Department of Electrical Engineering

Remote Triggered Dual Axis Solar Irradiance Measurement System

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Contents

Introduction

- Solar Energy is one of the most abundant renewable energy source available to mankind.
- Knowing the quantity and quality of solar energy that can be harnessed at a site is very crucial.
- Here a cost effective system developed for solar irradiance measurement is discussed.

Motivation

- Solar irradiance is the output of light energy from the Sun, as received and measured here on Earth. In more technical terms, it's the power per unit area received in the form of electromagnetic radiation.
- Solar irradiance is also useful to help determine solar insolation, or how much energy your solar system may produce on an average in a given time period and thus how much you can save on energy costs.
- Thus knowing solar irradiance at an area is very beneficial and a cost effective method is discussed.

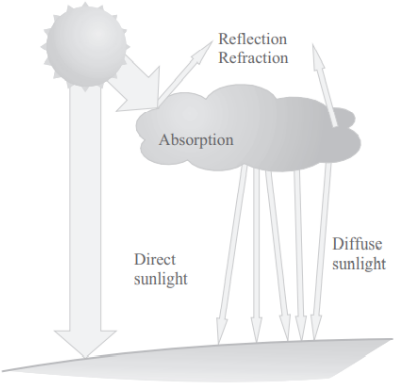
Objective

- Design of an efficient ,low cost system to measure solar irradiance using dual axis tracking,irradiation sensors and an algorithm to track the solar position.
- Provide user-friendly remote access using a platform to monitor and control realtime data with options to change parameters and graphically display the data and live streaming.

Solar Energy Concepts

- **Direct Normal Irradiance** is the amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky.
- **Diffused Horizontal Irradiance** is the amount of radiation received per unit area by a surface (not subject to any shade or shadow) that does not arrive on a direct path from the sun, but has been scattered by molecules and particles in the atmosphere and comes equally from all directions.
- **Global Horizontal Irradiance** is the total amount of shortwave radiation received from above by a surface horizontal to the ground. This value is of particular interest to photovoltaic installations and includes both Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DHI).

Solar Energy Concepts
Continued



$$\text{GHI} = \text{DNI}*\cos(\theta) + \text{DHI}$$

Solar energy Concepts

Continued

- The declination angle (δ) varies on different days and is calculated as

$$\delta = sin^{-1}(0.39795cos(0.98563[N - 173]))$$

- The solar elevation or altitude angle(α) is the angle between the central ray from the sun and a horizontal plane containing the observer.

$$\alpha = sin^{-1}(sin\delta sin\phi + cos\delta cos\phi)$$

- The azimuth angle (ψ)is the clockwise measurement (when looking down at the surface of the earth) between the north pointing coordinate axis and the perpendicular projection of the line of sight to the sun, on a horizontal plane containing the observer.

$$\psi = cos^{-1}\frac{(sin\delta cos\phi) - (cos\delta cos\omega sin\phi)}{cos\alpha}$$

System Design

- There are three distinct parts to the system design of the solar tracker. These include:
- Solar Tracker
- Data acquisition and instrumentation system
- Collaborative Accessibility platform that allows remote access, trigger, scheduling and monitoring of solar tracker.

- The objective of the tracking system was to provide azimuthal and altitudinal (elevation) tracking of the sun.
- Includes 3 solar radiation sensors i.e two pyranometers and a pyrheliometer and a shading eye.
- The pyrheliometer is used to measure the DNI ,one pyranometer to measure GHI and other used with a shading eye to measure the DHI.
- In order to provide dual axis tracking ,pan/tilt camera mount was used.
- It uses stepper motor controllers for control of 2 bipolar stepper motors, to handle the torque of sensors and holding equipment.

Solar Tracker

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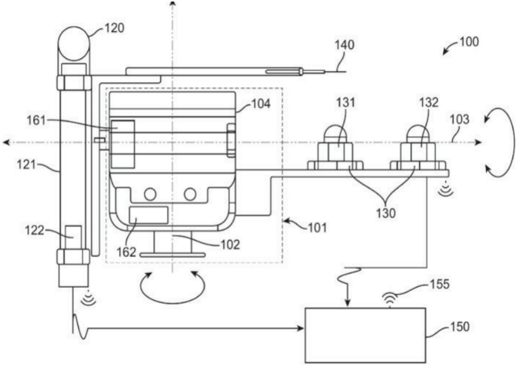

