Integrated Self-Sustained Renewable-Energy Explorer (iSEE)

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Abstract

In World Energy Transitions Outlook 2022, IRENA projects that the annual solar PV addition will need to be 3.5 times that of 2020. With the global adoption of solar photovoltaic (PV) projects and cost reductions for solar power generation, solar PV is the top priority in end-use decarbonisation to reduce dependence on fossil fuels. Thus, the Electrical and Mechanical Services Department of the Hong Kong SAR Government invented the Integrated Self-sustained renewable-Energy Explorer (iSEE). iSEE is developed to assess microclimate data and optimise renewable energy generation. The iSEE is the first-of-its-kind, integrating an all-in-one tool and novel cloud-based software with powerful functionalities for assessing solar potential and managing and enhancing PV system performance. The iSEE is self-sustainable with built-in solar panels and batteries, that can be readily deployed in remote locations for potential and existing solar energy systems. The iSEE adopts emerging technologies such as digitisation, IoT sensors, big data analytics, digital twins and artificial intelligence (AI). End-users can access the data on mobile devices or computers at remote locations, which enables remote asset management. Academia, government and other stakeholders may access the open data for further technology development. Three prototypes have been successfully deployed at schools and a university in Hong Kong. The invention has received two patents and won the Gold Prize at the 2023 Geneva International Exhibition of Invention. This paper will provide details of the features of the iSEE, the state-of-the-art technologies adopted, and the challenges tackled during its development.

Keywords: photovoltaic (PV), self-sustainable, IoT sensors, big data, digital twins, artificial intelligence

1. Introduction

With the development and demand of technology, PVs have emerged as a significant contender, gradually replacing traditional energy sources [1–4]. In World Energy Transitions Outlook 2022,

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IRENA projects that the annual solar PV addition will be 3.5 times that of 2020 [5]. Before investing in renewable energy (RE) systems, especially PV systems, the lack of data hinders Governments' policy support to aid RE deployment, investors to make critical business decisions, and owners to increase profitability. After deploying PV power generation systems, the rapid growth also brings along certain complexities inherent to PV power generation systems management [6–9]. Notably, PV systems often span extensive geographical areas and comprise multiple panel arrays, which results in time-consuming inspections. Additionally, the demand for operational monitoring for PV power generation systems has also increased, including assessing energy potential, operating performance indicators, different faults that might occur, and associated energy loss.

To address the aforementioned issues, there is an urgent need for intelligent PV assessment and management systems [10–12]. Sensors are necessary for collecting essential information for intelligent PV assessment and management systems [13]. However, current PV performance monitoring systems cannot achieve all-around information collection, that is, simultaneous perception of environmental and electrical information. Moreover, an external energy supply is still required to realize data processing and transmission. Meanwhile, a device suitable for long-range flexible data transmission with low power consumption in the monitoring system is always a key goal.

Thus, we invented the Integrated Self-sustained renewable-Energy Explorer (iSEE), which can assess microclimate data and optimise renewable energy generation. The iSEE is the first-of-its-kind, integrating an all-in-one tool and novel cloud-based software with powerful functionalities of assessing solar potential and managing and enhancing PV system performance. The iSEE originated from the concept that "Prevention is better than cure", offering preventive management of the solar energy systems to minimise system downtime and reduce power generation costs and maintenance costs, as these systems are often located remotely or at height. The overall system efficiency and solar energy generation will be increased. The iSEE adopts emerging technologies such as digitisation, IoT sensors, big data analytics, digital twins and artificial intelligence (AI). It is a cloud-based software system that collects territory-wide solar energy system information and provides instantaneous system performance analysis. End-users can access the data on mobile or computer at remote locations, which enables remote asset management. Academia, government and other stakeholders may access the open data for further technology development. Three prototypes have been successfully deployed at schools and a university in Hong Kong. The invention has received two patents and won the Gold Prize at the 2023 Geneva International Exhibition of Invention.

