporation Rate in a Solar Still Equipped with a Heat Exchanger”, Nano energy.

Metha, A.,Vyas, A. Bodar, N. & Lathiya, D. (2011) “Design of Solar Distillation System”, Int. J. Adv. Sci. Technol., vol.29, pp. 67–74.

Nafey, A. S., Abdelkader, M., Abdelmotalip, A., Mabrouk, A. A. (2001) "Solar still productivity enhancement", Energy Convers Manage 42(11), pp-1401–1408.

Nafey, A. S., Abdelkader, M., Abdelmotalip, A., Mabrouk, A. A. (2002) "Enhancement of solar still productivity using floating perforated black plate", Energy Convers Manage 43, pp-937–946.

Nijmeh, S., Odeh. S., Akash, B. (2005) “Experimental and theoretical study of a single-basin solar sill in Jordan”, International Communications in Heat and Mass Transfer 32, pp-565- 572.

Omara, Z. M., Kabeel, A. E., Abdullah, A. S., (2017) "A review of solar still performance with reflectors", Renewable and Sustainable Energy Reviews 68, pp-638–649.

Panchal, H. (2017) “Enhancement of distillate output of double basin solar still with vacuum tubes”, J. King Saud Univ. -Eng. Sci., vol. 27, no. 2, pp. 170–175.

Panchal, H., Patel, P., Patel, N., Thakkar, H. (2015) “Performance analysis of solar still with different energy-absorbing materials”, Int. J. Ambient Energy, pp- 1–5.

Panchal, H. & Patel, S. (2017) “An extensive review on different design and climatic parameters to increase distillate output of solar still”, Renew. Sustain. Energy Rev., vol. 69, pp-750–758.

Sahota, L. & Tiwari, G. (2016) "Effect of Al2O3 nanoparticles on the performance of passive double slope solar still", Solar Energy, 130, pp- 260-272.

Sharshir, S. W., Peng, G., Wu, L., Yang, N., Essa, F. A., Elsheikh, A. H., Mohamede, S. I., Kabeel, A. E. (2016) "Enhancing the solar still performance using Nanofluids and glass cover cooling: Experimental study", Applied Thermal Engineering.

Tanaka, H., Iishi, K. (2017) “Experimental study of a vertical single-effect diffusion solar still coupled with a tilted wick still", Desalination 402, pp-19–24.

Thakur, A., Khandelwal, P., Sharma, B. (2018) "Productivity Comparison of Solar Still with Nano Fluid and Phase Changing Material with Same Depth of Water", Nanotechnology for Energy and Water, Springer International Publishing AG 2018 Chapter 17.

Velmurugan, V., Gopalakrishnan, M., Raghu, R., Srithar, K. (2008) "Single basin solar still with fin for enhancing productivity" Elsevier, Energy Conversion and Management 49, pp-2602–2608.

Velmurugana, V., Srithar, K. (2011) "Performance analysis of solar stills based on various factors affecting the productivity- a review", Renew Sustain Energy 15, pp-1294–1304.

Ruchir Parikh
Ph.D. Research Scholar,
Indus Institute of Technology, Indus University

Dr. Umang Patdiwala
Assistant Professor,
Indus Institute of Technology, Indus University

4

ACHIEVING INCLUSIVE DEVELOPMENT THROUGH SMART VILLAGE

Anand Singh, Megh Patel

ABSTRACT: Cities are being crowded at an unprecedented pace globally, 30% of the world's population was urban in 1950 with a projection of 66% by 2050 (World Urbanization Prospects, 2014). Lack of basic amenities and limited economic growth in villages leads toward uncontrolled migration from rural to urban area. Current scenario of urban living shows cities are struggling to cope up with the basic infrastructure like transportation, healthcare, housing and utilities. 30% of urban residents are living in slums. While upcoming urban development projects are focused on developing smart cities, development of smarter villages have been ignored. Rural development will avoid further migration and can help to bring the balance in the entire ecosystem.

KEYWORDS

Smart village, Village, Rural development, Holistic development

Introduction

Out of 6,50,000 villages in India, most of them have inadequate and rudimentary infrastructure which fails to fulfill the primary need of villagers. Villages and other remote locations have poor educational facilities, irregular water supply, electricity supply, improper sanitation, transport, road connectivity and infrastructure. India being a billion-strong nation has 68.84% of villagers less than 30 years old. Thus, a huge resource pool is underutilized and left with poor standard of living with meager wages. All these factors push villagers to migrate to towns and cities in search of better employment opportunities and quality of life.

Agriculture has been a major contributor to India's GDP since independence. It is decreasing year by year from 45.48% in 1950 to 15.79% in 2013 ("Sector-wise contribution of GDP of India", 2017) because of lack of strong policies and its execution at grass-root level. It has been the primary source of livelihood for villagers, which creates 50% employment followed by Small and Medium Enterprise (SME) sector with a share of 40%. Employment in India's agriculture sector has decreased considerably, from 60% in 1994 to 50% in 2013 (World Development Report, 2013).

Migration leads to overcrowding of cities in no time, it runs out of resources to cater everyone's needs. Infrastructure, deforestation and pollution is increasing at a faster rate. To deal with this situation, Government of India (GoI) launched 'Smart Cities Mission' across country with 100 cities in 2015. Infrastructure cannot be improved beyond a certain level so every existing and upcoming city has a limitation to deal with population problem. To avoid migration "smart village" is one of the most suitable options, which can be easily implemented with lesser-cost and small gestation period.

Rural development through investment in infrastructure will improve the situation. It will create platform to develop local entrepreneurship in villages to boost the rural economy. Electricity access in villages has been a major challenge for its economic growth; globally, 1.3 billion people have no access to electricity whereas 70% of the poor people living in remote areas lack access to electricity (Holmes, Jones, & Heap, 2015). Suitable and cheaper "plug - n - play" energy solutions can be installed in rural homes (Holmes et al., 2015) to create smart village.

Cause of Migration

People from most of the backward states like Bihar, Orissa, Jharkhand, Uttar Pradesh, Rajasthan, and Uttar Pradesh are travelling to big cities like Kolkata, Delhi, Pune and Mumbai in search of better job opportunities. This is causing additional burden to the cities. Lack of job opportunity, limited economic activities, unavailability of better education and insufficient support from government has caused huge migration from village to cities. The 2011 Indian Census pegged Uttar Pradesh as the state with the most out-migration (26.9 lakh) followed by Bihar at 17.2 lakh. Migration in UP has also been a growing affair; between 2001 and 2011, over 5.8 million people between the ages of 20 and 29 migrated from the state in search of jobs ("Peedhiyon ka Palayan: In Uttar Pradesh's Bundelkhand survival continues to drive hordes to migration", 2018). Though there has been an initiative from GOI to develop smart villages but the ground level improvements is yet to be seen. NGOs and other international organizations are playing active role to develop smart village models. This initiative needs to be encouraged by providing government support and funds.

