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IOT Based Solar Grid Monitoring and Performance Analysis System

[1]Taskin Hayat, [2]Namrata Kataki

[1]P.G Scholar, [2]Assistant Professor, [1, 2]Girijananda Chowdhury Institute of management & Technology, Guwahati, India, [1]taskinhayat23@gmail.com, [2]namratakataki15@gmail.com

Abstract **Sun power is a standout amongst the most productive yet clean wellsprings of natural energy. There are no expanded fuel expenses or conditions, no connections to toxins, and it's both dependable and reasonable. The solar grid uses sun's energy to generate electricity for various uses. In solar grid system the electricity produced by the system is routed to the grid from where it is used to run the various appliances. Internet of things (IoT) is a sort of "universal global neural network" in the cloud which associates various things. The IoT allows objects to be sensed or controlled remotely over existing network infrastructure, creating opportunities for pure integration of the physical world into computer-based systems, and resulting in improved efficiency, accuracy and economic benefit in addition to reduced human intervention. The main problem of solar grid system is that dust particles accumulating on solar panels reduce the solar energy getting in the cells, thereby falling overall power performance. In this project we are going to use solar panels for generation of electricity from the sun's energy and also automatically cleaning the solar panels with the help of IOT. The proposed system refers to the online display of the power usage of solar energy as a renewable energy. This monitoring is done through cost effective hardware like 8 bit microcontroller with Wi-Fi Modem using client server technology. We are thus solving this problem of cleaning the solar panels using IOT thereby increasing its efficiency and also keeping the system clean.**

Keywords — Current Sensor, IoT, LCD, Microcontroller, Solar grid, Temperature Sensor, Voltage Regulator,

I. INTRODUCTION

In this modern world, Electricity is also added to the most basic needs in everyone's life. The graph of energy consumption is getting increased day by day whereas the energy resources are diminishing parallel. In order to balance the scarcity for electricity, various sources are used to generate electricity. For the generation of electricity, there are two ways: one is by conventional method and other one is nonconventional method[1]. Some of the energy carriers like fossil fuels and nuclear fuels are also used, but they are not renewable resources (i.e., they are not 'refilled' by nature) and it is said to be non-conventional. In its broadest sense, sustainable power source can be achieved by using the solar power as source. Solar energy has the wide availability throughout the world. Even The sun has produced energy for billions of years. The sun's rays may act as an important source for the generation of electricity by converting it into an electric power. Such application is called as solar thermal energy, which is conventional [2]. Even though various sustainable sources are available such as wind, rain, tides and geothermal, natural based bio fuels and conventional biomass, solar power have huge benefits. Nowadays in India, frequent power cut is very common. For that it is primary to use the renewable energy and monitoring it secondarily. The rapid growth in renewable energy applications have been empowered by a critical drop in cost over the earlier decades and specialized change in their productivity, unwavering quality and lifetime. And by means of monitoring the energy forecasting, households and communities, the productivity gets increased [7]. At present, the solar photovoltaic (PV) energy is one of the pivotal renewable energy sources. The solar energy is becoming a potential solution towards sustainable energy supply in future. As more and more Rooftop Solar Photovoltaic systems are getting integrated into the existing grid, there is a growing need for monitoring of real time generation data obtained from solar photovoltaic plants so as to optimize the overall performance of the solar power plant and to maintain the grid stability [9]. Implementation of IOT platform with solar grid will add more features like monitoring of different parameters such as current, voltage, power and temperature over the internet to IOT server.

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II. EFFECTS OF DUST ON SOLAR PANEL

