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Research Paper

Standalone solar streetlamp sharing an interactive buck-boost converter

Jin-Wook Park [1]*, Yeo-seo hyun [1], Ho-Yun Soen [1], Seong-Mi Park [1], Sung-Jun Park [1], Gwang-Heon Kim [1]

[1] *Department of Electrical Engineering, Chonnam National University, 77, Yongbong-ro, Buk-gu, Gwangju, 61186, Republic of Korea*
**Corresponding author E-mail: 1hebojago@naver.com*

Abstract

Background/Objectives: Typically, the stand-alone solar streetlight system is used independently of DC/DC converter for battery charging and for LED lighting control. Such an independent power conversion system uses a DC/DC converter with only a voltage raising or reducing function for cost reduction (power semiconductor, inductor, capacitor, etc.). However, these DC/DC converters have limitations on efficiency increase in all voltage ranges when controlling MPPT. In addition, DC/DC converters for LED lighting have limitations in the design of the lighting voltage because the LED lighting operates only at voltages lower or higher than the battery voltage. Therefore, In this paper, a new power conversion system using a DC/DC converter for battery charging and for streetlight using a bi-directional buck and boost DC/DC converter.
Methods/Statistical analysis: A prototype was fabricated and tested. The used equipment was a Tektronix oscilloscope, 24V (Lead-Acid) Battery, PV Simulator (ETS 1000X10D PVF_Sorensen) and WT 3000 (YOKOGAWA).
Findings: By using a shared converter, cost savings were achieved by reducing the number of power semiconductor devices and the number of inductors and capacitors. In addition, it works as an input / output step-down converter to compensate the voltage design limit.
Improvements/Applications: In <30 words.

Keywords: *Solar Converters; LED Drivers; DCDC Converters; Renewable Energy; Battery Charger*

1. Introduction

Recently, electrical grid using solar photovoltaic power receives attention for prevention of the global warming and the exhaustion of resources. The independent streetlight including solar panel is representative system of new regeneration energy.
For operating of independent streetlight including solar panel, there must be function of time-shift to save the energy during daytime and to use that at night. battery which can save electrical energy is used for this function. The system using battery is really necessary for next generation industry because this system is convenient, efficient and economical. Furthermore, the need of this system is much growing [1-3].
LED is getting the spotlight as a light of new generation and the market of LED has comprised widely such as display, back-light, general light, etc. Especially, LED is outstanding as light so lots of vendors who want to dominate the market are conducting to aim at realizing low price and high efficiency [4-7].
The representative system using solar panel, battery and LED light is independent streetlight including solar panel. The figure of this light is that it charged the energy made by the solar panel to the battery in the daytime and it discharged the energy at night. Therefore, this system need the power converter able to manage power supply for operating of LED light and the charge and discharge of the battery [8-10].
In the general system of independent streetlight using solar panel, DC/DC converter for each battery charging and DC/DC converter for control of LED light are separately used. In these method, DC/DC converter which only can boost the voltage or only can reduce the voltage is used for reducing of the unit cost. However, the battery charger can't do MPPT (Maximum Power Point Tracking) in the wide range of voltage and there is the limitation of efficiency enhancement. In DC/DC converter for LED light, the power converter is only used in lower voltage than the voltage of LED light or higher voltage than that. Thus, there is restriction on deciding the voltage of light.
Therefore, this paper proposes the new system of power converting using singular duplex buck-boost DC/DC converter. The reason why this converter is singular is that these two abilities of charging battery and turning on LED light are operated individually. And the proposed power converting system can reduce the number of semiconductor device. Also, it has reduced the price of unit cost by sharing one inductor to two types of converter. This power converting system can track maximum power point in every range of voltage during charging the battery. And the existing problem is solved by using buck-boost converter possible for control of LED light.

2. The independent power converter for solar photovoltaic

2.1. The existing converter for buck and boost

DC/DC converter is the device covert input voltage to other level voltage and it consists of power-semiconductor for control of voltage and current, capacitor and inductor for saving electrical energy. And transformer is added as occasion demands. The price and efficiency of power converter is decided by the number of element for switching and saving energy. Therefore, it is necessary to reduce that number of element in the economical aspect and the topology of system should reflect this aspect.

