Monitoring and load regulation of photovoltaic solar energy conversion system using internet of things

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Abstract. Worldwide, all the countries looking towards the renewable energy based electrical power generation. The solar energy is the primary renewable energy source. In the photovoltaic solar energy conversion system (PVSECS), the electrical energy is generated from the solar energy. In the rural area, operation and maintenance of PVSECS is difficult. If the systems are monitored through online, only under repairing conditions, the respective expert will visit the plant and it reduces the operating cost. In this paper, presents the maximum power point tracking is maintained by controller (ESP32), light dependent resistors, and DC servomotors with driver circuit. The load is regulated by the controller using relays and the data send to the cloud. This data is useful for the online monitoring of the system. A prototype of PVSECS is developed and its simulation results also presented in various conditions.

Keywords. Battery Energy Storage System (BESS), Internet of Things (IoT), Light Dependent Resistor (LDR), Photo Voltaic Solar Energy Conversion System (PVSECS) and Relays

1. Introduction
Solar energy is the major renewable energy source in the world. The solar energy can be used as solar power with solar thermal power plants (STPP) and solar photo voltaic systems (SPVS). In STPP, the solar energy is observed by the water or any other liquid and they can produce the steam. The generated steam is used to operate the generator and it supplies the electrical power to AC loads at rated voltage. The SPVS generate the electricity from the solar energy. The Output of SPVS is DC power and it is directly connected to DC loads. The DC power is connected to AC loads through DC-AC inverter.
As compared with STTP, the SPVS has many advantages like simple design, easy operation, and maintenance, as per the requirement, a suitable number of PV cells are connected as series and parallel, and this system also generates the electricity under cloudy days etc. Hence most of the solar plants established using solar PV panels. In this system, power electronic devices, sensors, microcontrollers, and driver circuits play a major role to improve the system efficiency and reliability. The components are useful for the effective operation and maintenance of the system. Different types of techniques and methods can be developed and implemented in the various applications of SPVS. The DC-DC boost converters can be used to tilt the solar panels to generate more electrical energy and dynamic maximum power point tracking is obtained by DC-AC converters [1]. A solar panel can be designed with inverter, Arduino Uno, linear actuator and motor control unit for the effective power generation and to supply the quality power to the loads [2]-[4]. In the SPVS system automatic controlling, identification of faults and its location is more difficult because such techniques were not implemented.

A solar water pumping system in a thick forest area is shown in the Fig. 1. The main aim of the system is to provide the water facility for the animals in the forest in summer. Where the motor is used to pump the water using solar energy as shown in figure 1(a) and 1(b). The water is filled in the water saucer wells and the animal easily drinks the water as shown in figure 1(c) and figure 1(d). However, they are located in thick forest area and regular monitoring is required. It is more difficult and sometimes identification of faults in the system also difficult.

![Figure 1. Implementation of solar water pumping system to fill the water in water saucer wells.](image)

In the solar power plant, many numbers of solar plates connected in series and parallel based on operating voltage and current. In such systems estimation of power generation, load regulation, fault identification is more difficult. The problems can be minimised and analyzed using online data monitoring systems. The implementation of Internet of Things (IoT) with suitable controllers and sensors is the best method for the effective data analysis of the solar systems.

A wireless sensor network with fuzzy logic based controller was implemented in PV system for the identification of faults and monitoring of the system [5]-[6]. Where the PV system was divided into various zones to reduce the number of nodes in the system. Wireless sensors with fuzzy based controller were provided for the identification of operating conditions. Development in the internet working technology and wireless sensor technology for communication to become easy from any system to system or operator to system using Internet of Things (IoT). The IoT based solar photo
Voltaic systems (SPVS) are useful for the wireless operation of the system to determine the maximum power point tracking, faults section and its location, reliable operation and maintenance, optimal power control and monitoring etc. [7]-[21].

In these existing methods the load regulation was not implemented. In this paper, we are proposing the solar energy online monitoring and load regulation using IoT with the controller (ESP32), relays and maximum power point tracking system (MPPTS) with suitable sensors.

