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Field experiences with the operation of solar radiation resource assessment stations in India

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Abstract

World's largest DNI measurement network of 51 automatic meteorological stations with solar radiation instruments fulfilling the highest commercially available standards is operating in India. The Indian Ministry of New and Renewable Energy (MNRE) in 2011 started this extensive solar resource monitoring cum meteorological station network under the Solar Radiation Resource Assessment (SRRA) project. This paper highlights the overall performance of the stations over more than one year and documents the specific problems and errors observed in field operation. Following best practices quality assessment tests, a data flagging system to identify, differentiate and quantify different types of errors and other functionalities have been implemented as part of the SolMap project. The quality assessment tests check the plausibility of data, differentiate trustworthy data from likely erroneous data and flag them accordingly. The quality flag statistics of all 51 stations reveals that some stations are performing very well and others need more attention to improve. In the period from January 2012 to March 2013 on an average over all 51 stations, 92 % of the solar radiation data are classified as correct. The quality control system has proven to be very effective for detecting errors in functionality of the stations. Values flagged erroneous along with missing values are considered as gaps. Many applications such as solar energy performance simulations need continuous time-series. Therefore it is required to fill the measurement gaps with reasonable data. This paper also describes a set of procedures called 'basic gap filling' for solar irradiance.. The accuracy of the applied basic gap filling methodology is tested and the results show a mean bias of ca. 3 % over GHI, DNI and DHI over all types of gaps. Automated alarms, sensor cleaning switch, bird protection cages for wind sensors etc. are some of the efforts SRRA took for smoother operation. Regular cleaning of the radiometers remains the most challenging task for the SRRA network.

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Keywords: *Solar irradiance; automated quality control; gap filling; DNI; GHI, BSRN, SRRA, SolMap, India*

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1. Introduction

As India is aiming for large-scale deployment of various types of solar energy, the Indian Ministry of New and Renewable Energy (MNRE) in 2011 has started the Solar Radiation Resource Assessment (SRRA) project. This project is executed by Centre for Wind Energy Technology (C-WET) in Chennai, which hosts the central archiving and processing unit. SRRA project is supported by the SolMap project, which is conducted by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) in cooperation with MNRE. The SolMap project contributes to SRRA project in establishing quality checks of the data following international best practices and further data processing as well as gap filling.

In its first phase, SRRA set up 51 automatic meteorological stations with solar radiation instruments fulfilling the highest commercially available standards. The 51 stations of SRRA phase 1 have been primarily installed at sites, where relatively high potential for solar power is assumed [1]. Each of these 51 SRRA stations is equipped with one secondary standard pyranometer to measure Global Horizontal Irradiance (GHI), one secondary standard pyranometer to measure Diffuse Horizontal Irradiance (DHI) and a first class pyrheliometer to measure Direct Normal Irradiance (DNI). A two-axis solar tracker is used to track the sun with pyrheliometer and the shading assembly for the DHI pyranometer. Apart from solar radiation parameters, these stations also measure auxiliary meteorological parameters like ambient temperature, wind speed and direction, relative humidity, barometric pressure and rain rate. All data were previously averaged in 10-minute time resolution. Since August 2012 they are measured in 1 s and integrated to 1 min. Continuous monitoring is needed for ensuring proper operation and maintenance of these stations. For regular operation of such a large network of stations it is essential to implement automated quality checks.

One of the main aims of SRRA is to provide investment grade bankable solar radiation data to the solar industry, project developers, decision makers in the financing institutions and policy and also to the scientific community. It is envisaged that this data will also be used for the improvement and validation of satellite-derived solar radiation data for India. Under such circumstances, quality assessment and control of data forms the backbone of this data collection and monitoring system, ensuring proper operation and maintenance of the system.

This paper highlights the overall performance of the stations over more than one year and documents the specific problems and errors observed in field operation. This paper also reports about major field experiences and measures taken by SRRA scientists to overcome the challenges for successful operation. The overall performance of the stations for last over a year and the specific problems and errors observed in real life are documented in this paper. The gap-filling methodology applied to the solar radiation data as part of SolMap project is presented The accuracy of the applied gap filling methodology is tested and the results show a mean bias of ca. 3 % over GHI, DNI and DHI over all types of gaps.

