Monitoring of Grid Connected 1.43 MWp Rooftop Solar PV Plant by Internet of Things (IoT)

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Abstract An installation of rooftop solar PV system is the most promising option to reduce the cost of power followed by manufacturing cost as well as mitigation of renewable power obligation for industries, but there are challenges to monitor the real time system parameters, actual power generation, plant efficiency, and working status of equipment of the plant due to its location on rooftop. In this paper, detailed engineering has been done for implementation of IoT to monitor the 1.43 MWp rooftop solar PV plant installed on industrial shed. The flow diagram, hardware requirement and software platform for implementation of IoT are discussed in details. This will facilitate historical analysis of plant performance, performance evaluation, fault detection, and real-time analysis of the plant. This paper also contains technical specifications of each component of rooftop PV plant and IoT platform to monitor the plant.

Keywords Internet of Things (IoT) · IoT architecture · Rooftop solar PV

1 Introduction

As a part of 'World's largest Renewable energy programme', India has taken of 175 GW renewable energy installation target till 2022. To meet the target, rooftop solar PV installations will be the key focus area considering rooftop solar installations can grow 13 GW or more by 2022 [1]. India is the solar richest country, and Indian industries are having large scale of industrial sheds where rooftop solar PV power plants can be installed easily. So, Indian industries are thinking differently to generate

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the solar power in large scale to meet their energy demand, reduce manufacturing cost, and mitigation of renewable power obligation (RPO).

Rooftop solar PV plant mean the complete installation of solar PV panels located on the roof top of buildings or industrial sheds. Total power generation from the PV plant can be effected by several factors such as average duration of daylight hours, panel temperature, tilt angle, intensity, and dust accumulation on panels, inverter efficiency, etc. [2]. To ensure maximum efficiency and optimum power output of the solar PV plant, sufficient measure needs to be taken and monitored, but due to location of the plant it always may not be possible to monitor the system by conventional method including manual inspection and hence the application of IoT comes.

The internet is a simple communication network that connects individuals to information banks where we can describe Internet of Things (IoT) as an interconnected system between differently addressed physical components with processing, sensing and evaluating capabilities and communicate through internet to a central platform. In other words, we can say IoT is an information sharing environment where objects are connected through wireless or wired network. The IoT applications are using in various sectors like health care, smart cities, energy system, security management, education, transport consumer electronics, etc. [3].

In this paper, detailed engineering has been discussed for implementation of IoT to monitor the MW level rooftop solar PV plant installed on industrial shed. The proposed flow diagram, hardware requirement and software platform for implementation of IoT has also been discussed in details. This will facilitate historical analysis of plant performance, performance evaluation, fault detection, and real-time analysis of the plant. In this paper detail technical specification of each component of rooftop PV plant and IoT platform to monitor the plant has also been discussed.

1.1 Grid Connected Rooftop Solar PV Plant

In current pandemic (COVID-19) situation, industries are taking initiatives for manufacturing cost reduction and increase of fossil fuels cost is the biggest challenge to achieve the same. To reduce the power cost followed by manufacturing cost, industries are looking differently to resource the power from cheapest sources or to generate power from renewable resources.

Figure 1 shows that industrial sector is the bulk power consumer and it is consuming approx. 43% of the total energy consumption [4]. Considering the sharp depletion of conventional resources it is therefore required to move forwards for non-conventional energy like wind, solar, biogas, etc. Among all renewable sources, solar energy is the easy and profitable resource for green energy generation.