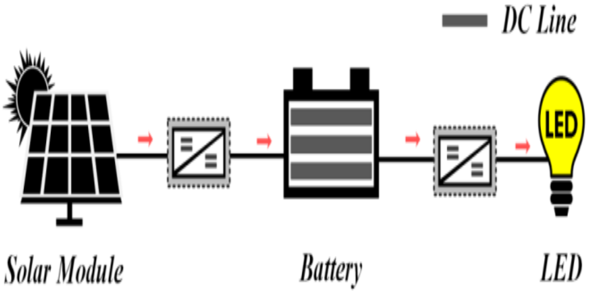
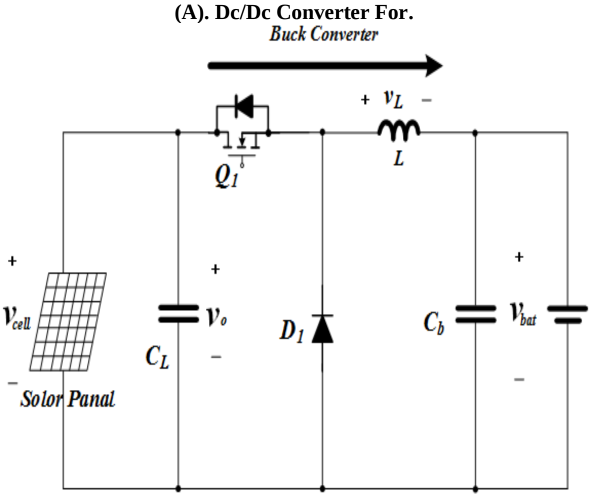


Fig. 1: Schematic of a Typical Stand-Alone Solar Streetlight.

(A). Dc/Dc Converter For.



(B). Dc/Dc Converter for Solar Street Light

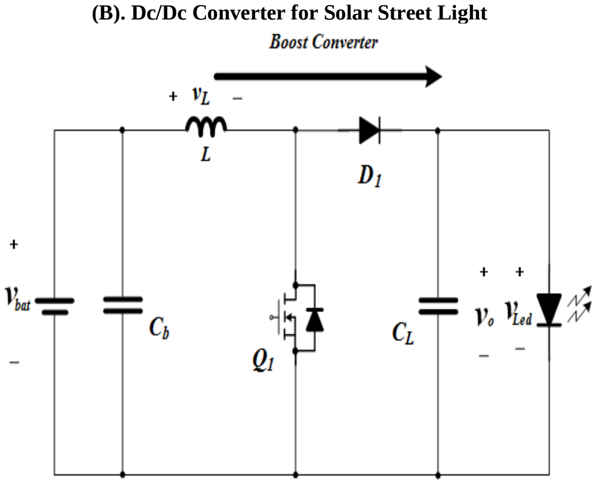


Fig. 2: DC/DC Converter for Solar Street.

Figure. 2 indicates the diagram of general DC/DC converter used in independent power converter for solar photovoltaic. The voltage of solar module is generally higher than the voltage of battery so buck converter is normally selected as DC/DC converter for charging battery.

$$V_{bat} = dV_{led} \quad (1)$$

$$V_{led} = 1/(1-d) \; V_{bat} \quad (2)$$

However, when the voltage from solar module is lower than the voltage of battery for charging, MPPT is disable(refer formula 1) so there is disadvantage that the power from solar module can't be saved into the battery. DC/DC converter for LED light includes buck and boost DC/DC converters for the maximum voltage of battery and the operating voltage of LED light. The operating voltage of LED light is higher than the maximum voltage of battery in Figure. 2 case. This case is an example of using boost converter. In this case, there is a shortcoming that it is unfit for use in LED light having lower voltage than the maximum voltage of battery. To solve this problem, if the power semiconductor element includes individual buck-boost converter, the input and output current can be discontinuous so it can make limitation for efficiency enhancement.

2.2. Module and buck-boost converter for sharing the voltage of LED

In the system of independent streetlight including solar panel, in order to save the maximum generated energy and overcome the restriction of the operating voltage of LED light, DC/DC converter for charging battery, DC/DC converter for LED light and the circuit including the ability of boosting and decompressing are necessary. However, the number of element of power semiconductor and the number of element for saving an energy are increasing. So, it makes the rise in unit cost and it becomes the obstacle to vitalize the independent streetlight including solar panel. Thus, this study proposes the bespoke DC/DC converter for independent streetlight including solar panel.