What is the Need of Smart Villages?

Holistic development of rural India is yet to come in shape because of declining agricultural output and absence of basic amenities. This has left the villages deserted with increasing slums in urban areas leading to poor health conditions and living standards. This imbalance will create a long term negative effect as more villagers are moving away from agricultural profession.

"Smart Village" is the rural analogy of "Smart City", which can bring overall development, sustainable and affordable utilities, access to good education, clean drinking water, sanitation and nutrition (Holmes et al., 2015). A smart village will facilitate:

- Entrepreneurial opportunities in agriculture and animal husbandry
- Improved education services
- Health services
- Focus on social welfare
- Enhanced democratic engagement
- Improved quality of life
- Technology as a means for holistic development

Even after 70 years of independence 25,722 villages are un-electrified across the country where 304 million people are left in darkness ("1.3 Billion are living in the dark", 2015). Use of kerosene for lighting lamps and wood for cooking causes household air pollution which is dangerous to health. Globally over 4 million people die prematurely from illness attributable to the household air pollution from cooking with solid fuels ("Household Air pollution and Health", 2016).

Access of electricity can be considered as a foundation stone for smart village as it helps to improve the socio-economic infrastructure of villages. Energy (electricity) and Information and Communication Technology (ICT) can go a long way to provide inclusive education to all and reduce social injustice (Ranade & Londhe, 2015). Government of India is running a drive to electrify all Indian villages, however there are many far flung areas where laying down the electrical grid is difficult. Extending existing grids to remote off-grid areas is highly expensive, which creates a need of local solutions using renewable energy sources (Bahaj, 2009).

Solutions Proposed:

Access to energy transforms the lives in a rural setting. Generally, daily activities of people living in rural areas are dependent on the availability of daylight hours. Children and house-wives use kerosene lamps to study and perform household works respectively, in late evening. Affordable and environment friendly solar lamps will encourage children to study during night. Solar streetlight system will promote a community life after sunset in villages. It will provide sustainable lighting solution for people who don't have access to conventional grid. It will increase safety on roads and streets thus allowing more economic activity (Soboyejo & Taylor, 2008). With help of available technologies like micro-grid, and renewable integration the purpose can be served. Governments have adopted policy and regulatory frameworks for establishing solar home systems (Holmes et al., 2015).

Infrastructure like roads, will ensure proper connectivity of village with outer world. This will improve transportation and means of business. Primary schools can be developed with proper infrastructure. With the help of ICT, primary education can be made smarter and digitized. Access to internet will create a leapfrog in village education as well as several other daily affairs. Mid-day meals and daily attendance should be monitored to encourage students to pursue education. It will help to decrease drop out ratio in primary schools.

Mostly villagers travel to town or cities for health treatment. Primary health centre can be constructed with adequate facilities in order to provide basic healthcare facilities. Vaccination camps along with general health awareness camps can be conducted to improve health awareness and avoid addiction to alcohol and drugs.

Natural disasters like drought, floods, earthquakes, etc. are very common in villages, necessary measures should be taken to cope up with the emergency. A Community Based Disaster Preparedness Plans (CBDP) has to be developed in all the vulnerable areas to prevent loss of life, livelihoods and property in case of such disasters. A Resource Inventory should be harnessed and enhanced for disaster preparedness and response (Bhagat, 2017).

Rain water harvesting should be promoted to conserve water at village level. Canals and ponds can be used for storage of water. Check dams can be utilized as reservoirs to ensure irrigation and potable drinking water.

Sewage infusion with fresh water bodies should be avoided. Public toilets and proper sanitation will avoid open defecation and will prevent epidemics.

Agricultural productivity has been a concern since long as Indian villagers use same old methods for it. Adaptation of new technology in field of agriculture will increase productivity. TV programs, Internet availability to explore better methods and market to sell the agricultural products will improve the situation. Subsidized animal husbandry and dairy farming, goshalas, renewable cold storage and processing plants will improve local trade and employment.

Vocational training will improve employment opportunities and will also create a platform for local entrepreneurship for villagers. Availability of banks and micro finance will support the eco-system for rapid economic growth.

Community centre in villages are being established as it can play a very important role in inclusive development of village. It can also act as a hub for basic health services, infrastructure, emergency response, agriculture, local trade, banking and microfinance and local participation. This will ensure overall development.

Our acronym for SMART should be:

S - Sustainable

M - Measurable

A - Affordable

R - Replicable

T - Technology

Key attributes of smart village include (Shukla, 2016):

- Homes with access to toilet, clean drinking water and affordable electricity.
- Diversified livelihood opportunities with micro – enterprise.
- Plans for development of people, assets, service centric information, revenue generation and maintaining its identity and cultural heritage.
- Interaction with government, NGOs, experts, social entrepreneurs, etc.
- Awareness of newer technologies which can be implemented in the village for its upliftment and holistic development.

With different schemes and drives government has done the preliminary job to setup a platform for smart village. There are several programs like Saansad Adarsh Gram Yojna, National Agriculture Development Program, Mahatma Gandhi National Rural Employment Guarantee Scheme, Mid-Day Meal Scheme, Integrated Child Development Scheme, Annapurna Scheme, etc. (Shukla, 2016). The output is not up to the mark since they are not being implemented in a cohesive fashion.

Smart village can integrate different programs to optimize the benefit of several schemes. The STERM (Science, Technology, Engineering, Regulations and Management) framework can be used to design and build these villages. We need to develop the ecosystem for each village depending on its location and investment climate (Viswanadham & Vedula, 2014).

Public-private partnership model is very suitable to develop smart village. There exists a tremendous potential for smart village in years to come. This can be replicated to millions of villages around the World; in India, China, Brazil and South Africa to name a few and this is in line with the inclusive growth that is being advocated by these Governments (Viswanadham & Vedula, 2014).

Case Study of Punsari Village

Punsari is a village located in Sabarkantha district in the state of Gujarat, India. Punsari has been dubbed as a "model village" by the state government (“Inside Punsari: A model Indian village”, 2014). The village houses 6000 villagers.