Industries are having large no. of industrial sheds, roof tops of which can easily use for installation of solar modules to reduce the cost of land required for solar power plants. Solar energy is profitable as it does not require any fuel. Due to fluctuating in nature and non-availability in night hours, solar power plant can be designed as

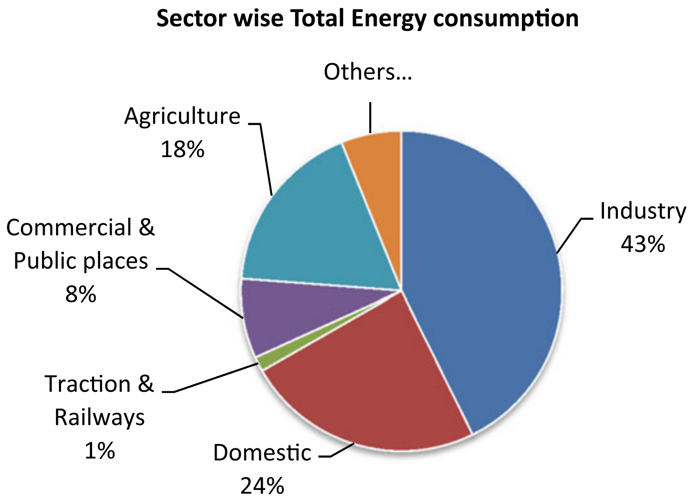

Fig. 1 Sector wise total energy consumption (*Source* Energy Statistics India 2021)

storage type and or grid connected type among which grid connected solar power plant is preferable for industries to ensure reliable power supply to the loads [5].

1.2 The Internet of Things

In the year 1999, Kevin Ashton was first instituted the phrase "Internet of Things". In these days, everyone is aware about the solar PV technology and about solar power generation system, but now the main challenge is how to measure and monitor the performance of solar PV plants located at remote locations or on roof tops [6]. With technology advancement and low cost solution, solar PV plants are installing in large scales across the world and these PV plants need to be monitored remotely to ensure maximum power output and efficiency. With the help of Internet of Things (IoT), performance of solar plants can be monitored easily from a central location [7].

Internet is the network between computer to computer or computer to data base, where we can describe IoT as a network between various devices, devices to computers to networks. Through the IoT, we can manage education to health-care system, agriculture to power g0rid management, every area can be monitor and control by IoT from our smartphone to available smart devices [8] (Fig. 2).

