International Journal of Engineering &Technology, 7 (3.12) (2018) 1033 -1037

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Role of Internet of Things (IoT) in Maximum Power Extraction from BIPV Modules: A Review for Developing Smart Zero Energy Buildings

Debayan Sarkar[1*], Apoorva Shukla[2], Anand Kumar[3], Pradip Kumar Sadhu[4]

[1,2,3,4]Department of Electrical Engineering, Indian Institute of Technology (Indian School of Mines) Dhanbad, Jharkhand, India
**Corresponding Author Email: [1]debayan.17dr000423@ee.ism.ac.in*

Abstract

Evolution of Building Integrated Photovoltaic's (BIPV) technology has resulted in the development of smart buildings as a clean source of electrical energy generation which can either be stand alone or grid connected systems. This paper briefs about the studies on the role of Internet of Things (IoT) in real-time controlling and monitoring of parameters like tilt angles, defected modules, shading effect in BIPV systems etc which decreases the dc power output. In addition, it also describes the use of IoT for maximum power extraction from BIPV modules present in rooftops and facades. Enabling IoT in BIPV installation makes the overall system cost-effective, energy efficient, reliable and can be operated remotely through android apps, smart phones, laptops, PCs, tablets etc via internet which is very easily accessible in recent times. IoT along with BIPV is showing a new direction towards smart generation from renewable energy resources like solar through PV integrated building or construction materials.

Keywords: *BIPV, smart buildings, IoT, real-time, tilt angles, smart generation.*

1. Introduction

Building-integrated photovoltaic's are photovoltaic materials which replaces the traditional construction materials that are normally used in building's like rooftops, facades or skylights. BIPV products serve a secondary architectural purpose, such as tiles or windows, as well as producing electrical power. The incorporation of this technology for the upcoming new generation buildings is very advantageous. BIPV has the huge potential to generate electricity which is both clean and green. It transforms the conventional energy demanding buildings to smart energy generating buildings [1]. It meets the load demand of the building as well as saves the electricity tariff. The electrical energy generated from BIPV modules is pollution free as it uses renewable energy resource. To increase the efficiency of these modules and for maximum power extraction, many important parameters like partial shadowing, module temperature, orientation of modules, installation angle, etc should be monitored. BIPV also face some challenges like safety aspect, durability & reliability of integrated solution, cost versus economic benefit etc. Internet of Things (IoT) as well as cloud computing are the major tools of interconnected systems present in smart energy efficient buildings [2]. They also play some important role in the addition of renewable energy resources to the electrical grid. Energy monitoring and control in buildings is very effectively done through IoT solutions. Different kinds of devices are connected via internet and a flexible layered architecture is built consisting of people, things and cloud services [3].

Intelligent energy management in buildings is done through this flexible IoT architecture for the development of smart cities. Different measurement data can be collected from various types of sensor placed in the close vicinity of distributed energy resources (DES) like solar and wind systems. Through wireless and wired communication networks both monitoring and control of standalone and grid connected DES is possible using three different types of technologies like Wi-Fi-based, Ethernet based, and ZigBee-based architectures [4]. Control and monitoring of standalone PV systems present in open environment is done remotely. This solution enables the best replacement of manually checking PV modules resulting in reliable measurements and robust control mechanism from a network of interconnected sensors. Human-machine interface (HMI) and microcontroller chip are the two important elements of the supervisory control system [5]. Remote PV station for monitoring and control of individual module parameters present on different locations are achieved in real-time.

This paper presents an extensive review on the role of IoT in maximum power extraction from BIPV modules present in rooftops, windows, facades etc. It converts traditional buildings to smart zero energy consuming and self generating buildings. The rest of this paper is organized as follows: Section II mainly provides maximum power extraction approach from BIPV modules. In Section III, IoT and its role in BIPV systems is investigated. Section IV explains about the proposed IoT enabled BIPV (IoT-eBIPV) modules for extracting maximum power. Finally, Section V concludes the paper.

2. Maximum Power Extraction from BIPV Modules

Extraction of global peak (GP) or tracking of maximum power point (MPP) from BIPV modules is not an easy task. Actually the power–voltage and the current–voltage characteristics of the solar modules distributed in various places of the building shows multiple peaks and steps under the conditions of partial shading. Moreover, the schemes which are already available for maximum power extraction from distributed modules present in rooftop solar plants are not so efficient in these shaded conditions. Fig. 1 present below shows typical MPP curve.