Table 1: *Comparison of leading products in solar energy management system [14–18]*

System name	Micro-climate information	Energy supply of sensors	Online diagnosis & maintenance	Smart operation & maintenance
SMA Energy APP	No	Parent system	No	No
Fronius Solar. web	No	Parent system	No	No
AP EasyPower	No	Parent system	Yes	No
mySolarEdge	No	Parent system	No	No
Enphase Enlighten	No	Parent system	No	No
iSEE	Yes	Self-sustained	Yes	Yes

The main difference between the iSEE and the leading products in the industry is shown in Table 1. Firstly, the self-sustained devices of iSEE enable this management system to work dependently, which can still record valuable information for the recovery of failure under parent

system failure. Secondly, the micro-climate information often improved the prediction accuracy of solar production. However, these information are not always available [19]. The iSEE can easily apply more elaborated algorithms with these inputs. The significance of environmental sensors in solar system fault diagnosis has been demonstrated in [20].

The remainder of the paper will introduce the functional features and constitution of the integrated Self-sustained renewable-Energy Explorer (iSEE) in detail, including hardware devices and software functions and the benefits of iSEE.

2. Hardware Devices

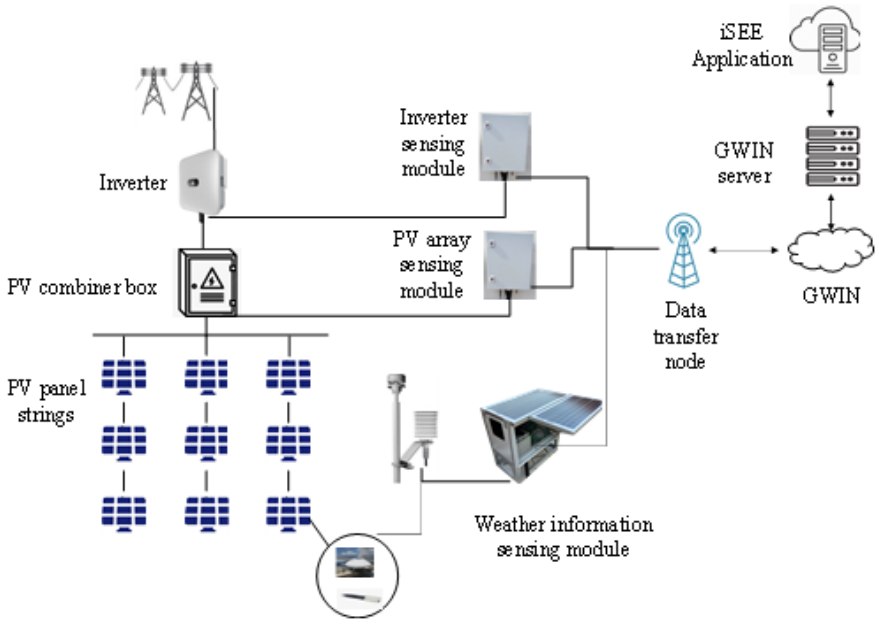


Figure 1: *The schematic system architecture of iSEE*

The iSEE system serves as a monitoring platform designed to sense and transmit weather and operational data from PV generation sites. The schematic system architecture of iSEE is shown in Fig. 1. It encompasses distinct components, notably a PV array-side measurement module responsible for capturing operational data from PV array strings. There is a specialised meteorological information sensing module that collects meteorological information. A DC/AC side measurement module can be integrated to sense operational parameters from grid-connected inverters. For communication from iSEE hardware to the cloud server, iSEE is configured with data transfer nodes. For power supply, the iSEE is self-sustainable with built-in solar panels and batteries for deploying in remote locations for potential and existing solar energy systems.

The sensing units for electrical parameters, alongside the weather parameter sensor unit, collectively establish a real-time monitoring solution for PV generation system operations. This setup enables the system to operate autonomously, drawing power for sensors internally and providing a data transfer interface for seamless data uploads. The electrical parameters encompass measurements of current, voltage, power, and energy. These measurements are deployed by the AI-equipped software of iSEE to oversee the PV system's operational status, facilitating analysis and proactive identification of potential faults. Concurrently, the weather information sensing

module gathers battery status information and several environmental parameters. Environmental parameters include ambient and panel temperatures, horizontal and in-plane solar irradiance, humidity, atmospheric pressure, wind speed, and direction.

