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Comparison of Satellite and Ground based Solar Data for Peshawar, Pakistan

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***Abstract*—**This study presents one of the first analyses carried out on solar energy resource measurement using meteorological station established at University of Engineering and Technology (UET) Peshawar by World Bank under Energy Sector Management Assistance Program (ESMAP). Ground based direct normal irradiance (DNI) and global horizontal irradiance (GHI) were measured and analyzed for year 2017 and then compared with the data of satellite based solar model called SUNY. Ground based data was measured with the help of Kipp & Zonen CMP10 Pyranometer and Twin sensor Rotating Shadowband Irradiometer (RSI). Data of satellite based solar model (SUNY) was based on daily total monthly mean averaged over 15 years, starting from 2000 till 2014. The maximum value of ground based GHI was found for the month of June which was 6,415 Wh/m^2 and minimum GHI was found for the month of December which was 1,605 Wh/m^2. On the other hand, highest DNI was recorded in the month of April which was 5,884 Wh/m^2 and lowest DNI was recorded in the month of January which was 1,718 Wh/m^2. Comparison of the data showed higher values of GHI and DNI for satellite based model (SUNY) in most of the months. In February, March and April, ground based GHI and DNI were overestimated compared to satellite based model. Maximum difference of 1,346 Wh/m^2 in GHI was noticed in November and minimum difference of -181 Wh/m^2 was recorded in the month of March. On the other hand, maximum difference of 2,348 Wh/m^2 in DNI was observed in the month of November and a minimum difference of -140 Wh/m^2 was seen in March. This study will be helpful in further assessment of solar energy resource at any location in Pakistan as it will provide help for base-line studies. Moreover, it will also help in establishing any solar energy program particularly concentrating solar power (CSP) in Pakistan.

***Keywords*—** GHI, DNI, UET Peshawar, satellite data, ground data

I. Introduction

Establishment of any solar energy program needs accurate solar energy resource measurement. Solar energy resource assessment is one of the important phases for development of any solar energy program to properly estimate the available solar energy received on earth. Solar energy resource can be estimated from satellite based models or real time ground based measurements. For any investor, to invest in any solar energy program, accurate ground based solar energy needs to be measured. There are various satellite based solar energy resource estimation models available worldwide; each has its own significance and estimation approach. These models can only provide data based on estimated value of solar energy. Satellite based solar energy resource and ground based measured solar resource need to be compared to each other in order to find correlation between them.

Various research studies have been carried out in different regions of the world to assess solar energy resource. One such study was done in Saudi Arabia which showed that DNI in the country ranged from 9,000 Wh/m^2/day in the summer to 5,000 Wh/m^2/day in the winter season. Same study showed that GHI in many regions of the country was as high as 8,300 Wh/m^2/day. DNI was locally measured at Qassim University which ranged from a maximum value of 8,367 Wh/m^2/day in July to a minimum value of 4,702 Wh/m^2/day in January [1].

Another study was done which investigated performance of photovoltaic systems at 32 different sites of Saudi Arabia on the basis of real time solar radiation data. In this research, grid connected photovoltaic system was used for study whose maximum output was 100,000 W. The performance of the system at 32 sites was measured through RETScreen program on the basis of collected data through RRMM (Renewable Resource Monitoring and Mapping) program for 2 years. This research showed that highest energy was produced in Najran site which was 218.5 MWh for fixed photovoltaic systems [2].

A study was done in Saudia Arabia which concluded that, for 30 stations, the annual average daily GHI was in range of 5,700 Wh/m^2 to 6,700 Wh/m^2. This study also stated the higher values of GHI for inland while lower values of GHI for coastal areas [3].

One of the studies in Chile shows very good agreement between ground based and satellite based irradiance, showing an

rRMSE (relative root mean square error) of 8.9% only. They also found that for radiation values less than 3,000 Wh/m^2/day, satellite based data overestimated the actual radiation received on earth [4].

A satellite based model was developed by using climatic conditions of Thailand. The model was used to analyze the data of 25 ground based measurement stations having pyranometers. They found that monthly average hourly global radiation agreed very well with ground based data having root mean square difference of only 10% from the mean value [5].

Peshawar is located at 34.01^o N latitude and 71.58^o E longitude in Khyber Pakhtunkhwa province of Pakistan [6]. Currently, country is suffering from severe shortfall of energy. In order to mitigate power crises, different energy programs are employed in the country. In connection to that, World Bank in collaboration with Alternative Energy Development Board (AEDB) Pakistan has established meteorological station at University of Engineering and Technology (UET) Peshawar. The purpose of this station is to record ground based solar radiation which will be used for assessment and generation of solar energy maps. Ground based data used in this study has been taken from station established at UET Peshawar.

A. Definitions

1) Direct Normal Irradiance (DNI)

The direct irradiance received on a plane normal to the sun is called direct normal irradiance [7]. The device which measures DNI is known as pyrheliometer. DNI is usually measured in Wh/m^2/day. DNI is very handy for concentrating solar technologies.