Solar Tracker

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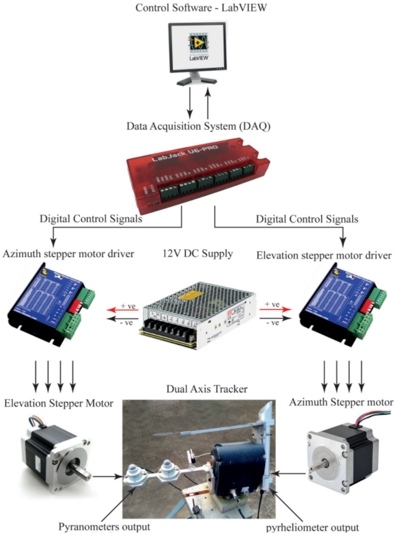


2.Tracking Algorithms and Sensor Measurements

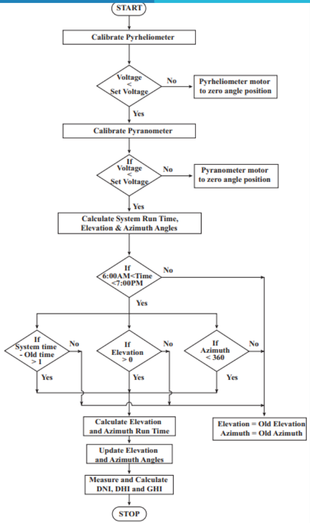
- The algorithm for tracking the sun and calculating radiation intensities are shown in figure.
- The process starts with checking if the elevation and azimuth stepper motors are at zero position using limit switches and if not rotate motors to calibrate them to zero position.
- Then it checks if the time of day is within the limits(6am to 7pm).
- After this the real time solar elevation and azimuth angles are calculated using the SUNAE algorithm coded into the program.
- The movements of the tracker are controlled by an application program which provides signals to the DAQ to control the azimuth and elevation stepper motors.

Tracking Algorithms and Sensor Measurements

Continued...

- There is a time delay between the tracker calculating the current angles and the stepper motor controller turning the motor to the desired angle.
- If difference in time is small, a short delay is added.
- When the tracking system reaches the desired position, the pyranometers and pyrheliometer measure the GHI and DNI.
- The output of the irradiance sensors is an analog voltage which is connected to the analog input ports of the DAQ. The voltage values are accessed from the DAQ and converted to the corresponding irradiance value in physical units, W/m^2.
- The data is then sent to the web interface for display.

Flowchart for Solar Tracking



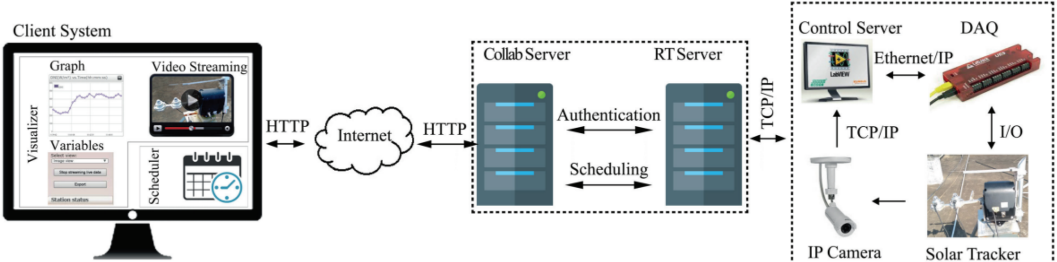
3.Data Acquisition System

- The DAQ receives control signals from application program.
- A micro stepper motor drive is connected to and commanded by the DAQ ,which turns the motor rotation on or off and also changes the direction of rotation.
- The DAQ unit commands are determined by solar position algorithm.
- The sensor outputs are connected to the analog input channels of the DAQ device and interfaced to the application program to calculate the irradiance values.
- To allow remote access, a web interface is implemented, which sends and receives control signals and data from the application program web server.

4.Collaborative Accessibility Platform

- Used for remote access scheduling of experiments and live streaming of data is a highly scalable,multi-tier architecture platform that supports collaborative development and deployment of remote systems.
- The CAP platform allows single user access to the system at any given time, as the experiment is remote triggered with a single hardware setup.
- The duration of an experiment is set to 15 minutes by default, which could be adjusted by an administrator to any desired value.

Architecture of the system



The key aspects of the GUI are

- There are system control buttons provided to start and stop the hardware.
- The measured solar data is displayed in graphs with defined x and y-axes.
- An animation of the tracker movement and a live streaming camera view of the hardware are available.

When the user clicks the “Start Streaming Live Data” control button,the experiment becomes “ON”, calculating the sun’s position angles, measuring the real time solar irradiance with the sensors, displaying the data in the station status section.

