

FUZZY MPPT BASED KY CONVERTER FOR PHOTOVOLTAIC ENERGY GENERATION SYSTEM

M. Venkatesan

Dept. of EEE, Vignana's Lara Institute of Technology & Science, Guntur, Andhra Pradesh, India.
E-mail: venkatesangct@gmail.com

Abstract – Environmental concerns and rising energy consumption have prompted people all around the world to consider alternative renewable energy sources (RES) including wind, solar and hydro energy resources. Photovoltaic (PV) energy generation system which is a RES have increasing popularity at present because of its availability, cleanliness, cheap maintenance costs and inexhaustibility. However, due to variations in cell temperature and solar irradiation throughout the day, the power generated by a PV system is stochastic. Therefore, a DC-DC KY converter is developed in this paper to produce stable voltage output by utilizing the stochastic PV source. It also has a non-pulsating current output which reduces the voltage ripple at the output while also minimising the stress in current across the capacitor at output. Thus the derivatives of KY converter are described in detail in this study, along with some simulated results. For tracking supreme power, fuzzy- maximum power point tracking (MPPT) algorithm is used. The entire system is designed as well as verified through MATLAB/Simulink simulation.

Keywords: RES, PV system, KY converter, Fuzzy-MPPT algorithm, MATLAB/Simulink.

1 INTRODUCTION

Energy is considered as the most important source related to every country's success economically. In the recent decades, number of commercial sectors and household consumers have expanded dramatically, resulting in an increase in worldwide energy consumption [1, 2]. The earth's fossil fuel reserves are rapidly decreasing and also the increasing usage of fossil fuels leads to pollution as well as global warming [3]. Also, it is commonly known that burning fossil fuel contributes to CO_2 emission. Owing to global warming and fossil fuel depletion, the electric energy generation networks shift from thermal energy to renewable energy resources. Solar energy, in particular has received far more attention than any other renewable energy sources, owing to its widespread availability [4, 5].

Generally, DC-DC converters are utilized to serve as a device for matching of impedance which is linked among the load as well as the PV panel. Hence, the converter's source impedance must be maintained equivalent to the PV panel's resultant impedance which is done by regulating the duty ratio across converter, and thereby load matching is achieved. Advantages and shortcomings of several DC-DC converters which are non-isolated for PV system have been discussed here to finalize the right one. For stepping up the PV source voltage boost, buck-boost, Cuk and SEPIC converters are most commonly used. For peak power tracking, these converters are widely used in conjunction with MPPT controllers [6-8]. A conventional boost converter [9] is a non-isolated DC-DC converter for boosting up the minimal source voltage without needing a high duty cycle.

But, due to high voltage stress, a high rated switch is required [10, 11]. Therefore, the DC-DC buck-boost converter possessing increased voltage gain has been utilized. To collect energy from PV panel and charging the battery, it contains two unidirectional ports (port-1 as well as port-3), a single bidirectional port (port-2). Anyhow, due to the buck mode, the duty cycle is limited and the performance of ports of DC-DC conversion are boosted. As the number of ports increases, the quantity of switches and inductors get increased which adds complexity to the circuit. On the other hand, six innovative multi-port converter topologies are handled using CUK and SEPIC converters. However, as a standard elements, they have a negative impact on dependability and operate as failure points. A significant count of semiconductor devices possessing increased voltage are also required for this converter which increases the switching stress [12-18]. In order to overcome the above issues, no voltage stress, high gain KY converter is proposed here.

Generally, PV panel output varies with changes in meteorological conditions like sun irradiance and cell temperature. Due to this non-linear PV source, tracking the panel's maximum power point is a difficult task [19]. Therefore, an MPPT tracking algorithm is adopted for improving the tracking speed as well as efficiency of the PV system. High tracking precision as well as reliable response in a transient as well as steady state manner are the crucial criteria for evaluating MPPT approach. Different MPPT strategies have been researched in this paper in order to meet such criteria.

The traditional P&O tracking algorithm is the most commonly used one for determining the maximal power of a PV system based on the PV curve slope. However, the P&O algorithm's output oscillates about

the MPP. On the other hand, the incremental conductance (INC) approach performs better in varying weather condition, but it increases the circuit complexity. Therefore, an artificial intelligence depending MPPT algorithm is considered for tracking the MPP in the PV panel. These strategies are designed to provide the highest level of accuracy in dynamic weather changing situations. Their tracking efficiency and speeds are really high [20-22]. The Fuzzy Logic Control (FLC) is considered to be an attractive method that does not necessitate system understanding in order to use MPPT.

The rest of this paper describes the proposed work along with the modelling of PV panel, KY converter and Fuzzy MPPT algorithm. Following this, the developed converter has been tested and verified.

2 RELATED WORKS

PV systems must always strive to minimize the overall cost and profile of power converters in order to maximize energy conversion efficiency [23]. A new topology has been suggested to improve the power quality of a standalone PV system while also attaining cost savings instead of using several converters directly, the suggested solution uses a shared bridge connection to combine a DC-DC converter [24] with a battery converter. The proposed converter boostup the source voltage and maintains the constancy of the output [25].

