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Review on devices used for Solar radiation measurement

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***Abstract*—There is a problem of availability of sufficient and functional instruments for measuring solar radiation in India due to higher importation costs and maintenance. So, it is preferred to construct devices from locally available equipment. This paper reviews the pyranometer to measure solar radiation, to assess the availability of solar energy arriving on Earth, it is important to measure solar radiation at some locations. From the reviewed existing research works, Silicon Photodiode-based pyranometers are preferred to thermopile-based pyranometers as the former has lower cost, more portable and requires little maintenance.**

Keywords—Solar radiation, thermopile, silicon based Photodiode

I. INTRODUCTION

Solar irradiance is an important parameter to be measured for both atmospheric science and renewable energy system design. Since the technology is rapidly developing, a large number of pyranometers have been proposed (Moiz et al., 2020; Kipp & Zonen, 2018) but both their cost and the maintenance requirements tend to be expensive. Hence, there is a need for a monitoring instrument that is robust, accurate, less expensive and capable of unattended long time operations. Instruments designed to measure radiation of any type are called radiometers. Two types of radiometers used to measure solar irradiance are pyrheliometers and pyranometers. Pyranometer measures various components of radiation. Their ability to receive solar radiation from two distinct parts of the sky sets their designs apart. Pyrheliometers are used to measure Direct Normal Irradiance (DNI) and pyranometers are used to measure Global Horizontal Irradiance (GHI), Diffuse Horizontal Irradiance (DHI), or plane-of array (POA) irradiances. A standard instrument for measuring the combined direct and diffuse components of the solar irradiance is the global solar pyranometer. The pyranometer is an instrument used for measuring solar radiation from a solid angle of 2π steradians into a plane surface with a spectral range of 0.3 to 3.0µm (Dissawa et al., 2017). Pyranometers are widely used by meteorologists, climatologists, atmospheric scientists, and renewable energy researchers (Shenoy et al., 2018). Pyranometers suitable for measurements of solar energy fall into one of two categories: those that measure the temperature rise of a black surface referenced against a thermal mass or a reflective white surface, as well as those that directly convert radiant energy to electrical energy, that is, photometric types (Eikeland, 2019). The black surface pyranometers typically offer spectrally uniform response from 300 to 3000 nm and some meet or exceed the world meteorological organization (WMO) specifications suggested for high quality instruments suitable for use as secondary standard measurements (Michalsky and Long, 2016). The photometric types, although less expensive to manufacture, have spectral responses governed by the semiconductor material, typically silicon, and are not classified by the WMO for reference-grade applications (Tohsing et al. 2019)

II. CLASSIFICATION, CONSTRUCTION AND WORKING

Meteorologists and climatologists use different sensor types, depending on the type of solar radiation that they aim to monitor. The measurement of the intensity of solar irradiation is based on pyranometer, pyrheliometers, sunshine monitor, and quantum sensors. Thermopile pyranometers: A thermopile pyranometer is a thermopile-based sensor designed to measure the density of the solar flux in the broadband. A thermopile pyranometer with broad, flat spectral sensitivity measures 300 to 2800 nm. Irradiation is calculated from the differential measurement between sun-exposed black-sector temperature and white-sector temperature not exposed to the sun or in shades (Figure 1). In all thermopile technology, irradiation is proportional to the difference between light exposed area temperature and sun exposed area and the temperature of shadow area. Figure 1: Block Diagram of Thermopile Pyranomter Source: Shenoy et al. (2018) Pyranometer based on photodiodes: it is also known as a silicon pyranometer. A photodiode-based pyranometer can detect solar spectrum portions between 400 nm and 900 nm, with the highest performance detection ranging from 350 nm to 1100 nm (Table 1). The photodiode transforms frequencies of the solar spectrum into high speed current based on the photoelectric effect. Photovoltaic pyranometer: A photodiode pyranometer derivative. The main part of the sensor is a photovoltaic cell which operates in near-short circuit condition. The generated current is in a range between 350 nm and 1150 nm directly proportional to the incident of solar radiation on cell. Photodiode-based pyranometers need less maintenance and are less expensive than the thermopile (Okonkwo and Onwuala, 2002). S/N Specifications Thermophile Pyranometer Photodiode Pyranometer Photovoltaic Pyranometer 1 Main Component Used Thermocouple Photodiode Photovoltaic Cell 2 Sensitivity Range 300 nm to 2800nm 400nm to 900nm 350nm to1150nm 3 Cost Expensive Reliable Moderate 4 Accuracy Highest Moderate High Source: Shenoy et al.2018