The accumulation of dust on the solar cells panels worsens the situation and lowers the efficiency of the solar cells day by day especially in the regions known by their high rate of dust, low frequency and intensity of rain [3]. The accumulated dust on the solar cells panel blocks the cells from the sun's rays and act as a screening effect as shown by the calculated spectral transmittance of dust which decreases the performance of the solar cells over time until the cell panels are cleaned manually or by rain. The main cause of the reduction of solar cells power is the attenuation in transmittance of light due to the dust accumulation on the glass cover. The dust accumulation process is very easy it starts first by a simple layer accumulation until it covers all the surface, then a second layer will deposit on top of it and so on. To calculate the scattered light efficiency, we suppose that the dust particles are spherical and are composed mainly by SiO_2 , thus the refractive index for the Silicon oxide as function of the wavelength was used[8]. When these particles are illuminated they will absorb and scatter the light, which will reduce the intensity of the light beam, this effect is known as the extinction efficiency that is governed by the ration of the particle size to the wavelength of the incident light. The deposition and accumulation of airborne dust significantly reduce the output performance of the solar cells. Experimental results show that the deposition and accumulation of airborne dust on solar cell panels caused a significant reduction of the short circuit current consecutively during 15 weeks for both tilts leading to a reduction of the efficiency of the solar cells. This effect is due to the reduction in transmittance that is greatly affected by dust deposition density and particle sizes affected itself by the exposure duration and the inclination angle. Almost 10.4% of efficiency is lost for a period of 16 weeks for the panels tilted at 30° and 9.7% for the panels tilted at 55° which is considerably high considering the short exposure time to the dust. Moreover the weak rainfall worsens the situation and a cleaning with natural water is necessary to remove all dust and therefore better solar cells efficiency is obtained. But this operation is a time wasting if we consider large field of solar cell panels. For such case it is strongly recommended to use a self-cleaning system especially in dusty areas that may be helpful to prevent dust accumulation and to enhance the module power performance. The particle size distribution of accumulated dust has an important and direct effect on the degradation of solar cell efficiency (PV). The size of the accumulated dust particles plays a role in the reflection, dispersion, and absorption of incident light on PV modules. They also play an important role in their interaction with wind speed. Large particles volatilize and attach to the air even at moderate wind speeds while small particles tend to hold together and with the PV module surface. Accumulation of fine dust particles causes more degradation in PV performance than larger particles. If they are compared on the basis of a constant mass of dust, fine dust particles have a larger surface area and are more uniformly distributed than larger particles. Small molecules also have less surface roughness than large dust particles, reducing the spaces between the particles through which light passes. Studies on the distribution of dust particle sizes accumulated on the surface of a PV found that most of the dust accumulated had sizes ranging from 1 to 50 μm. Studies of dust accumulated on PV surfaces have identified 15 types of dust elements such as ash, limestone, red soil, calcium carbonate, silica, and sand have a significant impact on the performance of PV modules Format (PDF).

III. PROPOSED SYSTEM

The working principle of the proposed system is based on microcontroller programming and interfacing various sensors to measure the parameters of a solar panel, that includes voltage, temperature, current and power. The microcontroller is responsible for collecting data/signal from various sensors, process it and display using a 20×4 LCD.

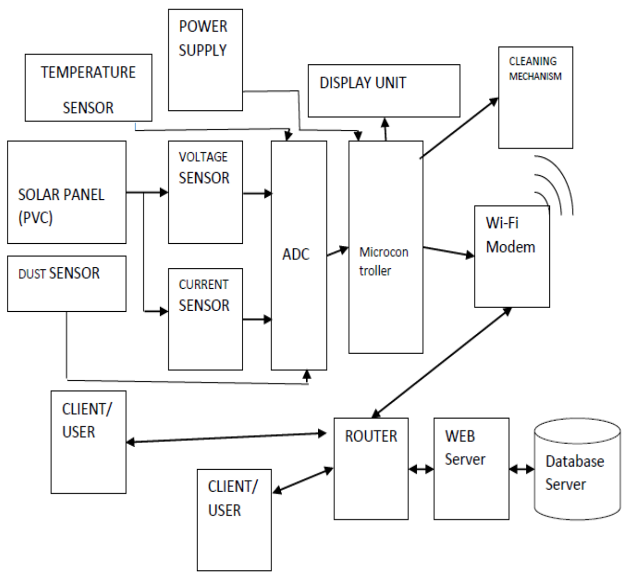

Fig 1: Block diagram of the proposed system

For temperature and current sensor we are using popular ACS712 current sensor, LM35 temperature sensor but we do not have any specific voltage sensor unit therefore the voltage divider circuit and the formula is used measure the voltage level. As we know the analog to digital converter (ADC) can handle at most +5V input but the solar panel is giving us 18.7V which is not possible to interface with ADC directly. To design the voltage sensor circuit such a way that the input voltage at the ADC pin does not go beyond +5V. From the voltage divider formula

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Vout =(R2/R1+R2)Vin

is simplified in our program so that from the Vout, the circuit can calculate Vin of solar panel. The voltage, current, temperature all are of type analog. Therefore we cannot directly interface those sensors with microcontroller.