2. Brief description of the SRRA system

The Solar Radiation Resource Assessment (SRRA) project consists of:

- **SRRA field stations:** 51 SRRA field sites in different regions of India where Automatic Solar Radiation and Weather Monitoring Stations (ASRWMS) are installed, see Fig. 1.
- **Central receiving and processing station:** Data reception, quality check and control, processing and dissemination at C-WET, Chennai

2.1. SRRA field stations

All the solar radiation sensors are mounted on a solar tracker, which is installed on a tower supported by a cemented platform. The SRRA stations also measure values of air temperature, relative humidity, wind speed & wind direction, atmospheric pressure and precipitation (Rainfall). Solar radiation parameters are measured at a standard height of 2 m, while wind speed is measured at a height of 6 m. The data pertaining to solar radiation and meteorological parameters are sampled every second and averaged and transmitted every one minute via GPRS mode of communication to the central data reception and processing center at C-WET, Chennai. The Components of the SRRA field stations installed in different parts of India are listed in

Table 1.

Table 1. Type of instruments, model and manufacturer details used to measure solar radiation and meteorological parameters in SRRA project.

parameter measured	type of instrument	model	manufacturer
GHI	1st pyranometer	PSP	Eppley Lab
DHI	2nd pyranometer	PSP	Eppley Lab
DNI	pyrheliometer	NIP	Eppley Lab
-	sun-tracker	SMT-3	Geonica
-	data logger	3000C	Geonica
ambient temperature and humidity	temperature humidity sensor	41382VC	Young
wind speed and wind direction	ultrasonic wind sensor	85000	Young
rain accumulation	rain gauge	52203	Young
barometric pressure	barometer	61302L	Young

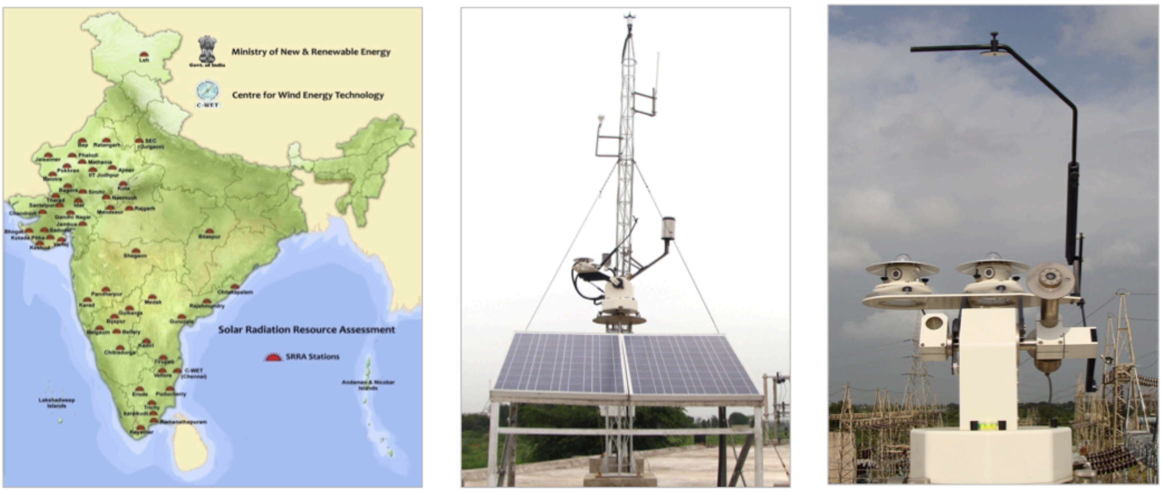

Fig. 1: Map of SRRA stations (left), SRRA station with 6 m wind tower, PV panel and solar tracker (middle), solar tracker with pyrheliometer, 2 pyranometers and shading assembly (right).

2.2 Quality check and quality control of SRRA data

The data from SRRA sites is received at the central data receiving and processing station, at C-WET Chennai, using GPRS mode of communication. The central station has been equipped with dual redundant hot standby servers with 2 Terra Byte effective storage volumes each. Both the servers have been loaded with software for reception of the data and storage to a database. The servers are running on 24×7, with the secondary server in hot standby mode operation. The database is updated in both the servers in real time mode to avoid any loss of data in case of server failure. Various tests are implemented that check the plausibility of data, and differentiate potentially correctly measured values from potentially erroneous data. The quality check tests applied here follow international best practices like those established by NREL's SERI-QC [2], WMO's BSRN [3], [4], and those used in the EU-project MESOR [5].

