KY Converter with Fuzzy Logic Controller for Grid-Connected Hybrid PV/wind power system

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Abstract: Wind and solar energy, are thought to be the principle properties of sustainable power source for power generation and are developing at quicker rate throughout the previous couple of decades. This paper comprises a novel coordination of solar energy system and wind energy from grid connected Permanent Magnet Synchronous Generator (PMSG) which is associated with the rectifier to rectify AC input. With the purpose of extract maximum power fuzzy logic controller has been adopted, in this work. We propose a multi-input KY converter for grid connected hybrid photovoltaic and wind power system by extracting as much renewable energy as possible using the fuzzy logic controller. The wind energy is rectified and then both the PV and wind outputs are given to the fuzzy logic controller. The KY converter is a voltage buck-boost converter possessing non-pulsating output current, in this manner diminishing the current stress as well as diminishing the yield voltage ripple. The fuzzy logic controller is the best controller to track maximum power. The output of the controller is the mission cycle of KY converter. The inverter is connected for regulating the AC load. The implementation is done using MATLAB / SIMULINK.

Keywords: Fuzzy Logic Controller, KY Converter, Rectifier, Permanent Magnet Synchronous Generator (PMSG), Inverter, Wind energy, Solar Energy.

1. Introduction

With the increasing expense and constrained accessibility of fossil fuels, much consideration has been converged around the utilization of renewable energy sources for electrical power generation [1]. Renewable power sources are getting more considerationin a wide scope of applications. With “more electric” components in stationary and portable applications, the interest for power has been expanding throughout the years, which, hence, forces an expanding trouble on electric generation and transmission frameworks [2, 3].Among this, tapping wind energy with wind turbines gives off an impression forthcoming reassuring source of renewable energy. Wind energy transformation frameworks are utilized to catch the energy accessible in the breeze to change into electrical energy [4]. The solar photovoltaic and wind systems have been advanced the world over on a larger scale. A hybrid renewable energy system utilizes two or more energy generation techniques, typically solar and wind power. The other advantage of PV panel / wind turbine hybrid system is that when solar and wind power generation is utilized together, the dependability of the scheme is upgraded [5]. For the applications of the power supply utilizing the low voltage battery, simple circuits, such as radio frequency (RF) amplifier, audio amplifier etc., frequently require high voltage to acquire adequate output power and voltage amplitude [6]. In many operations, high voltage conversion converters play an essential part in boosting the low output voltages of green power services to the high voltages which the loads need [7].Recently, DC/DC converters have induced incredible consideration by researchers. Voltage bucking/boosting is needed in much utilization such as fuel-cell systems, portable equipment for example notebooks and cell phones, light-emitting diode items and car electronic gadgets [8]. DC-DC converters are the devices that are utilized to change over and control the DC electrical power proficiently and effectively starting with one voltage level then onto the next. The DC-DC converter is a device for changing over one DC voltage level to another DC voltage level with a negligible loss of energy [9]. The existing converters utilized comprises of a coupling inductor utilized in the boost/ buck-boost converter. A voltage- lift approach is employed previously to boost the output voltage along with the output voltage ripple when considered [10].

Fundamental dc-dc converters comprising buck and boost converters and its derivatives don't have bidirectional power stream limit. This restriction is because of the existence of diodes in their structure which avoids reverse current stream. Generally, a unidirectional dc-dc converter be able to converted into a bidirectional converter by reconstitution of the diodes along with a manageable switch in its framework [11, 12]. Regarding the conventional non-isolated voltage-boosting converter, for example the boost converter and the buck–boost converter, their output currents are pulsating, along this causing the relating output voltage ripples to tend to be wide [13].A couple of sorts of non-isolated voltage-bucking/boosting converters such as Cuk converter, buck-boost converter, Zeta converter, SEPIC converter, and so forth., working in continuous conduction mode (CCM) and have right–half plane, in this way making the system stability to be low, load transient reactions to be direct around a few milliseconds and consequently equivalent model for relating transient reactions to be troublesome [14, 15].

This trouble can be corrected by the KY Converters. Generally, for the decrease of the ripple content the approach chosen are Equivalent Series Resistant (ESR) capacitor or by adding an inductance-capacitance (LC) filter in KY Converter [16]. KY converter is a step-up converter. The behaviour of KY converter can be assuming as synchronous rectification. In the case of synchronous rectification, the diode is changed by a MOSFET switch to to expand the effectiveness and to reduce the conduction losses. But this can be accomplished just on account of light loads. The element of KY converter, which makes it not the same as different converters, is that it generally works in [17]. KY converter is a step-up dc-dc converter. It is discovered by the Mr. K. I Hwu and Y. T Yau and therefore, it is named as KY converter [18]. In order to diminish the quantity of power switches utilized the KY converter and the SR buck converter, is pooled into a buck–boost converter, i.e., 2D converter, where both use a similar power switches [19]. Furthermore, sometimes the controller creates some issues while controlling the output voltage ripple that reduces the peak overshoot and settling time of the converter. Existing controller circuits such as the Proportional Integral (PI) controller don't provided better control results [20]. dditionally, the existing KY converter still includes of issues such as with the power factor and very low Total Harmonic Distortion (THD). In order to vanquish these issues, a KY converter is proposed along with a controller technique. The remaining paper is planned as follows: Section 2 comprises of some of the recent existing approaches related to the proposed KY converter along with the contribution of the proposed work, Section 3 comprises of the proposed KY Converter, and Section 4 portrays the simulation results and performance analysis describing the improvement of our proposed work. Section 5 explains the conclusion of the work followed by the references.