The data collected by iSEE can be efficiently transmitted to a network server. Subsequently, other management systems can access this data, enabling comprehensive operational management of the PV generation system.

3. Software Features

This section presents the primary features of the iSEE software, including its Graphic User Interface (GUI) components: Climate, RE Resource, PV Plant, and E-logbook. These are displayed on the iSEE software's main screen, as illustrated in Fig. 2. By clicking the ellipsis button located at the top right of Fig. 2(b), a function menu appears.

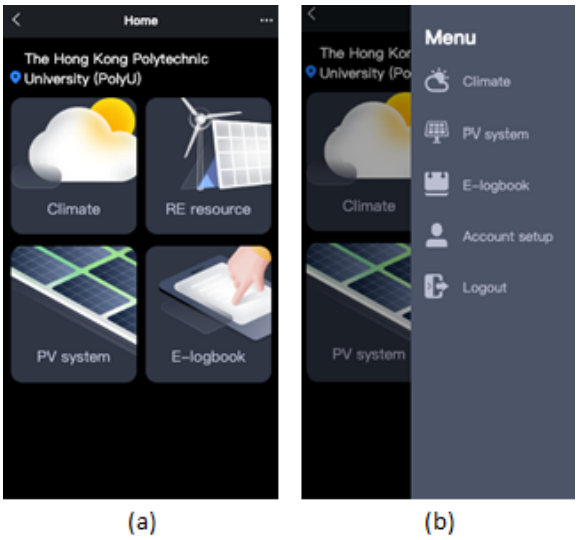


Figure 2: *The interface of iSEE*

The Micro-climate feature is depicted in Fig. 3. The Micro-climate function showcases five types of real-time environmental data from the on-site PV station: global horizontal irradiance (GHI), wind direction, wind speed, temperature, and relative humidity. The potential renewable energy—specifically, photovoltaic and wind power—generated in 100 square meters per hour is also computed using real-time measurements, and their respective contributions are displayed.

3.1. RE resources

The renewable resource feature provides detailed insights into solar irradiance and wind direction, as shown in Fig. 4. Specifically, it displays solar irradiation and evaluates the degree of irradiance intensity. Regarding wind resources, the system breaks down the wind by direction and assesses the wind speed for each.

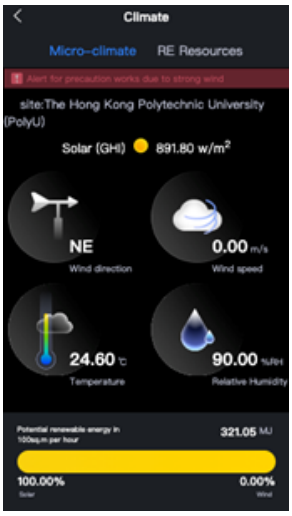


Figure 3: *Micro-climate*

3.2. PV system

This page includes two tabs, Plant Status and Alert, as shown in Fig. 5. Users can switch by clicking the tab page. In the Plant status interface, the real-time measurement of the DC side of the PV plant is displayed, including the statistics of the day energy output, the panel temperature, and the performance of the PV string. Voltage and current information on the DC side meters is also displayed. The estimated energy output on the AC side is shown, and the conversion efficiency is assumed to be 90%. On the Alert page, the extreme weather warning information can remind users to pay attention to the weather status to protect the station equipment. At the same time, some device failures or alerts in PV operation and maintenance are listed. The Optimization function in the Plant status provides users with optimization suggestions for station operation and maintenance, as shown in Fig. 5(b). The optimum tilt and azimuth angle of the PV panels and their optimum operating temperature are provided, respectively. Predictive maintenance work based on the AI model is also offered, effectively suggesting maintenance advice in advance.

3.3. E-logbook

The iSEE serves as a digital logbook that optimises solar energy generation, promotes the wider adoption of solar energy systems, benchmarks solar energy production, and facilitates owners, operators, and end-users to visualise system performance. The E-logbook function includes three tabs: Alert & Fault, Inspection, and Reporting, which digitally record important operation and maintenance information of related sites.

