International Journal of Trend in Research and Development, Volume 9(1), ISSN: 2394-9333
www.ijtrd.com

To Study and Review of Solar Energy and its Various Applications in the Field of Internet of Things

Shyam Gupta
Shri Guru Sandipani Institute of Technology & Science, Ujjain, India

***Abstract*—**There are various applications of Solar energy harvesting in the field of Internet of Things (IoT).This paper will describe, analyze and review the key technologies in solar energy harvesting systems. Comparing the characteristics of several typical DC-DC converters, charge pump, especially, kinds of reconfigurable charge pump are designed to decrease the voltage gain discrete and extend conversion ratio matching for MPPT techniques. Besides, This paper also describe various MPPT techniques which shows evolution from 1-D MPPT to 3-D MPPT. Multi-batteries storing the unstable and discontinuous energy has been paid more attention in energy harvesting systems. Modelling solar cell by ANN technique is prospected in later research in the field of milliwatt solar energy harvesting.

Keywords- *Solar Energy Harvesting; Charge Pump; MPPT; Energy Storage; ANN Model*

I. INTRODUCTION

With the fast improvement of wearable clever devices, implantable clinical devices, environmental tracking systems, clever domestic and different fields, the internet-of-things (IoT) were broadly utilized in those devices. In traditional way, IoT programs are normally powered via way of means of batteries. However, the batteries have the risks of bulky, constrained life, problem of ordinary alternative and pollutants of the environment, that rarely suit the necessities of providing the small volumes and complex distributions of the IoT programs. In this circumstance, power harvesting generation is taking interest as a electricity answer for the low electricity IoT programs. Harvesting power from ambient reassets like, vibration, sun radiation, thermal gradient or radio frequency waves, has come to be an appealing and promising choice for powering an IoT node [1], [2]. Due to excessive electricity density and ubiquitous nature of light, sun power is extensively favored over different power reassets for powering an IoT node. Solar power harvesting era has been evolved swiftly over the past many years from offering area application to human beings day by day activities. The conversion performance of the photovoltaic (PV) panel is the important thing of sun power harvesting. Kinds of most electricity factor tracking (MPPT) strategies had been proposed to transform greater sun power to digital power. Because the enter voltage from PV is risky, the layout of DC-DC converter for sun power harvesting is different era hotspot. Moreover, due to the risky and discontinuous feature for the power of the ambient power reassets, power garage is likewise essential. Fig. 1 suggests the standard shape of a sun power harvesting system. This paper overviews the DC-DC converter technologies for solar energy harvesting for IoT applications in section II firstly. Then, section III discusses the MPPT techniques. Charger technologies for energy storage are reviewed in section IV. Section V prophesies the future research hotspot of solar energy harvesting. Summary and conclusion are presented in the last section VI.

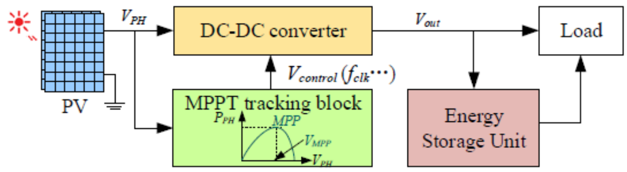

Figure 1. Typical structure of a solar energy harvesting system.

II. OVERVIEW OF DC-DC CONVERTERS FOR SOLAR ENERGY HARVESTING

In order to transform the risky input voltage to a strong desirability voltage, DC-DC converter is a important unit in a sun power harvesting system. The DC-DC converter may be carried out via way of means of low-dropout (LDO) voltage regulator [3], inductor-primarily based totally transfer converter [2], [4], [5], and switched capacitor converter (fee pump, CP) [6], [7]. There is such a stability among the ones 3 converters: (1) LDO has the gain of small area, excessive degree of integration, however its performance is set 80% or even decrease with better input to output dropout voltage; (2) inductor-primarily based totally converter is greater typically used at excessive cutting-edge stages with approximately 95% efficiency, however it can't be included properly for a cumbersome off-chip inductor; (3) CPs have excessive performance at low cutting-edge stages and may be completely included in widespread CMOS processes, however its converter benefit is discrete and the output voltage ripple ΔVout is a bit large.