2. Related Works

Some of the existing KY converter implementations are discussed as:

Hwu, K. and Y. T. Yau [21] proposed a voltage-bucking/boosting converter called KY buck–boost converter (i.e., 2D converter). Dissimilar to the traditional buck–boost converter, this converter had quick transient responses, like the behaviour of the buck converter with synchronous rectification. Moreover, it possessed the non-pulsating output current, in this manner not only diminishing the current stress on the output capacitor yet additionally shortening the output voltage ripple. Additionally, it had the positive output voltage, various from the negative output voltage of the classical buck–boost converter. Most importantly, there are two kinds of KY buck–boost converters conferred. These two converters had fast transient responses similar to the behaviour of the buck converter with Synchronous Rectification (SR), good line and load regulations and low output voltage ripples due to non-pulsating output currents. Venkatanarayanan S and Jeyalakshmi G [22] presented the evaluation of integrated SEPIC & KY, a hybrid dc–dc converter with applications for low-voltage renewable energy sources. The PV systems was rapidly expanding and had increasing roles in electric power expertise, that provided augmented solid power sources and pollution free electric supplies. The method comprised of solar panels, MPPT (Maximum Power Point Tracking) controller and integrated SEPIC & KY converter. The MPPT is controls the duty cycle of this KY converter by giving constant dc bus voltage. A P&O (Perturbation & Observation) approach was applied for MPPT. To maintain the power quality a feedback control was used. The complete system was designed, and modelled to appraise its efficiency. Moreover, the SEPIC converter doesn't require current snubber for the diodes. By incorporation of two converters SEPIC converter provided extra step up gain and KY converter diminished the voltage stress; likewise, they gave higher voltage conversion proportion and lessened the output voltage ripples.

Zhang *et al*. [23] depicted KY converter showed little output voltage ripples and quick transient response assessed with the boost converter to its buck-converter-like characteristics. An exhaustive study of integrated KY converter that considered parasitic resistance was declared as design instruction for its IC utilization, and different attributes of KY converter versus boost converter were also explored to specify its benefits. Particularly, optimum transistor sizes, power losses and output voltage ripples were analysed in depth. The ideas of power components included energy transferring capacitor, inductor, and filter capacitor.

Radhika *et al*. [24] analysed and well-ordered procedure of designing, feedback control of a voltage bucking-boosting converter by connecting KY and Synchronous Buck converter for power battery applications. Unlike the customary buck–boost converter this converter had just the positive output voltage, not the same as from the negative output voltage of the conventional inverting buck–boost converter. This converter works just in Continuous conduction mode. The output current was the non-pulsating waveform accordingly not only the current stress on the output capacitor was reduced yet in addition the output voltage ripples was diminished. By blend of the KY converter with the synchronous buck converter, a positive buck–boost converter was acquired and utilizes a similar power switches with no right-half-plane zero. With the goal that the circuit was made to be compact. Moreover, this converter constantly operated in Continuous Conduction Mode inherently, through causing varieties in obligation cycle everywhere throughout the load range not to be so plenty, and thus, the control of the converter to be simple.

Hwu and Peng [25] presented a buck–boost converter, i.e., 2D converter with a positive output voltage which joins the KY converter and the conventional synchronously rectified (SR) buck converter. As a result of, the issue in voltage bucking of the KY converter can be illuminated, thereby expanding the application capacity of the KY converter. Since such a converter works in continuous conduction mode inalienably, , it has the non-pulsating output current, consequently not only diminishing the current stress on the output capacitor additionally decreasing the output voltage ripple. Most importantly, both the KY converter and the SR buck converter, consolidated into a buck–boost converter with no right-half plane zero, utilize a similar power switches, in this manner making the required circuit be compact and the relating expense to be down. Besides, amid the magnetization period, the input voltage of the KY converter originates from the input voltage source, though amid the demagnetization period, the input voltage of the KY converter originates from the output voltage of the SR buck converter.

The fundamental contribution of the work is given as:

- Initially a KY Converter is formed by incorporating two methods of activity with multiple inputs such as the contribution from renewable power sources such as the solar panel and wind turbine. Due to this multi-input the accuracy of the system is upgraded.
- The output from KY Converter is fed as the input to the Fuzzy logic controller which is responsible for handling uncertainties and track highest power from the renewable sources.
- By this Fuzzy logic controller, the voltage parameter obtained from the PV panel and wind turbine is tracked for providing better output (power) or to remove highest power and is then transferred to load.

3. Proposed KY converter

Here a multi-input KY converter is proposed for grid-connected hybrid photovoltaic and wind power system by extracting as much renewable energy as possible. The KY converter is a voltage buck-boost converter possessing non-pulsating output current, so the output capacitor reducing the current stress and also reducing the output voltage ripple. The wind energy is rectified and then both the PV and wind outputs are given to the fuzzy logic controller. The fuzzy logic controller records the maximum power from the wind turbine and PV panel. Fuzzy logic is identified as the best controller to track the maximum power point. The output from the fuzzy controller is the duty cycle of the KY converter. By modifying the duty cycle of KY converter, the maximum power can be accomplished. The inverter is utilized for DC/AC conversion which drives the load. The process flow for the proposed methodology is demonstrated in figure 1.