An innovative high gain DC-DC converter as well as a model-2 predictive controller (MPC) based MPPT algorithm along with optimal number of sensors for using PV modules in energy production has been presented. The proposed design produce voltage gain ratio up to ten times the input voltage, with a tested efficiency of roughly 93%. MPC is a common control approach in PV system that provide greater transient and steady state response. In DC/DC converters with PV, however, the traditional MPC-dependent MPPT approach often necessitates the use of one current and two voltage sensors. This paper provides an MPC-based MPPT methodology using two sensors with the goal of lowering system costs [26].

Two-stage PV configuration is extensively popular because of decoupling among the voltage of PV and the inverter dc-link voltage, thereby allowing MPP tracking range to be extended. On the other hand, the employed DC-DC converter improves the losses in power. This impact can be mitigated by using partial power converters (PPC), that mitigates total power that has been controlled by the dc stage [27].

The PV energy generation system continues to rise and the large scale production systems are already several hundred megawatts in size. This trend will force the power producers to develop a new PV system design

with greater levels of voltage at point of common coupling (PCC) and larger power ratings. The medium voltage PV configuration with an increased gain interleaved boost converter is described in this paper. This interleaved configuration increases the flexibility of the converter, and thereby allow high current and voltage ratings which helps improving the overvoltage power rating of the converter. This type of system configuration includes a step up transformer [28].

An MPPT control technique with varying weather condition is developed in this study to attain the MPP of a PV panel as rapidly as feasible as well as increase the tracking ability under changing conditions of weather. The variation in MPP between a PV system is evaluated and utilized as the foundation for obtaining the control signal for MPP in this technique. Moreover, the curve-fitting methodology is used to determine the direct link between the VWP as well as control signal, which is the most important step in putting this proposed plan into action [29].

To achieve MPP tracking and DC voltage control, the grid integrated PV system typically require two stages of DC-DC converters. In this work, a single stage DC-DC converter is presented with high voltage to resolve the two stage conversion problem. The ability of this converter to achieve synchronized MPPT and DC voltage management is because of the functioning of switches with 2 distinct duty ratios. The inverter is separated from the DC bus and this synchronized management serves to supply the DC loads with continuous DC voltage [30].

3 PROPOSED CONTROL SCHEME

An environmental friendly design of PV system with high gain converter has been designed to avoid the harm caused by greenhouse gas emission and the model of which is represented in Figure 1. The indicated block diagram comprises of a PV panel, KY converter, fuzzy MPPT controller and a load.

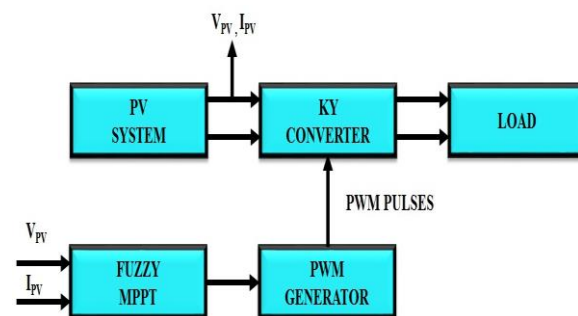


Figure 1 Proposed block representation

The low level dc voltage generated from the solar panel is given to the KY converter which is a non isolated converter with better transient and steady state response. The key benefit of utilizing KY converter is, that it produces non-pulsating current output and thereby minimize the output voltage ripples. In order for tracking maximal power from the PV panel, an efficient fuzzy based MPPT control algorithm has been utilized. The outcome of the fuzzy MPPT controller is given to the PWM generator which delivers appropriate pulses to the converter.

3.1 Modelling of PV Panel

A PV cell, also known as photoelectric cell is a semiconductor device that uses the PV effect to convert light into electricity. If the sunlight fall on the PV is greater than the band gap, the electrons get induced and are liberated, thus the flow of electron produces current. A PV panel is made by connecting numerous PV cells connected series as well as parallel. Cells connected in series are needed for improving the system's voltage whereas the cells in connected parallel are needed for improving the system's current. Also an inverted diode in parallel and a current source is used to build a solar cell model which is portrayed in Figure 2.

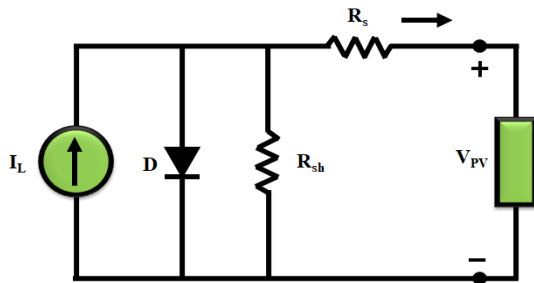


Figure 2 Equivalent circuit model of PV panel

Series resistance is caused by a barrier in the path of electrons whereas the resistance in parallel is caused by the leaked current. The generated current from the solar array is,

$$I_{PV} = I_L - I_D \quad (1)$$

$$I_D = I_0(e^{qV_D/wQ}) \quad (2)$$

$$I_{PV} = I_L - I_0(e^{\frac{qV_D}{wQ}} - 1) \quad (3)$$

$$I_{PV} = I_L - I_0(e^{q(\frac{V_{PV} + I_{PV}R_s}{nwQ})} - 1) \quad (4)$$

Where,

I_0 - Reverse saturation current

I_L	-	Photo current
q	-	Electron charge
V_D	-	Diode voltage
Q	-	Junction temperature
w	-	Boltzmann's constant
I_{PV}	-	Panel output current