- There is a 66kV sub-station that supplies power to the village. The village is producing its own electricity from the waste collected. Their aim is to generate surplus so that they can sell it to government and make revenues which ultimately will be utilised for the welfare of the people (“Punsari to generate green power”, 2014).
- Sarpanch of the village has provided Wi-Fi connectivity in the entire village.
- Infrastructure and facilities of schools have improved with furniture, air conditioning, projectors for better teaching and CCTV cameras for surveillance. Mid-day meal scheme of the central government was very well regulated and the benefits of the scheme were being properly reached out to children. They have been successful in stopping the migration of children to schools in nearby towns. All this has collectively made school dropout rate to 0.
- Apart from schools, 25 CCTV cameras are installed at public places to keep surveillance.
- Mini-buses are used for transportation purpose within the village. A bus facility called the Atal Express has been started for women to collect milk from every house.
- For communication purposes, 120 waterproof speakers have been installed which the Sarpanch uses to inform people about new schemes and initiatives.
- Panchayat has installed a Reverse Osmosis (RO) plant in 2010 to supply clean drinking water to the village people (“This Smart Village in Gujarat Went from Having No Electricity to Wifi, RO Water Purification and Solar-Power Streetlamps”, 2016).
- The village has a proper sanitation and drainage system which is completely underground.
- Every household has a toilet which is fulfilling the objectives of Swachh Bharat Mission.
- There are two banks in the village which have been successful in opening accounts of every household. This was possible through their awareness campaign in the village.
- The village has been successful in making Anganwadis, ATM for cash withdrawal and has even brought in skill development centres, health care centres, and even veterinary centre.
- The village has been successful in reducing the infant mortality rate and maternal mortality rate to 0. This is in itself a landmark achievement.
- There is a door to door waste collection two times in a day.
- They have even started a monthly newspaper called Kalam Sandesh newspaper to keep people updated with the development in the village as well as around the world.
- Vocational training for people of the village was carried out which ensured employment to every able villager.
- The last six years have been without any crime which has resulted in zero FIRs.

Case Study of Akodara Village

Akodara village near Ahmedabad is a fully digital village. The village of 1,200 people has been adopted by ICICI Bank and helped by the local administration.

- The first of such useful interventions is financial inclusion and access to modern banking.
- This digitization has promoted use of technology in education.
- Audio-visual devices, computers, electronic tablets and electronic attendance of students is employed in schools throughout the village (“At Akodara, India’s first digital village”, 2015).
- All normal transaction of the bank was made by their mobile phones through net banking.
- There’s a community-owned RO based water treatment plant.
- Wi-Fi tower for internet connectivity have been installed in the village (“Demonetisation: Modi's cashless economy dream is a reality in this tiny Gujarat village”, 2016).

Comparative Study of Smart Village

Based on the suitable indicators for a smart village, Punsari and Akodara villages is being compared. The objective of domain based comparison is to understand the scenario in which smart village can take shape and the gaps the needs to be taken care of. Following domains have been identified for comparison.

Infrastructure:
For any settlement, a basic infrastructure is always needed to thrive and grow. For villages to become smart, connectivity through roads, availability of transportation facilities, waste management systems and water conservation bodies like construction of lakes, canals, reservoirs, etc. from agriculture perspective is important.

Utility:
Availability of basic utilities is important. Access to electricity, drinking water, sanitation, basic healthcare, access to clean cooking fuel and access to internet is necessary to make a village smart.

Education:
From the social point of view, education is a very important domain as a society will become healthier, safe and economically independent with education. Primary education, skill development for local pool and community awareness will play an important role.

Security:
Security is one of the most important aspect; installation of CCTV camera for surveillance will help smart village to take adequate measures for social security.

Finance:
Availability of banking and micro finance facilities at village level will encourage villagers to participate in economic affairs and will help to grow local entrepreneurship.

Technology:
Use of technology is a key factor for making a village smart. Digital education and use of technology through mobile phones, mobile applications and computers, etc. will put smart village development on a faster pace.

Alternative Energy:
Alternative energy sources are important in areas where electrical grid supply is unavailable; as absence of electricity can hamper several basic activities. Integration of Renewable energy sources to existing setup will ensure affordable and reliable power when needed.

Disaster Management:
Emergency response comprising of a CBDP and resource inventory will make smart villages more independent to handle emergencies.

Parameters	Punsari	Akodara
Access of Electricity	✓	✓
Drinking water	✓	✓
Sanitation	✓	✓
Healthcare	✓	x
Access to clean cooking fuel	✓	✓
Access to internet	✓	✓
Connectivity	✓	✓
Transportation	✓	✓
Waste management	✓	x
Water conservation	✓	x
Primary education	✓	✓
Skill development	✓	x
Community awareness	✓	x
Security	✓	x
Banking / micro-finance	✓	✓
Digital education	✓	✓
Use of technology	x	✓
Clean energy integration	x	x
Emergency response	x	x

Access of power supply to Punsari village has ensured uninterrupted power. It has helped to improve the socioeconomic infrastructure of village. Power generated through waste collection has made village sustainable and independent, it has potential to create a source of revenue for village. Wi-Fi connectivity in village will bring transformation to access of information by villagers. This helps villagers to keep pace with agricultural assistance and trade and to understand the different schemes run by government. Primary school in village has set up the foundation for education. CCTV camera across village had made continuous surveillance possible and the crime rate is negligible. Availability of local transport system provides better connectivity to outer world and it has improved the economic activity of village. Availability of clean R.O water for village has improved the health condition. Availability of toilet and adequate drainage has improved the sanitation facility of village. Local skill development and Anganwadi has opened the door for employment in village. Healthcare centre and veterinary centre takes care of health issues of villagers and cattle. Infant mortality rate has reduced to zero. Monthly newspaper in village has improved awareness of villagers about own village and activities happening around.

There are couple of things which have been ignored like disaster management system for village and clean energy integration. Such provision will make villages more responsive to emergencies and renewable integration will improve the reliability of power.

Akodara village lacks couple of facilities like health care, water conservation and waste management, skill development, community awareness, security, clean energy integration and emergency response. It has done pretty well in use of technology in banking and digital education.

Case Study of Akodara Village

Quality of life in “Punsari” village has changed by many folds. People from middle class and above in the village has found the changes suitable, whereas people from lower class i.e., lower income group are the biggest beneficiary of smart village. Every facility provided is a boon for them.