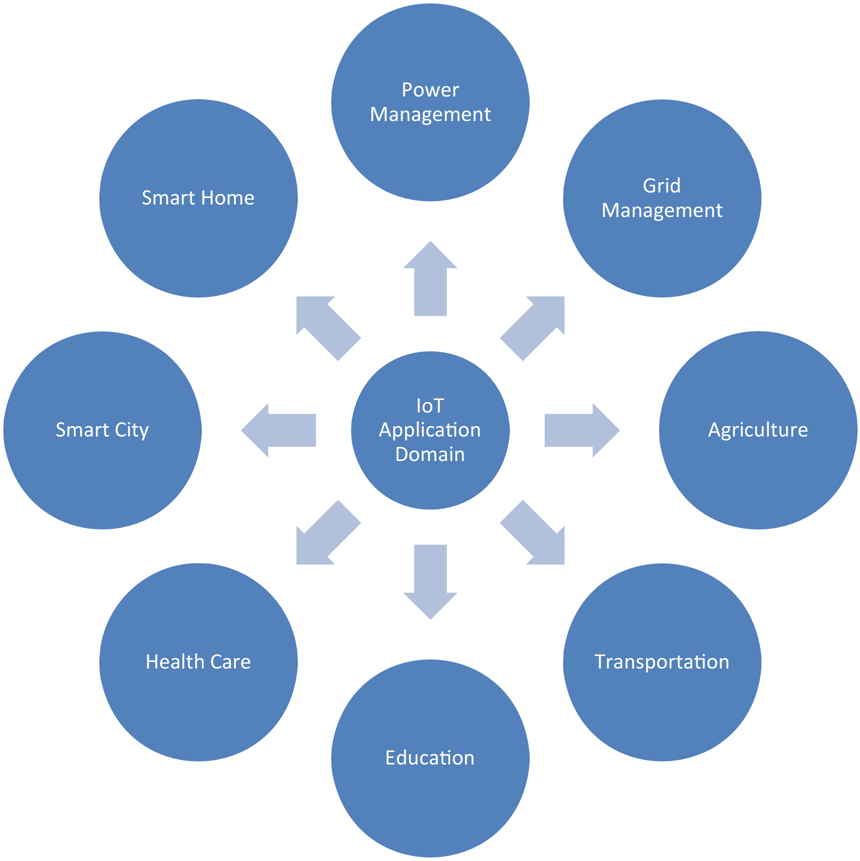

Fig. 2 IoT application domain

2 Plant Description

Design of a rooftop solar PV plant in MW level is always challenging for designer. In the current trend of frequent technology upgradation, designer shall need to know about the technical details of the plant including the communication system through IoT [9]. Communication system through IoT need to be designed for real time monitoring of solar power generation, irradiance, temperature of solar cells, working condition of ON grid inverters, winding temperature of transformers and other operational parameters [10].

Plant Location

The proposed implementation of IoT is carried out on 1.43 MWp rooftop solar PV plant located at 22.8°N, 86.3°E. The complete plant was installed on roof top of an industrial shed having tilt angle of 19°. Detail about the plant is depicted in Table 1.

Table 1 Details of plant location

Location details		
S. No.	Parameters	Specification
1	Latitude and longitude	22.8°N, 86.3°E
2	Facing	South
3	Glob Hor	1810.80 (kWh/m^2/year)
4	Tilt angle	19°
5	Location of plant	Rooftop
6	Distribution grid voltage	6600 V

Table 2 Technical parameters of PV module

PV panel specification		
S. No.	Parameters	Specification
1	PV panel type	72 cell polycrystalline
2	No of cells in each panel	72 Nos
3	Peak power (P_{max})	320 Wp
4	Module efficiency	16.40%

Solar PV Panels

Efficiency, cost, and availability are top factors that decide the selection of the solar PV panels. The 1.43 MWp rooftop solar PV plant was designed by 320 Wp Polycrystalline module as depicted in Table 2.

ON Grid Inverters

To convert the DC output of the solar module to AC, two nos. 630 KW each grid tied inverter has been installed with overloading consideration of 40% as depicted in Table 3.

Table 3 Technical parameters of ON grid inverters

Inverter specification		
S. No.	Parameters	Specification
1	Type	Grid-connected PV inverter
	DC- input	
2	V_{max} PV	1000 V
3	Max. input current	1356 A
	AC-output	
4	Rated output power	630 kW
5	Rated output voltage	3–360 V
6	Rated output frequency	50 Hz

Step-up Transformer

To synchronize the solar PV generation with the 6.6 kV power distribution grid one no. 1250 KVA, 0.36/6.6 kV, 3 winding cast resin transformer has been installed. The vector group of solar transformer is selected YNd11d11) as depicted in Table 4.

Energy Meter

Total generation of the solar power plant is monitoring through three phase, four wire energy meter. The energy meter is having the communication port RS 485 for network connectivity through which real-time generation of solar plant can be monitored with the implementation of IoT. The detail technical parameters of energy meter used for this plant as depicted in Table 5 (Fig. 3).

Table 4 Technical parameters of solar transformer

Transformer specification		
S. No.	Parameters	Specification
1	Power rating	1250/625–625 KVA
2	Vector group	YNd11d11
3	Phase	3
4	No load voltage	HV: 6.6 kV
		LV-1: 0.360 kV
		LV-2: 0.360 kV
5	Current	HV: 109.35 A
		LV-1:1002.34 A
		LV-2: 1002.34 A
6	Communication port	RS 485

Table 5 Technical parameters of smart energy meter

Energy meter specification		
S. No.	Parameters	Specification
1	Type	3 phase, 4 wire
2	Energy parameters	MWh, MVArh, MVAh, MW, MVA
3	Voltage	6.6 kV/$\sqrt{3}$/110 V/$\sqrt{3}$
4	Ib	5 A
5	Imax	10 A
6	Frequency	50 Hz
7	Class	0.2 s
8	Communication port	RS 485

Fig. 3 Actual site photographs of 1.43 MWp rooftop solar PV plant

3 Implementation of IoT

The proposed IoT application for this 1.43 MWp solar PV plant is designed using four layer architecture named as field and control, data communication, and IoT platform and analytics [11]. The field is designed with smart sensors, smart meters, measuring, and monitoring devices to capture the desired data. The field devices are then connects to IoT platform with communication cables and through communication port of devices. After processing and cleaning of data, the IoT application transform the data from storage device to cloud for access from smart application devices, mobile apps, etc. [12] (Fig. 4).