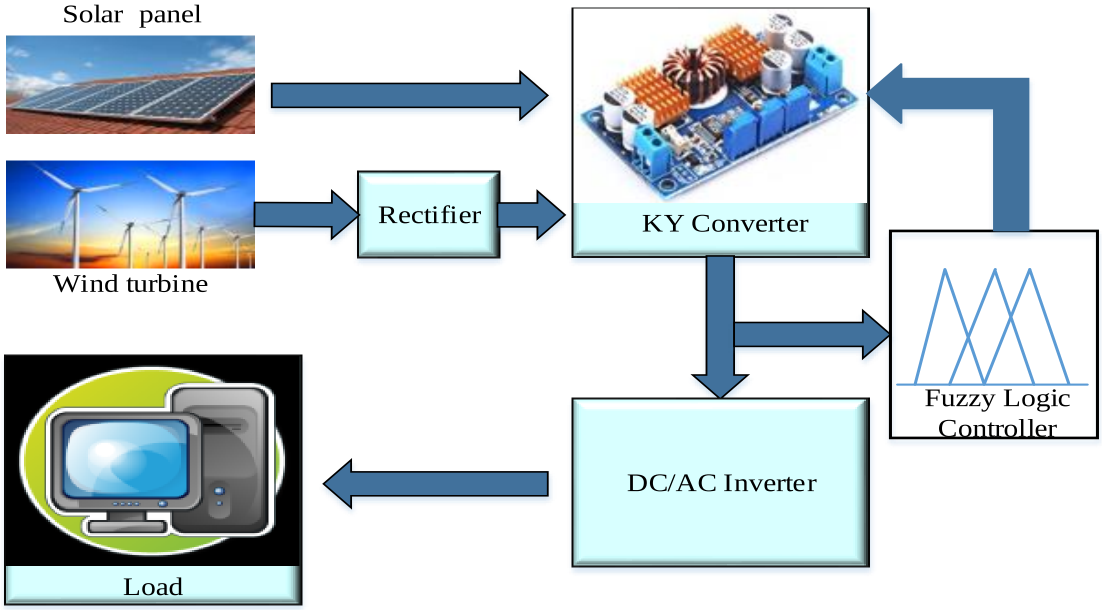


Figure 1: Block Diagram of Proposed System

Initially the electricity is generated from the solar panel and the wind turbine. To generate electricity from solar light photovoltaic (PV) panel is used. When solar light hit the surface of photovoltaic panel it generates direct current (DC) electricity. Likewise wind turbines produce electricity by usage of power from wind to drive an electrical generator. The rotating blades in the turbine turn a shaft inside the nacelle, which goes into a gearbox. The gearbox manufactures the rotational speed to that which is convenient for generator, and utilizes magnetic fields to change over the rotational energy into electrical energy. This wind turbine is generally associated with a rectifier which is in charge for achieving maximum power from the wind by controlling generator torque. The output from this solar panel and wind turbine is fed as input to KY Converter.

3.1Rectifier

The PV and wind turbine voltage and current is given to the rectifier. The rectifier is used to rectify the given voltage and current of the PV and wind system.

3.2KY Converter

The KY converter is the important part because it acts like a buck boost converter. It is used with the fuzzy logic controller circuit to gain more power.

3.2.1 KY Converter Operating Principles

The proposed multi-input dc–dc converter is the combination of the buck-boost and the buck converter. Compounding of the multi stage KY converter are done by the buck converter of pulsating voltage source is inserted into the buck boost converter. The buck converter must be series-connected with the output inductor. In order not to hamper the normal operation of the buck-boost converter and to utilize the inductor for the buck converter. Base on the conduction status of the switches M_1, M_2, M_3, M_4 are the four operating modes of multi-input KY converter. the equivalent electrical circuits for Mode I through Mode IV, is illustrate in fig 2. The switches of M_1 or M_2 are turned off, the M_3,and M_4 will be turned on. The diode D_b will give a free-wheeling path for the inductor current. If the single voltage sources is failed, the other voltage can still provide the electric energy, normally. Therefore, it is very suitable for renewable energy applications.

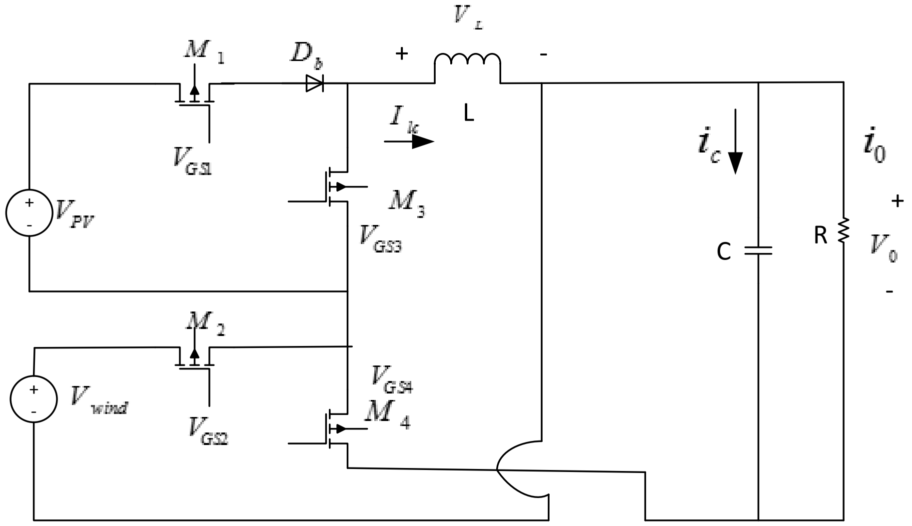
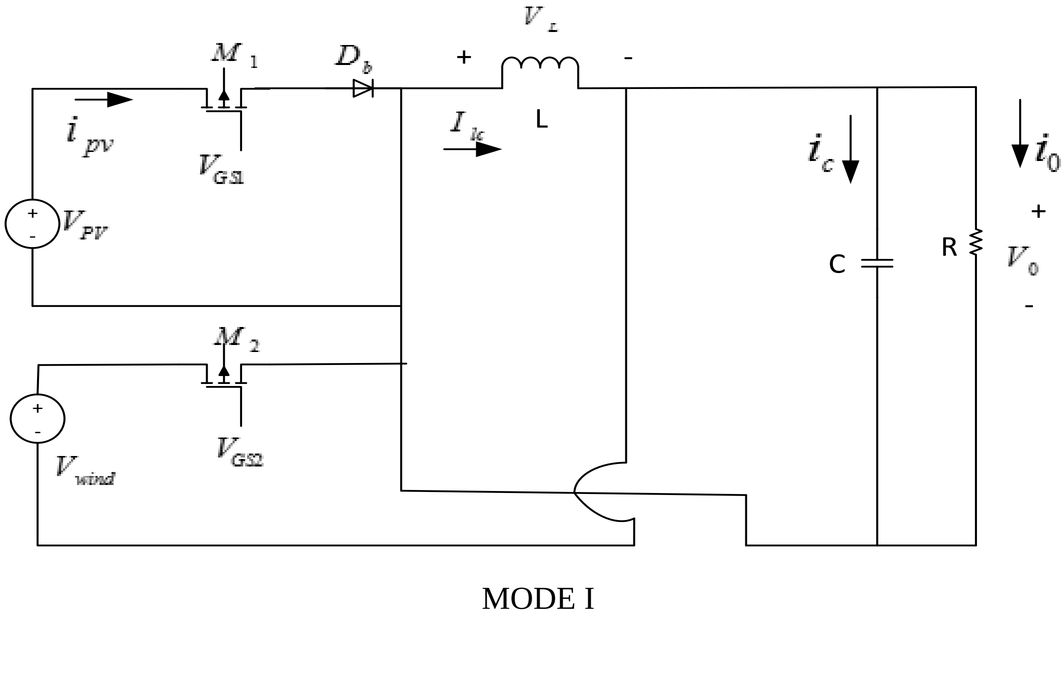