Villagers have 24 hours of electricity access. They also have their own waste based power generation plant to produce surplus electricity. Because of unavailability of raw material it is not operational science last six months. RO based drinking water has improved the health condition. Now it is hard to find any water borne disease in village.

The village has a proper sanitation and drainage system, every house has a toilet and there is no public defecation. Water proof speakers across village has increased the speed of cooperative work in village. People are more aware and proactive for village development.

After having a branch of State Bank of India in village financial transaction has become very easy, everyone in village has a bank account. ATM for cash withdrawal has improved the ease of transaction. Earlier one had to travel 10 kilometres to reach the nearest bank.

Primary healthcare facility for villagers has reduced health complication, especially for women. Individual supervision of pregnant women and health education about child delivery has reduced the risk of maternal mortality, infant mortality rate has reached to zero.

Vocational training for villagers has improved their employability. It has also enhanced the scope of their skill development.

CCTV cameras has reduced the crime rate. Interestingly a theft case was detected and solved with the help of surveillance camera. It has improved the villager’s security.

WiFi services has made internet available to everyone. Youths are much aware about internet application that can be downloaded to mobile for various usage. It has improved the cashless transactions in villages, during demonetisation period this village was well prepared for cash crunch and available alternatives for money transactions.

Minibus transportation across village and nearby places has solved a big problem for local transport, villages who traveled to sell their milk by their own convince can now reach to an identified place to sell their milk by spending only 2 rupees. Now females also can travel to sell milk with ease.

With good primary education facility in village school dropout rate has reached to zero. A considerable change has been observed after smart village implementation.

Couple of issues were observed regarding maintenance of the facilities. Once any system goes down it takes time to repair; in couple of cases the systems are not working since last 6 months.

By developing local entrepreneurship and trade, a fixed cash flow can be made available for maintenance of the systems. As every village is unique, a proper study of socio economic potential will lead to a sustainable smart village. Sustainability of smart village is an important aspect to look for. This can be scope for further study.

SMART VILLAGES’’ can be the answer of current situation. This will help to reduce the migration from villages to towns and cities so the burden on cities will reduce in near future. It will create a suitable platform for villagers to have a sustainable life and economic growth and will improve quality of life for villagers.

A well planned smart village with micro and small enterprises can provide villagers ample opportunity of employment. The potential of young India can be unleashed by a little change in our development strategy by focusing more on rural economy. ‘Smart Villages’ can go a long way in strengthening country’s untapped potential to bring inclusive development for all.

References

Bahaj, A.S. (2009). Delivering developing country growth: A new mechanistic approach Driven by the photovoltaic industry. Renewable and Sustainable Energy Reviews, 13(8): 2142–2148. DOI: 10.1016/j.rser.2009.01.029.

Soboyejo, W.O. and Taylor, R. (April 2008). Off-grid solar for rural Development. Researchgate. DOI: 10.1557/mrs2008.74

SireeshaKumar. P. D., Subhalakshmi M. (December 2016). Internet of Things (IoT) gateway to smart villages.

International Journal of Innovative Research in Advanced Engineering 2349-2763. Retrieved from *http://ijirae.com/volumes/Vol3/iss12/15.DCAESP90.pdf*

Shushma (2017). A Comparative Study of Smart City vs. Smart Villages Startup, Opportunities and Challenges. Asian Journal of Management, 2321-5763. DOI:10.5958/2321-5763.2017.00199.8

Ranade P, Londhe S. (July, 2015). Smart Villages through Information Technology – Need of Emerging India, IPASJ International Jounal of Information Technology, 3(7). Retrieved from *http://ipasj.org/IIJIT/Volume3Issue7/IIJIT-2015-07-10-2.pdf*

Bailey, M, Henriques, J., Holmes, J., & Jain, R., (2012). Providing Village-Level Energy Services in Developing Countries "Smart Villages Initiative. Retrieved from *http://e4sv.org/wp-content/uploads/2014/02/Scoping-report-final-230113with-Iogos.pdf*

Heeks, R. (2002). Information Systems and Developing Countries: Failure, Success, and Local Improvisations. The Information Society, 18(2), 101-112. DOI: 10.1080/01972240290075039

United Nations (2014). Report on World Urbanization Trends 2014: Key Facts. World Urbanisation Prospects. Retrieved from *https://esa.un.org/unpd/wup/publications/files/wup2014-highlights.pdf*

World Development Report 2013: Report on Jobs - World Bank Group. Retrieved from *https://siteresources.worldbank.org/EXTNWDR2013Resources/8258024-1320950747192/8260293-1322665883147/WDR_2013_Report.pdf*

Holmes J., Jones B., Heap B. (2015, February). Can Smart Villages help to stem biodiversity loss? Retrieved from *http://e4sv.org/wp-content/uploads/2017/05/TR15-Can-Smart-Villages-help-to-stem-biodiversity-loss_web.pdf*

Shukla, P. (2016). The Indian smart village: Foundation for growing India. International Journal of Applied Research, 2(3), 72-74. Retrieved from *http://www.allresearchjournal.com/archives/2016/vol2issue3/PartB/2-2-111.pdf*

Viswanadham, N., & Vedula, S. (2014). Design of Smart Villages. Computer Science and Automation. Indian Institute of Science, Bangalore. Retrieved from *http://drona.csa.iisc.ernet.in/~nv/Mypublications/C/z.pdf*

1.3 Billion Are living in the dark (2015, November 6). The Washington Post. Retrieved from *https://www.washingtonpost.com/graphics/world/world-without-power/*

Household Air pollution and Health (2016, February). WHO Fact Sheet – February. Retrieved from *http://www.who.int/mediacentre/factsheets/fs292/en/*

Bhagat, S. (2017). Community-Based Disaster Management Strategy in India: An Experience Sharing. Journal of Energy and Management, 2017 (11-17). Retrieved from *http://www.pdpu.ac.in/downloads/1%20Community-Based-Disaster-Management.pdf*

Sector-wise contribution of GDP of India (21 Mar 2017). Statistics Times. Retrieved from *http://statisticstimes.com/economy/sectorwise-gdp-contribution-of-india.php*

Peedhiyon ka Palayan: In Uttar Pradesh's Bundelkhand survival continues to drive hordes to migration (2018, April 26). Firstpost. Retrieved from *https://www.firstpost.com/india/peedhiyon-ka-palayan-in-uttar-pradeshs-bundelkhand-survival-continues-to-drive-hordes-to-migration-4445053.html*