III. REVIEW OF LITERATURE

(Beaubien, Bisberg, and Beaubien 1998) The three pyranometers are similar in performance in that they all offer very low azimuth errors, are generally insensitive to changes in ambient temperature, and offer the spectrally uniform 300–3000-nm response of the black surfaces. The PRT instrument meets or exceeds the WMO specifications for a high quality pyranometer, and the bismuth telluride and bismuth antimony thermopile units meet the WMO requirements for use in networks The bismuth telluride thermopile pyranometer offers excellent cosine response, a very low output impedance, and output coefficients an order of magnitude higher than those obtained from other thermopile instruments. Its 1/e response of 12 s is adequate for most climatological and meteorological applications.

(Bush et al. 2000)it is possible to correct for thermal offset errors in pyranometers. An algorithm and thermal offset calibration procedure is proposed to improve the accuracy of the data. It should also be noted that particular designs and environmental circumstances might result in smaller or larger corrections than those found in this study for the PSP instrument. To maximize the quality of surface insolation data acquired with pyranometers, it is suggested that the inherent thermal offset errors be evaluated in every case and that the proposed algorithm be applied when necessary.

(Haeffelin et al. 2001)During daytime the PSP output signal contains both the shortwave component from solar radiation and the thermal offset that is due to the temperature gradient in the instrument. We use the PSP temperature measurements to estimate the PSP thermal offset. Once estimated, the thermal offset is removed from the PSP output and a corrected diffuse solar irradiance is produced

(Wood, Muneer, and Kubie 2003)The BF3 provides a reliable straightforward measurement of global and diffuse irradiation, without needing polar alignment or regular adjustment. It also provides a measure of sunshine hours that is within the WMO accuracy requirements, and is significantly more accurate than the Campbell-Stokes recorder.

(Link, Marks, and Hardy 2004)Solar and thermal radiometer arrays are robust, highly portable tools that can be easily deployed at the snow surface beneath a wide variety of vegetation canopies. Radiometer arrays provide measurements of spatially averaged direct and diffuse radiation within forest canopies when sampled at a high temporal resolution. These data have been used for a variety of applications, including inputs to snowmelt models and for development, validation, and parameterization of canopy radiative transfer models. Although more-complex canopy radiative transfer models exist, simple, computationally efficient algorithms parameterized with radiometer array data are advantageous for spatially distributed snowcover simulations.

(Raïch 2007)A series of expressions have been presented which correct the angular and spectral responses, as well as the temperature effect of Li200SA photovoltaic sensor regarding CM11 thermoelectric sensor, for clear skies conditions. Corrections to angular and spectral responses of both instruments are analytical functions that depend on the solar zenith angle. Their application has allowed us to uncover dependence on temperature of the Li200SA response: below 20◦C there is a tendency for linear asymptotic behaviour and above 35◦C this levels out. This behaviour, so linked to the studied temperature interval, explains the great variability of Li200SA temperature coefficients present in scientific literature. A possible technological application to counteract the global temperature irradiance characteristic would be to maintain the Li200SA sensors and in general all photovoltaic sensors at a constant temperature of 35◦C, mainly in climates colder than that of the Mediterranean.

(Martínez, Andújar, and Enrique 2009)This paper presents the design, construction and testing of a photodiode-based pyranometer for the visible spectrum. Tests carried out on the developed device show it can compete successfully with high-end commercially available pyranometers at a much lower price and with additional features in terms of connectivity, measurement and remote programming and operation. The newly developed pyranometer can be used in any installation where reliable measurement of solar irradiance is necessary, especially if cost becomes a deciding factor when choosing a pyranometer. This new pyranometer presented in this work brings together features which make it a very competitive alternative to what the market offers at present time.