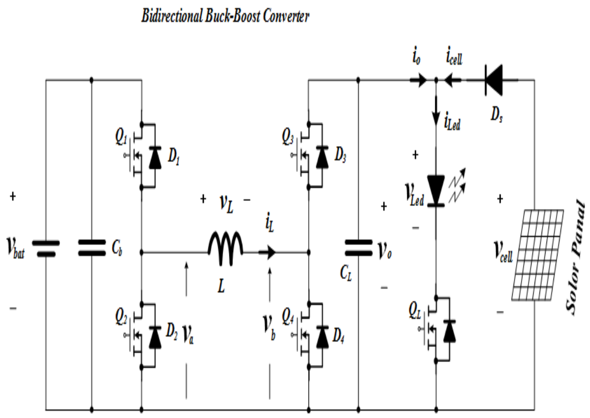
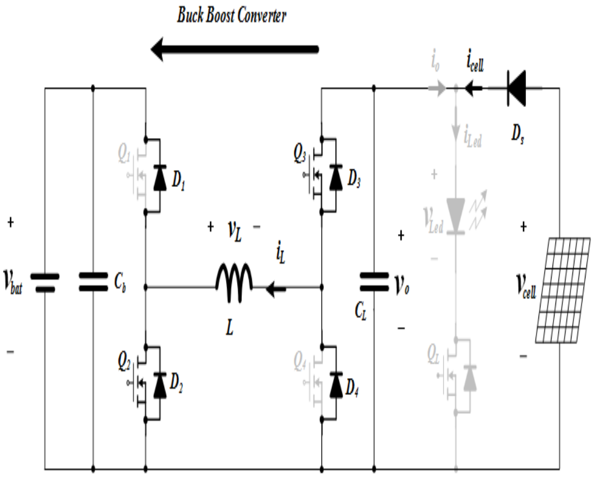


Fig. 3: Proposed DC / DC Converter System.

In Figure. 3, the converter is controlled as the duplex buck-boost converter by the switches Q1, Q2, Q3, Q4. The QL switch is in charge of On/Off ability. Ds, reverse current protection Diode, has the ability of voltage-detection for transference from night-mode to day-mode.

(A). DC/DC Converter for charging.



(A). DC/DC Converter for Lighting

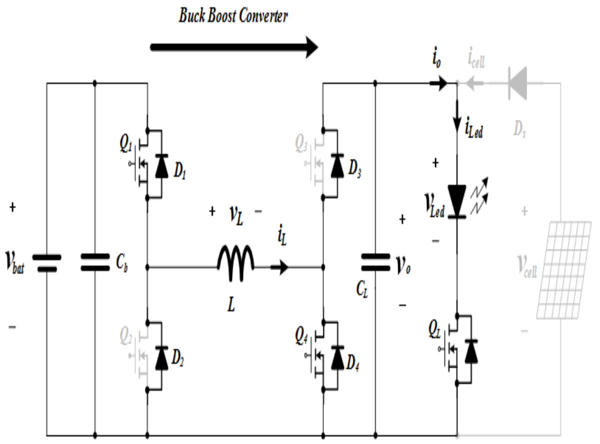


Fig. 4:.DC / DC Converter System Circuit according To Operation Mode.

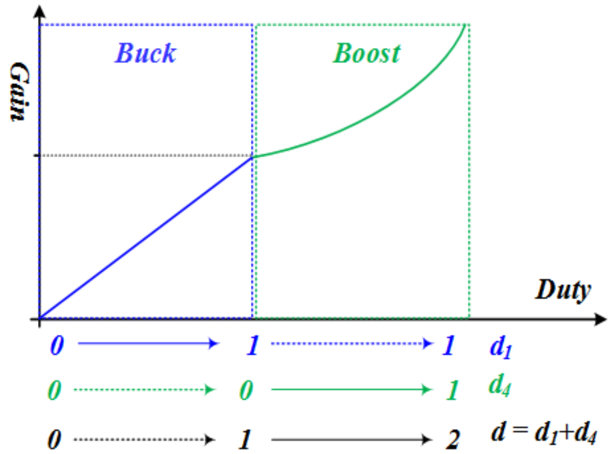


Fig. 5: Correlation between Operating Mode and Application Rate.