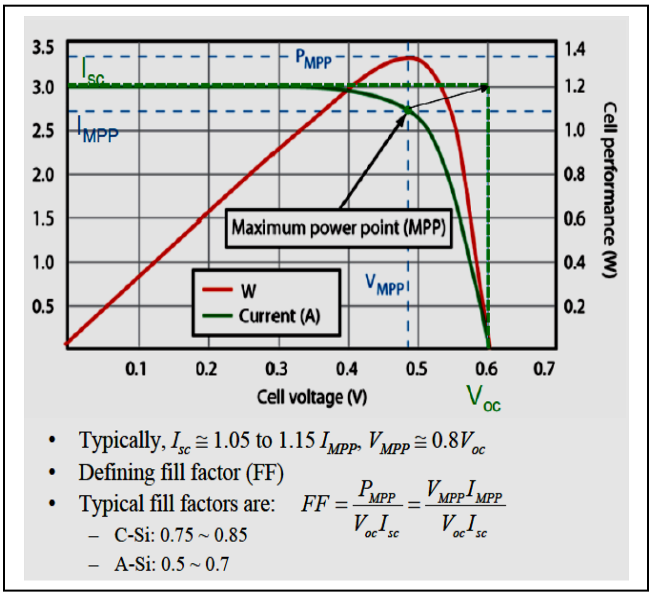

Fig. 1: Maximum Power Point (MPP) curve for typical solar PV modules [17]

A novel algorithm for global peak power extraction is formulated by Patel and Agarwal (2008) on the basis of various observation results like the behavior and characteristics of local and global peaks from the survey conducted under partial shaded conditions [6]. The proposed method uses feed forward (FF) control scheme for acceleration of GP tracking speed of dc-dc converter operation. This FF controller shifts the whole tracking operation towards MPP using the voltage reference information of the maximum power tracking algorithm. The main advantages lies here is that this FF controller takes very less tracking time which is only one-tenth as compared to the controllers used conventionally.

P–V characteristics of BIPV systems under partial shading becomes more complex and shows multiple peaks. Based on different parameters like temperature, solar insolation, configuration of PV module arrays etc the GP depicted from P–V characteristics varies from one point to another. Extensive study made from P–V and I–V characteristics during partial shaded condition of modules shows some salient features and critical observations. They are given as follows.

- Under the conditions of uniform solar insolation, this algorithm is very useful.
- Inexpensive microcontroller can be used for GP tracking from partially shaded BIPV modules. Thus, it is very simple and effective in terms of technology and economy.
- The proposed method does not involve the entire scanning of the *P–V* curve. Hence, time consumed in tracking is less.
- Using an external interrupt of the microcontroller present, additional remote supervisory control can be incorporated to the algorithm used in MPP tracking. This enables GP tracking for maximum power extraction from large BIPV systems whenever there is requirement.

Maximum power point tracking (MPPT) from distributed BIPV modules installed throughout the buildings can also be realized by calculation of the junction conductance and the instant conductance of the solar PV systems. Junction conductance being a function of PV array junction current is modeled by the use of adaptive neuro-fuzzy (ANFIS) technique [7]. Instantaneous conductance can be determined using the current and voltage of BIPV array module. It is difficult to measure cell temperature and solar radiation as it needs two more sensors which increases the measurement noise and makes the hardware circuit complex. So a denoising-based wavelet algorithm is used to estimate the analytical model. This proposed MPPT technique by Chikh and Chandra (2015) uses only a single voltage sensor in order to reduce the hardware setup and increases both the response time and array power efficiency. Moreover, this optimal method is also tested in various climatic and weather conditions. A mean MPPT error in efficiency of 2% is observed with a response time of 1.7 millisecond. Thus, this developed method can accurately perform maximum power extraction from BIPV module. It also has extremely less response time and ensures optimal operation with reduction in the hardware circuitry.