(Medugu et al. 2010)This paper presents the design, construction and testing of a reliable model pyranometer for measuring solar irradiance. Construction of the pyranometer is conceptually very simple and cheap. However, it was designed based on an understanding of the underlying physical principles. The pyranometer was then calibrated against a reference high quality Kipp and Zonen CMP3 pyranometer whose calibration was trusted to obtain a calibration constant of 5230±0.024Wm. It was finally studied under actual environmental conditions of Mubi, Adamawa State of Nigeria. Tests carried out on the constructed pyranometer show it can compute favorably with the standard reference pyranometer (CMP3).

(Xie, Lee, and Feng 2010)A novel CMOS MEMS-based TPG was designed and fabricated by a CMOS-compatible process. Three unique features are included in the proposed generator. First, top and bottom vacuum cavities are created to manage the heat flow and maximize the temperature difference between the two junctions of the thermocouples. Second, a heat-sink layer is coated on the cold side of the device to effectively disperse heat from the cold side of the device to ambient air. Third, a peripheral cavity is designed to cut off heat from the surrounding silicon substrate, so that cold junctions of thermocouples at the rim edge of the TPG device area are not affected by the heat coming from the surrounding silicon.

(Wang and Zender 2010)Compared to the 10-year record of these GC-Net measurements, a five year record of MODIS satellite-retrieved snow albedo shows a systematic negative bias that increases with SZA for SZA larger than about 55°. The consistency and accuracy of the MODIS radiative transfer methods and BRDF models face serious challenges at high SZA, especially in polar regions. When SZA is smaller than 55°, MODIS albedos successfully capture the snow albedo dependence on SZA and show a relatively good agreement with GC-Net measurements. The discrepancy of MODIS with in situ albedo and with theory is caused mainly by two related factors, SZA and retrieval quality, that depend on both location and season. Although the in situ instruments suffer from significant uncertainties themselves,in aggregate they provide clear and compelling evidence for an artificial behavior in MODIS snow albedos at large SZA.

(Reda 2011)The International Guidelines of Uncertainty in Measurement GUM (JCGM/WG, 2008) are used for calibrating solar radiometers at the National Renewable Energy Laboratory (NREL) (Reda et. al 2008). This report describes a method for calculating estimated measurement uncertainties of solar irradiance data obtained with properly calibrated pyranometers and pyrheliometers. It also outlines GUM guidelines used to calculate the estimated uncertainty for field measurement. Uncertainty in field measurement is a result of radiometer calibration, equipment installation, data acquisition, system maintenance methods, and the environmental conditions at the site where the radiometer is deployed.

(Chow, Lee, and Li 2012)The evaluation and forecasting of energy demands have become concerns for facility managers. Short-term load forecasts are aimed at predicting system loads from minutes to several days and play an important role in the operation of power systems. To cope with energy demand, forecasting plays a critical role in power system management, scheduling, and dispatch operations. System fault detection, minimizing extravagant consumption with energy efficient buildings and saving on peak load energy generation for plants and systems are the merits of energy prediction. Forecasting the power generated by PV systems is necessary in reducing energy costs and environmental loads in energy networks by means of optimization techniques. The greatest advantage of artificial neural networks (ANNs) over other modeling techniques is their ability to model complex, nonlinear processes without assuming the form of the relationship between input and output variables. Real-time prediction and a short-term forecast of energy generated by a PV system are described in this paper.

(Paul 2012)An apparatus has been designed so that it can be used for the multipurpose measurements of different thermoelectric parameters. It is noted that the accuracy of the measurements of the temperature gradient is a major concern for such measurements. So, care has been taken to implement this design aspect relating to measurement of temperature gradient. Further, the measurement of temperature dependent electrical resistivity simultaneously with the Seebeck coefficient with this equipment makes it easy for electrical characterization and causes much reduction in time consumed by the measurement process, particularly due to quick mounting of the samples in the holder.