A data flagging system is implemented to identify, differentiate and quantify different types of errors. Such flags give feedback to users for identification of possible types of errors, which prove useful for rectification. Quality check tests and all other functionalities have been implemented in Matlab programming environment for this project. In addition to solar radiation parameters, since the stations also measure auxiliary meteorological parameters like ambient temperature, relative humidity, wind speed and direction, rain accumulation and atmospheric pressure different quality control tests have been applied to solar radiation and auxiliary meteorological parameters. The following major eight quality check tests are performed on solar radiation data:

1. Missing values test
2. Tracking error test
3. Minimum diffuse radiation test
4. Test for relation between GHI and DHI
5. Coherence test between GHI, DNI, DHI
6. Clear-sky test
7. Maximum physical limit test
8. Minimum physical limit test

For auxiliary meteorological parameters, tests (1), (7), (8) are carried out. During quality check of data, an individual data flag is assigned to all parameters for each of the time stamp being checked. The data flag contains information about the result of the quality check tests, which type of error is observed (if any), the amount of error (if any) and if the value is replaced or not in case of an error. These quality control procedures are also described in detail in [1].

In order to prove the functionality of the quality assessment tests, an experiment was carried out over a period of four days at one of the 51 stations by removing the shading disc of the pyranometer measuring DHI. With this new configuration of the station, both pyranometers measured global horizontal irradiance. Quality assessment tests were applied to data over this experiment period, the anomaly was detected by quality assessment tests and the data were flagged accordingly as shown in Fig. 2. The shading disk was removed on 4th May 2012 between 14:10 and 15:50 during which the station was offline and data was missing (represented by Flag 0). From 15:50 onwards GHI and DHI are almost identical and hence most of the values do not pass the coherence test (flag 5). At night since GHI and DHI values are 0, the night values are flagged correctly (flag 1) for GHI and DHI. Night values of DNI are greater than 0 and hence flagged as being greater than maximum physical limit (flag 4). During low DNI periods, when GHI, DHI and DNI values pass the coherence test, DHI and GHI values are flagged with flag 6 meaning measured DHI is greater than GHI. Tracking error is represented by flag 8 and is observed around noontime on 4th May 2012.

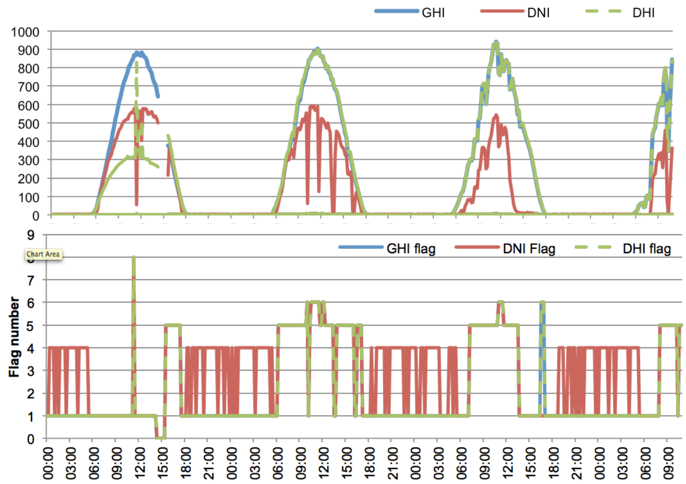

Fig. 2: Graph showing irradiance values (top) and associated error flags (bottom) both in 10 min time resolution measured at C-WET, Chennai during the period of the QC test experiment from 4th May 2012 to 7th May 2012. Time refers to UTC + 5 h.

3. Field experiences from and during the operation of SRRA network

Currently there exists over 1.5 years of operating experience with these 51 SRRA field units. The overall performance of the stations for 1.5 years and the specific problems and errors observed in field operation are highlighted. Following are the major operational problems, which have been observed from the field experiences

- Weathering of solar radiation sensors
- Soiling of solar radiation sensors
- Bird hit of wind measuring sensors
- Changing of site exposure conditions
- Vandalism of equipment
- Difficulty in approaching sites in extreme weather conditions

- Loss of data due to failure of GPRS communication
- Equipment failure
- Data gaps

Weathering of sensors and in particular solar radiation sensors has been a matter of concern for the SRRA/SolMap project team. At a few places pyrheliometers measuring DNI are found to be completely rusted and their Quartz window disfigured and turned to opaque. Studies have been made regarding the rusting of such a high quality sensor in some of the field sites and it is inferred that an acidic environment prevalent near the site of city garbage could be one of the reasons of such weathering of a sensor. The calibration was found to be beyond acceptable limits and hence the equipment was changed. To overcome this type of problem the site is required to be relocated to a place where acidic gases are not prevalent in the atmosphere.