Table 1: Comparison Of The Characteristics Of Dc-Dc Converters

Characteristics	LDO	Inductor-based switch converter	Charge pump
Type of convert	$V_{in} > V_{out}$	$V_{in} > V_{out}$ or $V_{in} < V_{out}$	$V_{in} > V_{out}$ or $V_{in} < V_{out}$
Efficiency	middle	very high	high
Load capacity	middle	high	middle
ΔV_{out}	very small	small	middle - large
EMI	very low	higher	low
Integration Difficulty	very easy	difficult	easy
Complexity of design	low	middle ~ high	middle - high
Cost	low	middle	low - middle

Table 1 lists the evaluation of the traits of DC-DC converters. Actually, for a few ultra-low strength power harvesting systems, for example, startup from 70 mV in [2], changing power from solar cells from 0.38V input voltage in [4], and harvesting voltage of 220 mV in [5], the input voltage of the DC-DC converter VPH is just too low to pressure a MOS tool withinside the power harvesting chips. The fee pump (CP) is typically used as a self-startup block to reinforce very low

VPH to a appropriate running voltage to make inductor-primarily based totally converter work.Combing CP and inductor-based converter to convert the unstable solar energy to a stable electronic energy is complex. Hence, CP designed as a single DC-DC converter in the energy harvesting system is another solution which can reduce the complexity of the system.

Many literatures consider the design of CPs for solar energy harvesting applications for two reasons: (1) it is easier to integrate than inductor-based switch converter; (2) the equivalent impedance of CP Rcp can be changed by adjusting the frequency, conversion ratio, capacitance and width of switch MOS devices so as to track the maximum power point (MPP) of the solar cell. However the discrete gain leads to a narrow input voltage range when a regulated output voltage is needed. Fortunately, reconfigurable CP is concerned by researchers [7]-[9] to extend conversion ratio and achieve impedance matching for MPPT techniques. A CP with a conversion rate of 7 and another with a conversion rate of 8 are presented in [7] and [8] respectively, which can operate over a wide input voltage range. But their efficiency is not high when load current is as high as hundreds of microamps. Reference [9] describes a reconfigurable CP with 14 conversion ratios whose efficiency achieves to 89%. On the other hand, the implementation of the reconfigurable CP in [9] is complex.