Therefore 12 bit ADC MCP3204 is interfaced with microcontroller. As MCP3204 is 12 bit ADC we have 212=4096 steps for a specific referral voltage. In our circuit we are using +5V as referral voltage, therefore 5000mV/4096 =1.22mV/step has to be calculated. Therefore when we get an ADC value from the sensor we need to multiply the ADC value by 1.22mV to get the actual voltage, then convert the voltage into different value for example if we use LM35 from datasheet we know 10mV=1◦ C , hence temperature=voltage mV/10 mV. Similarly to calculate the current flow, the output voltage has to be divided by 186 for 5A sensor

IV. HARDWARE IMPLEMENTATION

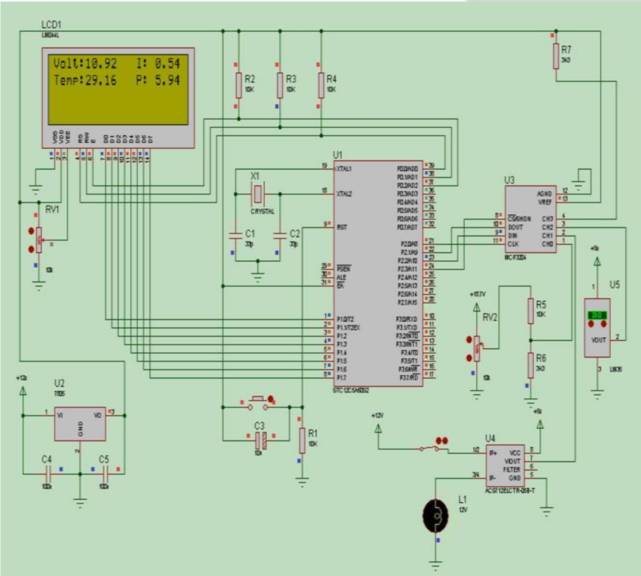

Fig 2: circuit diagram of the system

The circuit for IOT based solar grid monitoring system is designed with easily available components and widely used in industry. The brain of the circuit is an 8 bit microcontroller from 8052 family but with enhanced features and capability. To provide power supply to the circuit 12V DC is used. We can use a 12V battery or AC adapter to power up the system. Most of the components used in the circuit require +5V. Therefore popular +5V regulator 7805 is used in the circuit. The 7805 has 3 pins V1, ground and Vo i.e., pin 1, 2 and 3 respectively. At V1 pin we can provide +5V to +18V regulated or unregulated DC power supply. Pin 2 is ground and Pin 3 is regulated output irrespective of input voltage at Pin 1, the output voltage at Pin 3 is always +5V(± 0.1). To reduce noise or ripple, two ceramic capacitor of value 100 nF connected between Pin 1 and Pin 2 and Pin 2 and Pin 3 has decoupling capacitor. The microcontroller STC12C5A60S2 is the most advanced microcontroller under 8052 family having 60k of flash memory, 1280 byte of RAM and 10 bit 8 channel internal ADC. It is also equipped with a secondary physical serial port. According to datasheets this microcontroller operate at minimum 3.5 V to max 5.5V. Pin number 40 is the VCC pin which is connected to regulated +5V (pin 3 of 7085), pin 20 is ground (pin 20 and pin 40 are not displayed in the circuit diagram). Any microcontroller or microprocessor need clock pulse to fetch instructions and execute it. According To datasheet STC12C5A60S2 and operate at 0 to 35 megahertz. Few microcontroller has internal oscillator, traditionally 8051/52 family doesn't provide internal oscillator but STC12C5A60S2 has internal oscillator. Though it has internal oscillator but it is recommended to use external oscillator in noisy environment for better stability hence we are using crystal oscillator of 11.0592 megahertz crystal at pin 18 and 19 i.e., XTAL2 and XTAL1 respectively. According to data sheet it is recommended to use ceramic capacitor of value less than 47 pF at pin 18 and 19 connected to ground. In our circuit we are using 33 pF to generate the frequency along with the crystal. Pin 9 of microcontroller is reset pin. If we provide high (3.6-5.5V) at pin 9, the device will restart and for normal operation pin 9 must be pulled down so that the program keep executing. To create reset circuit push to on momentary tactile switch is connect between pin 9 and VCC and 10k resistance is connected from pin 9 to ground as pull down. Pin 31 is ex_LVD/p4.6/RST2 which has been replaced with EA. For traditional 8051/52 if we have to use external memory pin 31 has to be connected with ground and to use the internal memory pin 31 has to be connected VCC. To maintain the compatibility with other 8052 microcontroller we have connected pin 31 to VCC in our circuit. To display the various parameters connected from the system i.e., voltage, current, power, temperature and light intensity we are using 20X4 LCD. LCD module is having 16 pins. Pin 1, 2 and 3 are VSS (ground), VDD (VCC) and VEE (contrast control) respectively. Pin 1 is connected to ground, pin 2 is connected to +5V and pin 3 of LCD is connected to central terminal of a potentiometer of value 10k. One terminal of the potentiometer is connected to +5V and the other terminal is connected to ground. By rotating the potentiometer to clockwise and anticlockwise we can adjust the contrast of LCD. Pin 4, 5 and 6 of LCD module are RS, RW and E respectively. The RS represent register selector. It specifies whether the microcontroller is sending data or command. At the time of sending command from microcontroller to LCD RS pin must be pulled down (RS=0). On the other hand at the time of sending data from microcontroller to LCD RS pin must