(Sengupta 2012)All measurements were taken using a single-axis tracking platform. As silicon devices have a variable response across the solar spectrum, they are calibrated to broadband thermopile devices at solar zenith angles below 45 degrees, in accordance with protocol. The solar DNI spectrum does not vary uniformly with air mass, because blue light is preferentially scattered out with an increase in air mass; therefore, the calibration coefficient calculated at a particular zenith angle is no longer valid at higher solar zenith angles. This results in over-predict ion of broadband solar radiation at higher zenith angles and under-prediction at lower zenith angles. This error must be corrected when determining the absolute efficiency of PV devices. It is expected that similar errors will occur if the calibration coefficient is calculated for a particular environmental condition and the silicon device is deployed in a different environment.

(JoonYong Kim, Seung-Hwan Yang, ChunGu Lee, Young-Joo Kim, Hak-Jin Kim, Seong In Cho, Joong-Yong Rhee) The use of pyranometers has been increasing in remote greenhouse control but high cost of the sensor acted as a limiting factor in the use of integrated environment sensors to farmers. This study was to develop a low cost solar radiation sensor with reasonable accuracy for the environment control in greenhouses using a solar module. Using experimental data, three statistical models for estimating solar radiation using short-circuit current of a solar module, cloud cover, ambient temperature, angle of incidence and air mass were developed and evaluated.

(Aakanksha Patil, Kartik Haria, Priyanka Pashte) This paper presents the design and construction of a photodiode based pyranometer for the visible spectrum. This device can compete with the traditionally available thermopile based pyranometers at a much lower price. This proposed pyranometer can communicate with a system (typically a PC, weather station, etc) using communication protocols USART, I2C, SPI, RS232, RS485 which can enable remote sensing, data logging applications. Thus the new pyranometer presented in this work brings together features which make it a very competitive alternative to what the market offers at present time.

(C. K. Pandey and A. K. Katiyar) This paper presents a brief account of the general introduction, principle, experimental technique, measurements of solar radiation data, and review of literature of solar radiation models and describes present trend of solar energy modeling which is of major interest to solar energy engineers, architects, designing building, and thermal devices for optimum and efficient utilization of this nonconventional energy resource.

(Muñoz-García et al. 2014)Solar irradiation inside a tree canopy can be assessed using low-cost solar cell-based radiation sensors. Two kinds of sensors, a-Si series-connected mini-modules and single c-Si cells, were tested in two different measurement years. According to the results, the use of mini-modules is only recommended when a qualitative and comparative analysis is going to be performed, as the quantitative error is high. Such error was around 50% due to the named "partial shadows " effect, where the shadowing of a cell of the mini-module affects the output current of the whole module.

(Geuder et al. 2014)The accuracy of RSI irradiance values and irradiation data has been studied from parallel measurement data of RSIs and high-precision thermopile instruments available from several sites worldwide in differing climatic zones.The analysis was performed for different time scales of the data for RSIs calibrated at PSA and via application of DLR corrections for the RSI raw response. With proper installation, an accuracy of ±7 W/m² RMSD is reached for GHI and about ±10 to ±15 W/m² for DNI for mean irradiance values with 10 minutes time resolution. The RMSD for DNI in the case of RSIs exceeds that for GHI due to the calculation of the DNI from the uncertainty-afflicted GHI and DHI. As these RMSDs are widely constant over the irradiance intensity, it translates to the corresponding percentage depending on the actual irradiance value; giving a percentage value is only reasonable with information on the range and frequency of the irradiance data it refers to.

(Abdel Akram HAFID, Karim MEDDAH, Mokhtar ATTARI and Youcef REMRAM) In this work, a pyranometer for global solar radiation measurement has been developed and characterized. Experimental results have shown that the designed device exhibit good response from solar radiation in the range of 400 to 1000 □□-2 for large spectrum (300 to 3000 nm).It was shown that the addition of graphic material has nearly doubled the sensitivity of the sensor and this issue can be investigated in the future work to consider other materials. Future investigations are also undertaken in order to meet WMO requirements. Quartz material can be proposed for instance to realize the glass dome in order to reach the wavelength supper to 3000 nm and get at the same time better isolating from solar radiation and bad weather.