III. COMPARISON OF MAXIMUM POWER POINT TRACKING TECHNIQUES

A. Review on MPPT techniques for excessive electricity solar device A huge quantity of studies has positioned the focal point at the MPPT strategies for excessive electricity sun device so far [10], including sun heaters, sun road lamps. Meanwhile, accuracy, value and velocity of MPPT need to be taken into consideration properly. Due to the gain of excessive accuracy, a great deal studies's awareness has been on hill mountain climbing, and perturb and observe (P&O) techniques [11]. However, hill mountain climbing and P&O techniques could fail while the solar situations alternate rapidly due to their low monitoring velocity. Incremental conductance (IncCond) [12] approach is primarily based totally at the reality the slope of the PV array electricity curve is 0 on the MPP, superb at the left of the MPP, and terrible at the right, and this approach can simplest discover the nearby most electricity factor. Since the reality that there exist a near-linear dating among most electricity factor voltage (VMPP) and open circuit voltage (VOC) has been given upward thrust to the fractional VOC approach [13], it's miles very smooth and reasonably-priced to put into effect because it does now no longer necessarily require DSP or microcontroller manipulate, however this approach has the drawback of very low accuracy. Microcontrollers have made the use of fuzzy common sense manipulate [14] famous for MPPT during the last decade. Along with fuzzy common sense controllers got here some other method of imposing MPPT---- neural networks [15], which might be additionally properly tailored for microcontrollers, model, and coping with nonlinearity. Since maximum PV arrays have distinctive traits, a neural community must be specially skilled for the PV array with which it is going to be used. The traits of a PV array additionally alternate with time, implying that the neural community must be periodically skilled to assure correct MPPT. B. Maintaining the Integrity of the Specifications Unlike excessive-electricity sun systems, MPPT strategies for sun electricity harvesting in IoT packages have extra restrictions. On account of the controller ingesting part of electricity of electricity from the harvester, the MPPT need to have roles inside an electricity harvesting systems: (1) ensuring to maximise the scavenged electricity from the harvester. (2) controlling DC-DC converter to maximise the transformed quantity of electricity harvested on the enter to the output. Therefore, maximum of MPPT strategies for excessive electricity sun device aren't appropriate and area-saving switched-capacitor primarily based totally converter will become the maximum accurate choice. At the identical time thinking about the call for of low value, hill mountain climbing approach is maximum broadly used for low electricity sun electricity harvesting in IoT packages. As a warm spot, the hill mountain climbing approach makes use of conversion ratio modulation (CRM), switching frequency modulation (SFM) and transfer width modulation (SWM) strategies to music the MPPs. The 1-D MPPT method became followed in [16] via way of means of tuning the capacitor values. Though they could collect excessive performance, they value a huge area. The 2-D MPPT in [9], [16] hired CRM and SFM. However, because the output load is going beneath 1 μA, the electricity performance decreases to much less than 50%. The 3-d MPPT became proposed in [17] with the assist of a unique Vgs-based transfer width modulation (SWM) method in conjunction with the SFM and CRM. All the ones hill mountain climbing techniques have the power of excessive performance however nonetheless have the negative aspects of sluggish convergence velocity and complicated manipulate circuits. Reference [18] presents a low-overhead MPPT algorithm based on the negative feedback control loop first time, which eliminates the power hungry current/voltage sensor and other complex control circuit. For any given light irradiance, the relationship between VPH and fclk is modeled by equation (1), as shown in Fig. 2, where C is the capacitance used in each stage, β is the CP loss factor. The curve Light1 and the curve Light2 are two different conditions.

$$f_{clk} = \frac{I_{sat}\left(e^{\frac{q}{AKT}(V_{OC})} - e^{\frac{q}{AKT}(V_{PH})}\right)}{NC(NV_{PH} - V_{out})/(N-1) + \beta}$$

When the system is operating at MPP, the corresponding optimal frequency can be rewritten by (2), as shown in Fig. 2, where α is the ratio (VMPP /VOC). The points in the dotted line are the maximum power points when the light irradiance varies.

$$f_{MPP} = \frac{I_{sat}\left(e^{\frac{q}{\alpha AKT}V_{MPP}} - e^{\frac{q}{AKT}V_{MPP}}\right)}{NC(NV_{PH} - V_{EB})/(N-1) + \beta}$$

Once closed loop operation starts, the only stable state that satisfies both equations (1) and (2) is the intersection point of the two curves. The critical thing to ensure they can intersect is designing a suitable voltage-controlled oscillator (VCO) to generate a switching frequency and its V-f relationship is close to equation (2).

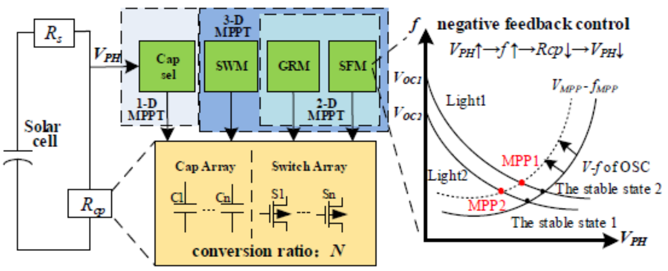

Figure 2. Review on MPPT techniques for solar energy harvesting. A small amount of literature has taken the effort to design the special oscillator, a polynomial VCO was employed in [18]. Reference [18] has a very limited tracking range as the frequency of polynomial VCO is uncontrolled at a certain voltage. Reference [19] employs a CS-VCO instead of a polynomial VCO to improve the tracking range, which is able to track the maximum power point successfully with a tracking error of 0.1-0.6%. Reference [20] employs an oscillator with an exponential relationship between the VPH and fclk and the charge pump switching frequency fclk by