Hardware Setup
The hardware part of the IoT system for 1.43 MWp rooftop solar PV plant designed by solar log module, network switch, smart meters, sensors, hard disk for data storage, and GPRS SIM. The smart energy meters and sensors are connected through communication cable to the network switch. The network switch further connected to solar log module by single pair communication cable [13]. The solar log module then connected to the cloud via GPRS SIM and the processed values can be monitored through desktop/mobile via app for real-time monitoring and analysis purposes [14]. Detail hardwires used in this project is summarized in Table 6 (Figs. 5, 6, 7 and 8).

Software Setup to IoT Platform
Implementation of IoT is carried out on 1.43 MWp rooftop solar PV plant through the designed software platform by solar log. The software is having inherent system to process and display of PV system performance at a glance. The system can also be easily accessed in mobile through the App.

Work Flow
Figure 9 represents the implementation of IoT process to monitor the performance and system parameters of 1.43 MWp rooftop plant. Real-time parameters of DC system

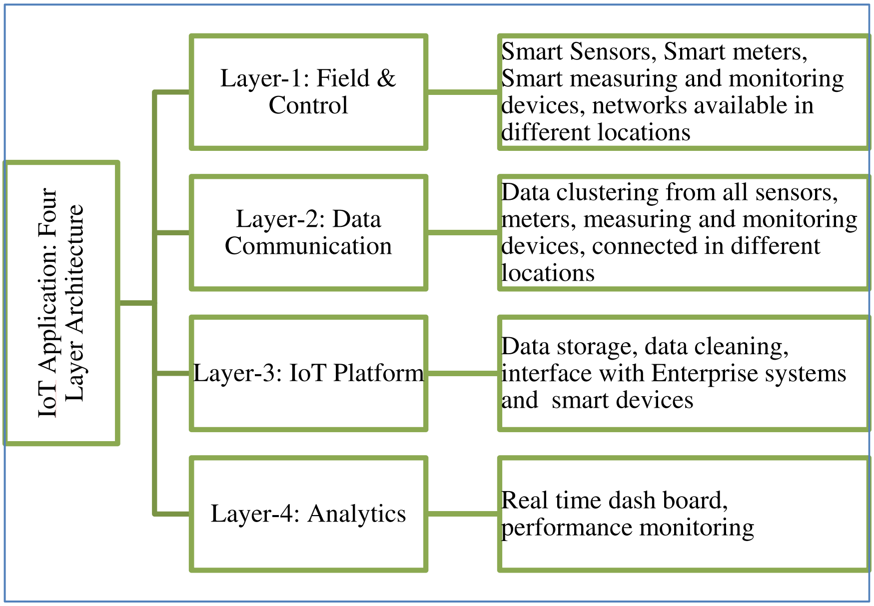

Fig. 4 Four layer architecture of IoT implementation

Table 6 Hardware details used in this project

S. No.	Components	Specifications
1	Solar log module	Operating parameters: 1 A, 12 V DC Connectivity: GPRS Communication port: RS 485
2	Adapter for solar log	Input: 220 V AC; output: 12 V DC
3	Network switch	8-channel network switch
4	Smart energy meters	Suitable to communicate with RS 485 port
5	Hard disk	500 GB
6	Communication cable	Single pair, 7 × 0.2 mm conductor stranding, tinned copper materials
7	Communication media	GPRS SIM

first sense the parameters and send to solar log for further process. The solar log sense the values, process for display and upload to the cloud through GPRS system [15]. Then the user can login into the web portal and mobile app for monitoring, record, and analysis the parameters.