This Smart Village in Gujarat Went From Having No Electricity to Wifi, RO Water Purification and Solar-Power Streetlamps, (2016, September 2). The Logical Indian. Retrieved from *https://thelogicalindian.com/story-feed/get-inspired/this-smart-village-in-gujarat-went-from-having-no-electricity-to-wifi-ro-water-purification-and-solar-power-streetlamps/*

Punsari to generate green power, (2014, October 4). The Times of India. Retrieved from *https://timesofindia.indiatimes.com/city/ahmedabad/Punsari-to-generate-green-power/articleshow/44325232.cms*

Inside Punsari: A model Indian village (2014, November 24). BBC News. Retrieved from *http://www.bbc.com/news/world-asia-india-29914208*

At Akodara, India's first digital village (2015, July 14). The Hindu. Retrieved from *http://www.thehindu.com/opinion/op-ed/at-akodara-indias-first-digital-village/article7418012.ece*

Demonetisation: Modi's cashless economy dream is a reality in this tiny Gujarat village (2016, November 28). Firstpost. Retrieved from *https://www.firstpost.com/india/note-ban-akodara-the-future-of-narendra-modis-cashless-villages-is-here-3127506.html*

About the Author
Mr. Anand Singh
Ph.D - SRDC
Co-founder - Utileaider
E-mail: *anand.sphd13@sse.pdpu.ac.in*

About the Co-author
Mr. Megh Patel
B.Tech - Civil Engineering
PDPU, Gandhinagar
E-mail: *meghpatel26@gmail.com*

5

ANALYSIS OF THE KEY FACTORS AFFECTING LEVELIZED COST OF ELECTRICITY OF SOLAR PV IN INDIA

Nisarg Shah

ABSTRACT: The Central Government, as well as many State Governments of India, have introduced solar PV policies to promote solar PV technologies as India has a very high potential for solar energy with 300 clear sunny days with solar radiation ranging from 4 KWh/m2 to 7 KWh/m2. The key feature of these policies is a selection of through reverse auction process. Recently, it has been claimed that through a reverse auction process, the tariff of power from Solar PV has been brought down below Average Power Purchase Cost (APPC) However, such low tariff has raised doubt about the viability of solar PV project at such low tariff given the high cost of debt prevailing in India. The government has recently set a target of deployment of 100 GW of Solar PV by the year 2022 which accounts for around $100Bn investment. Under this condition, it is important to rationalize power tariff by analysing the impact of various sets of factors affecting the LCOE. The present paper intended to do the same. This analysis will be helpful to investors for avoiding the problem of underbidding and/or overbidding. This analysis is also helpful to policy makers for maintaining the competitive nature of markets as well as the sustainability of the market.

KEYWORDS

Levelised Cost of Electricity, Solar PV, India

Introduction

India has a very high potential for solar energy with 300 clear sunny days with solar radiation ranging from 4 KWh/m2 to 7 KWh/m2. (Sharma et al., 2012) It has been that 12.5 % of India's total land mass or in other words, the area of around 43,000 Km2 can be used to generate solar energy. Currently, around 68 % of power is being produced through fossil fuel based conventional technologies (Shrimali et al., 2016). It has been estimated that for the next 5 years India's GDP would grow at 8% year to year basis. The energy demand would also grow at around 9 % year to year basis (Dawn et al., 2016). To meet this demand India has to import a massive amount of clean coal. However, from recent experience, it has been observed that sudden changes in royalty terms by coal exporting countries can increase power producing cost and make it uncompetitive resulting massive financial burden on energy producing companies. In such a situation, it is necessary for India to harvest its solar potential by introducing the favourable solar policy. On the other hand, being one of the most carbon polluting countries in the world, there is also international pressure building up for reducing carbon foot print by measures such as the deployment of clean energy technologies (Bloomberg New Energy Finance, 2016).

Since 2009, The central government of India, as well as many state government, has introduced Solar policy such as National Solar Mission as part of a broader framework called National Action Plan for Climate Change (NAPCC) (Government of India, 2008). To create energy market for renewable technologies, Central Government has set targets for Renewable Purchase Obligation (RPO), in which power utility companies and captive power consumers have to purchase a certain quantity of renewable energy. As per the direction is given by the Central Government under Electricity Act 2003, various State Electricity Regulatory Commissions (SERCs) have set their respective RPO targets specific different renewable technologies such as bio gas, wind energy and solar technologies (Shrimali & Rohra, 2012).

As Solar PV was much expensive technology at that time, the central government as well as many state governments have introduced Feed in Tariff with long term contract of 25 years in which utility companies had to sign Power Purchase Agreement (PPA) with premium on Average Power Purchase Cost (APPC) to make Solar PV project viable (Dawn et al., 2016). However, as the financial health of most of the utility companies were already poor (Planing Comission, 2014) and there was a sharp decline in solar PV modules prices, the Central government, as well as many state government, have introduced reverse auction process in feed n tariff to let market forces decide the prices. Recently, to address the concern about bankability of Solar PV project, the central government have to change the policy with fixed Feed in tariff and capital subsidy (known as Value Gap Funding (VGF)) upto 30% of capital cost. The projects are being selected through a reverse auction process with the lowest requirement of VGF (Ministry of New & Renewable Energy, 2013). However, the state governments continue to select Solar PV project through a reverse auction process in Feed in Tariff (Umamaheswaran & Rajiv, 2015).

At present, the reverse auction process is a key driving policy instrument in the deployment of solar PV projects. This process has some inherent benefit. (Mayr et al., 2014) It has successfully brought down power purchase cost of Solar PV very near to APPC . In last year the bidder won the project in revers auction process, have quoted solar tariff in range of Rs. 2.50 to Rs. 2.70 per KWh (Ghosh & Prasad, 2017). These prices were below than APPC of Rs. 3 to 4/ KWh (Shrimali & Rohra, 2012). It has been claimed that the reverse auction process encapsulated the benefit of continuous decline of module prices and low cost of capital prevailing in the international market. However, some recent bids with very low tariff have raised the questions regarding the viability of solar PV projects and sustainability of market (Bhaskar, 2017; Sambit Basu, 2011). The government has recently set a target of deployment of 100 GW of Solar PV by the year 2022 which accounts for around $100Bn investment(Niti Ayog, 2015). Under such situation, it is important to rationalize power tariff by analysing the impact of various factors affecting the Levelized Cost of Electricity of solar PV and to analyze whether bidding with such low tariff is possible or not.