The Figure. 4 shows the operating circuit of DC/DC converter during day-time and night-time in this system of independent streetlight including solar panel. And the Figure. 4(a) shows the operating circuit of DC/DC converter for charging from the solar module to battery in day-mode. It is operated as a buck-converter by the duty ratio of switch Q3. When the switch Q3 is on, it is operated as a boost-converter by the duty ratio of switch Q2. The switches of Q1 and Q4 are operated as a synchronous switch to minimize the drop of electric pressure of diode.

The Figure.4(b) indicates the operating circuit for DC/DC converter when control the constant current from battery to LED light in night-mode. It is operated as a buck converter by the duty ratio of the switch Q4 and when the switch Q1 is on, it is operated as a boost converter by the duty ratio of the switch Q4. The switches of Q2 and Q3 are operated as a synchronous switch to minimize the drop of electric pressure of diode. In Figure.3, Va and Vb are the voltage of both ends of inductor; d1 is the duty ratio of switch Q1; d4 is the duty ratio of switch Q4.

〖〖V_a = d_1〗 V〗 _bat (3)

$V_b = 〖(1 - d〗_4)\, V_{led}$ (4)

The voltages of both ends of inductor, Va and Vb, are same by voltage min zero. Therefore When assuming formula (3) is same as formula (4), formula (5) is made.

〖V_led = 〗 〖d_1/(1 - d_4)〗 V_bat (5)

As the formula (5) shows, there are so many duty ratio d1 and d4 which satisfied the output voltage. In this paper, one of d1 and d4 is set to 0 or 1 for reduction of switching. And that is defined in the below formula.

〖〖if(V〗 _led < V_bat) then d_4 = 〗 〖0,〗 V_led = d_4 V_ba

〖if(d〗 _1 = 1) then V_led = 1/(1 - d_4) V_bat (6)

The d1, the duty ratio, is controlled in buck converter mode by formula (6). The d4, the duty ratio, is controlled in boost converter mode. And the duty ratio of controller is defined in the below formula.

$d = d\_1 + d\_4 \;, 0 \le d \le 2$ (7)

The defined duty ratio in formula (7) generates the switching signal of boost-mode or buck-mode by comparing the condition of formula(6). This process is schematized in the Figure.6.

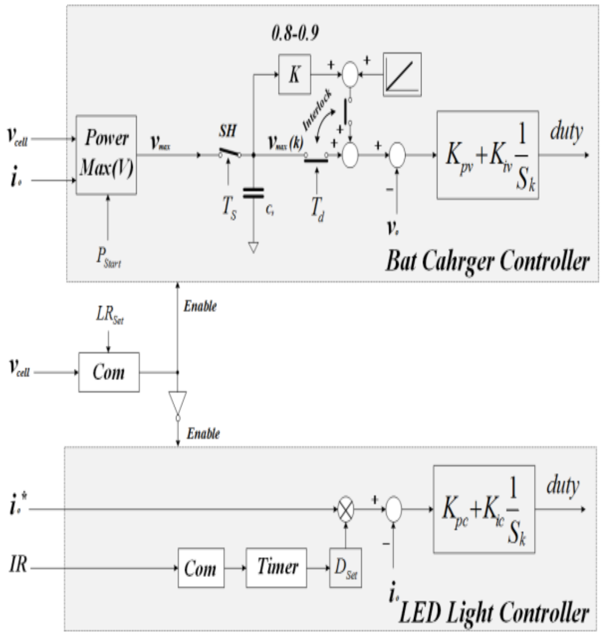


Fig. 6: Solar Street Light System Control Block Diagram.

Above all, the two modes are classified into day-mode and night-mode by measuring the voltage of solar module. And it becomes the standard to be operated for turning on LED light or for charging battery. The DC/DC converter for charging battery is controlled with voltage to conduct MPPT of solar module. And The DC/DC converter for LED light controls the constant current. Also, the human body is sensed by an external IR sensor and when the sensor sensed the body, it will conduct the control with a rated current as much as the set time in a timer and the reminder control with a set current by dimming control. In case of the charged capacity is lacking, It control the current value which is proportional to the voltage of battery. And this function last the operation time of LED light longer.