Remote communication technologies like the Web Services and Remote Panels of LabVIEW software is used for Maximum Power Point (MPP) tracking or extraction from solar PV systems. This proposed method by Bauer and Ionel (2013) undergoes complex control of instrumentation and monitoring of PV array [8]. Implementation of distance laboratory experiments and remote monitoring technologies for electrical characteristic analysis of PV module parameters is becoming a wide spread tool of educational institutions in the present scenario.

3. IoT and its Role in BIPV Systems

The term IoT or (Internet of Things) was coined in 1999 by Kelvin Ashton. Internet of Things (IoT) refers to smart objects or “things belonging to Internet” for exchanging information with the real world. In recent times, Internet of people is being shifted towards Internet of everything. In near future it can be anticipated that billions of devices will be connected to the internet [9]. This requires an efficient manageable system for sensing, monitoring, control and communicating with these objects and things.

3.1 Vision of IoT

The IoT vision is under development and varies from context, places, application areas, respective needs, interests, etc. Some general vision are as follows:

- Web level integration.
- Standardization for Interoperability.
- Anywhere, anytime, anything and anyone.

3.2 Architecture of IoT

IoT involves multidisciplinary fields of engineering and technology like microelectronics, computer science, sensors, wireless communication etc. Thus, we can divide the IoT architecture into layers. They are as follows:

- Layer of sensing the object (device or parameter).
- Layer of communication or data exchange.
- Layer of cloud platform or information integration.
- Layer of application service.

3.3 Applications of IoT

IoT is being increasingly used almost in each and every fields or domain nowadays . The real world applications of IoT are as follows but are not limited to:

- Industrial Internet enabling remote asset control.
- Wearable's like Smart watch, activity tracker, Smart glass, etc.

- Connected Systems like Connected health and Connected car.
- Smart Systems which include Smart grid, Smart home, Smart city, Smart retail, Smart supply chain and Smart farming.

The use of IoT for supervision of BIPV power generating systems significantly enhances the control, monitoring, maintenance and performances of the solar array modules. Use of advanced technologies for manufacturing of renewable energy equipments has resulted in the reduction of cost of PV modules. This encourages in the development of large solar plants and BIPV installations as shown in fig. 2.

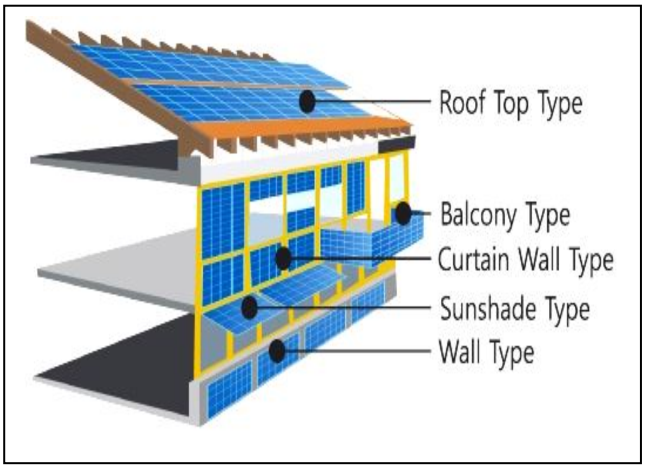

Fig. 2: Typical BIPV installations [18]

The large scale operation of BIPV systems require sophistication in automating the monitoring system of PV plant through web based interfaces. The major advantage lies here is that it can be remotely monitored and installed in inaccessible location likes facades of buildings.
A novel cost effective method for evaluating the performance of solar PV systems through remote monitoring is implemented by Adhya et al. (2016) [10]. This helps in fault detection, preventive maintenance and historical analysis of PV plant along with monitoring in real time. Energy efficiency of this particular IoT enabled remote monitoring system is significantly improved by the use of advanced low power wireless modules.
Implementation of an Power Conditioning Unit (PCU) for intelligently and effectively monitoring of solar Photovoltaic (PV) modules remotely in a greenhouse environment is proposed by Shrihariprasath and Rathinasabapathy (2016) [11]. This idea can be equally applied to BIPV systems as BIPV-PCU in order to mitigate problems like management of solar modules present in facades, rooftops, windows etc and also module maintenance in buildings. Hence the remote PCU decreases the total repairing time. Remote monitoring of BIPV-PCU can be done via internet using host, embedded system gateway, network of Global Positioning Radio Service (GPRS) and other related components. In solar BIPV-PCU systems, real time data can be monitored, controlled and stored making the overall maximum power extraction from BIPV systems very smart and effective.
A reliable method for managing solar PV plants which generates dc power is proposed by Ilias et al. (2016). In this method a programmable microcontroller is used which communicates via an RS232 link with the user interface and enables SMS based remote controlling of PV systems [12]. GSM modem is used for communicating the operator and the system through SMS. In real time, various alerts is sent via SMS like start, stop, any malfunction, transfer of system data like dc power, voltage, current etc. This technique can be implemented as BIPV-SMS alert systems.