subtracting the Vgs of two sub-threshold-region transistors. By reason that no trace is required and they avoid extra hardware such as an integrator, current sensor, and microcontroller, those low-overhead MPPT techniques take few microsecond to track MPP and power consumed is very low. However, those methods are suitable for customized design and designers should design the special oscillator during pre-simulation carefully.

IV. CHARGER TECHNIQUES FOR ENERGY STORAGE

A complete energy harvesting system involves the collection, storage and use of energy. The long-term stable operation of the system relies on continuous energy [21]. However, the source of micro-energy is extremely unstable, so the only use of DC-DC converter will further lead to energy waste or insufficient. Energy storage unit is responsible for storing the excess portion of the input energy and acting as a supplemental energy source for the system when input energy is scarce. For the design of the energy storage unit, it is necessary to consider the system stability and energy utilization, in addition to the characteristics of the energy storage element.

From the point of view of the choice of energy storage components, the structure of super capacitor alone is the simplest, and no additional control circuit is needed. It can directly store the input electrical energy or directly supply power to the device, However the energy storage capacity of super capacitor is limited unless extra-large volume. Lithium battery, with higher energy density, is used as the energy storage component in many applications which can ensure long-term stable operation of the system. While, in order to protect the lithium battery from prolonging its service life, it is necessary to introduce a voltage protection module to prevent permanent damage of the lithium battery caused by excessive voltage or deep discharge. In addition, if the lithium battery life is further improved, the charging process needs to be controlled, for example, following a constant current - constant voltage charging rules. In order to improve system stability, super capacitors and lithium batteries can be used as energy storage units at the same time [22]. Super capacitors can be deeply discharged, which is very suitable for temporary storage of electric energy. Lithium is used as a backup energy source for the system long-term stable operation. Considering more complicated energy requirements, it can adopt the masterslave battery scheme, which needs a large capacity battery, a small capacity auxiliary battery and a control circuit [23]. In addition, if there are multiple energy sources, because there are differences between the energy sources, not only the difference in time, but also the power density is very different. Then there are cases where the output voltages of the two energy sources are inconsistent. In this case, the current direction must be considered. The problem is the current reversal will not only interfere with the normal operation of the pre-stage circuit of the energy storage unit, but will seriously damage the pre-stage circuit. This phenomenon is not allowed, so it is necessary to design a current antibackflow system to avoid this situation, such as the unidirectional conduction device [24]. Furthermore, the converter can operate in a time-multiplexed manner, two switches isolate two input sources and avoid interactions[25].

V. PROSPECT OF SOLAR ENERGY ARVESTING IN IOT APPLICATIONS USING AI TECHNIQUES

In references [18]-[20] as mentioned above, the simplified single-diode model is most frequently used to represent the actual solar cell. During designing the MPPT circuit, designers don’t have the real input of the actual solar cell but the rough equivalent circuits. As a result, the correctness of the new energy harvesting method cannot be verified accurately. Moreover, it becomes difficult to simulate various light irradiance. In recent years, artificial intelligence (AI) technology has been greatly developed in many fields. Just like the analysis of the section II, AI techniques like fuzzy logic controlling and neural network cannot be utilized in MPPT directly. Nevertheless, as a nonlinear computing tool, neural network can be utilized reasonably. Reference [26] uses artificial neural network (ANN) models and polynomial curve fitting models to simulate solar energy output. ANNs will have the best performance if large amounts of data are available. For the prediction of the full range, the polynomial curve fitting model shows the best result. Hence, ANN techniques to model solar cell will be a good way to solve the accurate design of solar energy harvesting in IoT applications.