(Daniel and Odinakachi 2014) The design, construction and calibration of the solar radiation meter was successful. The obtained expression correlating solar radiation intensity with the measured voltage values is similar in form with an earlier measurement made in Umudike. Device can be used to collect radiation data which are reliable and comparable to that of a standard solarimeter.

(M.O. Osinowo, A.A. Willoughby, T. Ewetumo, L.B. Kolawole) The developed low –cost pyranometer has sensitivity of 868.19 Wm-2V-1 with a correcting factor of 27.77 Wm-2was obtained from standardization of Figure 5 using SRS100 pyranometer. Also, the output voltage of the amplifier ranges from 0.1 mV to 4 V. The instrument was placed in the observatory after calibration for a few days. The result obtained a very good agreement with SRS100 except at early hours of day around 7 to 8.30 am and around 5.30 pm downward. The correlation is 0.89 with possible error of 9.67 %. The response frequency of the sensor ranges from 400 nm to 1100 nm.

(Frank Vignola) The diffuse responsivity of the LiCor pyranometer has been compared with that of an Eppley PSP. It was found that under clear sky conditions that the LiCor pyranometer significantly underestimated the diffuse irradiance by 30 to40%. By correlating the difference in the diffuse values divided by the global irradiance against global irradiance, a simple correlation was developed to correct for this systematic shift. The use of an automatic tracker to accurately measure the diffuse irradiance by both the Eppley PSP and the LiCor solar cell pyranometer may be one reason why such a clear sign of diffuse spectral dependence was found. Another possibility remains that the spectral dependence is site specific. These results were studied only in the Pacific Northwest. Other investigations using different techniques in the southwest and at the National Renewable Energy Laboratory did not report such a large spectral effect.

(Norbert Geuder, Roman Affolter, Maria Eckl, Birk Kraas, Stefan Wilbert) A new RSI design with a Twin-Sensor element consisting of two LI-COR sensors within the influence of the shadowband has been operated aside high-precision thermopiles and corresponding irradiation data analyzed concerning their coincidence and accuracy. The data evaluation yields comparable data from both individual sensors but also among different Twin-RSIs when properly calibrated and their systematic deviations corrected. The remaining deviations between the different Twin-RSI values are in the order of the combined measurement error of the thermopiles as derived from their redundant measurements. The Twin-Sensor RSI finally shows an improved performance concerning sensor back-up, detection of measurement errors, soiling or sensor drift and in principle yields higher accuracy.

(Shafa et al. 2015)We have measured the Irradiance of the designed Pyranometer and compared it with existing Pyranometer Apogee (model SP-110 and SP-230). The investigated results between the values obtained from both instruments represented a good agreement. By the Analysis and discussion of the collected data, tables and graphs in relation with this research investigation, it has been concluded that the constructed Pyranometer is quite efficient for reliable measurement of solar irradiance. This designed Pyranometer has similar characteristics as compared to mentioned standard Pyranometers and cost of this designed Pyranometer is several times cheaper than standard Pyranometer and it can forecast the variability of clear sky condition, solar radiation and detect cloudy weather. Statistical analysis proves that there is 98% matching between the developed Pyranometer and Standard Pyranometer. Time responses of fabricated pyranometers lie in the range of 3–6 minutes and have broadband operational spectral range against Standard Pyranometer. It is portable and easy to use where reliable measurement of solar irradiance is required. Time response which measures transient behavior of metallic slabs varies from 1 to 2 minutes which describes that Cu, Al and Fe slabs are in operation after 120 sec, 65 sec and 55 sec. Al-fabricated Pyranometer response is 1000 w/m² after 100 minutes while Fe-fabricated reaches 800 w/m² at 250 minutes and Cu-fabricated Pyranometer gives 800 w/m² at 180 minutes.

(Jessen et al. 2015)The influence of the RSI calibration duration and the seasonal fluctuations of two calibration methods at PSA were investigated. Small but noticeable seasonal dependencies were observed. Also some fluctuations of RSI calibration results were found that are influenced by the calibration duration. Thus, it was possible to quantify relations which can be used to optimize the calibration duration in dependence on the time of the year in which a calibration takes place.