4. IoT Enabled BIPV (IoT-eBIPV) Modules for Extracting Maximum Power

In electrical energy generation from renewable resources like BIPV system, a major concern is maximum power extraction from PV modules. In this regard, IoT is an important solution for allowing BIPV modules to generate maximum power making the PV modules efficient and smart. Thus, IoT enabled BIPV (IoT-eBIPV) systems have the potential to form smart BIPV modules. The IoT-eBIPV prototype is shown in fig. 3 below.

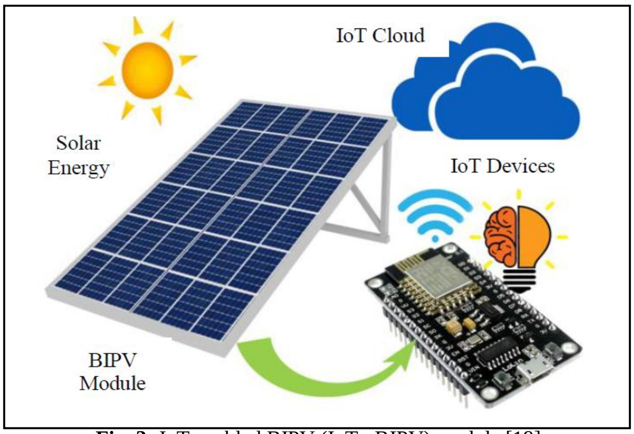

Fig. 3: IoT enabled BIPV (IoT-eBIPV) module [19]

Xiaoli and Daoe (2011) in their research work implements the instrumentation and design details of smart photovoltaic modules. The overall system consists of a software and a wireless sensor network for sensing and control of PV module in real-time with maximum power point tracking option [13]. The major parameters like temperature, solar irradiance, current and voltage for determining PV field conditions are monitored in this proposed system. At a base station, sensor data is sampled periodically and transmitted. An integrated DC-DC converter can be used to control the maximum power point (MPP). A digital controller regulates the converter output voltage. A neural network model is used for reference voltage calculation, which is used for identifying the MPP. A low-cost ZigBee based wireless network for successful transmission of communication data for distributed control and remote monitoring is used. Stable remote access and real-time control of MPP in smart PV systems can be achieved using the developed web based software.
Energy generation from sun requires efficient management and monitoring systems and is moving towards BIPV technology for development of net zero energy buildings. A dependable control system within a micro-grid based on IoT for managing and controlling dc power extraction by solar panels is proposed by Phung et al. (2017). This proposed system not only optimally controls data from local sensor measurement but also retrieves meteorological information from online sources in real-time. The distributed control system features multiple controllers for fault tolerance in PV systems. To optimize and control the tracking performance of PV arrays to capture solar radiation maximally, dependable controllers are developed [14]. Thus, the proposed system maintains system reliability and flexibility in real-time inspite of controller failure due to a problem with hardware, communication, cybersecurity or hardware. Validity of this approach is evaluated through experimental results. Some already installed rooftop BIPV projects are presented in Table I.