CONCLUSION

Review on solar energy harvesting techniques for IoT applications is summarized in this paper, including DC-DC converting, MPPT techniques, and energy storage methods. CP is preferred among the several DC-DC converters because of its high efficiency and good integration. Reconfigurable CPs can improve the continuity of output voltage of DC-DC converter, extend conversion ratio and achieve impedance matching for MPPT techniques, which are widely using in milliwatt energy harvesting system. MPPT techniques have been already developed from 1-D MPPT with only tuning capacitor values to 3-D MPPT employed SWM, CRM and SFM, which makes MPP tracking accurately and flexibly.

Adopting super capacitors and lithium batteries in one energy storage unit at the same time is a tendency to improve energy harvesting system stability. Different combinations of different input energy sources and load requirements should pay more attention in the future design of charger, as well as the corresponding protection circuit. ANN techniques to model solar cell will be good auxiliary to accurately and quickly design for solar energy harvesting systems.

References

[1] M. Dezyani, H. Ghafoorifard, S. Sheikhaei and W. A. Serdijn, “A 60 mV input voltage, process tolerant start-up system for thermo- electric energy harvesting,” IEEE Transactions on Circuits and Systems I:Regular Papers, pp.1–10, June 2018.

[2] Chien-Yi Wu;Jen-Chung Lou; Zhi-Bing Deng. “An ultra-low power capacitor-less LDO for always-on domain in NB-IoT applications”. 2018 IEEE International Conference on Applied System Invention (ICASI). pp.137–140, April 2018.

[3] J. Goeppert and Y. Manoli, “Fully integrated startup at 70 mV of boost converters for thermoelectric energy harvesting,” IEEE J. Solid-State Circuits, vol. 51, no. 7, pp. 1716–1726, July 2016.

[4] A. Shrivastava, Y. K. Ramadass, S. Khanna, S. Bartling, and B. H. Calhoun, “A 1.2 µW SIMO energy harvesting and power management unit with constant peak inductor current control achieving 83–92% efficiency across wide input and output voltages,” in Symp. VLSI Circuits Dig. Tech. Papers, pp. 1–2, June 2014,.

[5] A. Das, Y. Gao, and T. T.-H. Kim, “A 76% efficiency boost converter with 220 mV self-startup and 2 nW quiescent power for high resistance thermo-electric energy harvesting,” in Proc. Conf. 41st Eur. Solid-State Circuits Conf. (ESSCIRC), pp. 237–240, Sep 2015.

[6] X. Liu and E. Sanchez-Sinencio, “A single-cycle MPPT charge-pump energy harvester using a thyristor-based VCO without storage capacitor,” in Proc. IEEE Int. Solid-State Circuits Conf. (ISSCC), pp.364–365, Jan. 2016.

[7] Wang Y, Luo P, Zheng X, et al. “A 0.3V–1.2V ultra-low input voltage, reconfigurable switched-capacitor DC-DC converter for energy harvesting system,” IEEE International Conference on Solid-State and Integrated Circuit Technology, pp.1333–1335, Oct. 2016.

[8] Saadat M, Murmann B. “A 0.6 V–2.4 V input, fully integrated reconfigurable switched-capacitor DC-DC converter for energy harvesting sensor tags,” IEEE Asian Solid-State Circuits Conference (ASSCC). pp.1–4. 9-11 Nov. 2015.

[9] X. Liu, L. Huang, K. Ravichandran, and E. Sánchez-Sinencio, “A highly efficient reconfigurable charge pump energy harvester with wide harvesting range and two-dimensional MPPT for Internet of Things,” IEEE J. Solid-State Circuits, vol. 51, no. 5, pp. 1302–1312, May 2016

[10] Viswambaran V K, Ghani A, Zhou E. “Modelling and simulation of maximum power point tracking algorithms & review of MPPT techniques for PV applications,” IEEE International Conference on Electronic Devices, Systems and Applications, pp.1–4. 6-8 Dec. 2016.

[11] Elgendy M A, Zahawi B, Atkinson D J. “Evaluation of perturb and observe MPPT algorithm implementation techniques,” IET International Conference on Power Electronics, Machines and Drives. pp.1–6. 27-29 March. 2012.