Fig. 5 Solar log module

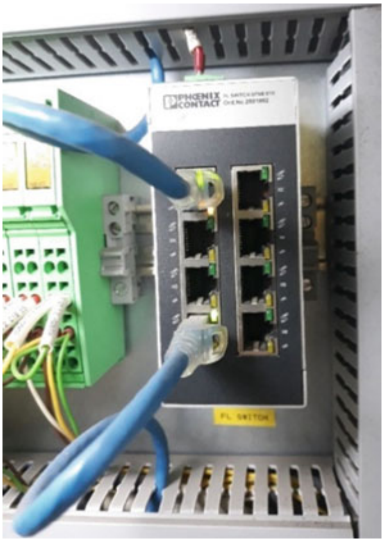

Fig. 6 Channel network switch

4 Results and Discussions

The 1.43 MWp rooftop solar PV plant is installed through 4480 nos. solar PV panels in combination of 224 strings on rooftop of industrial shed. After installation of the PV plant, toward monitoring of the real-time parameters and performance of the solar PV plant, IoT system has also been installed.

Fig. 7 Smart meters with RS 485 port communication

Fig. 8 Portable antenna for GPRS

From the IoT platform, it can easily be monitored the day wise solar power generation for 12 h. as well as for 24 h. for any typical day. Sample power generation graph for different days are showing in Figs. 10 and 11.

This PV plant is consisting two nos. 630 KW Inverter and through the IoT implementation, inverter (Inverter-I & Inverter-II) wise power generation can also be monitored. Inverter wise solar power generation for any typical days are showing in Fig. 12.