Table 1: Some Rooftop BIPV Installation Projects (1MW & above)

Project Name	Project Details		
	Location	**Country**	**Nominal Power (MW_p)**
Shanghai No.1/2 Metro	Hongqiao railway station, Shanghai	China	6.68

Project Name	Project Details		
	Location	Country	Nominal Power (MW_p)
Operation Co. Ltd.copy			
Sharp	Kameyama	Japan	5.1
Sonnenfleck-tts-Bürstadt	Bürstadt, Hessen	Germany	5
Hartmann AG	Muggensturm, Baden-Württemberg	Germany	3.84
The Shenergy Group	Shanghai World Expo, Shanghai	China	3.12

Chieochan et al. (2017) develops a small prototype of off-grid solar cell system for providing renewable power to a smart mushroom farm. The proposed method uses IoT with current and voltage sensors for monitoring and measuring the charging current and voltage from the PV module into a battery and the current supplied from the battery to irrigation systems consisting of fogs and sprinkler pumps [15]. Development of an IoT cloud service was made for processing current and voltage data through Blynk which stores real-time data and displays in mobile devices. The Blynk application enables functional status notifications like on and off switching periods, current consumption through Blynk IoT cloud. This proposed method uses tools and equipment like voltage and current sensors, relay modules, NodeMCU, fog pumps and DC sprinkler. IoT along with current and voltage sensors encourages the smart farming prototype as an alternative and clean resource of electrical power production.

Rooftop solar PV systems for feeding domestic loads in house is being increasingly used in the society recently. Sometimes or the other these expensive PV modules stops working due to external damages and gets unnoticed by the user. So there is a requirement of cost effective monitoring system for getting information of defective solar panels for maintenance and repair. Ranhotigamage and Mukhopadhyay (2011) proposes the development, design, and trial work of distributed solar PV panel performance monitoring system. It is equipped with low- cost wireless sensor network (WSN) with automatic data logging features [16]. The proposed system can be used up to the voltage range of 146 V and the current range of 15.5 A. This system can be equally applied to BIPV modules as well as wide range of solar PV systems for developmental activities and material research. This fabricated system can also be used for obtaining satisfactory results from field trials.

5. Conclusion

In this paper, a detailed review from previous research work based on solar MPPT systems and IoT applications in PV systems is effectively presented. Moreover, the role of IoT in maximum power extraction from BIPV module is also explored in a systematic way. Hence the IoT enabled BIPV (IoT-eBIPV) prototype can be proficiently implemented to conventional BIPV modules for extraction of maximum dc power very efficiently, resulting in the development of smart zero energy buildings. The conclusions drawn from this critical study are as follows:

- IoT reduces human intervention like visiting PV plant sites, recording performance data manually, fault monitoring by deployment of maintenance personnel etc and increases reliable & secure interaction with internet connected devices for fast, cost effective and smart monitoring of BIPV systems.
- Use of IoT mitigates the problem of shading, module defects, tilt angles etc and enables maximum power extraction from BIPV modules without much hard work and complexity.
- IoT facilitates the continuous recording of data from performance and failure statistics and thus helps in further analysis for prediction and forecast of future power generating potential from BIPV systems.
- The application of IoT technology plays a significant role in the complete control of BIPV modules that are installed in remote places & inaccessible building locations from the central base station through both wired & wireless communication networks.

6. Acknowledgement

Authors are thankful to Indian Institute of Technology (Indian School of Mines) Dhanbad, for giving the financial and moral support to carry out this research work.