2. System schematic diagram
The schematic diagram of photo voltaic solar energy conversion system (PVSECS) is shown in figure 2. It has solar panel, microcontroller with Wi-Fi module, maximum power point tracking system (MPPTS), battery energy storage system (BESS), Light Dependent Resistor (LDR), sensors and relays. The generated electrical power and available power in BESS can be measured by the respective sensors and suitable AC and DC loads connected to the PVSECS through the relays. The maximum power can be obtained by LDRs, driver circuit and servo motors. The generated power, available power (it is the combination of instantaneous power generated in the solar panel and storage power in the battery), load demand on the system, and other information send to the cloud through the Wi-Fi module which is inbuilt in the controller. The complete data will be stored in the cloud and the same information sends to the higher officials or owner registered email. Based on the information, the respective persons will take the necessary action. The storage data is also useful for the forecasting of the load variations and solar power generation.

![Block diagram of photo voltaic solar energy conversion system.](image)

3. Components in the hardware System
For the implementation of hardware system, various components are required. The importance of the components is explained as follows:

- **Solar panels:** The Solar photo voltaic panels used to convert solar energy to electrical energy. As per the required voltage and current, suitable numbers of solar modules are connected in series and parallel.
• **Battery energy storage system**: The generated electrical energy is stored in the battery. The regulated DC supply is connected to controller and DC loads.

• **Controller**: It is the main part of the PVSECS. It has inbuilt Wi-Fi and it sends the data to the cloud. It has analogue comparator, analogue to digital converter, etc.

• **Inverter and LC filter**: The panel and storage battery output are DC supply. The DC power is converted into AC power with the help of inverters. The AC power has voltage and current ripples. They can be eliminated by LC filter.

• **Switching module**: The available power is measured by the sensors and the data is sent to the controllers. Based on the controller commands, the suitable loads are connected to the PVSECS.

• **Maximum power point tracking system**: The maximum power point will be obtained by the coordination of LDRs, controller, driver circuit and DC servomotors. The LDRs are used to obtain the direction of solar radiation and it sends to the controller. The controller operates the DC servomotors through the driver circuit to tilt the solar panel position.

4. **Software implementation**

The sequence of operation of the controller is depending on the program coding. The figure 3 describes the execution sequence of the program.

**Step(1):** Read the generation instantaneous power in the solar panel

**Step(2):** If the measured power is greater than the load demand, then all the loads are connected to the system and the remaining power stored in the battery otherwise goes to the next step

**Step(3):** Measure the storage energy in the battery. If the measured power is low, all the loads are disconnected from the system, otherwise goto the next step

**Step(4):** If the measured power is within the medium power range, then only DC loads are connected to the system, otherwise goto the next step

**Step(5):** Again measure the power. If it is greater than medium power, then all the loads are connected, otherwise goto step(3)

In each step, the measured data will send to the cloud with the help of controller

![Figure 3. Flow chart for the sequence of implementation of controller program.](image-url)
5. Implementation and results

The prototype of PVSECS is shown in figure 4. In the prototype system, LED bulbs are considered as DC loads and Bulbs are considered as AC loads. In figure 4(a), shows that only DC load is connected to PVSECS in case of generating power is in the medium range. In this case, the simulation results are shown in figure 4(b). In figure 4(b), it is observed that only DC load indicator is brighter (green colour) and AC load indicators are in dull colour (red colour). From figure 5(a), it is observed that DC and two AC loads are connected to the PVSECS. In this case, the system simulation results are shown in the figure 5(b). In the simulation results, it observed that the DC load indicator is ON and the last two indicators of AC load are also ON. It shows that based on the available power suitable loads are connected to the PVSECS and that data send to the cloud.

Figure 4(a). Only DC loads (LED bulb) are connecter to the PVSECS; (b). Simulation results of the system.

Figure 5(a). Two AC loads are connecter to the PVSECS; (b). Simulation results of the system.
6. Conclusions
From the results, it can be observed that in the photo voltaic solar energy conversion system (PVSECS), the loads as per the consumer requirement are automatically regulated by the controller with the help of the relay system. The load operating data is sent to the cloud server and customer registered email. The maximum power tracking is obtained with the help of solar tracking system to improve the output of solar panel. This proposed method is very useful for the monitoring of PVSECS.