Measurement of DHI,DNI,GHI

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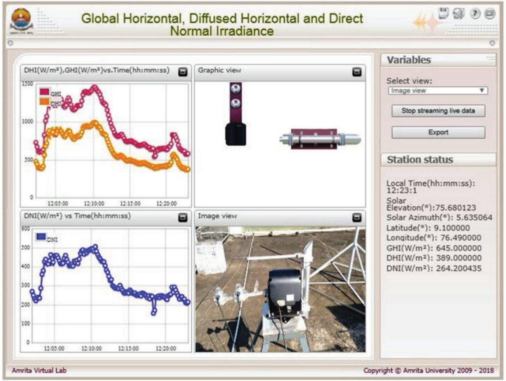
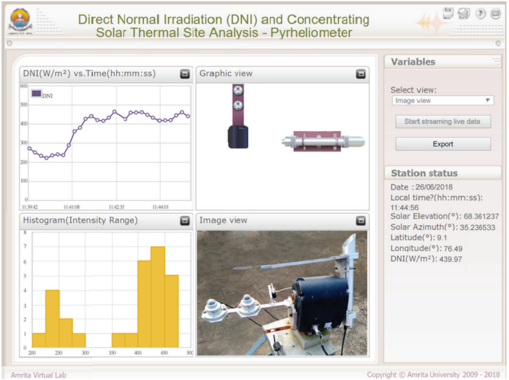


GUI of the measurement system



GUI of DNI interface

Results and Discussion

Typical Solar Irradiance Profile

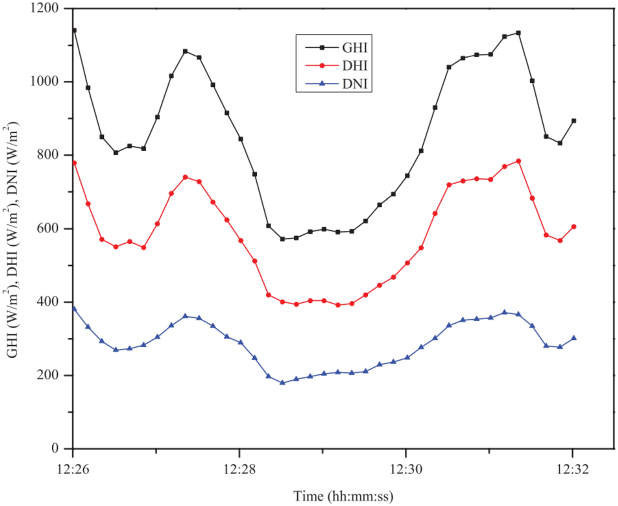


TABLE I
COMPARISON WITH EQUIVALENT INDUSTRIAL SYSTEMS

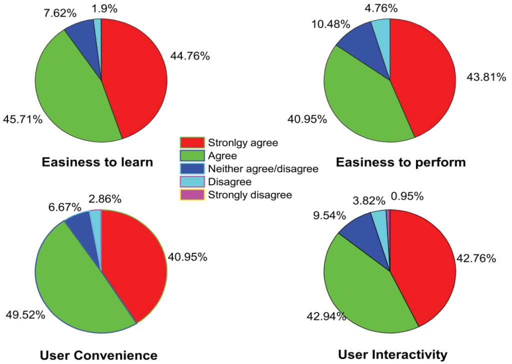
System	Solar Radiation Components	Movement Range (°)		Tracking Resolution	Ingress Protection	Data Interface For Remote Access	Data Logging	Cost (USD)
		Zenith	Azimuth					
Amrita	DNI, DHI, GHI	0 to 90	0 to 360	Elevation: 0.27 Azimuth: 0.18	IP66	Yes	Yes	6000
Kipp & Zonen - Razon +	DNI, DHI, GHI	0 to 110	0 to 600	>0.2	IP65	Yes	Yes	12450
Eko - STR21G - S	DNI, DHI, GHI	-15 to 95	0 to 360	0.009	IP65	**	**	15000

**Additional Hardware Required.

Results and Discussion

User Feedback

- The user feedback was based on ease of use of the platform,usefulness of the content,user satisfaction after usage for a period of about 24 months.



Conclusion

- A novel low cost solar intensity measurement tracker was designed, developed and deployed to measure the three components of solar irradiation namely DNI, GHI and DHI.
- The design included the integration of solar tracker, specific geometry of the mechanical axes of rotation along the azimuthal and elevation axes, methods of movement control and effective two-way communications of the sensors mounted on a two-arm assembly.
- To make the system accessible to remote users for monitoring and measurement purposes,the collaborative accessibility platform (CAP) was built and interfaced with a DAQ unit.
- The cost comparison with other available systems were also conducted and user feedback was analyzed.

References

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- V. Quaschning, Understanding Renewable Energy Systems, 2nd ed. Routledge, 2016.
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Thank you!