References

[1] M. Tripathy and P. K. Sadhu, "Building Integrated Photovoltaic Market trend and its Applications", TELKOMNIKA Indonesian Journal of Electrical Engineering, vol. 14, no. 2, pp. 185-190, May 2015. https://doi.org/10.11591/telkomnika.v14i2.7338.
[2] R. Al-Ali, "Internet of Things Role in the Renewable Energy Resources," 3rd International Conference on Power and Energy Systems Engineering (CPESE 2016), pp. 34-38, September 2016. https://doi.org/10.1016/j.egypro.2016.10.144.
[3] Khajenasiri, A. Estebsari, M. Verhelst, and G. Gielen, "A Review on Internet of Things Solutions for Intelligent Energy Control in Buildings for Smart City Applications," 8th International Conference on Sustainability in Energy and Buildings (SEB 2016), pp. 770-779, September 2016.
[4] https://doi.org/10.1016/j.egypro.2017.03.239.
[5] M. A. Ahmed and Y. C. Kim, "Communication Networks of Domestic Small-Scale Renewable Energy Systems," 4th International Conference on Intelligent Systems, Modelling and Simulation (ISMS 2013), pp. 513-518, January 2013.
[6] https://doi.org/10.1109/ISMS.2013.21.
[7] O. B. BELGHITH and L. SBITA, "Remote GSM module monitoring and Photovoltaic System control," First International Conference on Green Energy (ICGE 2014), pp. 188-192, March 2014. https://doi.org/10.1109/ICGE.2014.6835420.
[8] H. Patel and V. Agarwal, "Maximum Power Point Tracking Scheme for PV Systems Operating Under Partially Shaded Conditions," IEEE Transactions on Industrial Electronics, vol. 55, no. 4, pp. 1689-1698, April 2008.
[9] https://doi.org/10.1109/TIE.2008.917118.
[10] Chikh and A. Chandra, "An Optimal Maximum Power Point Tracking Algorithm for PV Systems With Climatic Parameters Estimation," IEEE Transactions on Sustainable Energy, vol. 6, no. 2, pp. 644-652, April 2015.
[11] https://doi.org/10.1109/TSTE.2015.2403845.
[12] P. Bauer and R. Ionel, "LabVIEW Remote Panels and Web Services in Solar Energy Experiment – A Comparative Evaluation," 8th IEEE International Symposium on Applied Computational Intelligence and Informatics (SACI 2013), pp. 263-268, May 2013. https://doi.org/10.1109/SACI.2013.6608979.
[13] N. Shahid and S. Aneja, "Internet of Things: Vision, Application Areas and Research Challenges," International conference on IoT in Social, Mobile, Analytics and Cloud (I-SMAC 2017), pp. 583-5 87, February 2017.https://doi.org/10.1109/I-SMAC.2017. 8058246.
[14] S. Adhya, D. Saha, A. Das, J. Jana, and H. Saha, "An IoT Based Smart Solar Photovoltaic Remote Monitoring and Control unit," 2nd International Conference on Control, Instrumentation, Energy & Communication (CIEC 2016), pp. 432-436, January 2016. https://doi.org/10.1109/CIEC.2016.7513793.
[15] B. Shrihariprasath and V. Rathinasabapathy, "A Smart IoT System For Monitoring Solar PV Power Conditioning Unit, " World Conference on Futuristic Trends in Research and Innovation for Social Welfare (WCFTR 2016), pp. 1-5, March 2016.
[16] https://doi.org/10.1109/STARTUP.2016.7583930.
[17] Ilias, M. Mustapha, K. Khalil, and H. Kamal, "Remote Control and monitoring of photovoltaic installations equipped with MPPT control," International Conference on Electrical Sciences and Technologies in Maghreb (CISTEM 2016), pp. 1-6, October 2016. https://doi.org/10.1109/CISTEM.2016.8066797.
[18] X. Xiaoli and Q. Daoe, "Remote Monitoring and Control of Photovoltaic System Using Wireless Sensor Network," International Conference on Electric Information and Control Engineering (ICEICE 2011), pp. 1-6, April 2011.
[19] https://doi.org/10.1109/ICEICE.2011.5778367.
[20] M. D. Phung, M. D. L. Villefromoy, and Q. Ha, "Management of Solar Energy in Microgrids Using IoT-Based Dependable Control,"

20th International Conference on Electrical Machines and Systems (ICEMS 2017), pp. 1-6, August 2017.
[21] https://doi.org/10.1109/ICEMS.2017.8056441.
[22] O. Chieochan, A. Saokaew, and E. Boonchieng, "Internet of things (IOT) for smart solar energy: A case study of the smart farm at Maejo University," International Conference on Control, Automation and Information Sciences (ICCAIS 2017), pp. 262-267, November 2017. https://doi.org/10.1109/ICCAIS.2017.8217588.
[23] C. Ranhotigamage and S. C. Mukhopadhyay, "Field Trials and Performance Monitoring of Distributed Solar Panels Using a Low-Cost Wireless Sensors Network for Domestic Applications," IEEE Sensors Journal, vol. 11, no. 10, pp. 2583-2590, October 2011. . https://doi.org/10.1109/JSEN.2011.2150214.
[24] Available online at: <https://www.feec.ece.vt.edu/>
[25] Available online at: <http://www.s-
[26] energy.com/epage.php?it_id=1426727258>
[27] Available online at:
[28] <https://transmitter.ieee.org/makerproject/view/35d15>
[29] Available online at:
[30] <https://en.wikipedia.org/wiki/List_of_rooftop_photovoltaic_installations>