3.2 Design of Proposed KY Converter

A voltage boosting KY converter which always function in CCM mode has been discussed in this section. Since it generates non-pulsating current output, there is no chance of getting output voltage ripple. Most importantly, it behaves similarly to a buck converter with synchronous rectification. However, the resulting voltage to the voltage at input ratio is one plus D, in which D refers to the PWM pulse duty cycle for the main switch. The KY converter comprises of two switches S_1 as well as S_2 , as well as two diodes D_1 and D_2 , capacitor C , inductor L , one diode D_b , and a capacitor C_b for energy transfer that is more than enough to maintain the constant voltage. The turn on state of two switches are given as $(D, 1 - D)$ in which, D indicates the duty cycle ratio of the PWM signal of switch S_1 . Figure 3 portrays the proposed model of KY converter.

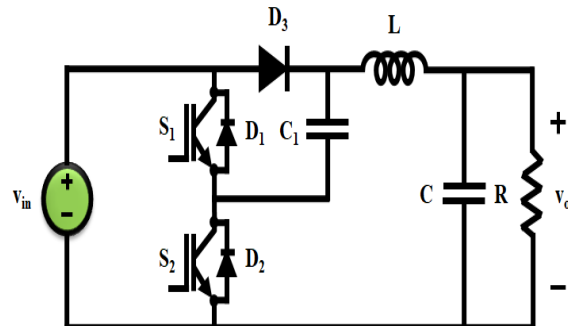


Figure 3 KY converter circuit

The two modes of operation in KY converter are described below,

Mode 1:

When switch S_1 is in ON and S_2 is OFF, voltage of L is source voltage v_i plus the voltage v_i in the energy transferring capacitor C_b minus the voltage output V_o resulting L to be magnetic. Moreover, the current flowing through the capacitor C equals the current passing across L minus the current running across R . Furthermore, discharging of C_b occurs in this mode. Figure 4 depicts the circuit of mode 1 operation of KY converter.

Thus the differential equations are given by,

$$\begin{cases} L \frac{\partial i}{\partial t} = 2v_i - v_o \\ C \frac{\partial v_o}{\partial t} = i - \frac{v_o}{R} \\ i_i = i \end{cases} \quad (5)$$

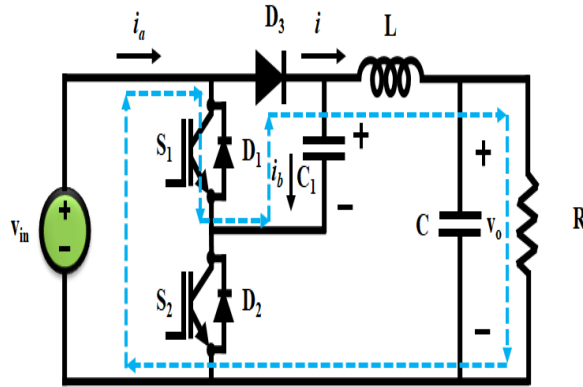


Figure 4 Mode 1

Mode 2:

The switch S_2 is made ON and S_1 is maintained OFF (as given in Figure 5), voltage in L indicates source voltage V_i minus resultant voltage V_o , demagnetizing the inductor L . Moreover, the current passing across C equals the current passing across the inductor L eliminates current running through R . Furthermore, in this mode, C_b gets charged to v_i in a fraction of section.

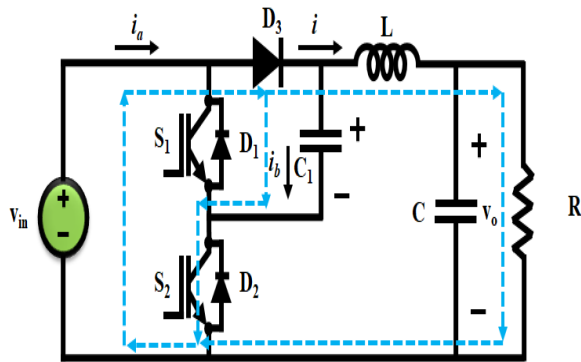


Figure 5 Mode 2

Thus the corresponding equation is given by,

$$\langle x \rangle = \frac{1}{T_s} \int_0^{T_s} x dt \quad (6)$$

From equation (5) and (6), the averaged equation can be expressed as,

$$\begin{cases} L \frac{\partial \langle i \rangle}{\partial t} = (1 + d)\langle v_i \rangle - \langle v_o \rangle \\ C \frac{\partial \langle v_o \rangle}{\partial t} = \langle i \rangle - \frac{\langle v_o \rangle}{R} \\ \langle i_i \rangle = \langle i \rangle + (1 + d)\langle i_b \rangle \end{cases} \quad (7)$$