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be pulled up (RS=1). The RW pin specify read/write mode. At the time of writing data or command from microcontroller to LCD RW pin must be pulled down(RW=0), on the other hand to read the busy bit(D7) from the LCD RW pin must be pulled up. The E pin represent enable. After or during providing data or command from microcontroller to LCD we have to send a high to low pulse. The RS, RW and E signal of the LCD is provided through pin 39, 38 and 37 of the microcontroller i.e., P0.O, P0.1, P0.2 respectively. As we know the port 0 of 8051/52 microcontroller are open drained hence we must have to use external pull up resistance to the input/output pin of port 0 which has been used in the circuit. Therefore three 10k resistance (R2, R3, R4) are connected from VCC to pin 39, 38 and 37 of microcontroller. Pin 7 to pin 14 of LCD module are used provide data or command from microcontroller to LCD. They are called data bus. An LCD can be used either in 8 bit mode or 4 bit mode. In our circuit we are using 8 bit mode of LCD. Therefore pin 7 to pin 14 of LCD are connected to pin 1 to pin 8 of the microcontroller

V. SOFTWARE IMPLEMENTATION

a) ***Flowchart of the current sensor:*** The current sensor in our project work is to measure the flow of current in the circuit so that we can calculate the power generating from the solar panel. The current sensor is to not only used for momentarily display the current value rather it will store those values permanently for further use. The microcontroller is collecting the data from the sensors and sending it to the cloud. As we are using 12 bit ADC so we have 2^{12}=4096 steps for a specific referral voltage. In our circuit we are using +5V as referral voltage, so 5000mV/4096=1.22mV/step has to be calculated.

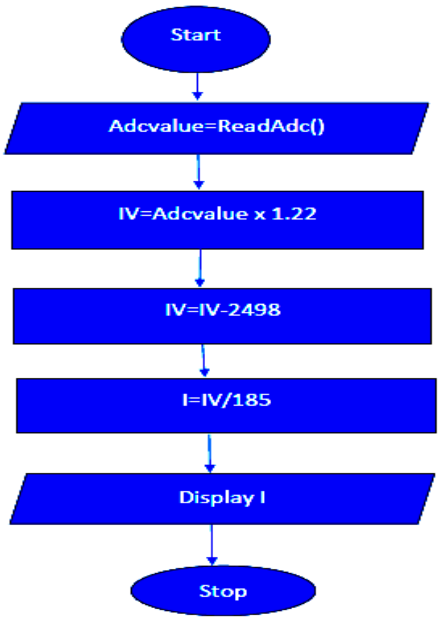

Fig 3: Flow chart for implementation of current sensor

Therefore when we get an ADC value from the current sensor we need to multiply the ADV value by 1.22mV to get the actual voltage then convert it into current value by dividing it by 185 .ACS712 returns the current value in terms of voltage for 5A, 20A and 30A version of ACS712 the current conversion ratio is 185,100 and 66 respectively i.e., if we are using 5A current sensor, the output value of the sensor (in volts) has to be divided by 185 to get current value.

b) ***Flowchart of the voltage sensor:*** In our project we have designed the voltage sensor by using the voltage divider circuit. As we know the analog to digital converter (ADC) can handle at most +5V input but the solar panel is giving us 18.7V which is not possible to interface with ADC directly. To design the voltage sensor circuit such a way that the input voltage at the ADC pin does not go beyond +5V. The voltage divider formula Vin=(R2/R1+R2)Vout is simplified in our program so that from the Vout, the circuit can calculate Vin of solar panel.