[12] Safari A, Mekhilef S. “Incremental conductance MPPT method for PV systems,” IEEE Electrical and Computer Engineering, pp. 345–347. 8- 11 May, 2011.

[13] Simjee F, Sharma D, Chou P H. “Everlast: long-life, supercapacitoroperated wireless sensor node,” IEEE International Symposium on Low Power Electronics and Design, pp. 197–202. 24-26 March 2015.

[14] Ziouh A, Abbou A. “Comparison of two MPPT methods fuzzy logic and ripple correlation control for the application of LED lighting supplied by photovoltaic panels grid,” International Renewable and Sustainable Energy Conference. pp.492–498, 4-6 Oct. 2006.

[15] Messalti S, Harrag A G, Loukriz A E. “A new neural networks MPPT controller for PV systems,” IEEE Renewable Energy Congress, pp. 1– 6. 24-26 March 2015.

[16] X. Liu and E. Sánchez-Sinencio, “An 86% efficiency 12 µW selfsustaining PV energy harvesting system with hysteresis regulation and time-domain MPPT for IOT smart nodes,” IEEE J. Solid-State Circuits, vol. 50, no. 6, pp. 1424–1437, Jun. 2015.

[17] Rawy K, Yoo T, Kim T H. “An 88% efficiency 0.1-300-µW energy harvesting system with 3-D MPPT using switch width modulation for IoT smart nodes,” IEEE Journal of Solid-State Circuits, pp.1–12, 22 May 2018.

[18] C. Lu, S. P. Park, V. Raghunathan, and K. Roy, “Low-overhead maximum power point tracking for micro-scale solar energy harvesting systems,” in 25th Int. Conf. on VLSI Design, pp. 215–220, Jan 2012.

[19] Mondal S, Paily R. “On-chip photovoltaic power harvesting system with low-overhead adaptive MPPT for IoT nodes,” IEEE Internet of Things Journal, vol. 4, no. 5, pp.1624–1633, April, 2017.

[20] Eltaliawy A, Mostafa H, Ismail Y. “Microscale solar energy harvesting for wireless sensor networks based on exponential maximum power locking technique,” IEEE, International Conference on Electronics, Circuits, and Systems, pp. 889–892. 8-11 Dec. 2013.

[21] D. El-Damak and A. P. Chandrakasan, “A 10 nW–1 µW power management IC with integrated battery management and self-startup for energy harvesting applications,” IEEE Journal of Solid-State Circuits, vol. 51, no. 4, pp. 943–954, April 2016.

[22] Q. Wang, C. Shen, K. Zhang and L. Zheng, “Super-capacitor and Lipolymer battery hybrid energy storage for kinetic energy harvesting applications,” 2017 IEEE Conference on Energy Conversion (CENCON), Kuala Lumpur, pp. 73–77, 30-31 Oct. 2017.

[23] Lueangamornsiri, Thanyanut, et al. “Design and development of a stand-alone solar energy harvesting system by MPPT and quick battery charging,” IEEE International Conference on Electrical Engineering/ electronics, Computer, Telecommunications and Information Technology, pp.1–5. 28 June - 1 July 2016.

[24] Habibzadeh, Mohamadhadi, et al. “Supercapacitor-based embedded hybrid solar/wind harvesting system architectures,” IEEE International System-On-Chip Conference IEEE, pp.215–220, 5-8 Sept. 2017.

[25] C. Shi, B. Miller, K. Mayaram and T. Fiez, "A Multiple-Input Boost Converter for Low-Power Energy Harvesting," in IEEE Transactions on Circuits and Systems II: Express Briefs, vol. 58, no. 12, pp. 827-831, Dec. 2011.

[26] Ma X, Bader S, Oelmann B. “Solar panel modelling for low illuminance indoor conditions,” Nordic Circuits and Systems Conference. IEEE, pp. 1–6. 1-2 Nov. 2016.