Figure 2: Electrical Circuit Diagram for KY Converter

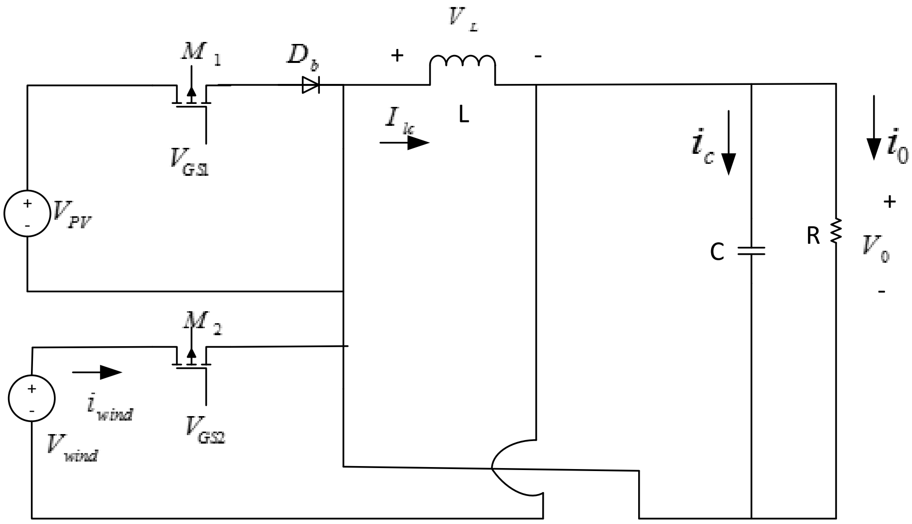
The steady state volt-second balance analysis of the inductor given the input-output voltage connection. The circuit diagram for one switching cycle will follow the sequence of Mode I, Mode II, Mode III, and Mode IV though has longer conduction time.

3.2.1.1 Different modes of dual KY converter

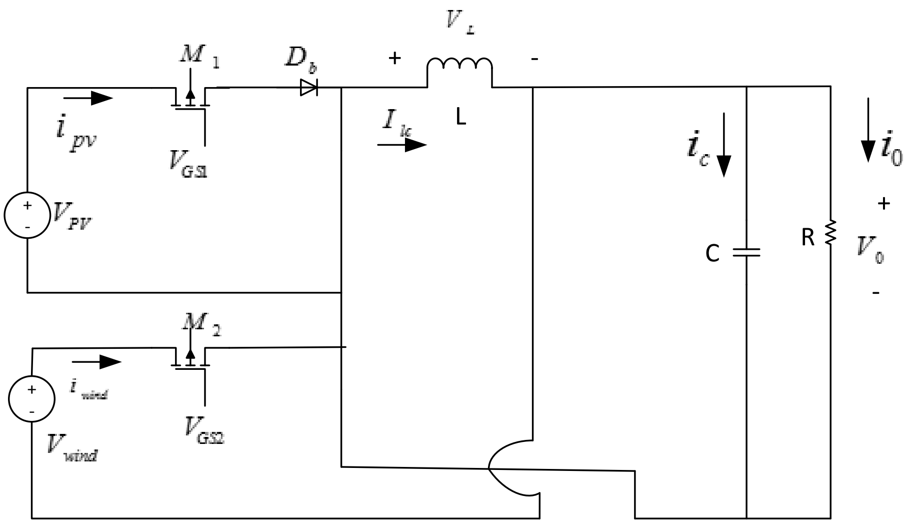
In the first mode the PV system of current is switched to the switch M1. In mode II the current of wind system is given to the switch circuit of M2. In the third mode both the current of PV system and wind system is applied between the switches of M1 and M2. The last IVth mode does not get the PV and wind current.



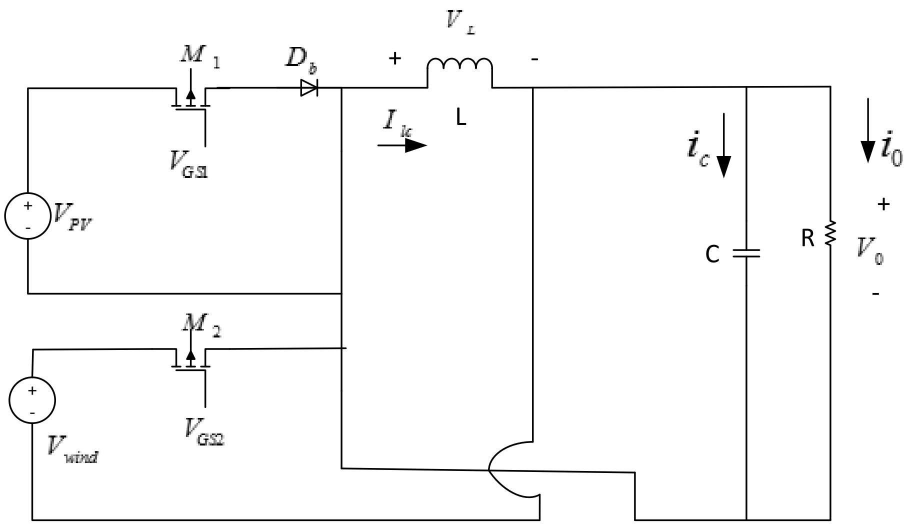
MODE I



MODE II



MODE III



MODE IV

3.3 DC/AC converter

It is used to convert the direct current (DC) into alternating current (AC). Then the converter is fed into the load circuit.