Where, d denotes the PWM signal duty cycle. On the basis of ampere-second balance, $\langle i_b \rangle$ is given as,

$$\langle i_b \rangle = \frac{d}{1-d} \langle i \rangle \quad (8)$$

By substituting equation (8) in (7), the equation (7) is given as follows,

$$\begin{cases} L \frac{\partial \langle i \rangle}{\partial t} = (1 + d)\langle v_i \rangle - \langle v_o \rangle \\ C \frac{\partial \langle v_o \rangle}{\partial t} = \langle i \rangle - \frac{\langle v_o \rangle}{R} \\ \langle i_i \rangle = (1 + d)\langle i \rangle \end{cases} \quad (9)$$

The perturbation and linearization of equation 6 are required. First, $\langle x \rangle$ is indicated with the equivalent dc quiescent value X plus a minor ac variation \hat{x} , assuming the ac variation to be tiny in magnitude. Therefore,

$$\begin{cases} \langle v_i \rangle = V_i + \hat{v}_i \\ d = D + \hat{d} \\ \langle i \rangle = I + \hat{i} \\ \langle v_o \rangle = V_o + \hat{v}_o \\ \langle i_i \rangle = I_i + \hat{i}_i \end{cases} \quad \text{with} \quad (10)$$

Substitute equation (10) in (9), the following equation can be expressed as,

$$\begin{cases} L \frac{\partial (I + \hat{i})}{\partial t} = (1 + D + \hat{d})(V_i + \hat{v}_i) - (V_o + \hat{v}_o) \\ C \frac{\partial (V_o + \hat{v}_o)}{\partial t} = (I + \hat{i}) - \frac{(V_o + \hat{v}_o)}{R} \\ I_i + \hat{i}_i = (1 + D + \hat{d})(I + \hat{i}) \end{cases} \quad (11)$$

Thus the quiescent equation is expressed as,

$$\begin{cases} 0 = (1 + D)V_i - V_o \\ 0 = I - \frac{V_o}{R} \\ I_i = (1 + D)I \end{cases} \quad (12)$$

The voltage conversion ratio is given as,

$$\frac{V_o}{V_i} = 1 + D \quad (13)$$

Therefore, by neglecting the ac terms of second order, the small signal equation is given as follows,

$$\begin{cases} L \frac{\partial \hat{i}}{\partial t} = (1 + D)\hat{v}_i - V_i \hat{d} - \hat{v}_o \\ C \frac{\partial \hat{v}_o}{\partial t} = \hat{i} - \frac{\hat{v}_o}{R} \\ \hat{i}_i = (1 + D)\hat{i} + I \hat{d} \end{cases} \quad (14)$$

3.3 Fuzzy based MPPT Control Algorithm

Fuzzy control is a technique that permits nonlinear controllers to be built using heuristic information derived from expert knowledge. A fuzzy controller's block diagram is shown in Figure 6. The fuzzification block is in charge of processing and assigning a fuzzy value to the incoming signals. The collection of rules is based on knowledge and experience and provides for a language description of the variables to be managed. The inference mechanism is in charge of interpreting the data while keeping the rules and their membership functions in account. The defuzzification block converts the inference mechanism's fuzzy data into non-fuzzy information which is utilized for controlling the operation.

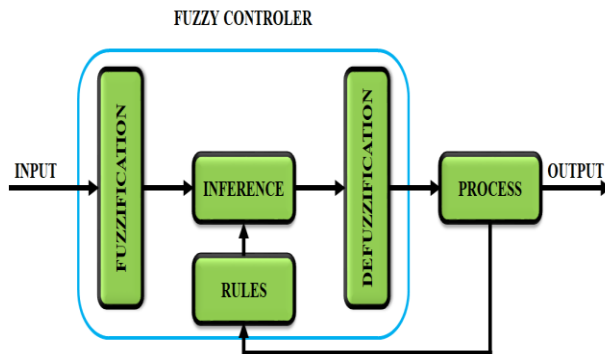


Figure 6 Fuzzy Control System

The design of fuzzy controller with E (error) as well as CE (change in error) has been considered. The values of input variables are given as follows,

$$E(k) = \frac{P(k) - P(k-1)}{V(k) - V(k-1)} = \frac{\Delta P}{\Delta V} \quad (15)$$

$$CE(k) = E(k) - E(k-1) = \Delta E \quad (16)$$

The input variable CE(k) determines whether the point of operation is moving in the direction of MPP or not. An increase in duty cycle (D) is the output variable, that consider positive or negative values relying on where the operational point is located. To drive the load, this output is delivered to the dc-dc converter. Outcome of the converter is given to the load. An accumulator was created using the value of D given by the controller to derive the duty cycle value.

$$D(k) = D(k-1) + \Delta D(k) \quad (17)$$

Flow chart of fuzzy MPPT controller is given in Figure 7.