(Srikrishnan et al. 2015)We have shown that the ASE design of an MPA (using either five or three pyranometers) and an ANN shows better skill at irradiance component separation than other empirical models. (see e.g. Gueymard, 2010 , Table 5). A single GHI measurement, even in combination with some environmental variables, is a low-quality data source for the purposes of component separation. This can also be seen by the results in Section 3, which show an improvement in irradiance component separation skill with five pyranometer measurements over three. This indicates that there is a dimensionality requirement for the input data to be suitable to separate the beam component from the diffuse radiation across all sky conditions. However, we would expect diminishing returns after a certain sensor resolution is reached.

(Anca Laura Dumitrescu,Marius Paulescu, Aurel Ercuta) The black and white pyranometer proposed in this paper represents an efficient low cost solution for measuring solar irradiance. The theoretical analysis and the laboratory calibration demonstrate that the instrument has a very good linearity.

(Nwankwo S.Nand Nnabuchi M.N) A locally developed Pyranometer can compete favorably with foreign standard Pyranometer when calibrated using Kipp and Zonen equation.The correlations between both instruments are strong and positive. Maximum Irradiances of 1095.10Wm-2 and 689.48Wm-2 recorded in Abakaliki during dry and rainy seasons respectively occurred between 12:00 –14:00hours local time, whereas the minimum values of 9.20Wm-2 and 9.86Wm-2 respectively are recorded during the sunrise and sunset.Partly cloudy conditions in Abakaliki cause conspicuous oscillations in global solar radiation.

(Y. Y. Agawa and S. B.Ibrahim) A system meeting the accuracy requirements established by the IEC61724 standard related to photovoltaic monitoring systems were presented. The system design features include easy-to-obtain hardware, making it accessible to any researcher or user for the development of systems of their own design and use. This flexibility makes the system more suitable for each intended application such as the monitoring of PV plants and the collection of data at remote locations in developing countries.

(Orsetti et al. 2016)In this work, we present an innovative low cost sensor and algorithm for the monitoring and measurement of solar irradiance. This parameter is usually estimated using pyranometers, often based on thermopile. They are quite expensive, also because they need additional hardware for data acquisition and manipulation as well as non-negligible installation costs. The system architecture and novel algorithm here proposed employ small Photovoltaic (PV) cells and a digital sensor interface. Moreover, the logic section permits to tilt the sensor allowing it to track the sun with improved accuracy.

(Michalsky, Kutchenreiter, and Long 2017)Ventilators are used to keep the domes of pyranometers clean and dry, but they affect the night time offset as well. This paper examines different ventilation strategies. For the several commercial single-black-detector pyranometers with ventilators examined here, high-flow-rate [50 cubic feet per minute (CFM) and higher] 12-VDC (where VDC refers to voltage direct current) fans lower the offsets, lower the scatter, and improve the predictability of the offsets during the night compared with lower-flow-rate (35 CFM) 120-VAC (where VAC refers to voltage alternating current) fans operated in the same ventilator housings. Black-and-white pyranometers sometimes show improvement with DC ventilation, but in some cases DC ventilation makes the offsets slightly worse. Since the offsets for these black-and-white pyranometers are always small, usually no more than 1 W m-2, whether AC or DC ventilated, changing their ventilation to higher CFM DC ventilation is not imperative. Future work should include all major manufacturers of pyranometers and unventilated and ventilated pyranometers. An important outcome of future research will be to clarify under what circumstances night time data can be used to predict daytime offsets.

(Vignola 2019)Three types of biases are examined for a Rotating Shadow band Radiometer (RSR): temperature bias, spectral bias, and deviation from a Lambertian cosine response. A step by step method is presented to illustrate how to use this information to develop a model for adjustment algorithms for a RSR. Comparisons are made with a RSR adjusted using the model and measure direct normal, diffuse, and global irradiance.