3.4 To extract maximum power using Fuzzy Logic Controller

The output voltage parameter from KY converter is fed as input to fuzzy logic controller is to track and extract maximum power. Fuzzy logic controller is then designed as in [26] to control the KY boost converter output voltage ripple. This is considered as most successful technology for developing sophisticated control system. Here the input is error (E) and change in error (CiE), where error (E) is the deviation in output voltage $v_O^{'}$ and reference voltage vo_{ref} . The output of Fuzzy logic controller is the duty cycle (D). It is fed to a switching signal to the KY boost converter switches to outcome a boosted voltage $v_o^{'}$. The Fuzzy logic controller for KY Converter of Block Diagram is demonstrated in figure 5. The input error E and change in error CiE are defined as

$$E = vo_{ref} - vo_o \quad (17)$$

$$CiE = E(k) - E(k-1) \quad (18)$$

Where k denotes the sampling rate.

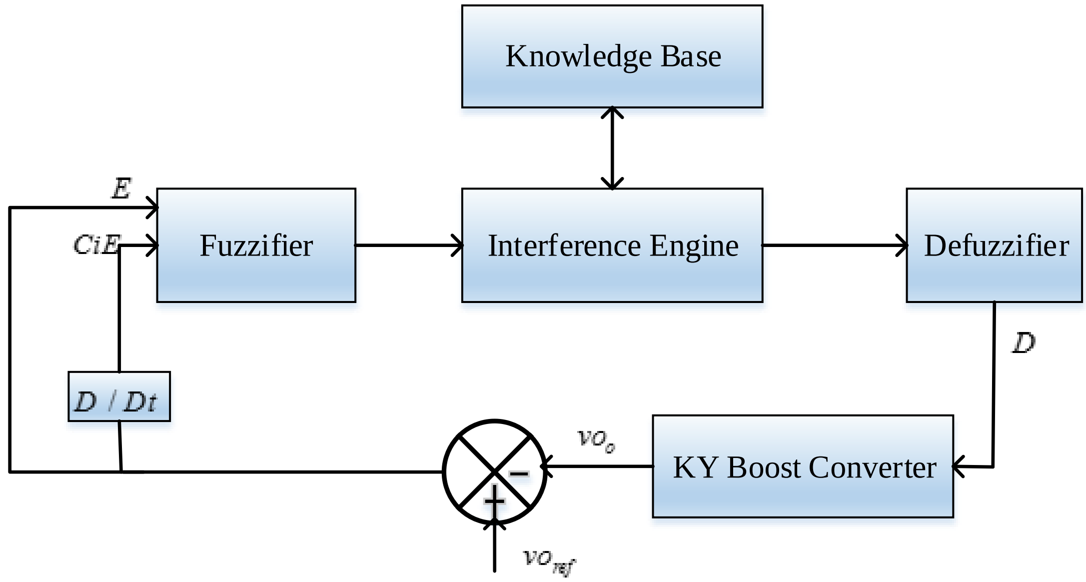


Figure 5: Block Diagram of Fuzzy Controller for KY Boost Converter

The fuzzifier inputs are classified into Gaussian membership function with five classifications they are namely Negative- Big (NB), Negative-Medium (NM), Zero (Z), Positive Medium (PM) and Positive-Big (PB). The defuzzifier comprises duty cycle of output D it is restricted with the above-mentioned membership function classifications. The fuzzy knowledge base comprises of 25 fuzzy rules it defines the input variables and the output variable differences for controlling the duty cycle to generate signal as given in table 1.

Table 1: Fuzzy Rule

$CiE \setminus E$	**NB**	**NM**	**Z**	**PM**	**PB**
NB	NB	NB	NM	NM	Z
NM	NB	NM	NM	Z	PM
Z	NM	NM	Z	PM	PM
PM	NM	Z	PM	PM	PB
PB	Z	PM	PM	PB	PB

Thus, the fuzzy logic controller provides a boosted voltage output $vo_o^{'}$ thus extracting maximum power. Additionally, the fuzzy logic controller tracks maximum power and this output is sent as a feedback to the KY converter and then the other process begins. Thus the rapid reduction in output voltage ripple KY boost converter i.e. output voltage ripple is controlled and also results in reduction of settling time. The extracted voltage $vo_o^{'}$ is given to KY converter as boosted voltage and is fed to inverter for conversion of DC to AC to transmit to load for commercial use, economical use etc.

4. Simulation Results and Performance Evaluation

The proposed multi-input KY converter is a voltage buck-boost converter possessing non-pulsating output current. The wind energy is rectified and then both the PV and wind outputs are given to the fuzzy logic controller. The fuzzy logic controller tracks the most extreme power from the wind turbine and PV panel. The specification of simulation parameter described in below table 2. The output of the fuzzy controller is the duty cycle of the KY converter and by adjusting duty cycle of KY converter the greatest power can be achieved. The process is implemented with aid of MATLAB/ SIMULINK. The simulation results are illustrated in figure 6 to 18.