Soiling of solar radiation sensor has been a major issue, which requires efforts to ensure that the sensors are cleaned daily. The quantum of soiling of a sensor also depends on the local conditions of a site. The SRRA sites located in Thar deserts or near Thar deserts in Rajasthan are prone to more soiling and require frequent cleaning. In the present SRRA network around 18 sites are located in such areas where daily cleaning of sensors is a prerequisite for getting good quality of radiation data. If the sensors are not attended to regularly it is found that the DNI values may be inaccurate and may show values lesser by 1 percent per day [6]. The values of GHI and DHI may also show the inaccuracies of the similar order if the pyranometers used for the measurement of GHI and DHI are not cleaned daily. From the experience we recommend to install such high quality solar radiation sensors only if the sensors can be cleaned daily. To make cleaning of sensors more effective all the SRRA sites have been provided with an electronic cleaning switch, which is required to be manually pressed by the site operator before starting the cleaning operation and again pressed at the end of cleaning operation. The signals of both the start and the end of cleaning operations are recorded at the data receiving and processing center at C-WET, Chennai. The compensation of the site operator is regulated based on the performance of the sensor cleaning as recorded at the central data receiving and processing center.

Bird hit is found to be a serious problem for ultrasonic wind sensors. The top of the sensors are completely ruptured by the bird hits and sensors are required to be replaced as they become beyond repairs. This problem is more prevalent either in rural areas or in sites located around forests. Bird guards have been introduced to overcome this problem but have not been found to be completely safe. Spikes around an ultra sonic sensor have also been introduced at some of SRRA sites. They also have limited success.

The reported equipment failures during the operation of the field equipment for the last 18 months are listed in Table 2.

Table 2. Reported equipment failures for the last 18 month of operation of SRRA stations.

equipment	number of failures	type of failure	reason	action taken
pyranometer	0	-	-	-
pyrheliometer	2	rusting	acidic environment	sensors replaced
solar tracker	1	gear broken	mishandling	replaced
data logger	1	hardware	electronic	replaced
temperature sensors	0	-	-	-
relative humidity sensor	0	-	-	-
wind sensor	7	sensor failure	bird hit	replaced
atmospheric press. sensor	0	-	-	-
rainfall sensor	0	-	-	-

Vandalism and theft have been noticed at SRRA stations in some parts of India. Solar panels and batteries have been the main targets, which are stolen due to which the station operation gets disrupted until the stolen parts are replaced.

Change of site exposure conditions has also been noticed at a few SRRA field sites. Bushes, shrubs and trees have grown at a few sites that have affected the site exposure conditions. Routine visits to sites and trimming/cutting of over grown trees, bushes etc. should be undertaken. This aspect is very important as India receives rains from two monsoon events, one is S-W and another is N-E Monsoon. Most parts of India get rains during S-W monsoon from June to September except some parts of Southern states get rain from October to December. The site exposure conditions are required to be checked after both the monsoons for the field sites located in respective regions.

4. Performance Analysis of SRRA Network

An extensive data analysis has been carried out to determine the performance of this large solar radiation measurement network. This analysis is done for the data from all 51 stations. The time period of analysis is from January 2012 until March 2013. The results of this data analysis are presented here in brief in terms of the statistical parameters over all 51 stations. The types of errors observed are shown in Table 3.

Table 3. Statistics of errors observed for GHI, DNI and DHI over all 51 SRRA stations.

solar irradiance	statistical parameter	error type, flag								
		0	1	2	3	4	5	6	7	8
		missing values	correct values	< min physical limit	> max physical limit	> clear sky limit	coherence test	DHI > GHI	DHI < DHI Rayleigh	tracking error
GHI	average	2.9%	92.5%	0.0%	0.0%	0.9%	3.8%	0.0%	0.0%	0.0%
	min.	0.1%	79.5%	0.0%	0.0%	0.1%	0.4%	0.0%	0.0%	0.0%
	max.	26.4%	98.2%	0.0%	0.3%	5.4%	13.2%	0.9%	0.0%	0.0%
	std. dev.	5.3%	4.7%	0.0%	0.1%	0.8%	3.1%	0.1%	0.0%	0.0%
DNI	average	2.7%	92.4%	0.4%	0.0%	0.3%	3.9%	0.0%	0.0%	0.5%
	min.	0.1%	77.6%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%
	max	26.4%	98.8%	18.0%	0.0%	5.0%	13.2%	0.0%	0.0%	6.1%
	stdev	5.2%	5.2%	2.5%	0.0%	0.8%	3.1%	0.0%	0.0%	1.0%
DHI	average	2.3%	92.1%	1.4%	0.1%	0.1%	3.9%	0.0%	0.0%	0.4%
	min	0.1%	65.8%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%
	max	26.4%	98.8%	38.0%	1.7%	1.5%	13.2%	0.8%	0.0%	5.9%
	stdev	4.9%	5.9%	5.9%	0.3%	0.3%	3.1%	0.1%	0.0%	0.9%

Fig. 3 to Fig. 5 give an overview of the amount of correct values (Fig. 3, flag 1), missing values (Fig. 4, flag 0), values with the error 'the solar irradiance values do not pass the coherence test' (Fig. 5, flag 5).