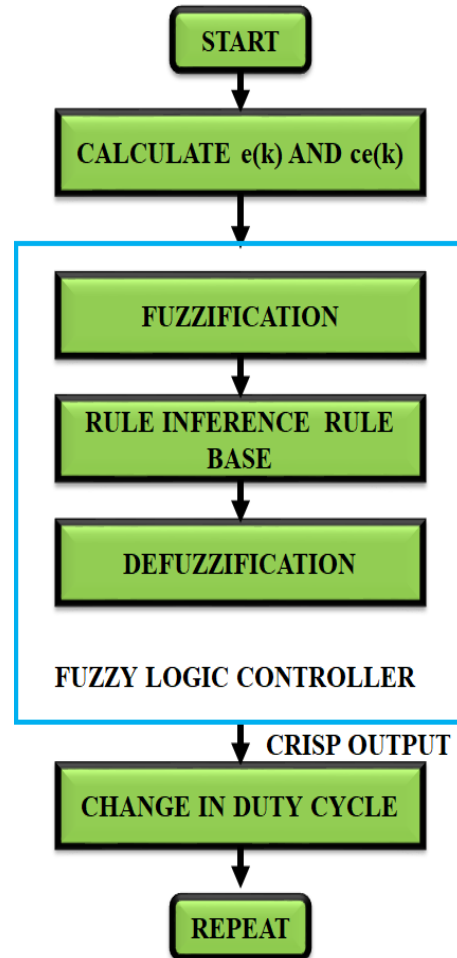


Figure 7 Fuzzy-MPPT algorithm flowchart

3.4 PWM Generator

The PWM generator generates a pulse width modulated signal, which is then applied to the converter's switch. The PWM generator divides the average power drop into discrete components. The voltage and current average values delivered to the load side by leaving the switch on for a longer period of time than the switch is turned off. The power delivered will be greater as a result of the extended ON time. The PWM generator's primary duty is to generate a pulse width modulated gate pulse signal that is fed to the converter's switch.

4 RESULTS AND DISCUSSION

The simulation of the described approach is carried out in MATLAB/SIMULINK. The obtained results are given as follows.

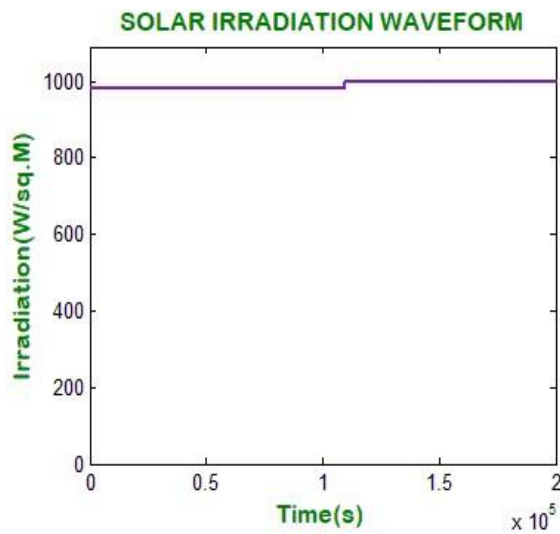


Figure 8 Waveform for solar irradiation

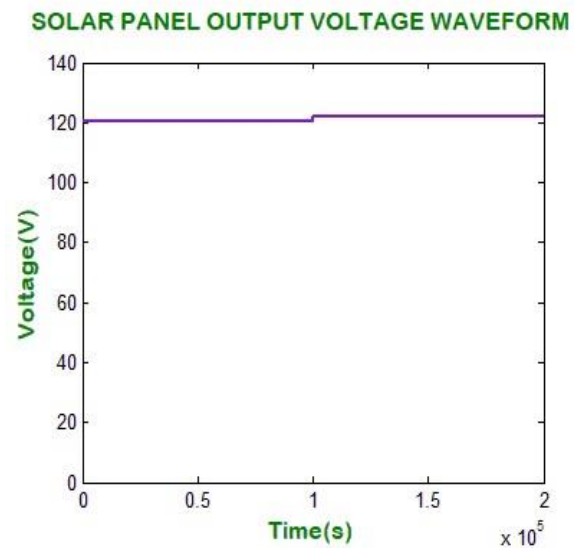


Figure 10 Waveform for solar panel output

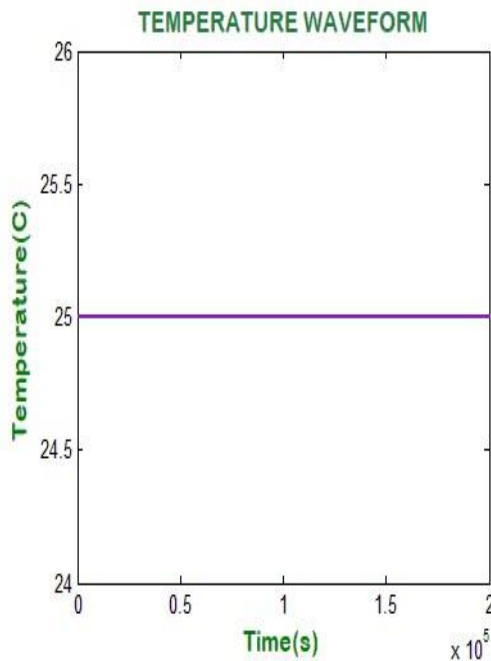


Figure 9 Waveform for temperature

Figure 8 indicates the waveform for solar irradiation and figure 9 indicates the waveform for temperature respectively. The temperature provided to the solar panel is considered as a constant value.