Table 2: Simulation parameters of KY boost converters

Parameter	Value
Input Voltage(V)	250
Rated Output voltage(V)	550
Rated load current(A)	3
Output Inductance(mH)	10
Buffer capacitance(mF)	100
Energy transferring capacitor(mF)	20
Output capacitance (μF)	850
Load(Hp)	783.6
Switching Frequency(kHz)	50
Input Inductance(mH)	20

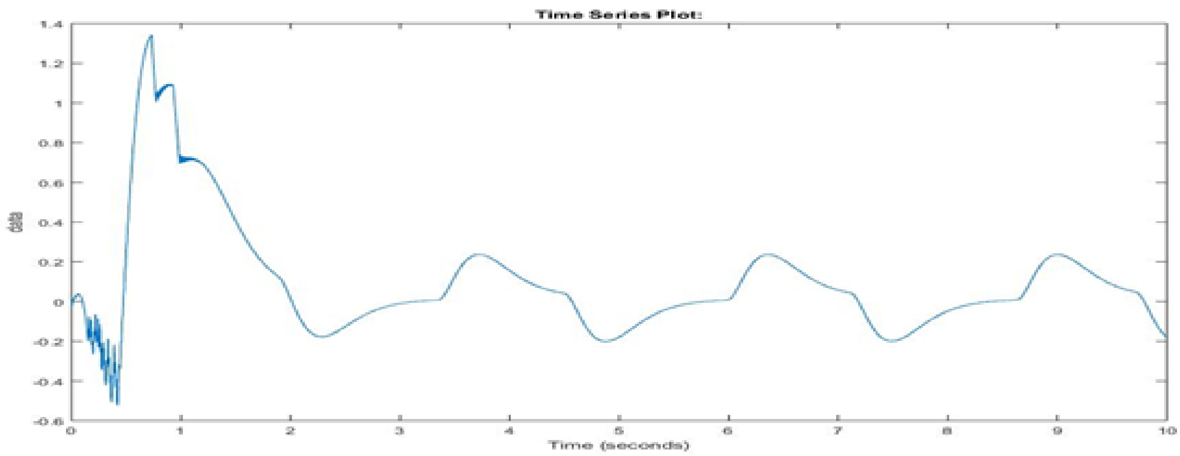


Figure 6: Current waveform of Wind Generator