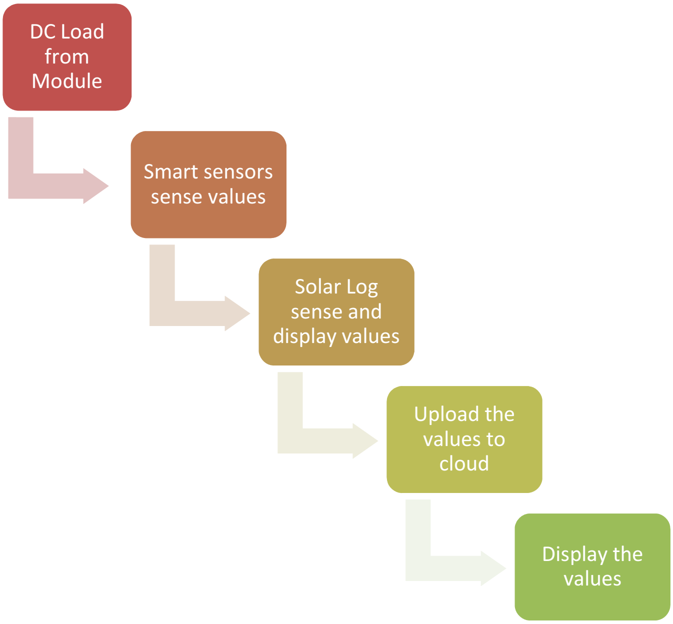

Fig. 9 Work flow of Iot implementation in rooftop solar PV plant

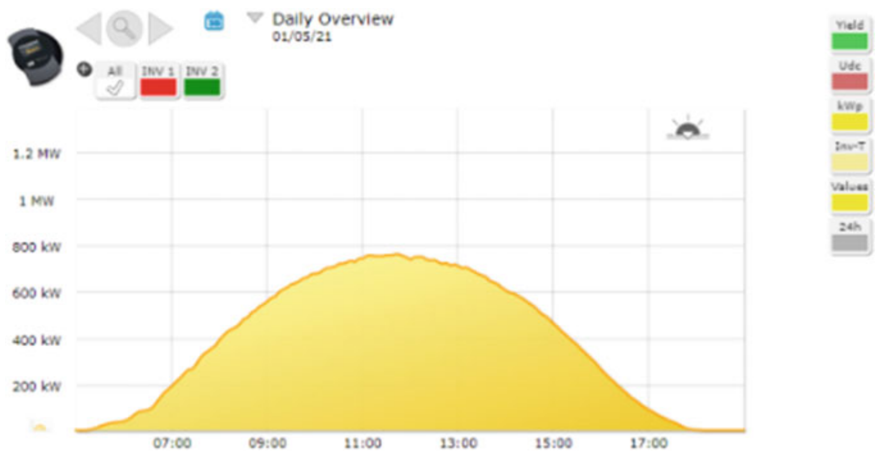

Fig. 10 Day (12 h) wise solar power generation of May, 1, 2021 monitored through IoT application

Through the IoT application it can also be monitor the yield history on daily, monthly, and yearly basis. The yield history of the plant is showing in Figs. 13, 14, 15 and 16.

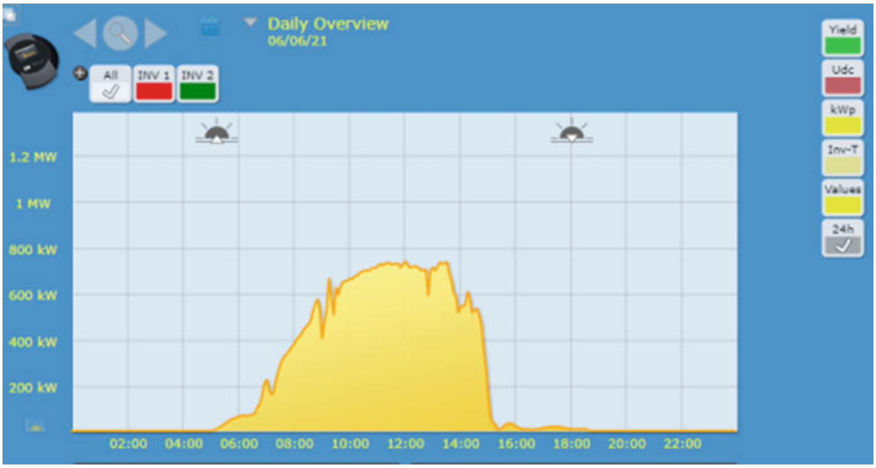

Fig. 11 Day (24 h) wise solar power generation of June 6, 2021, monitored through IoT application

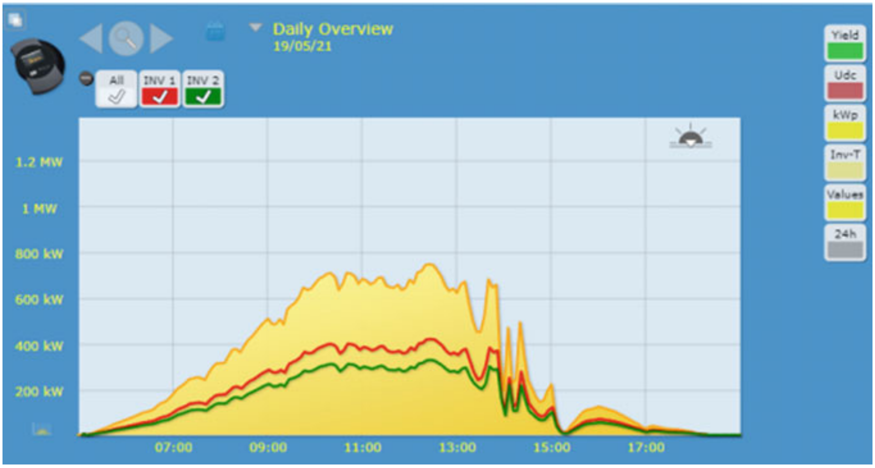

Fig. 12 Inverter wise solar power generation of May 19, 2021, monitored through IoT application

The IoT application can also monitor inverter wise running status as showing in Figs. 17 and 18.