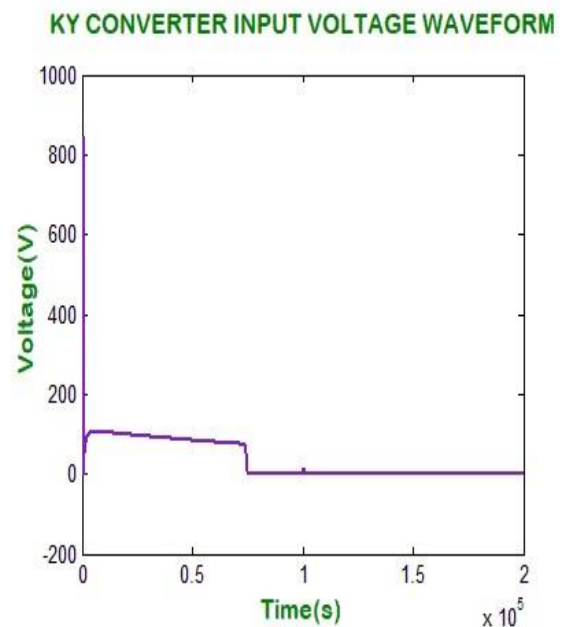


Figure 11 Converter input waveform

PWM PULSE TO KY CONVERTER SWITCH WAVEFORM

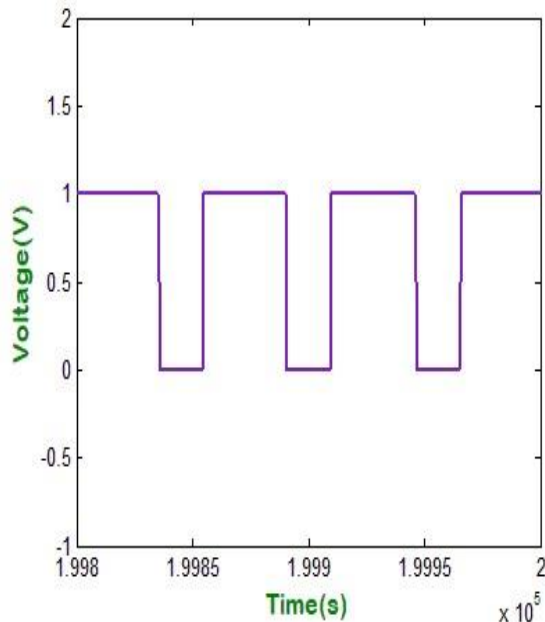


Figure 12 Pulse for converter switch

KY CONVERTER OUTPUT VOLTAGE WAVEFORM

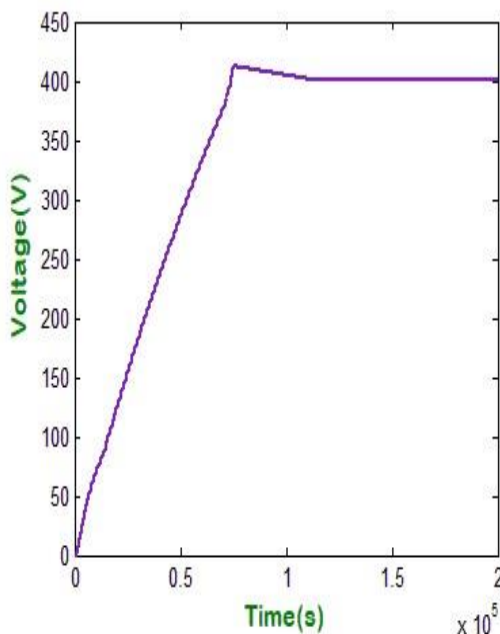


Figure 13 Converter output waveform

Figure 11 represents the input voltage to the KY converter figure 12 represents the pulse signal

obtained from the PWM generator which is fed to the switch of the converter. Figure 13 indicates the enhanced output from the converter.

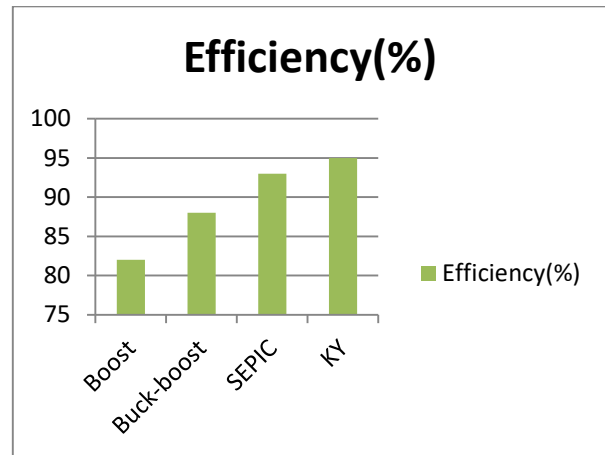


Figure 14 Comparison of efficiency

Figure 14 represents the comparison graph of KY converter with existing converters like boost, buck-boost and sepic converters. From the graph it is clear that the proposed KY converter generated improved efficiency of 95%.