(K Tohsing, D Phaisathit, S Pattarapanitchai, I Masiri, S Buntoung, O Aumporn and R Wattan) In this work, we proposed a low-cost and reliable pyranometer, which applied a phototransistor as a light detector combined with other electronic elements for measuring broadband solar radiation. This pyranometer was controlled by the microcontroller and all components were located inside the black box. To overcome the saturation of the phototransistor, the Teflon sheet has been used as a solar attenuator. After the development, the sensitivity of the pyranometer has been analysed and then applied this sensitivity to estimate the global irradiance. The comparison of global irradiance from our pyranometer and the standard pyranometer showed satisfactory performance. However, this prototype pyranometer still needs further development and investigation to get more accuracy of the solar radiation from the measurement.

(Walter-Shea et al. 2019)The effects of calibration approach, calibration timing, and sensor age on errors in estimating global irradiance were investigated. Calibrations which accounted for solar zenith angle and temperature effects improved global irradiance estimates for older SiPs (in service for seven or more years), but obtaining a wide range of temperatures and solar zenith angles requires a year of calibration data. Monthly calibrations are recommended using the adjusted calibration approach (adjusting for solar zenith angle only), with reliable results for calibration months of April through August, as evidenced by smaller standard errors in these months when using a range of sensor ages. However, the age of the sensor should be considered as older sensors apparently become more sensitive to solar zenith angle (and air temperature), such that the response drifts more over time than it does with the newer sensors.

(Moiz, Alahmadi, and Aljohani 2020)In this review, we primarily concentrate on the general, electrical, optical and photovoltaic design issues of the SiNW array for efficient PEDOT: PSS–SiNW hybrid solar cells. The photovoltaic response of PEDOT: PSS–SiNW is very complex in nature and many design issues of the SiNW array are required to optimize the solar cell for higher efficiency. The radial p-n junction with vertically aligned SiNW is the most favourable structure as it offers optical absorption and carrier collection separately to each other for PEDOT: PSS–SiNW hybrid solar cells. The randomness of SiNWs also plays a vital role along with its geometry and direction, which improves light trapping and strong optical absorption for the PEDOT: PSS–SiNW hybrid solar cell. The photovoltaic response of a hybrid solar cell is degraded in the presence of SiNW's surface trap states, which are the major sources of leakage current for recombination losses. These traps states can be reduced either by using the various passivation techniques or by reducing the surface to volume ratio by tapering the SiNWs. Although PEDOT: PSS can passivate, a separate passivation for SiNW surfaces is required before PEDO: PSS deposition over SiNW array. The passivation of SiNW not only improve the short circuit current, fill-factor but also enhance the open-circuit voltage and hence power-conversion efficiency of the PEDOT: PSS–SiNW solar cell. The proper passivation blocks the oxidative chemical reaction between PEDOT: PSS and SiNW and causes to improve the stability of the hybrid solar cell. The coverage of PEDOT: PSS along a SiNW is very serious concern and severally degrade the photovoltaic response, which can be improved by removing the top agglomeration of SiNW by using the alkali treatment of SiNWs for hybrid solar cell. We believe that this review will help our researchers, experimenters and especially freshers to design and fabricate the high efficiency PEDOT: PSS–SiNW hybrid solar cell.

IV CONCLUSION

From the literature review it is observed that the conventional pyranometer uses the thermopiles as detectors. The thermopiles are thermocouples connected in series. The hot junction has to heat up under the solar radiation. This takes sufficiently longer time based on thermal conductivity of material used to build the blackened disc. The detector is enclosed by inner and outer quartz dome. The following shall be considered as severe limitations of thermopile pyranometer. The time required to heat up the detector under the solar radiation and produce thermo emf is termed as response time/rise time. The high precision Eppley PSP pyranometer typically have response time of maximum 5 seconds. This larger rise time causes greater deviation from actual irradiance while day/monthly's average is calculated. To maintain the cold/compensation junction at lower temperature the pyranometer have to made heavy structure and painted in white. This prevents heating up of cold junction from heat transfer through radiation. The negative output could be obtained in the night. This is because the cold junction temperature of detector is different than the temperature of inner dome. This could cause the offset errors.

V FUTURE SCOPE

In order to overcome these limitations, the suitable detector which replaces the thermopile has to be identified and also evaluate the performance of proposed novel pyranometer with the existing one in terms of quality and price.

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