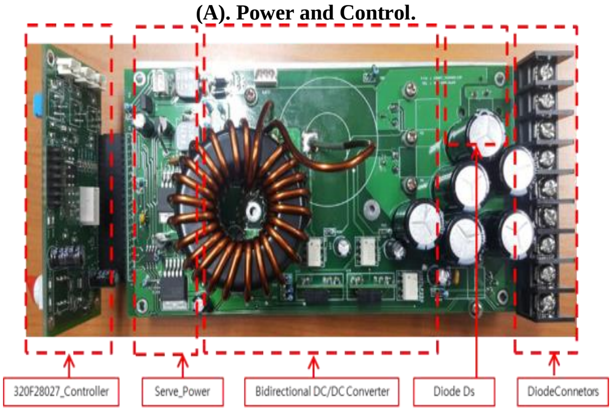
3. Results and discussion

Table 1: Parameters

Title	Item	Spec.
Solar Module	Rating Power	300W
	Operation Voltage	12V ~ 60V
	Max allowed Voltage	DC 60V
	Max DC current	15A
LED (1 Module)	Max Power	30W
	Max DC current	1.4A
	Operation Voltage	19V~21V
Battery	Charging Mode	CC Mode
	Rating Voltage	DC 24V

In order to prove the superiority of the system of streetlight including solar panel which unified only one converter for solar panel and LED light, a prototype is produced like Figure.7. The independent streetlight including solar panel consists of 3 parts largely. These parts are power part(duplex converter), control part(TMS320F28027) and sub-power part(SMPS) operated by the voltage of solar panel and battery (refer Figure.7 (a)). The setting of power converter includes three variable resistors(refer Figure.7 (b)). First one is for operating of light and intensity of illumination. Second one is for operating time and last one is for setting the ratio of dimming. There is rotary switch for choosing 10 types of display mode on LCD display and also the rotary switch is used for setting of the communication protocol. The system of independent streetlight including solar panel is set to operate smoothly by including the temperate sensor and IR sensor. The spec of the used LED for this experiment is VF 3.3V, Max Current 175mA and it is consist of 6 serials and 8 parallel in MLBAWT-A1 for a proper power of 20W(refer Figure.7 (c)). The parameter of the used power converter in this experiment indicated in the table 1.

(A). Power and Control.



(B). System Setting.

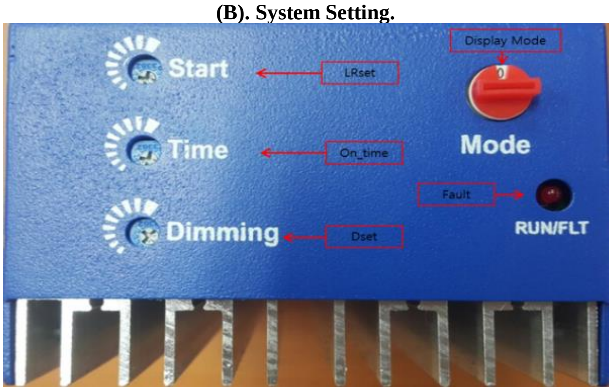
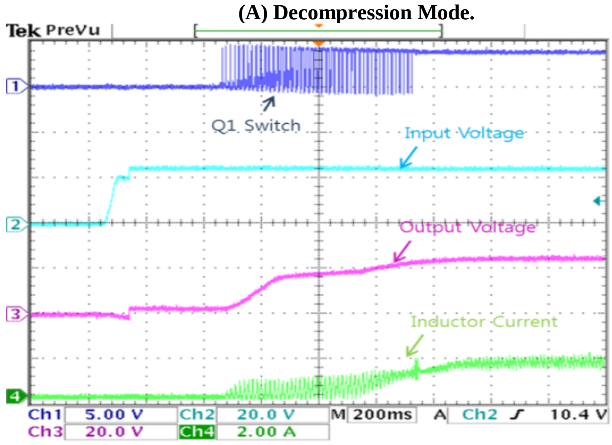


Fig. 7: 300W Solar Street Light System Diagram.