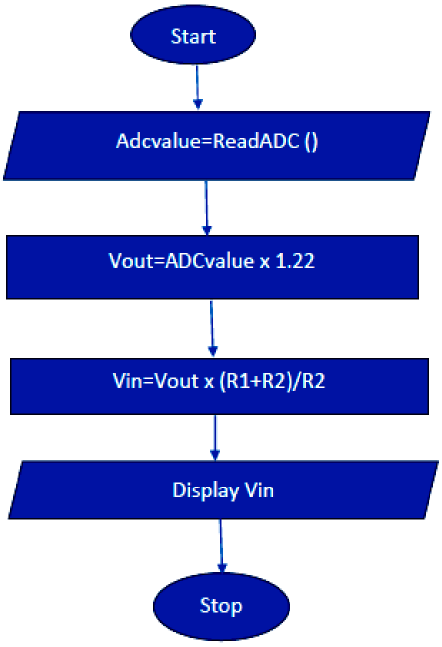

Fig 4: Flow chart for implementation of voltage sensor

The resistances used in our circuit are-

R1=3.3K

We know, from voltage divider formula

Vout =(R2/R1+R2)Vin ……(1)

Putting, Vin= 5V and Vout=4V (since Vout is always smaller than input) in eq 1, we get,

R2 = 13.2 Ω.

Since we don't have standard 13.2K resistor so we used 10K as R2.

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c) ***Flowchart of the temperature sensor:*** The temperature sensor used in our project is LM35. The LM35 series are precision integrated-circuit temperature devices with an output voltage linearly proportional to the Centigrade temperature. LM158 series can be directly operated off of the standard +5V power supply voltage which is used in digital systems and will easily provide the required interface electronics without requiring the additional ±15V power supplies. Rated for Full −55°C to 150°C range. The microcontroller is collecting the data from the sensors and sending it to the cloud. As we are using 12 bit ADC so we have 212=4096 steps for a specific referral voltage. In our circuit we are using +5V as referral voltage, so 5000mV/4096=1.22mV/step has to be calculated. Therefore when we get an ADC value from the temperature sensor we need to multiply the ADC value by 1.22mV to get the actual voltage then convert it into temperature value by dividing it by 10. From datasheet of LM35, we know 10mV=1°C, hence temperature=Voltage mV/10 mV.

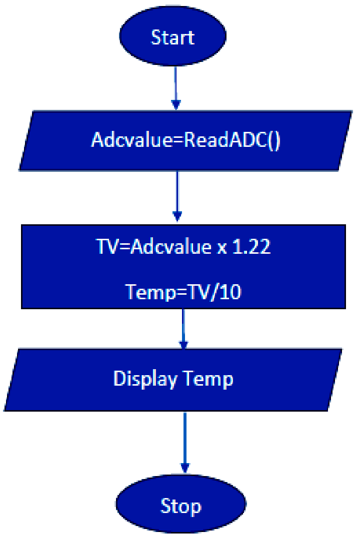

Fig 5: Flow chart for implementation of temperature sensor

VI. IMPLEMENTATION OF IOT IN THE SYSTEM

WAMP Server is a dependable web development software package that allows us to create web apps using MYSQL and PHP Apache2. The application's easy interface and various functionality make it the favoured choice of developers all around the world. The software is free to use and does not require a subscription or purchase. Moreover, the program installs on the system automatically, so we can fine tune the server without making any changes to the 'Setting' files. The WAMP Server download is a Windows utility package aimed at experienced programmers. We can quickly develop a number of web apps, access the server in a secure environment, and manage databases with this tool. Compared to Apache HTTP Server and Server2Go, WAMP is a robust tool. It allows us to easily configure the local development environment using MySQL, PHP, and Apache2. Furthermore, for best efficiency, we can use multiple versions of PHP. We can also change configuration files using this web server software. Most importantly, the program is available in multiple languages. Once we install the tool on our Windows PC, we can add as many MySQL, Apache, and PHP releases as you need.

Once downloaded and installed, the program works in the same way as leading server software, such as XAMPP. It places a small icon in the system tray, from where we can start or stop multiple services in the stack. It also gives access to key directories, such as the one with the root of the web server. The tray icon is also a simple way to open configuration logs or files and access service-specific settings. For instance, when we are working with Apache, we can choose from a list of modules to edit or load alias directories. However, if we make direct edits to this file, the changes don't show up in the tray icon's list unless we restart the program. Over time, this can be tedious and difficult to remember.

Fig 6: Login page of the web application

We always need to be aware of changes to keep the stack's actual configuration and the tray app's information synchronized. The tray icon features convenient handler options, including 'Put Online/Offline', which lets us disable access to the web stack's offline mode within seconds. After using this option, we will be able to access the stack offline only on the local host server.