This study is carried out to identify and analyse the factors (if any) responsible for bringing down LCOE at such a low level. Such analysis will be helpful for policy makers to focus on such factors and co relate its effect on other macroeconomic parameters considering the massive projected investment of $100Bn in this sector. This analysis is also helpful for investors for determining the best combination various factors which will increase margins of LCOE during bidding.

Literature Review

In this section, the financial parameters used for this feasibility analysis are explained.

Levelised Cost of Electricity (LCOE): The Levelised Cost of Electricity (LCOE) is the net present value of life cycle cost of the project divided by electricity production over the life time of the project. It can be seen as the production price of electricity adjusted over the life time of the project.

Branker et al., have described The levelized cost of electricity (LCOE) as benchmarking or ranking tool to assess the cost-effectiveness of different energy generation technologies. The LCOE methodology is designed to remove biases between the technologies. The method considers the lifetime generated energy and costs to estimate a price per unit energy generated (Branker et al., 2011).

In simple term, it is a measure of lifetime costs, divided by total lifetime energy production represented by following formula:

$$\text{LCOE} = \frac{\text{total life time cost}}{\text{total life time energy production}}$$

The less a system costs and the more energy it produces, the lower the LCOE. The LCOE represents the price point at which the energy is to be sold in order to achieve a zero NPV. LCOE can be affected by financial parameters such as capital cost, depreciation, cost of debt, cost of equity and annual operating cost (which also includes spare part replacement cost & fuel cost). While in the case of solar it is effected by technical parameters such as plant efficiency, plant capacity factor, and plant degradation rate.

It can be calculated based on the following formula (Mahmud & Prince, 2016):

$$LCOE = \frac{PCC - \sum_{n=1}^{N} \frac{DEP + INT}{(1+DR)^n} TR + \sum_{n=1}^{N} \frac{LP}{(1+DR)^n} \sum_{n=1}^{N} \frac{Aoc + In}{(1+DR)^n} (1 - TR) - \frac{RV}{(1+DR)^n}}{\sum_{n=1}^{N} \frac{\text{Initial generation in KWh } (1 - \text{Degradradtion rate})^n}{(1+DR)^n}}$$

Where LCOE is Levelised Cost of Equity, DEP is annual applicable depreciation, INT is annually paid Interest, TR is Tax Rate, PCC is Project Capital Cost, LP is Annually paid Loan amt, Aoc is annual operation cost, In is annually paid insurance premium, RV is Residue value of the project after its life cycle, DR is discount rate n is nth year of project, N is total no of years of project life.

Cost of Equity: Cost of Equity is the rate of return which share holders ask as compensation for investing their capital. In this paper, the cost of equity is estimated using bond-yield -plus- risk premium approach. According to this approach, cost of equity is divided into two parts,

a) base rate of government bonds, which is also called risk free return and

b) risk premium asked by equity holders for investing their equity. It is represented by the following formula (Baker & Powell, 2009)

$$k_e = b_r + R_p \quad (1)$$

Where (k_e) is the cost of equity, (b_r) is base ratthe e of government bond and(R_p) is risk premiuma.

The risk premium is linearly proportional to risk involved in the project in which equity is invested.

Cost of Debt: Cost of debt is the rate of interest expected for the lending money. Usually, the rate of interest on debt prevailing in the market is referred to as the cost of debt before tax. The rate of interest after adjusting tax is referred to as the effective cost of debt (Khan & Jain, 2007) represented by

$$k_{de} = k_d (1 - T) \quad (2)$$

Where (k_{de}) is effective cost of debt, (k_d) is the cost of debt before tax and (T) is tax rate.

In India, The debt is mainly financed by the domestic bank with a high interest rate of 12% and shorter debt tenure. Recently, many companies with good credit rating have started to finance their debt through corporate bonds. In addition to that, there is also an international financial institution which financed renewable energy project with the very low interest rate. However as these loans are in foreign currency, to negate the effect of fluctuating currency exchange rate, currency hedging is required. The open market the hedging cost adds 5 - 6% to the interest rate.

Research Methodology

LCOE being benchmarking tool is highly sensitive to the assumptions made, especially when extrapolated several years into the future. Thus, if it is used to analyse policy initiatives, assumptions should be made as accurately as possible, with respective sensitivity analysis (e.g., Monte Carlo) and justifications(Branker et al., 2011)

As the main aim of this study is to analyze key factor affecting LCOE of solar PV in India under the present policy framework such as selection thorough reverse auction:-

The objectives of the present study are as follows:

- Analysis of variation in the cost of capital (cost of debt & cost of equity) on LCOE
- Analysis of variation in tenure of the cost of debt on LCOE
- Analysis of variation in Value Gap Funding (VGF) or in other words capital subsidy on LCOE
- Finally, to analyse upward margin and downward margin of LCOE with various combination of parameters such as the cost of capital, debt tenure and capital subsidy which will help to determine upward and downward limit of bidding price within which solar PV project become viable.

The scope of this study is limited to analyse the effect of below mentioned parameters on LCOE:

- Cost of Capital (Cost of equity & Cost of debt)
- Debt tenure
- Capital Subsidy provided as Value Gap Funding (VGF)

Now, the sensitivity of the Cost of Capital is analysed by Categorizing different possible combination of cost of debt and cost of equity into five groups of investors. The sensitivity of debt tenure is analysed with two levels, while the sensitivity of capital subsidy is analysed with four different levels of subsidy.

So, in the matrix of sensitivity analysis, different types of investors are classified in to different groups on the basis of their cost of capital. The effect of the cost of capital of different groups is analysed with two different scenarios on the basis of debt tenure against four different level of capital subsidy provided in the VGF scheme.

The classification of investors on the basis of the cost of capital is described as below.

Group 1: This group includes mainly domestic investors asking the low cost of equity at around 10%. (Ernst & Young, 2017) They have financed debt by acquiring a loan from a domestic bank with interest rate of 12% p.a. or from the international financial institution by hedging foreign currency. The landed cost of debt in such a situation is assumed to be 12% (5-6% interest rate in foreign currency + 5-6% market cost of hedging foreign currency (Farooquee & Shrimali, 2016)) .

Group 2: This group includes domestic investors having a good credit rating (AA or AAA) and the ability to finance their debt by issuing a bond with a coupon rate of 7%. However, they ask the cost of equity of 15% (Ernst & Young, 2017).