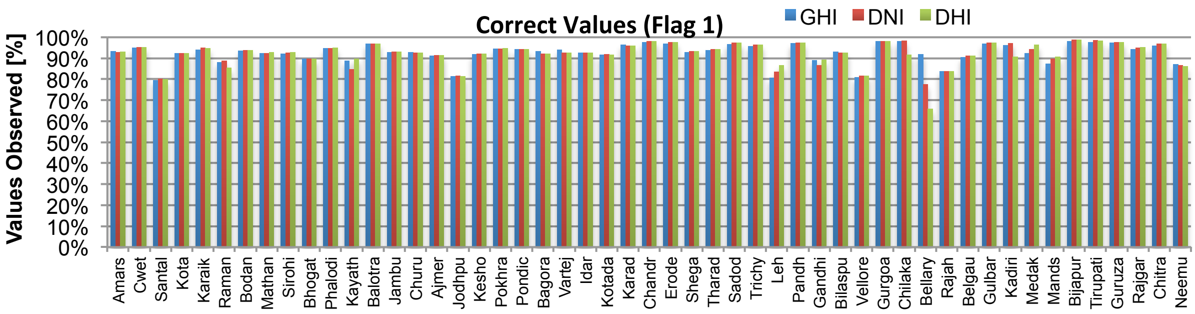

Fig. 3: Rate of correct values (flag 1) observed over all 51 SRRA stations.

One can notice that there are stations with almost no missing data against stations with ca. 26% missing data. On an average over all 51 stations, 92 % of the solar radiation data are classified as correct. From the values mentioned in Table 3, it can be seen that the most frequently observed error is 'the solar irradiance values do not pass the coherence test'. On an average over all 51 stations, ca. 4% of solar radiation data do not pass the coherence test. There are some stations that perform very well, for example it can be seen in Table 3, that the minimum amount of data, which do not pass the coherence test for a particular station was only 0.4%. At the same time the maximum amount of this error observed at a particular station is 13%. Due to missing information on sensor cleaning, it is assumed that since the cleaning of solar irradiance sensors is not done frequently, a major source of error is due to soiling of instruments. The error due to tracking is not observed frequently, 0.3 % on an average over all 51 stations during the considered period.

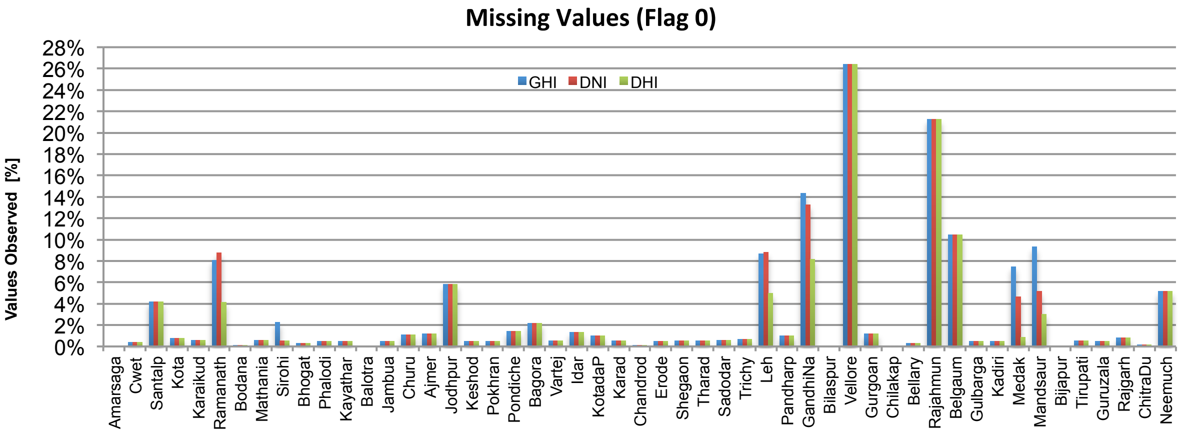

Fig. 4: Rate of missing values (flag 0) observed over all 51 SRRA stations.