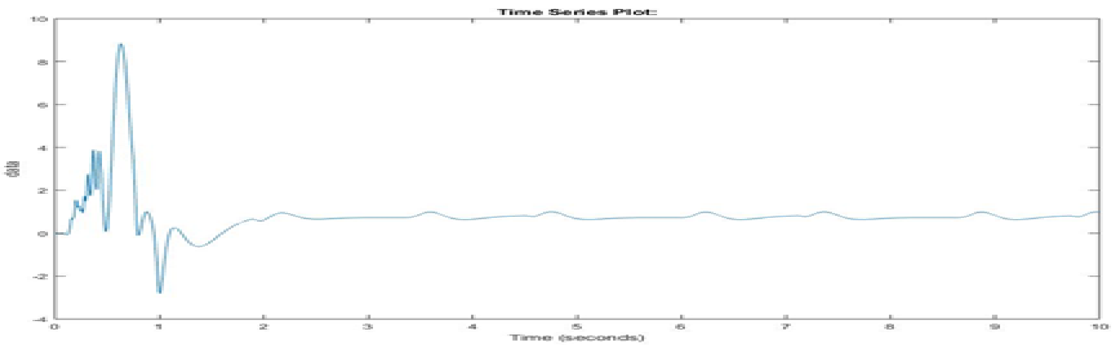


Figure 7: Voltage waveform of Wind Generator

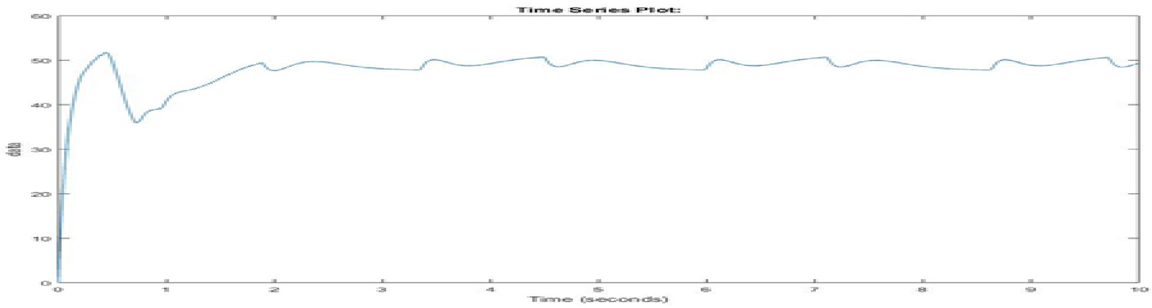


Figure 8: Total power waveform of wind generator

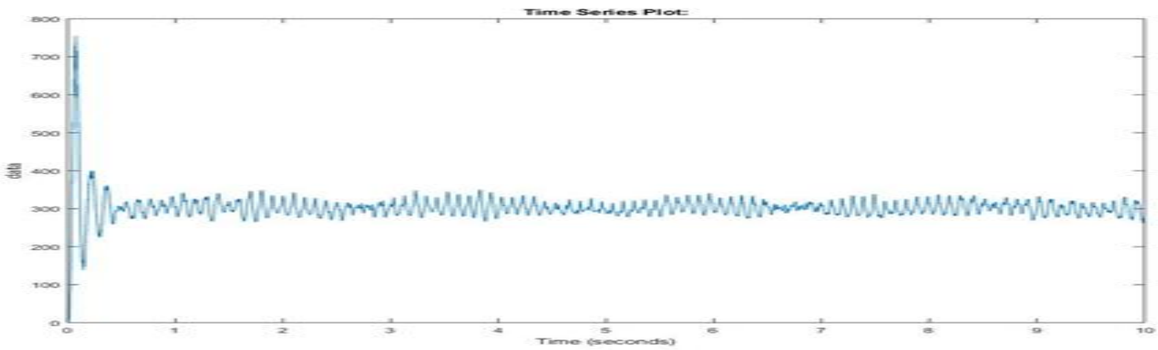


Figure 9: Output Real Power Waveform

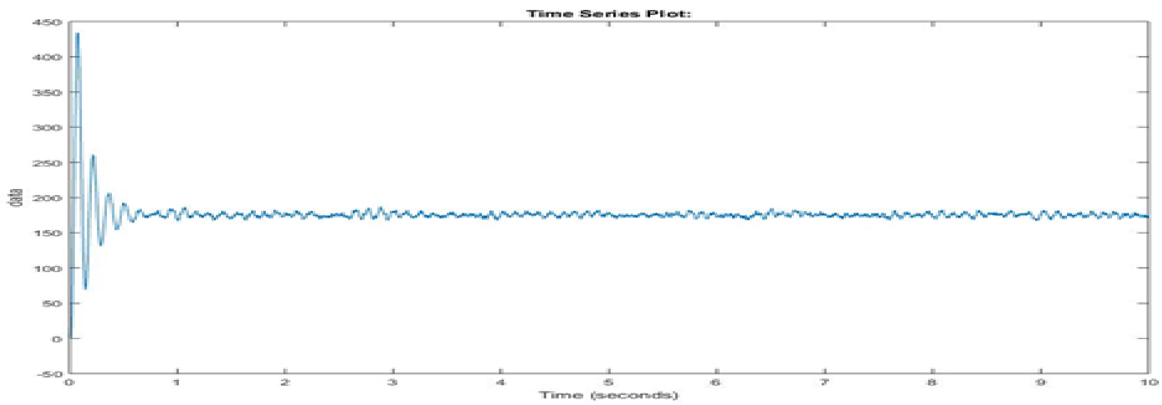


Figure 10: Output Reactive Power Waveform

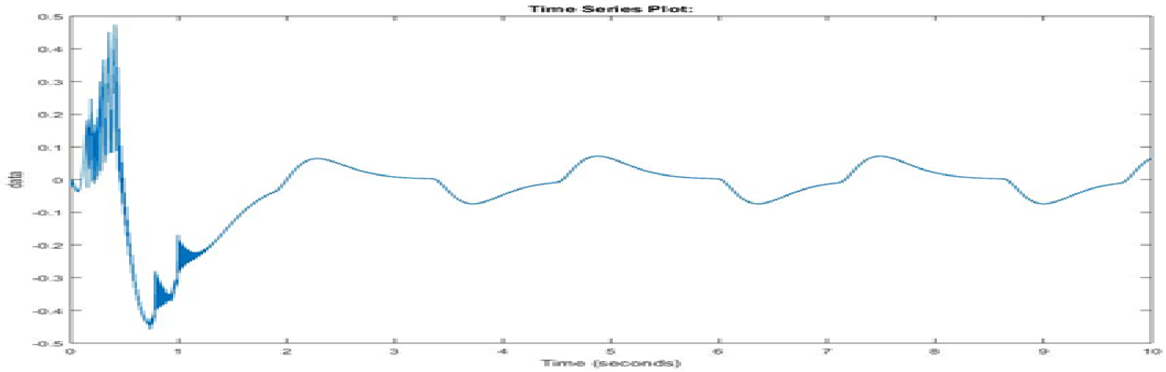


Figure 11: Voltage waveform for solar panel