We have used the WAMP server for our web application part. The web application is designed using HTML and CSS programming language. MySQL is used for database management for managing the datas from the solar panel.

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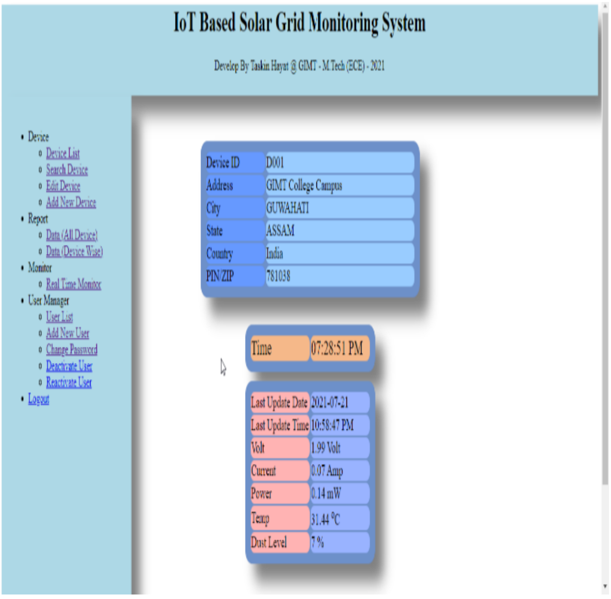

Figure 7: Real time monitoring of the IoT based solar grid monitoring system

VII. RESULTS AND DISCUSSION

For experimental purpose we are using 20 Watt solar panel from Topsun. It offers high efficiency modules with consistent performance; quality workmanship and AR coated antimony free glass material.

Voltage at Max Power (Vmax) : 18.72V

Open circuit Voltage(Voc) : 22.32V

Current at Max Power (Imax) : 1.08A

Short Circuit Current (Isc) : 1.15A

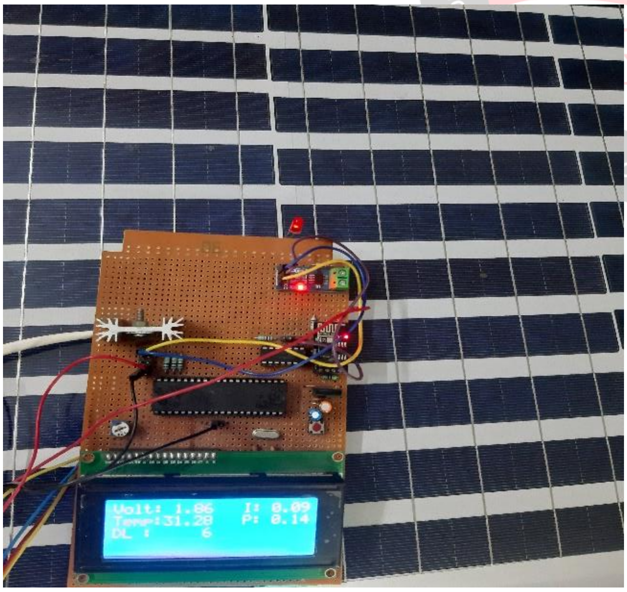

Fig 8: Snapshot of the system

1) OBSERVATIONS FOR DAY 1

Table 1: Power of the solar panel without dust

Time	Temperature(°C)	$Power_{system}$ (W)	$Power_{multimeter}$ (W)	Error %
9:00 AM	29	3.92	3.96	-1.01010101
10:00 AM	30	4.46	4.36	2.293577982
11:00 AM	31	5.72	5.8	-1.379310345
12:00 PM	32	6.33	6.31	0.316957211
1:00 PM	33	7.42	7.48	-0.802139037
2:00 PM	34	8.9	8.81	1.021566402
3:00 PM	33	8.11	8.09	0.247218789
4:00 PM	32	6.49	6.4	1.40625
5:00 PM	30	4.72	4.7	0.425531915

Table 2: Power of the solar panel with partial dust (~75gm)

Time	Temperature(°C)	$Power_{system}$ (W)	$Power_{multimeter}$ (W)	Error %
9:00 AM	29	2.29	2.21	3.619909502
10:00 AM	30	2.91	2.94	-1.020408163
11:00 AM	31	3.56	3.5	1.714285714
12:00 PM	32	4.42	4.47	-1.118568233
1:00 PM	33	5.61	5.56	0.899280576
2:00 PM	34	6.46	6.4	0.9375
3:00 PM	33	5.23	5.2	0.576923077
4:00 PM	32	3.44	3.47	-0.864553314
5:00 PM	30	2.65	2.6	1.923076923