5 CONCLUSION

This paper presented an efficient approach utilizing KY converter for enhancing the power generated from photovoltaic energy generation system. It generated a stable output and a non-pulsating current output with minimized current stress. The adopted fuzzy- MPPT algorithm provided efficacious tracking of maximal power. The proposed approach was simulated in MATLAB/SIMULINK and comparison of KY converter was performed with other converters which revealed efficient results.

References

- [1] Vishnuvardhan Telukunta, Janmejaya Pradhan, Anubha Agrawal, Manohar Singh, Sankighatta Garudachar Srivani, "Protection challenges under bulk penetration of renewable energy resources in power systems: A review", CSEE Journal of Power and Energy Systems, Vol.3, no. 4, pp. 365 - 379, 2017.
- [2] Ershun Du, Ning Zhang, Bri-Mathias Hodge, Qing Wang, Chongqing Kang, Benjamin Kroposki, Qing Xia, "The Role of Concentrating Solar Power Toward High Renewable Energy Penetrated Power

- Systems”, IEEE Transactions on Power Systems, Vol: 33, no. 6, pp. 6630 - 6641, 2018.
- [3] Lawan, M. M. G., J. Raharijaona, M. B. Camara, and B. Dakyo., “Power control for decentralized energy production system based on the renewable energies—using battery to compensate the wind/load/PV power fluctuations”, 2017 IEEE 6th International Conference on Renewable Energy Research and Applications (ICRERA), pp. 1132-1138, 2017.
- [4] Van der Meer, Dennis, Gautham Ram Chandra Mouli, German Morales-Espana Mouli, Laura Ramirez Elizondo, and Pavol Bauer., “Energy management system with PV power forecast to optimally charge EVs at the workplace”, IEEE transactions on industrial informatics 14, no. 1, pp. 311-320, 2016.
- [5] Comello, Stephen, Stefan Reichelstein, and Anshuman Sahoo., “The road ahead for solar PV power”, Renewable and Sustainable Energy Reviews, vol. 92, no. 1, pp. 744-756, 2018.
- [6] Singh, S. N., “Selection of non-isolated DC-DC converters for solar photovoltaic system”, Renewable and Sustainable Energy Reviews , vol.76, pp. 1230-1247, 2017.
- [7] Palanisamy, R., K. Vijayakumar, V. Venkatachalam, R. Mano Narayanan, D. Saravanakumar, and K. Saravanan, “Simulation of various DC-DC converters for photovoltaic system.”, International Journal of Electrical and Computer Engineering, vol. 9, no. 2, pp. 917, 2019.
- [8] Omar Abdel-Rahim, Haoyu Wang, “A new high gain DC-DC converter with model-predictive-control based MPPT technique for photovoltaic systems”, CPSS Transactions on Power Electronics and Applications, Vol.5, no. 2, pp. 191 - 200, 2020.
- [9] V. Karthikeyan, S. Kumaravel, G. Gurukumar, “High Step-Up Gain DC–DC Converter With Switched Capacitor and Regenerative Boost Configuration for Solar PV Applications”, IEEE Transactions on Circuits and Systems II: Express Briefs, Vol. 66, no. 12, pp. 2022 - 2026, 2019.
- [10] Pradhan, Arjyadhara, and Bhagabat Panda, “A simplified design and modeling of boost converter for photovoltaic sytem”, International Journal of Electrical and Computer Engineering , vol.8, no. 1, 2018.
- [11] Shelas Sathyan, Hiralal Murlidhar Suryawanshi, Bhim Singh, Chandan Chakraborty, Vishal Verma, Makarand Sudhakar Ballal, “ZVS–ZCS High Voltage Gain Integrated Boost Converter for DC Microgrid”, IEEE Transactions on Industrial Electronics, Vol. 63, no. 11, pp. 6898 - 6908, 2016.
- [12] Balaji Chandrasekar, Chellammal Nallaperumal, Sanjeevikumar Padmanaban, Mahajan Sagar Bhaskar, Jens Bo Holm-Nielsen, Zbigniew Leonowicz, Samson O. Masebinu, “Non-Isolated High-Gain Triple Port DC–DC Buck-Boost Converter With Positive Output Voltage for Photovoltaic Applications”, IEEE Access, Vol.8, pp 113649 - 113666, 2020.
- [13] Baharudin, Nor Hanisah, T. M. N. T. Mansur, Fairuz Abdul Hamid, Rosnazri Ali, and Muhammad Irwanto Misrun, “Topologies of DC-DC converter in solar PV applications”, Indonesian Journal of Electrical Engineering and Computer Science, vol.8, no. 2, pp 368-374, 2017.
- [14] Siouane, Saima, Slaviša Jovanović, and Philippe Poure, “Open-switch fault-tolerant operation of a two-stage buck/buck–boost converter with redundant synchronous switch for PV systems”, IEEE Transactions on Industrial Electronics, vol. 66, no. 5, pp 3938-3947, 2018.
- [15] S Saravanan, N. Ramesh Babu, “Performance analysis of boost & Cuk converter in MPPT based PV system”, 2015 International Conference on Circuits, Power and Computing Technologies [ICCPCT-2015], 2015.
- [16] Priyadarshi, Neeraj, Sanjeevikumar Padmanaban, Jens Bo Holm-Nielsen, Vigna K. Ramachandaramurthy, and Mahajan Sagar Bhaskar, “An adaptive neuro-fuzzy inference system employed cuk converter for PV applications”, 2019 IEEE 13th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG), 2019.
- [17] Kumaran Nathan; Saikat Ghosh; Yam Siwakoti; Teng Long, “A New DC–DC Converter for Photovoltaic Systems: Coupled-Inductors Combined Cuk-SEPIC Converter”, IEEE Transactions on Energy Conversion, Vol.34, no. 1, pp 191 - 201, 2019.
- [18] Nagarajan, R., J. Chandramohan, R. Yuvaraj, S. Sathishkumar, and S. Chandran, “Performance analysis of synchronous SEPIC converter for a stand-alone PV system”, International Journal of Emerging Technologies in Engineering Research (IJETER), vol. 5, no. 5, pp 12-16, 2017.
- [19] Ratnakar Babu Bollipo, Suresh Mikkili, Praveen Kumar Bonthagorla, “Hybrid, optimal, intelligent and classical PV MPPT techniques: A review”, CSEE Journal of Power and Energy Systems, Vol. 7, no. 1, 2021.
- [20] Azadeh Safari, Saad Mekhilef, “Simulation and Hardware Implementation of Incremental Conductance MPPT With Direct Control Method Using Cuk Converter”, IEEE Transactions on Industrial Electronics, Vol.58, no. 4, pp. 1154 – 1161, 2011.
- [21] Sah, Bikram, and Gudey Venkata Eswara Satish Kumar, “A comparative study of different MPPT