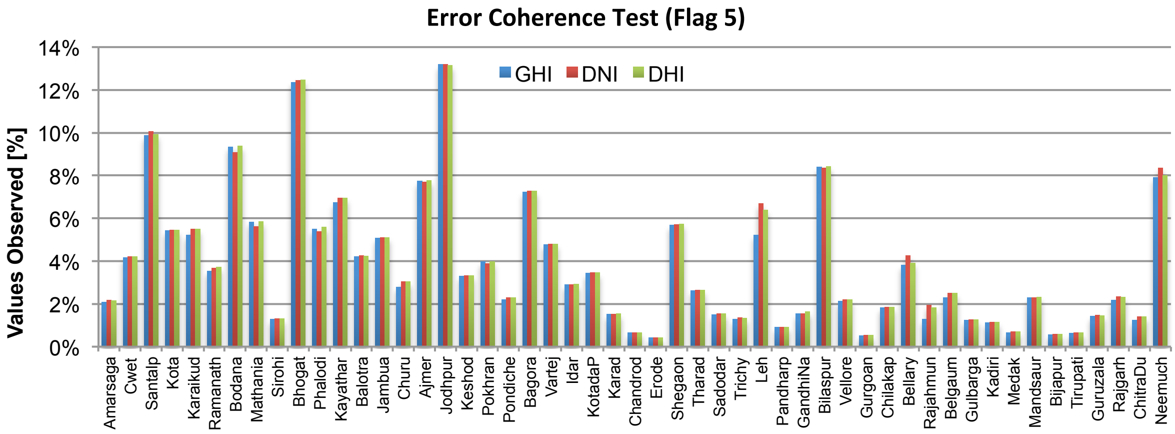

Fig. 5: Rate of error type failing coherence test (flag 5) observed over all 51 SRRA stations.

5. Gap filling procedure

As part of SolMap/SRRA projects gap filling procedures have been developed, which are divided into basic gap filling and satellite-based gap filling. The main difference between the two procedures is that basic gap filling procedure does not require additional overlapping satellite-derived data, whereas it is a must for satellite-based gap filling procedure. Due to the non-availability of additional satellite-derived data, satellite-based gap filling is not implemented for SolMap/SRRA project. In the following basic gap filling procedure implemented as part of SolMap/SRRA project is explained.

5.1 Basic gap filling procedure

The basic gap filling procedure considers solar radiation and auxiliary meteorological data separately. For gap filling of solar radiation data, the applied methodology depends on a) the availability of three components of solar radiation being measured i.e. Global Horizontal Irradiance (GHI), Diffuse Horizontal Irradiance (DHI) and Direct Normal Irradiance (DNI) and b) the duration (length) of the gap. The gap filling methodology differentiates if only one, two or all three solar radiation components are not available (gaps). In terms of the length of gaps, the methodology differentiates between gaps up to 3 hours, greater than 3 hours and gaps greater than 24 hours.

Depending on the availability of the three components of solar radiation and the duration (length) of gaps, gaps are filled either by using equation relating the three components, modeled values, linear interpolation of clearness indices or by replacing data from neighboring days.

Case 1: One (1) component of solar irradiance is flagged as incorrect or is missing (gap): If only one of the three solar irradiance components is flagged as incorrect or is missing, then this parameter will be calculated from the remaining two correctly flagged solar radiation parameters based on the physical relationship.

$$GHI = DHI + DNI * \cos\theta_z \qquad (1)$$

Case 2: Two (2) components of solar irradiance are flagged as incorrect or are missing (gap): When two of the three solar irradiance components are flagged as incorrect or are missing and one solar irradiance component is flagged correct, then a two-step approach is followed. This case is applicable only when GHI is available and both DNI and DHI are missing.

- Using the correctly flagged solar irradiance component (GHI) as input to Skartveit Model described in [6]. DHI is determined from this model for the missing time stamp.
- In the next step, these two solar irradiance components (GH) & DHI) are used to calculate the third solar irradiance component (DNI) just like in Case 1 using Equation 1.

Case 3: All three (3) solar irradiance components are flagged as incorrect or are missing (gap): When all three solar irradiance are flagged as incorrect or are missing, statistical techniques are applied to fill the gaps. In this case, the duration (length) of gaps is taken into consideration.