5 Conclusion

To meet the manufacturing cost reduction industries are looking for renewable energy resources, and solar PV is the most promising options to meet the target. Industries

Fig. 13 Day wise yield history

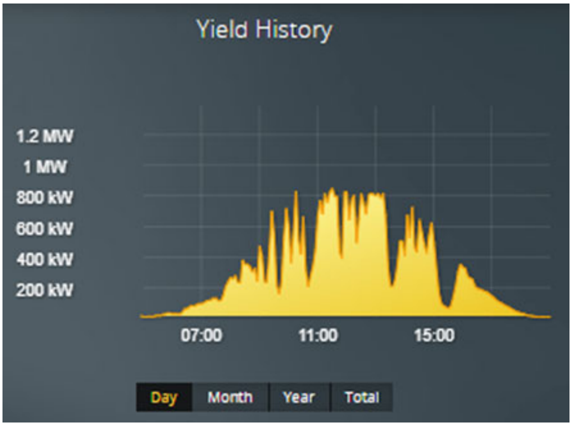

Fig. 14 Month wise yield history

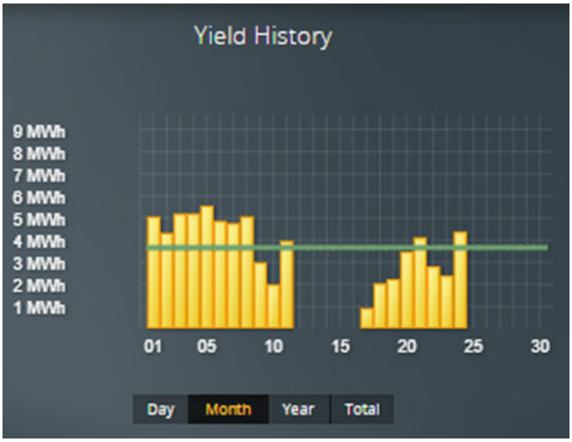

Fig. 15 Yearly (Jan-21 to June-21) yield history monitored through IoT

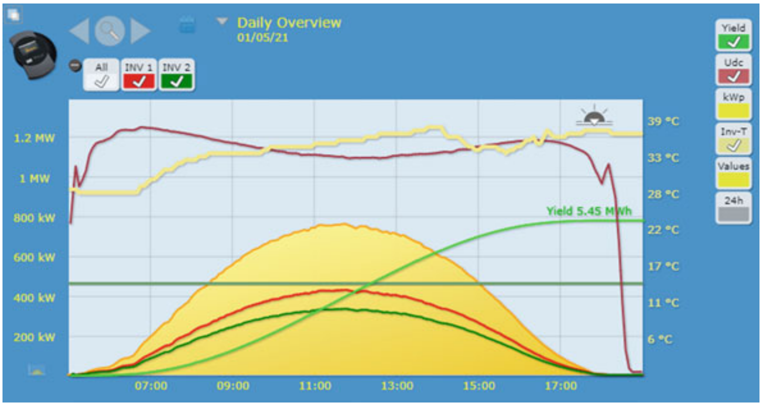

Fig. 16 Web based monitoring of inverter wise generation, yield, inverter temperature, input voltage