7. References
[1] Yang Y and Blaabjerg F 2015 Overview of single-phase grid-connected photovoltaic systems Electric Power Components and Systems 99 1-10
[2] JengNan Juang and Radharamanan R 2014 Design of a solar tracking system for renewable energy Proceedings of 2014 Zone 1 Conference of the American Society for Engineering Education https://doi.org/10.1109/ASEEzone1.2014.6820643
[3] Chinthamalla R, Karampuri R, Jain S, Sanjeevikumar P and Blaabjerg F 2018 Dual solar photovoltaic fed three-phase open-end winding induction motor drive for water pumping system Application Electr Power Comp Syst 46(16) 1896-1911
[4] Rajababu D, Sudhakar A V V and Sathyavani B 2019 Development of technology for high-power industry converters Int J Innov Technol Explor Eng 8(10) 3130-32
[5] Ali Al-Dahoud, Mohamed Fezari, FatmaZohraBelhoucet and ThamerA Al-Rawashdeh 2016 Remote monitoring system for solar power panels using intelligent sensors network 24th Telecommunications forum TELFOR 2016 https://doi.org/10.1109/TELFOR.2016.7818739
[6] Mudi J, Shiva C K, Vedik B and Mukherjee V 2020 Frequency stabilization of solar thermal-photovoltaic hybrid renewable power generation using energy storage devices Ipn. J Sci Technol Trans Electri Eng. https://doi.org/10.1007/s40998-020-00374-w
[7] Andreas S Spanias 2017 Solar energy management as an internet of things (iot) application 8th International Conference on Information, Intelligence, Systems and Applications (IISA) https://doi.org/10.1109/IISA.2017.8316460
[8] Aoife Hegarty, Guy Westbrook, Damien Glynn, Declan Murray, Edin Omerdic and Daniel Toal 2019 A Low-Cost Remote Solar Energy Monitoring System for a Buoyed IoT Ocean Observation Platform IEEE 5th World Forum on Internet of Things (WF-IoT) 386-391 https://doi.org/10.1109/WF-IoT.2019.8767311
[9] Subba Rao A and Vidyagarige S 2019 IoT based smart energy meter billing monitoring and controlling the loads International Journal of Innovative Technology and Exploring Engineering 8(4S2) 340-344
[10] Karampuri R, Jain S and Somasekhar V T 2019 Common-mode current elimination PWM strategy along with current ripple reduction for open-winding five-phase induction motor drive IEEE Trans Power Electron 34(7) 6659-68
[11] Arulmurugan R and Chandramouli A 2019 Modeling of PV powered seven-level inverter for power quality improvement Smart Innov Syst Technol 105 113-21
[12] Vedik B, Shiva C K and Harish P 2020 Reverse harmonic load flow analysis using an evolutionary technique SN Appl. Sci. 2, 1584 https://doi.org/10.1007/s42452-020-03408-4
[13] Vedik B, Ritesh K, Deshmukh R and Shiva C K 2020 Renewable energy based load frequency stabilization of interconnected power systems using quasi-oppositional dragonfly algorithm J Control Autom. Electr. Syst. https://doi.org/10.1007/s40313-020-00643-3
[14] Vedik B, Naveen P and Shiva C K 2020 A novel disruption based symbiotic organisms search to solve economic dispatch Evol. Intel. https://doi.org/10.1007/s12065-020-00506-5
[15] Kumar R, Sahu B, Shiva C K and Rajender B 2020 A control topology for frequency regulation capability in a grid integrated PV system Archives of Electrical Engineering 69(2) 389–401
[16] Basetti V, Chandel A K and Subramanyam K B 2018 Power system static state estimation using JADE-adaptive differential evolution technique *Soft Computing* 22(21) 7157-76 https://doi.org/10.1007/s00500-017-2715-3

[17] Shiva C K, Vedik B and Kumar R 2019 Integration of distributed power sources to hydro-hydro power system subjected to load frequency stabilization *International Journal of Engineering and Advanced Technology* 8(2) 128-32

[18] Rajasri I, Gupta AVSSKS and Rao YVD 2016 Generation of Egts: Hamming number approach *Procedia Engineering* 144 537-542 10.1016/j.proeng.2016.05.039

[19] Rajasri I, Gupta AVSSKS and Rao YVD 2014 Symmetry and its effects on structures of planetary gear trains *Journal of The Institution of Engineers (India): Series C* 95(1) 77-81 10.1007/s40032-014-0101-9

[20] Rajasri I, Gupta AVSSKS and Rao YVD 2012 Structural aspect of symmetry and its effect on generation of planetary gear trains *Applied Mechanics and Materials* 110 2619-2622 https://doi.org/10.4028/www.scientific.net/AMM.110-116.2619

[21] Ch Vinay Kumar Reddy, Rajasri I and V Mahesh 2020 Comparison between hamming method and modified path matrix approach to identify isomorphism in PGTs *Materials today: Proceedings* https://doi.org/10.1016/j.matpr.2020.06.158