The Figure.8 shows the waveform of this experiment to analyze the starting characteristic of the duplex DC/DC converter in the proposed system for streetlight to have flexibility of deciding the voltage of LED light using battery in Figure.8. In Figure.8 (a), It indicates the starting characteristic when a LED light of 22V, 2.2A is used and the voltage of battery is 24V. As the Figure shows, the switching signal (Q1) for Buck converter makes the duty ratio increased as time passes. So, the output voltage and current of the converter generates stable power as buck mode in 22V, 2.2A after 0.4sec. In Figure.8 (b), It shows the starting characteristic when two LED lights (2V, 2.2A) are connected in serial and the voltage of battery is 24V. As the Figure indicates, the switching signal (Q1) for Buck converter makes the duty ratio increased to 1 as time passes. And then, the output voltage and current of the converter generates stable power as boost mode in 44V, 2.2A after 0.4sec.

(A) Decompression Mode.



(B) Boost Mode.

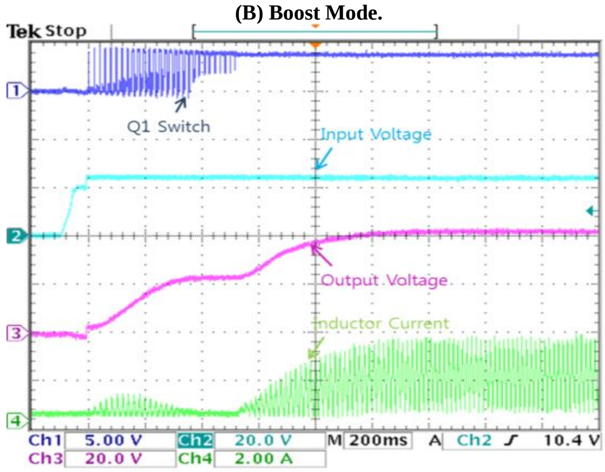
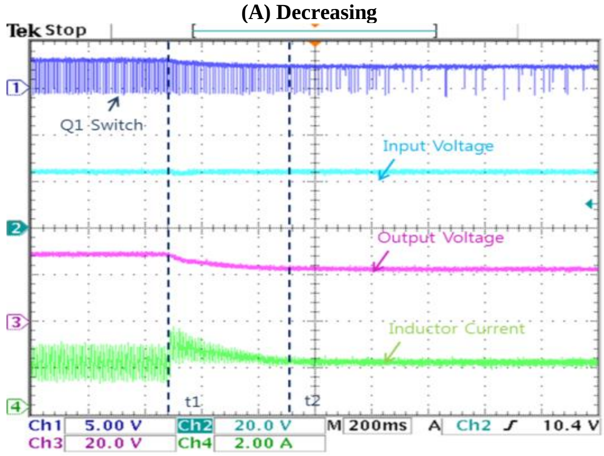


Fig. 8: Converter Starting Characteristics for Solar Streetlight.

(A) Decreasing



(B) Decreasing.

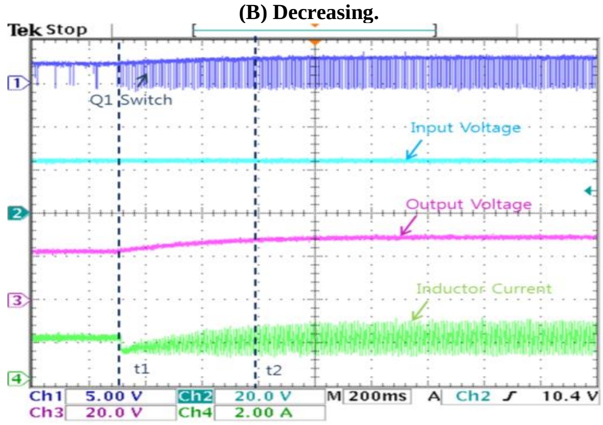


Fig. 9: Input Voltage Fluctuation Characteristics increase.

The Figure.9 shows the waveform by the discrete variable voltage of 2V in the same condition of Figure.8 (a) to analyze the characteristic of controlling constant current for LED voltage regulation on the variation of input voltage. The Figure.9 (a) is the characteristic waveform when the input voltage is changed from 24V to 22V. And the Figure.9 (b) is the characteristic waveform of controlling constant current when the input voltage is changed from 24V to 22V. As these pictures show, the both cases are using various MPPT algorism for maximizing generated power in sunlight generation but in this paper the P&O (perturbation & Observation) is used for analyzing the characteristic. The Figure.10 indicates the characteristic of MPPT in this system. This MPPT function can track properly in 30V, 5.35A. The result shows the efficiency of this MPPT is 99.8% or more in the wide range of voltage (from 12V to 60V).