Group 3: These are foreign investors having low cost of equity of 10% and low interest rate of 6-7% in foreign currency without any type of hedging (mainly from Japan) (Ikeda, 2017; KPMG International, 2015) Also this group includes domestic public sector investors with high credit rating which can issue a bond with coupon rate of 6-7%.

Group 4: These are investors with the high cost of equity of 15% and the high cost of debt of 12% (small and medium scale domestic companies) (Ernst & Young, 2017).

Group 5: This group represents foreign investors who can finance their debt at a very low interest rate of 3.5% and low cost of equity of 7% (from EU and US) (KPMG International, 2015). However, in such cost of capital, the cost of currency hedging is not included. It is assumed that such investment come through 100% (Foreign Direct Investment) route.

The Scenarios on the basis of debt tenure are classified as below:

- Long term debt tenure of 15 years
- Short term debt tenure of 10 years

The VGF or capital subsidy is classified into four different levels with 0%, 10% of capital cost, 20% of the capital cost and 30% of capital cost.

The technical design and simulation of PV plant at Jodhpur Rajasthan are carried out using PV Syst software (PVSYST, 2013). The selected location has the highest level of solar radiation in the country. So, the results of this analysis are also applicable to all other locations of India due to a lower level of solar radiation than selected location. In the absence of any scientific publications in this area, input parameters for simulations are assumed on the basis of practices, followed by EPC (Engineering, Procurement, and Construction) service providers in India. Financial input parameters are assumed based on various regulatory orders and government documents.

For simulation, polycrystalline silicon based modules have been selected. Other technical specifications of solar PV plant assumed for simulation are mentioned in following Table 1.

Technical specification	Data
Plant Capacity	1 MW
Latitude & Longtitude	26.3°N & 73.0°E
GHI	2306 (kWh/sq. m annually)
Module life time	25 Years
Inverter capacity/ total no. of inverter	500KWac/ 2
Inverter life time	13 Years

TABLE 1. Technical specifications of Solar PV plant

- The degradation rate is assumed at 1% per year.
- The tilt angle of the PV module w.r.t horizontal plane is assumed as the latitude of location and azimuth angle is assumed as zero (south facing).

Financial input parameters are assumed based on various regulatory orders and government documents. Input data assumed for this study are mentioned in the following Table 2.

Financial Parameters	Values
Capital Cost	Rs. 5,64,00,000 (Niti Ayog, 2015)
O&M Cost	Rs. 2,82,000 (for first year)
Insurance Cost	Rs. 1,69,200
Debt: Equity Ratio	70% : 30% (Rajasthan Electricity Regulatory Commission, 2015)
Corporate tax	34.00% (Rajasthan Electricity Regulatory Commission, 2015)
Depreciation	6.00% for 10 years (Rajasthan Electricity Regulatory Commission, 2015) 2.00% for next 15 years
Residue Value	10% of Capital Cost

TABLE 2. Financial inputs used for this study

- Like any other democratic country, changing corporate tax drastically is a very politically sensitive issue and also has a major impact on the overall economy. So, it is assumed that corporate tax will remain stable throughout the project life cycle.
- The cost of land is included in the capital cost.
- The tax benefit due to accelerated depreciation is not included in this analysis.
- Administrative and other costs such as wheeling charges and transmission costs are included in O&M cost.
- It is assumed that O&M cost will escalate at the rate of 5.72% per year.
- Inverter life time is assumed as 13 years, and its replacement cost is added in O&M cost of the 13th year.
- The applicable discount rate equals the cost of equity of a selected group of investors.

Result and Discussion

The analysis of the effect of selected parameters on LCOE is shown in Table 3. The interpretation and our opinion based on the present analysis are explained below:

- With the best combination of key factors such as lowest possible cost equity, lowest possible cost of debt, highest possible debt tenure and fully granted capital subsidy of 30%, the LCOE can be brought down to reported tariff between Rs. 2.00 to Rs. 3.00 due to extremely cost of capital prevailing in EU and US.
- From the present analysis, it can be observed that for most of the investors the debt tenure is not affecting their LCOE significantly as few previous studies reported (Shrimali et al., 2017).
- It can be observed from the results that the investors with low cost of equity (Group 1 and Group 3) may able to bring down LCOE at par with APPC provided they get a high level of capital subsidy (more than 20% of capital cost). However, due to the low cost of capital the investors of Group 5 can bring down LCOE without any requirement of capital subsidy.

Group No.	Debt Tenure (Yrs.)	VGF (0%)	VGF (10%)	VGF (20%)	VGF (30%)
Group 1	10	5.71	5.11	4.51	3.91
	15	5.67	5.06	4.47	3.88
Group 2	10	7.01	6.27	5.54	4.80
	15	6.73	6.02	5.32	4.61
Group 3	10	5.32	4.76	4.20	3.64
	15	5.16	4.62	4.07	3.53
Group 4	10	7.40	6.62	5.85	5.08
	15	7.21	6.45	5.70	4.95
Group 5	10	3.95	3.54	3.04	2.70
	15	3.85	3.45	3.12	2.63

TABLE 3. Effect of Selected Parameters on LCOE of Solar PV

- Under a present reverse auction system, only investors with the overall low cost of capital (Group 5) will be able to bid below APPC provided they get a full capital subsidy. The dominance of these investors can be clearly observed from the results.
- The medium size and new start up EPC player (Group 4) who may have the only option to financed their debt by acquiring loan from domestic banks or from foreign banks with currency hedging has no chance to survive in this reverse auction system as their cost of capital is very high compare to foreign investors from US and EU.
- Under this reverse auction system, there is very little scope generating short term profit by discounting cash flow with the high cost of equity.
- The public sector investors with high credit rating (Group 3) will able to bring down LCOE of solar PV at par with APPC provided they financed their debt though issuing a bond. through without any subsidy due to their low cost of equity.
- The result shows the clear dominance of western investors from EU and US in reverse auction system due to their low cost of capital. The difference between western investors (Group 5) and Asian foreign investors as well as public sector investor with high credit rating is so, high (about Rs. 1.00) that it may create a monopoly of western investors in the market. However, in the flow of such capital without any hedging may create pressure on the exchange rate and impact on the macroeconomic condition of India.