Table 3: Power of the solar panel with dust (~140gm)

Time	Temperature(°C)	$Power_{system}$ (W)	$Power_{multimeter}$ (W)	Error %
9:00 AM	29	0.96	0.99	-3.03030303
10:00 AM	30	1.24	1.27	-2.362204724
11:00 AM	31	2.21	2.23	-0.896860987
12:00 PM	32	2.77	2.7	2.592592593
1:00 PM	33	3.42	3.47	-1.44092219
2:00 PM	34	3.87	3.81	1.57480315
3:00 PM	33	3.56	3.52	1.136363636
4:00 PM	32	2.37	2.34	1.282051282
5:00 PM	30	1.07	1.17	1.9230769

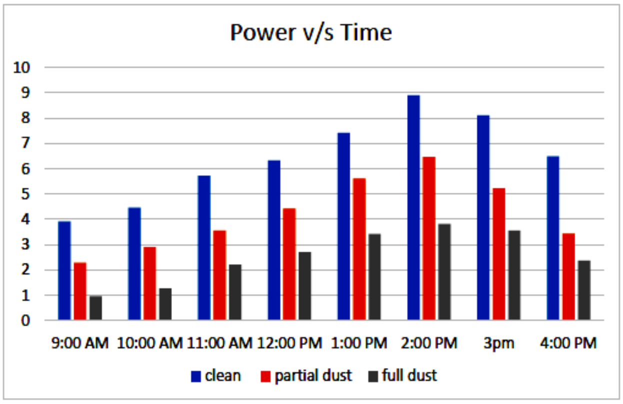

Fig 9: Graphical representation of effect of dust on solar panel on different time of a day

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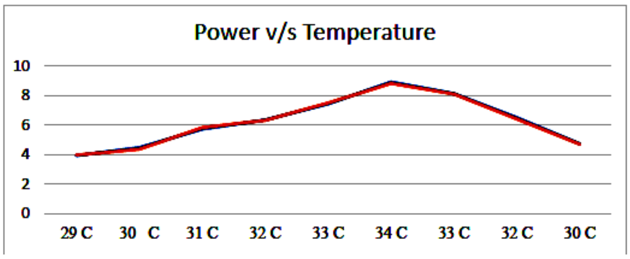

Figure 10: Power v/s temperature curve

From the above graph we can infer that the power of the solar panel is highest at 1-3 pm having temperature of about 34◦C.

2) **OBSERVATIONS FOR DAY 2-**

Table 4: Power of the solar panel without dust

Time	Temperature(◦C)	Power$_{system}$ (W)	Power$_{multimeter}$ (W)	Error %
9:00 AM	28	3.46	3.44	0.581395349
10:00 AM	29	4.56	4.51	1.10864745
11:00 AM	30	5.77	5.76	0.173611111
12:00 PM	31	6.64	6.62	0.302114804
1:00 PM	33	8.23	8.19	0.488400488
2:00 PM	34	11.65	11.63	0.171969046
3:00 PM	33	9.55	9.53	0.209863589
4:00 PM	32	6.25	6.22	0.482315113
5:00 PM	31	4.26	4.17	2.158273381

Table 5: Solar panel with partial dust (~75gm)

Time	Temperature(◦C)	Power$_{system}$ (W)	Power$_{multimeter}$ (W)	Error %
9:00 AM	28	2.94	2.92	0.684931507
10:00 AM	29	3.45	3.41	1.173020528
11:00 AM	30	4.63	4.62	0.216450216
12:00 PM	31	5.55	5.52	0.543478261
1:00 PM	33	7.41	7.39	0.270635995
2:00 PM	34	9.77	9.74	0.308008214
3:00 PM	33	7.88	7.85	0.382165605
4:00 PM	32	5.25	5.22	0.574712644
5:00 PM	31	3.31	3.3	0.303030303

Table 6: Solar panel with dust (~140 gm)

Time	Temperature(◦C)	Power$_{system}$ (W)	Power$_{multimeter}$ (W)	Error %
9:00 AM	28	1.21	1.19	1.680672269
10:00 AM	29	2.85	2.83	0.706713781
11:00 AM	30	3.44	3.41	0.879765396
12:00 PM	31	5.67	5.64	0.531914894
1:00 PM	33	6.34	6.35	-0.157480315
2:00 PM	34	6.79	6.75	0.592592593
3:00 PM	33	2.04	2.01	1.492537313
4:00 PM	32	1.66	1.65	0.606060606
5:00 PM	31	0.44	0.43	2.325581395

In a similar pattern readings are monitored for number of days and parameters are analyzed depending upon different requirements. Thus, it is seen from the graph that there is gradual decrease of power with the increase of dust.