- In the first step, gaps less than 3 hours are taken into consideration. For this case, clearness indices are calculated for GHI & DNI for all the time stamps, when these components are available and flagged correctly. Then for the missing time stamps, clearness indices are calculated by applying linear interpolation. The values of GHI and DNI are then calculated for the missing time stamps. From these newly calculated GHI & DNI values, DHI is calculated using equation 1. For this procedure of linear interpolation of clearness indices, the duration (length) of gap is limited to 3 hours following the method proposed in MESOR project [5].
- When gaps in data are more than 3 hours, such gaps are replaced with data from neighboring days (in case they are available). In its current stage, the gap filling procedure can fill gaps up to 10 days if data for days before and after the gaps is available. The first 5 days will be replaced with data from the day before start of the gap, whereas the last 5 days will be replaced with data from the day after end of the gaps. This limit of 10 days is set due to the fact that in atmospheric science it is assumed that weather stays constant for a period of 5 days. Moreover, since the sun position does not deviate significantly for a period of 5 days, this procedure is applied to solar radiation data, so that the data matches with sunrise and sunset times and also with sun elevation and azimuth angles.

For gap filling of auxiliary meteorological data, only Case 3 discussed for solar radiation data is applied and the applied methodology depends only on the duration (length) of the gap. When duration (length) of gaps is less than 3 hours, instead of linear interpolation of clearness indices the values of the parameters are directly linearly interpolated. The outcome of gap filling is a continuous time-series without gaps in hourly time resolution.

5.2 Quantification of the effect of gap filling

In the next step of analysis, the aim was to quantify the effect and determine the accuracy of gap filling by creating artificial gaps in time series with correctly measured data. For this a sample of 9 SRRA stations located in different states of India and hence representing different climatic conditions and also operational condition of the stations was taken. Artificial gaps were created in the time-series of data from all these stations based on four main categories of gaps: when the gap is in only one component of solar irradiance (DHI) b) when the gap is in two components of solar irradiance (DNI and DHI) and when the gap is in all three components of solar irradiance (GHI, DNI and DHI) for c) gaps smaller than 3 hours and d) gaps greater than 3 hours. Gaps were created on a continuous basis for these four types of gaps.

After creating these artificial gaps, basic gap filling procedure was applied to the time series and results obtained are presented. The results are presented in Fig. 6a), Fig. 6b), Fig. 7a) & Fig. 7b) as relative mean bias between the gap-filled data and original data without gaps. After applying basic gap filling procedure to data with artificially created gaps, it is found that:

- When gaps are present in one component only (GHI, DNI or DHI), GHI increases by 0.3 %, DNI decreases by 0.8 % and DHI decreases by 0.7 % on an average over all 9 SRRA stations after applying basic gap filling procedure. These values are found to be quite reasonable taking into consideration the inaccuracies involved in the averaging of hourly values of solar radiation and zenith angles.
- When gaps are present in two components of solar radiation (DHI and DNI), DNI increases by 19 % and DHI decreases by 9 % on an average over all 9 SRRA stations after applying basic gap filling procedure. On cloudy days the model used for gap filling underestimates values for DHI, which leads to an overestimation of DNI. For Station Kayathar (Figure 6b)) days used for this analysis were mainly cloudy, resulting in a higher mean bias compared to other stations that included more clear days.
- When gaps smaller than 3 hours are present in all three components of solar radiation (GHI, DNI and DHI), GHI decreases by 2 %, DNI decreases by 2 % and DHI decreases by 1 %.
- Finally, when gaps greater than 3 hours are present in all three components of solar radiation (GHI, DNI and DHI) GHI increases by 4% and DHI decreases by 0.5 %. DNI increases for some stations to a large extent, because here data from the neighboring day is taken to fill the gaps.

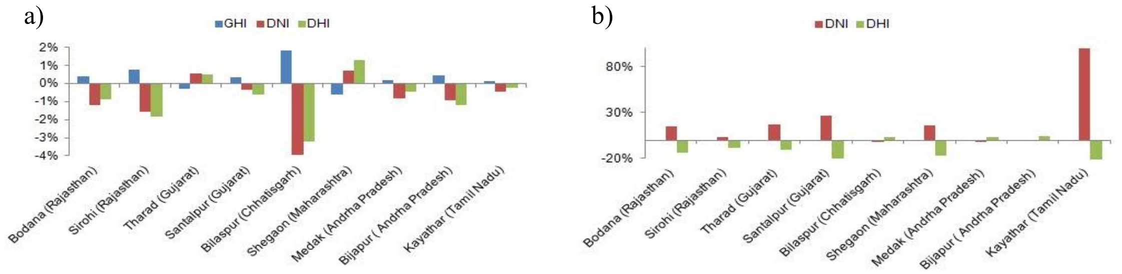

Fig. 6: Artificial gaps for a) one and b) two solar irradiance component are created for all 24 hours in original solar irradiance data (Level 2) from 10 SRRA stations with good data on purpose to quantify the performance of basic gap filling procedure. Results from the tests of basic gap filling procedure are represented as relative mean bias in % between original (Level 2) and gap-filled values (Level 3). A positive mean bias indicates increase in the solar irradiance average after applying basic gap filling. A negative bias indicates decrease in the solar irradiance average after applying basic gap filling.