- techniques using different dc-dc converters in a standalone PV system”, 2016 IEEE Region 10 Conference (TENCON), pp.1690-1695, 2016.
- [22] Al-Gizi, Ammar Ghalib, “Comparative study of MPPT algorithms under variable resistive load”, 2016 International Conference on Applied and Theoretical Electricity (ICATE), 2016.
- [23] Ting Qian, “A Converter Combination Scheme for Efficiency Improvement of PV Systems”, IEEE Transactions on Circuits and Systems II: Express Briefs, Vol. 65, no. 11, pp. 1668 - 1672, 2018.
- [24] Moumita Das; Vivek Agarwal, “Novel High-Performance Stand-Alone Solar PV System With High-Gain High-Efficiency DC–DC Converter Power Stages”, IEEE Transactions on Industry Applications, Vol. 51, no. 6, pp.4718 - 4728, 2015.
- [25] Teuvo Suntio; Alon Kuperman, “Comments on “An Efficient Partial Power Processing DC/DC Converter for Distributed PV Architectures”, IEEE Transactions on Power Electronics, Vol. 30, no. 4, pp. 2372 - 2372, 2015.
- [26] Omar Abdel-Rahim, Haoyu Wang, “A new high gain DC-DC converter with model-predictive-control based MPPT technique for photovoltaic systems”, CPSS Transactions on Power Electronics and Applications, Vol. 5, no. 2, pp. 191 - 200, 2020.
- [27] Jaime W. Zapata, Samir Kouro, Gonzalo Carrasco, Hugues Renaudineau, Thierry A. Meynard, “Analysis of Partial Power DC–DC Converters for Two-Stage Photovoltaic Systems”, IEEE Journal of Emerging and Selected Topics in Power Electronics, Vol. 7, no. 1, pp. 591 - 603, 2019.
- [28] Choi, Hyuntae, Mihai Ciobotaru, Minsoo Jang, and Vassilios G. Agelidis, “Performance of medium-voltage DC-bus PV system architecture utilizing high-gain DC–DC converter”, IEEE Transactions on Sustainable Energy, vol. 6, no. 2, pp. 464-473, 2015.
- [29] Li, Shaowu, Honghua Liao, Hailing Yuan, Qing Ai, and Kunyi Chen, “A MPPT strategy with variable weather parameters through analyzing the effect of the DC/DC converter to the MPP of PV system”, Solar Energy, vol. 144, no. 2, pp.175-184, 2017.
- [30] Lakshmi, M., and S. Hemamalini, “Coordinated control of MPPT and voltage regulation using single-stage high gain DC–DC converter in a grid-connected PV system”, Electric Power Systems Research, vol. 169, pp. 65-73, 2019.