2) Global Horizontal Irradiance (GHI)

The maximum solar radiation at a specific time and place on the earth's surface when no cloud is present is called global horizontal irradiance [8]. GHI is measured in Wh/m^2/day. GHI is useful for flat plate solar collectors.

II. METHODOLOGY

Study presented in this paper has been done using World Bank's Energy Sector Management Assistance Program (ESMAP). This program focuses to monitor and map various parameters out of which wind and solar energy is of prime importance. Under this program, ESMAP tier 2 meteorological station has been installed at roof top of Mechanical Engineering Department, University of Engineering and Technology (UET) Peshawar on April 10, 2015. Other stations installed through this program at various locations of Pakistan are listed in Table 1.

Meteorological tier 2 station at UET Peshawar consists of various instruments to measure different parameters. It is equipped with Concentrated Solar Power Services (CSPS) Twin sensor Rotating Shadowband Irradiometer (RSI) and Kipp & Zonen CMP10 Pyranometer. They are used to direct normal irradiance (DNI), global horizontal irradiance (GHI) and diffuse horizontal irradiance (DHI) received at this station. It is also equipped with CS215 Temperature and Relative Humidity probe which measures temperature and relative humidity of the ambient air. This station also has CS100 barometric pressure sensor which measures barometric pressure. NRG #40C Anemometer and NRG #200P wind direction sensor are also part of the station which are fixed on a wind mast at 10 m height above the surface of roof top. Data logger used in this station is Campbell Scientific CR1000. All these sensors have been integrated into the same meteorological tier 2 station data acquisition system. All the components are being powered by a battery connected to solar panel which is fixed in the station. Figure 1 shows portion of meteorological station established at UET Peshawar.

Table 1: Meteorological Stations installed at different location by World Bank in collaboration with AEDB Pakistan [9]

S. No.	Location
1	Quaid e Azam Solar Park, Bahawalpur
2	National University of Science and Technology (NUST), Islamabad
3	Kala Shah Kaku (KSK) Campus of UET Lahore, KSK
4	MNS Campus of UET Lahore, Multan
5	NED University, Karachi
6	Mehran University, Jamshoro
7	Balochistan University of Information Technology (BUITEMS), Quetta
8	Balochistan Univeristy of Engineering and Technology (BUET), Khuzdar

Figure 1: Portion of meteorological station at UET Peshawar

Data chosen for this research was taken from the tier 2 meteorological station established at UET Peshawar. Ground based measured data used in this study is for year 2017. Satellite based data has been taken from National Renewable Energy Laboratory NREL's National Solar Radiation Database (NSRDB). NRSDB provides solar resource data based on different models for different regions of the world. For South

Asia which includes Pakistan, NRSDB has developed a satellite based model, which it has named SUNY. SUNY has temporal resolution of 1 hour and spatial resolution of 10 x 10 km. SUNY provides data for Peshawar region from year 2000 to 2014.

In this study, data received for both GHI and DNI at the established station were analyzed for the year 2017. Satellite based DNI and GHI were taken from SUNY. For Peshawar, data of SUNY was downloaded from NREL's website [10]. These satellite based GHI and DNI were analyzed on the basis of monthly mean daily total averaged over 15 years (2000 to 2014). All values reported are in Wh/m2. A comparison between ground based and satellite based measurements for both GHI and DNI was made by plotting data against each month.

III. Results and Discussion

A. *Analysis of ground based data*

All values of DNI and GHI reported here are based on monthly mean daily total. Ground based measured data chosen for analysis is for year 2017. It can be seen from Figure 2 that maximum GHI is reported for the month of June which is 6,415 Wh/m^2. Similarly, Figure 2 shows minimum GHI for the month of December which is 1,605 Wh/m^2. On the other hand, Figure 3 shows maximum DNI recorded in the month of April which is 5,884 Wh/m^2 and lowest DNI noted in the month of January which is 1,718 Wh/m^2.

B. *Comparison of ground based measurements with satellite based model SUNY*

As discussed above, values reported here for ground based DNI and GHI are based on monthly mean daily total for year 2017. For SUNY model, values of DNI and GHI are based on monthly mean daily total averaged over 15 years period starting from 2000 and ending on 2014.

Figure 2 shows that for most of the months satellite based averaged GHI is greater compared to ground based measured GHI except for the months of February, March and April where GHI measured at UET Peshawar Station is more compared to Satellite based model SUNY. In February, March and April, ground based measurements report values 277 Wh/m2, 181 Wh/m2 and 366 Wh/m2 respectively higher than that of satellite based model SUNY.

Figure 3 shows the same trend for DNI. For most of the months, satellite based averaged DNI is higher compared to ground based measurements except for the month of February, March and April. In February, SUNY reports a value 794 Wh/m2 less than that of ground based measurements while for the months of March and April, SUNY shows values 140 Wh/m2 and 641 Wh/m2 lower than that of ground based measurements respectively.

In most of the months ground based DNI is underestimated compared to satellite based models. This could be due to varying aerosol optical depth (AOD) as aerosols are considered to be one of the main reasons for attenuation of solar irradiance through atmosphere. Optical properties of aerosols highly vary with time and space and may be the prime cause for extinction of DNI in our study.