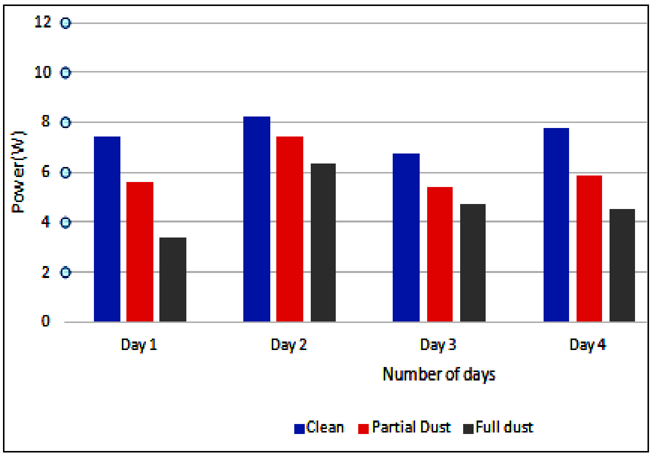

Fig 11: Representation of power for 4 days at 1 pm

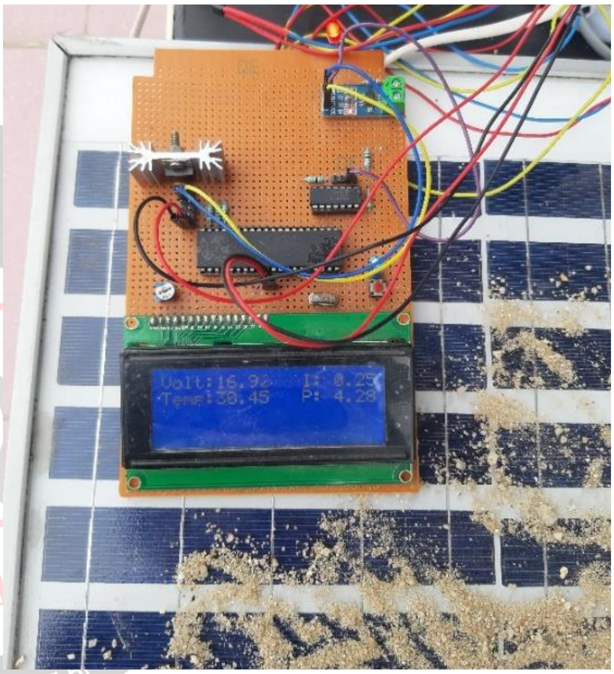

Fig 12: snapshot of dust on solar panel system

Figure 13: A solar panel after cleaning

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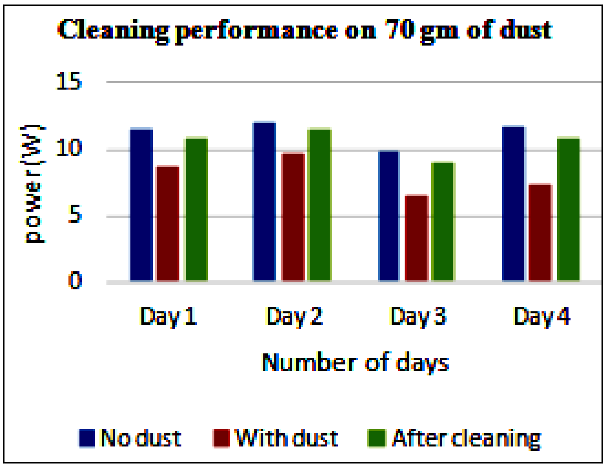

Figure 14: Cleaning performance of the system

VIII. Conclusion

In this project the proposed IoT based solar grid monitoring and performance analysis system has been designed successfully. The various sensors such as current, voltage, temperature and dust sensor are interfaced and the output is displayed on the LCD for monitoring purpose. It is seen that dust on solar panel reduces its output power. Higher the amount of dust deposited higher is the reduction in its power. The generated power of the solar panel is highest at 1-3 pm when the sun is almost directly above the head. The results of various parameters such as voltage, current, power, temperature and dust level is sent through the Wi-Fi-module and displayed on the developed web application to implement the concept of IoT for monitoring and analysis. In future we are going to implement the automatic cleaning system where depending upon the amount of dust deposited on the panel, water pump will start automatically to clean the panel.

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