Inverter	Date	Status	Error
1	24.06.2021 18:34 -	Stand-by	
1	24.06.2021 05:21 - 24.06.2021 18:34	Alarm	
1	24.06.2021 05:20 - 24.06.2021 05:20	Run	
1	24.06.2021 05:15 - 24.06.2021 05:19	Stand-by	
1	24.06.2021 05:06 - 24.06.2021 05:15	Alarm	
1	24.06.2021 05:05 - 24.06.2021 05:06	Run	
1	24.06.2021 04:48 - 24.06.2021 05:05	Initial Stand-by	
1	23.06.2021 18:35 - 24.06.2021 04:48	Stand-by	
1	23.06.2021 05:26 - 23.06.2021 18:34	Alarm	
1	23.06.2021 05:26 - 23.06.2021 05:26	Run	
1	23.06.2021 05:25 - 23.06.2021 05:25	Start-up	
1	23.06.2021 05:21 - 23.06.2021 05:25	Stand-by	
1	23.06.2021 05:12 - 23.06.2021 05:21	Alarm	
1	23.06.2021 05:11 - 23.06.2021 05:12	Run	
1	23.06.2021 04:51 - 23.06.2021 05:11	Initial Stand-by	
1	22.06.2021 18:33 - 23.06.2021 04:51	Stand-by	
1	22.06.2021 05:15 - 22.06.2021 18:33	Alarm	
1	22.06.2021 05:14 - 22.06.2021 05:15	Run	
1	22.06.2021 05:09 - 22.06.2021 05:14	Stand-by	
1	22.06.2021 05:00 - 22.06.2021 05:09	Alarm	
1	22.06.2021 04:59 - 22.06.2021 05:00	Run	
1	22.06.2021 04:54 - 22.06.2021 04:59	Initial Stand-by	
1	22.06.2021 04:54 - 22.06.2021 04:54	Start-up	
1	22.06.2021 04:47 - 22.06.2021 04:54	Initial Stand-by	
1	21.06.2021 18:21 - 22.06.2021 04:47	Stand-by	
1	21.06.2021 18:12 - 21.06.2021 18:21	Alarm	
1	21.06.2021 18:11 - 21.06.2021 18:12	Run	
1	21.06.2021 18:05 - 21.06.2021 18:11	Stand-by	
1	21.06.2021 05:12 - 21.06.2021 18:05	Alarm	
1	21.06.2021 05:11 - 21.06.2021 05:12	Run	
1	21.06.2021 05:06 - 21.06.2021 05:11	Stand-by	
1	21.06.2021 04:57 - 21.06.2021 05:06	Alarm	
1	21.06.2021 04:56 - 21.06.2021 04:57	Run	
1	21.06.2021 04:45 - 21.06.2021 04:56	Initial Stand-by	
1	20.06.2021 18:22 - 21.06.2021 04:45	Stand-by	
1	20.06.2021 05:22 - 20.06.2021 18:22	Alarm	

Fig. 17 Running status of inverter-I

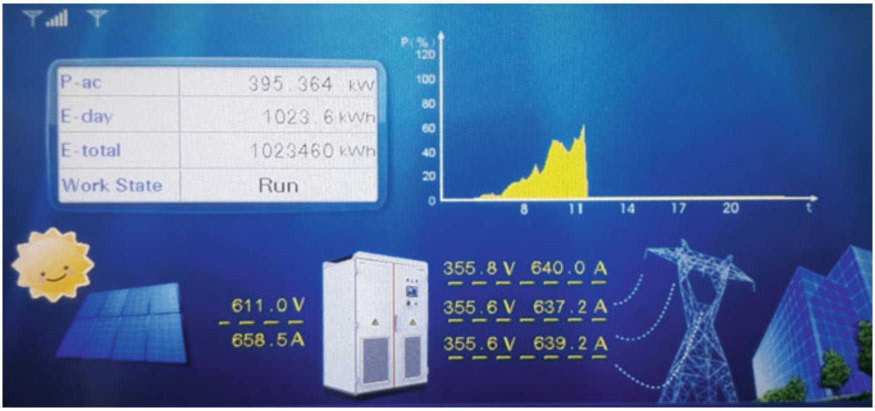

Fig. 18 Display of real-time power generation in web-based application

are having large rooftops and installation of solar PV plants on rooftop is more cost effective solution. But, monitoring of rooftop solar PV plant is not a very easy task due to its location. In view of this, it was decided to implement the IoT system to monitor the generation of the plant, system parameters, running status of equipment of the plant and accordingly IoT implementation has been done with the help of solar log system. All the communication has been established by communication cable through RS 485 port of smart devices to solar log module. Solar log module then process and transfer the data to cloud via GPRS SIM, and the parameters are visible to desktop and smart mobile application.

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