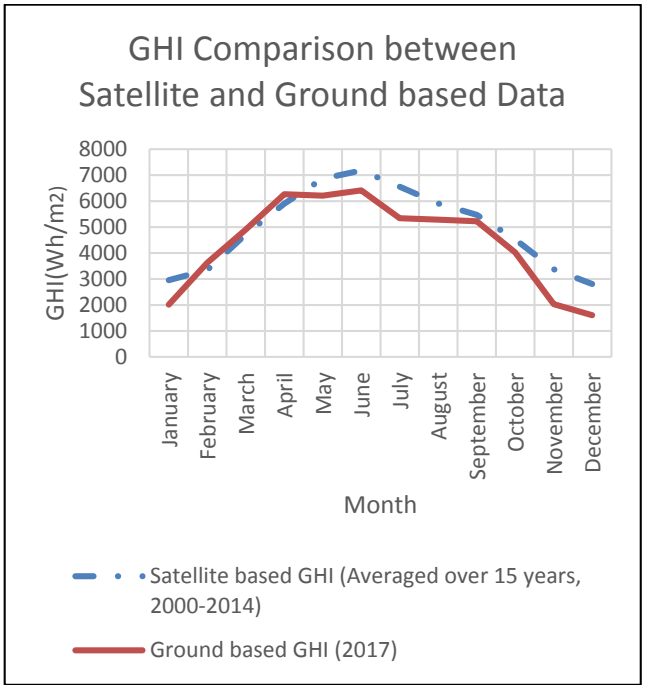

Figure 2: GHI Comparison

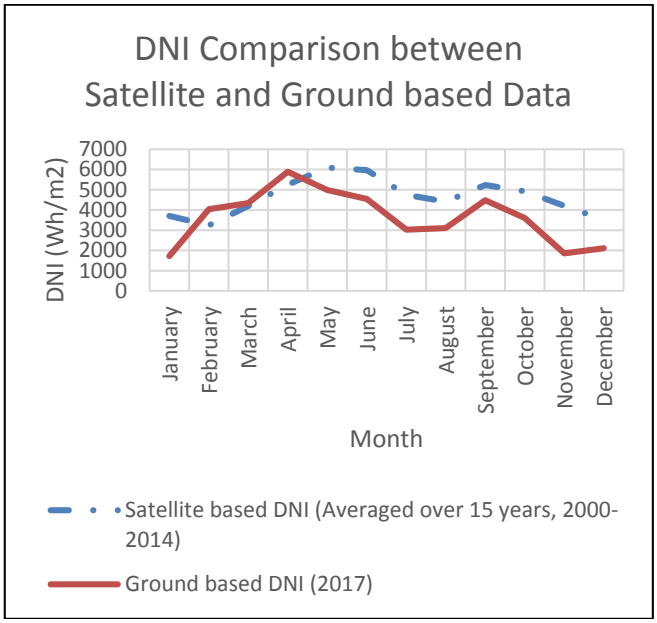

Figure 3: DNI Comparison

IV. Conclusion

This paper presents one of the first studies done on meteorological station of UET Peshawar. Station at UET Peshawar is fully functional and currently recording all weather parameters for which it was desired and established. Solar resource data collection is one of the core objectives of this station. In connection to that, this paper analyses DNI and GHI for year 2017. Highest GHI received at this station is 6,415 Wh/m2 which has been recorded in the month of June. Lowest

GHI recorded at this station is 1,605 Wh/m2 which has been reported for the month of December. Similarly, highest DNI recorded at this station is 5,884 Wh/m2 for the month of April while lowest DNI recorded is 1,718 Wh/m2 for the month of January. It can be easily concluded that maximum global irradiance received at this station is in month of June which is summer time in Peshawar. Minimum global irradiance received at this station is in month of December which is winter time in Peshawar.

Data comparison in the study is based on 15 years average estimated data of SUNY satellite based model (averaged data between year 2000 and 2014) and ground based measurements recorded in 2017 at meteorological station of UET Peshawar. The comparison of the data showed higher values of GHI and DNI for satellite based model SUNY when compared to ground based measurements except for the months of February, March and April where ground based measured values of GHI and DNI are higher compared to satellite based values of model SUNY. Maximum difference of 1,346 Wh/m2 in GHI is recorded in November and minimum difference of -181 Wh/m2 is noted in the month of March. Average difference of 556 Wh/m2 in GHI is observed between ground based measurements and satellite based model SUNY. On the other hand, maximum difference of 2,348 Wh/m2 is observed in November and a minimum difference of -140 Wh/m2 is seen in March. Average difference noted in DNI between ground based data and satellite based data is 983 Wh/m2.

It is perceived that results presented in this study will be fruitful for establishing any solar energy program, particularly establishing solar power plants in Peshawar. Ground based measurements will act as evidence for actual assessment of any solar energy program to carry out feasibility studies.

In future, same study can be done for other eight stations installed by World Bank and Alternative Energy Development Board (AEDB) Pakistan at different locations of Pakistan. This sort of study at other locations of Pakistan will provide ground based data which will be really helpful for feasibility studies to establish solar power plants in those locations.

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