Conclusion

Under a present reverse auction system, the western investor will clearly dominate the market as they can bring down LCOE at the level of reported tariff between Rs. 2.00 to Rs. 3.00 while the medium scale and start-up companies will not have any chance of survival. However, the key group of investors is the domestic public sector investors with a high credit rating. They can bring down LCOE at par with APPC by financing their debt through the issuance of the bond. However, there is the high difference between their margins of LCOE with western investor due to the huge difference between their cost of capital. Under the present reverse auction system, there is the possibility of the creation of mono poly of western investors due to their extremely low cost of capital. However, the inflow of such capital through FDI route without any currency hedging may create huge pressure on the exchange rate, Forex, and other macroeconomic parameters. So, instead of focusing on a foreign investor with the lowest cost of capital which may bring down LCOE to a significant level, the policy makers should facilitate public sector investors with high credit rating though development of domestic currency dominated the bond market.

Policy Implication

From the above analysis, the clear dominance of one particular type of investors is observed which may able to bid with the present level of aggression in bidding with a tariff of Rs. 2.00 to 3.00. There is fear of creation of a monopoly of such investors. The inflow of such foreign capital without any hedging will have a serious effect on the macroeconomic condition of country considering requirement of the huge investment of $100 bn in this sector. So, instead of introducing policy measures to attract Foreign Direct Investment in this sector, the government should focus on developing the domestic bond market with low coupon rate though will public sector investor or other domestic investors with low cost of equity can compete in the bidding process and competitive nature of the market. For the sustainable growth of the market and to avoid the problem of under bidding, the government must decide the floor price of bidding below which bidding should not be allowed. The floor price should be revised just like any other tariff by concern regulatory authority through a public hearing. From results it can be observed that in few cases, the government should introduce some fund to subsidize the cost of capital of medium scale and start-up companies in this sector so, they can compete in this market.

Acknowledgement

We would like to thank the staff of Dr. K C Patel R&D Centre and management of CHARUSAT University for their support.

References

Baker, H. K., & Powell, G. (2009). Understanding of Finanical Management (pp. 355- 356). Oxford, UK: Blackwell Publishing.

Bhaskar, U. (2017). Will low tariffs eclipse India’s solar run?, Live mint. Retrieved from *http://www.livemint.com/Industry/YP4O4FOY598j9CqmRaRfOM/Will-low-tariffs-eclipse-Indias-solar-run.html*

Bloomberg New Energy Finance. (2016). Financing India's Clean Energy Transition. New York, USA: Bloomberg Finance L.P.

Branker, K., Pathak, M. J. M., & Pearce, J. M. (2011). A review of the solar photovoltaic levelized cost of electricity. Renewable and sustainable energy reviews, 15(9), 4470-4482.

Dawn, S., Tiwari, P., Goswami, A., & Kumar Mishra, M. (2016). Recent developments in solar energy in India: Perspectives, strategies and future goals. 62, 215-235. doi: 10.1016/j.rser.2016.04.040

Ernst & Young. (2017). Cost of Capital-India Servey 2017.

Farooquee, A. A., & Shrimali, G. (2016). Making renewable energy competitive in India: Reducing financing costs via a government-sponsored hedging facility. Energy Policy, 95, 518-528.

Ghosh, S., & Prasad, R. (2017). India’s solar mission can cause new debt problems, Live mint. Retrieved from *http://www.livemint.com/Opinion/xgMuV3kJD8vZBRrwLjEsvK/Indias-solar-mission-can-cause-new-debt-problems.html*

Government of India. (2008). National Action Plan on Climate Change. Prime minister's Council on Climate Change.

Ikeda, K. (2017). Impact of Japanese Banks' Strategic Stockholdings on their Cost of Capital: Bank of Japan.

Khan, M. Y., & Jain, P. K. (2007). Basic Financial Management (Second edition ed., pp. 7.5-7.6). New Delhi, India: Tata McGraw-Hill.

KPMG International. (2015). Cost of Capital Study 2015. Germany: Deal Advisory, Valuation.

Mahmud, R., & Prince, S. M. A. (2016). On the Determination of Levelized Cost of Electricity for Solar PV

System.

Mayr, D., Schmidt, J., & Schmid, E. (2014). The potentials of a reverse auction in allocating subsidies for cost-effective roof-top photovoltaic system deployment. Energy Policy, 69(Supplement C), 555-565. doi: https://doi.org/10.1016/j.enpol.2014.01.029

Ministry of New & Renewable Energy. (2013). Guidelines for setting up of 750 MW Grid Solar PV power projects with Viability Gap Funding (VGF) under (JNNSM), Phase-II, Batch-I. New Delhi.

Niti Ayog. (2015). Report of The Expert Group on 175 RE by 2022. New Delhi: Govt of India.

Planing Comission. (2014). The Working of State Ulitilies and Electricity Department. New Delhi, India: Government of India.

PVSYST. (2013). PVSYST Version 5.66. Switzerland: University of Geneva. Retrieved from *www.pysyst.com*

Rajasthan Electricity Regulatory Comission. (2015). Determination of generic tariff for Solar Power Projects for FY 2015-16. Jaipur, Rajathan.

Sambit Basu. (2011). India Solar Policy: Elements Casting Shadow on Harnessing the Potential India: IDFC Policy Group.

Sharma, N. K., Tiwari, P. K., & Sood, Y. R. (2012). Solar energy in India: Strategies, policies, perspectives and future potential. Renewable and Sustainable Energy Reviews, 16(1), 933-941. doi: *http://dx.doi.org/10.1016/j.rser.2011.09.014*

Shrimali, G., & Rohra, S. (2012). India's solar mission: A review. Renewable and Sustainable Energy Reviews, 16(8), 6317-6332.

Shrimali, G., Srinivasan, S., Goel, S., & Nelson, D. (2017). The effectiveness of federal renewable policies in India. Renewable and Sustainable Energy Reviews, 70, 538-550.

Shrimali, G., Trivedi, S., Srinivasan, S., Goel, S., & Nelson, D. (2016). Cost-effective policies for reaching India's 2022 renewable targets. Renewable Energy, 93(Supplement C), 255-268. doi: *https://doi.org/10.1016/j.renene.2016.02.062*

Umamaheswaran, S., & Rajiv, S. (2015). Financing large scale wind and solar projects—A review of emerging experiences in the Indian context. Renewable and Sustainable Energy Reviews, 48, 166-177. doi: *http://dx.doi.org/10.1016/j.rser.2015.02.054*

Nisarg Shah
Charusat University, Gujarat
E-mail: *kesminh@gmail.com*