4. Features of iSEE

The patented iSEE comes with 6 features.

- All-in-one renewable data collection solution via mobile apps for on-site yield assessment, real-time remote monitoring, and optimisation of RE system efficiency.
- One-stop solution to collect data for asset management and audit reporting.

Figure 4: *RE Resources*

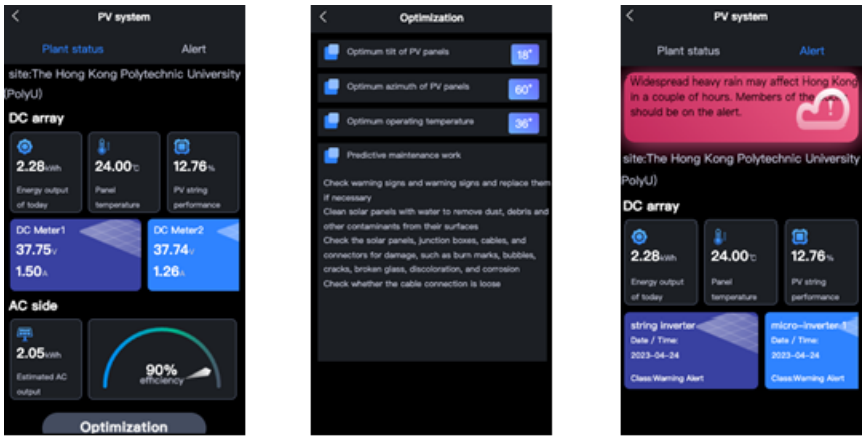
- Self-sustained with solar power supply and battery storage for deploying in any potential and remote sites and does not sacrifice the yield of the parent system.
- Add-on module to measure DC power generation.
- Plug-n-Play interface is universally applicable for quick and safe deployment to new and existing systems with untrained workers.
- AI software to advise system optimisation opportunities, prevent potential problems, and generate alerts and maintenance orders with a digital logbook to minimise downtime and maximise profits.

5. Benefits of iSEE

With the ability to operate without a power connection and the ease of deployment, iSEE will be an important tool for site surveys of potential renewable energy sites. Artificial intelligence diagnostics and remote notifications help to detect undetected faults in unattended systems, minimising system downtime and emergency repairs. In addition, system owners can optimise individual systems, benchmark and remotely manage their portfolio of assets to maximise profits. A further saving in labour costs can be achieved by replacing scheduled maintenance with predictive maintenance.

The self-contained iSEE does not require an auxiliary power supply and can be connected with interchangeable MC4 connectors. iSEE has a modular design that allows it to be scaled up to accommodate renewable energy systems for a wide range of applications, including residential, commercial, industrial and infrastructure.

The digitisation of renewable energy management systems is a mandatory requirement for ESG corporate reporting and carbon trading. iSEE software serves as a data-sharing platform, facilitating global asset management and technical collaboration. Neighbouring users can bench-



(a) Plant status (b) Optimization in plant status (c) Alert

Figure 5: *The interface of the PV system*

mark each other to improve system production. Academia and governments can utilise regional data for R&D and develop policy support to help renewable energy deployment in response to the energy and climate crisis.

6. Conclusion

In this paper, we introduced the iSEE system, an integrated solution for renewable energy management. It offers a comprehensive view of solar radiation and wind patterns, facilitating on-site yield assessments for potential investments and enabling real-time remote monitoring for system performance optimisation. The system meticulously measures electrical and micro-climate data at PV plants, establishing a robust data foundation for owners and operators. With the convenience of mobile applications, real-time data is readily available, and the system's prompt alert mechanism ensures immediate attention to maintenance needs, thereby reducing downtime and enhancing profitability. iSEE is self-sustainable, powered by solar energy and battery storage, making it an ideal choice for deployment in any location. Furthermore, its user-friendly plug-and-play design ensures that even individuals without prior training can safely integrate iSEE into new or existing systems.

Declaration of interest: None

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