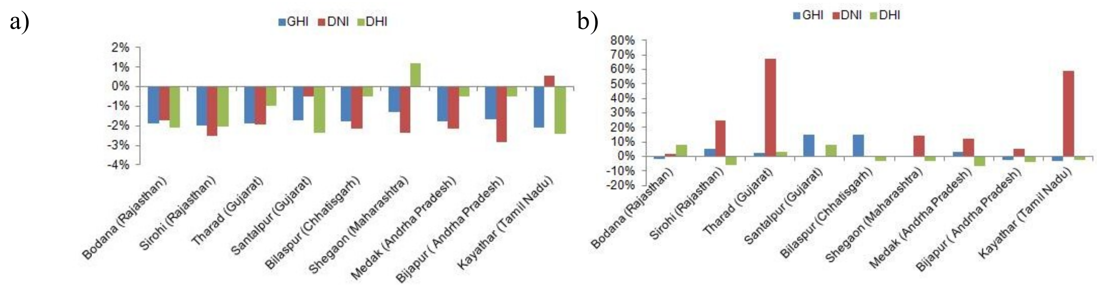

Fig. 7: Artificial gaps for all three solar irradiance components (GHI, DNI and DHI) for a) gaps <3h between 7 & 9, 11 &13, 16 & 18 (UTC+5) and b) gaps >3h gaps between 7 & 18 (UTC+5) are created in original solar irradiance data (Level 2) from 10 SRRA stations with good data. Results from the tests of basic gap filling procedure are represented as relative mean bias in % between original (Level 2) and gap-filled values (Level 3). A positive mean bias indicates increase in the solar irradiance average after applying basic gap filling. A negative bias indicates decrease in the solar irradiance average after applying basic gap filling.

The accuracy of the applied basic gap filling methodology is tested and the results show a mean bias of ca. 3 % over GHI, DNI and DHI over all types of gaps. This accuracy is close to the accuracy of the applied solar irradiance measuring instruments, indicating that the gap filled values stay within the tolerance limits.

6. Conclusions and Outlook

SRRA infrastructure has developed investment grade solar radiation resource information to assist project activities under the National Solar Mission of India. Until now the availability of ground-measured solar radiation data in India is very limited. In terms of the type and quantity of solar radiation data that is being measured, processed and stored by this network of 51 high precision stations, this is one of its kind systems not only in India but also the world.

A quality control and flagging system has been implemented to make SRRA functional and operational. This system has proven to be very efficient for detecting errors in functionality of the stations, which can be useful for their easy and fast rectifications. From the data analysis, it is observed that some stations are performing very well. Other stations show some operation issues. On average the network is running well. The most frequent error observed in the data from this network is when GHI, DNI and DHI values do not pass the coherence test (ca. 4 %). Missing values due to unavailability of the solar radiation sensors was the second most frequently observed error (ca. 3 %). This analysis helps in future to improve the operation of the network.

Basic gap filling procedure presented in this paper is implemented as part of SRRA and SolMap projects. The accuracy of the applied basic gap filling procedure is determined by creating artificial gaps in time-series of correctly measured solar irradiance values. After applying basic gap filling procedure to data with artificially created gaps, the results show a mean bias of ca. 3 % over GHI, DNI and DHI over all types of gaps, representing the accuracy of the applied basic gap filling procedure. This accuracy is close to the accuracy of the applied solar irradiance measuring instruments, indicating that it stays within the tolerance limits.

Considering that the SRRA equipment has been working at remote sites, the experiences from sites has been very valuable. Effective measures and action were initiated in time by the C-WET and associated organizations like GIZ to ensure that the quality of SRRA data does not get adversely affected. The quality of sensors and associated equipment like solar tracker, data logger, power supply system etc. were found to be mostly trouble free. From the experience gained with this system it can be said that daily cleaning and maintenance is an integral part of such high precision measurement system and hence such sensors should be installed only when necessary daily cleaning can be assured at the sites.

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