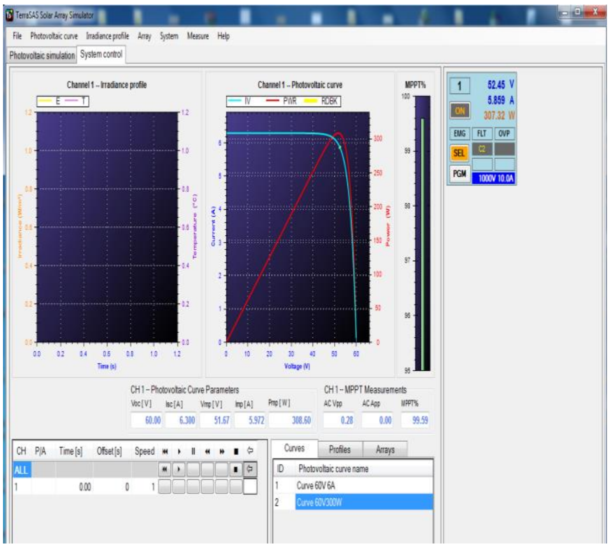


Fig. 10: MPPT Tracking Characteristics.

4. Conclusion

The existing system of independent streetlight including solar panel is consist of two converters (DC/DC converter for charging and DC/DC converter for turning on the LED light). It has the disadvantage that it makes the different characteristic depending on the voltage of the solar panel, battery and the LED light. To prove the validity of the proposed system, the operating characteristic in normal condition is analyzed and the circuit we proposed in this paper is proved by experiment. And there are advantages of the proposed converter below.

4.1. The proposed power converting system is using only one DC/DC converter for two ability of charging battery and turning

On the LED light. It reduces the price of unit

4.2. This system is including the duplex converter able to use for buck and boost

As compared with the existing buck converter and boost converter, the proposed converter had expanded the operating range of MPPT. It expected the improvement of efficiency and easiness for design of independent streetlight including solar panel.

References

[1] Sergio Vazquez, Srdjan M. Lukic, Eduardo Galvan, Leopoldo G. Franquelo, Juan M. Carrasco, “Energy Storage Systems for Transport and Grid Applications”, IEEE Transactions Industrial Electronics, 57(12), 2010, pp. 3881-3895.
[2] Zhenhua Jiang, Xunwei Yu, “Modeling and Control of an Integrated Wind Power Generation and Energy Storage System”, IEEE, Power and Energy Society General Meeting (PES), 2009, pp. 1-8.
[3] SS Choi, KJ Tseng, DM Vilathgamuwa, TD Nguyen,“Energy Storage Systems in Distributed Generation Schemes”, IEEE, Power and Energy Society General Meeting (PES), 2008, pp. 1-8.
[4] L. Gu, X. Ruan, M. Xu, and K. Yao, “Means of eliminating electrolytic Capacitor in AC.DC power supplies for LED lightings,” IEEE Trans. Power Electronics, 24(5), 2009, pp. 1399-1408.
[5] J. Y. Tsao, “Solid-state lighting: Lamps, chips and materials for tomorrow,”IEEE Circuits Devices Mag., 2004, 20(3), pp. 28–37.
[6] D. A. Steigerwald, J. C. Bhat, D. Collins, R. M. Fletcher, M. O. Holcomb, M. J. Ludowise, and P. S. Martin, “Illumination with solid state lighting technology,” IEEE J. Sel. Topics Quantum Electron., 2002, 8(2), pp. 310–320.
[7] M. G. Craford, “LED’s challenge the incandescents,” IEEE Circuits Device Mag., 1992, 8(1), pp. 24–29.
[8] Fengge Zhang, Yuxin Wang, Erxin Shang, “Design and Realization of Controller in Wind Solar Hybrid Generating System”, Power System Technology and IEEE Power India Conference 2008, pp 1-6.
[9] Huanying Yin, Shenghong Ma, "Fuzzy Control Application for Load Management in PV/Wind System", RENEWABLE ENERGY, 2005, 122(5), pp32-34.
[10] Takashi HIYAMA, Shinichi HOUZUMA, Tomofumi IMAKUBO "Evaluation of neural network based real time maximum power tracing controller for PV system" IEEE Transactions on Energy Conversion, 1995, 10 (3).