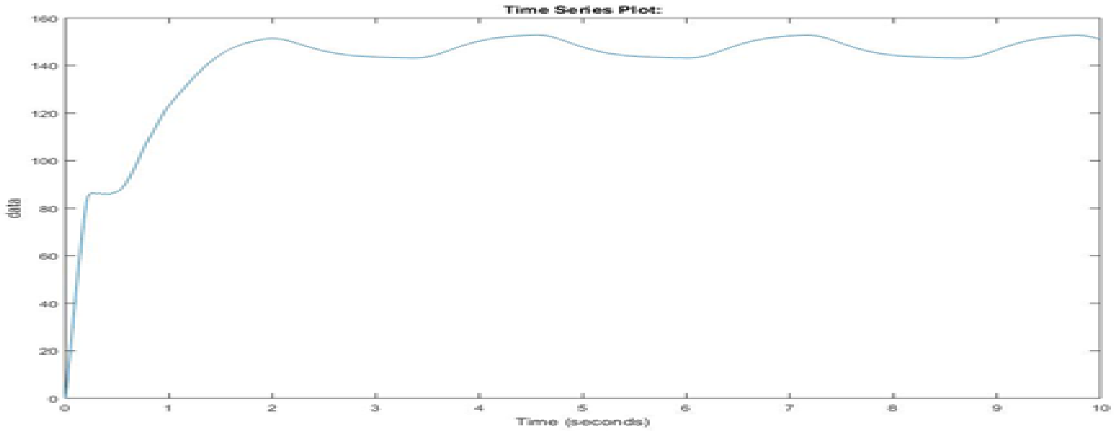


Figure 12: Current waveform for solar panel

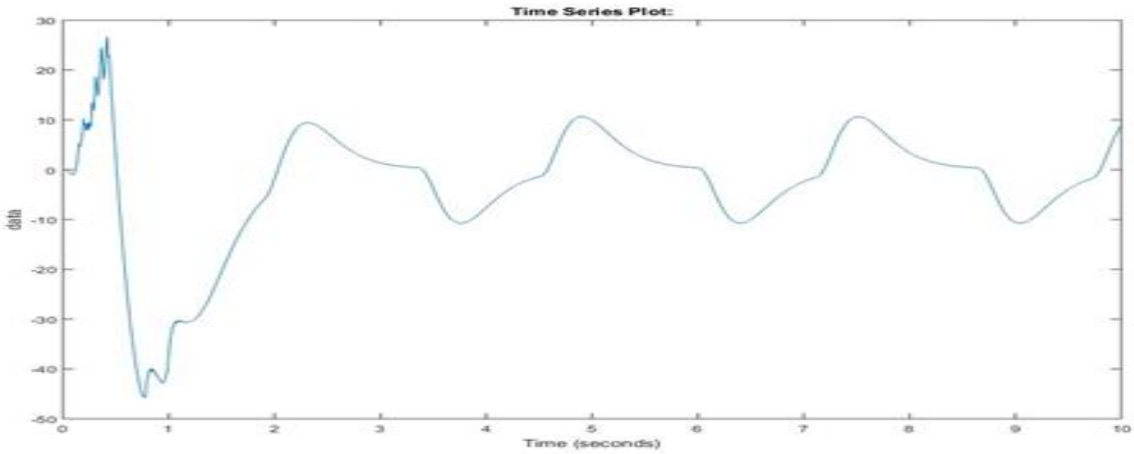


Figure 13: Power waveform for solar panel

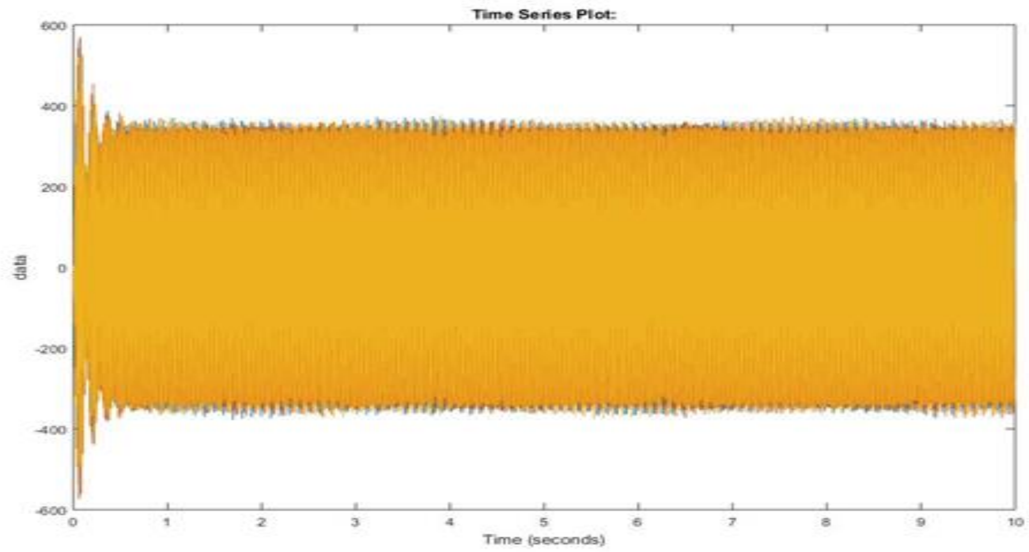


Figure 14: Three Phase Output Grid Voltage Waveform

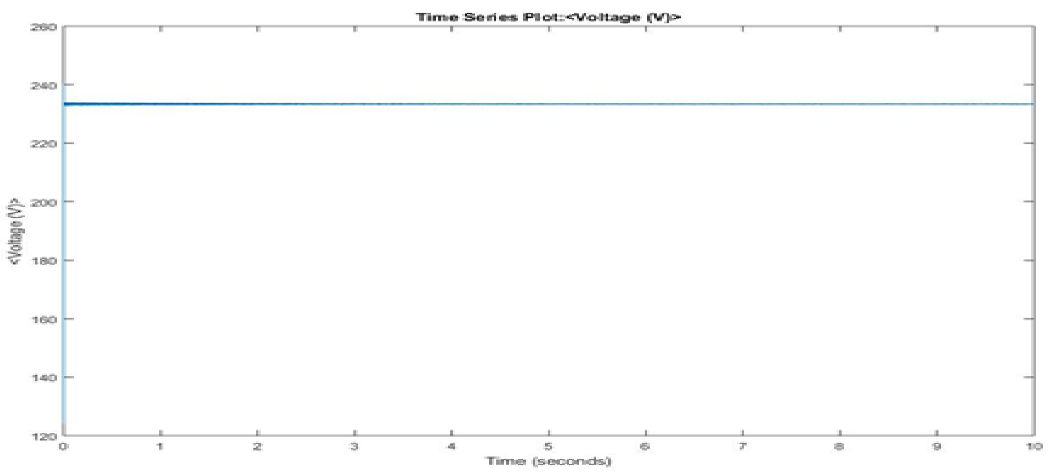


Figure 15: Voltage Waveform for Battery

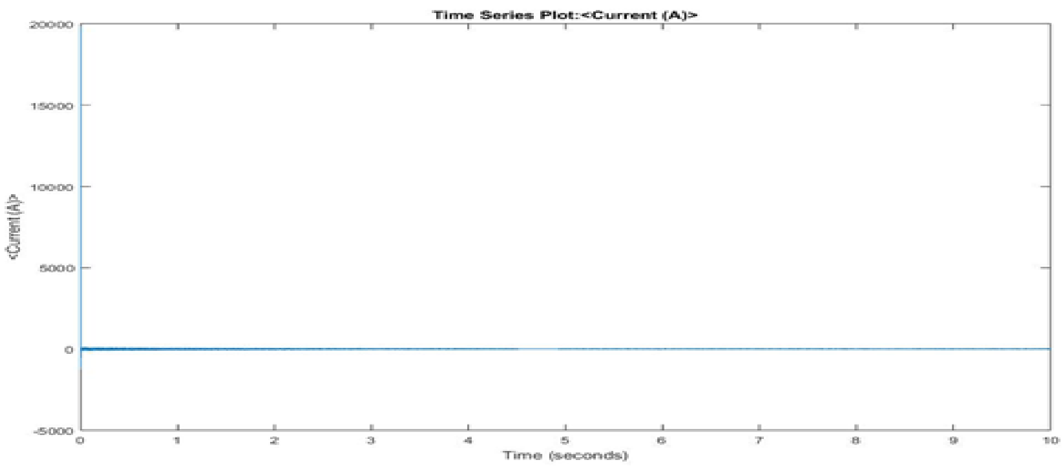


Figure 16: Current Waveform for Battery

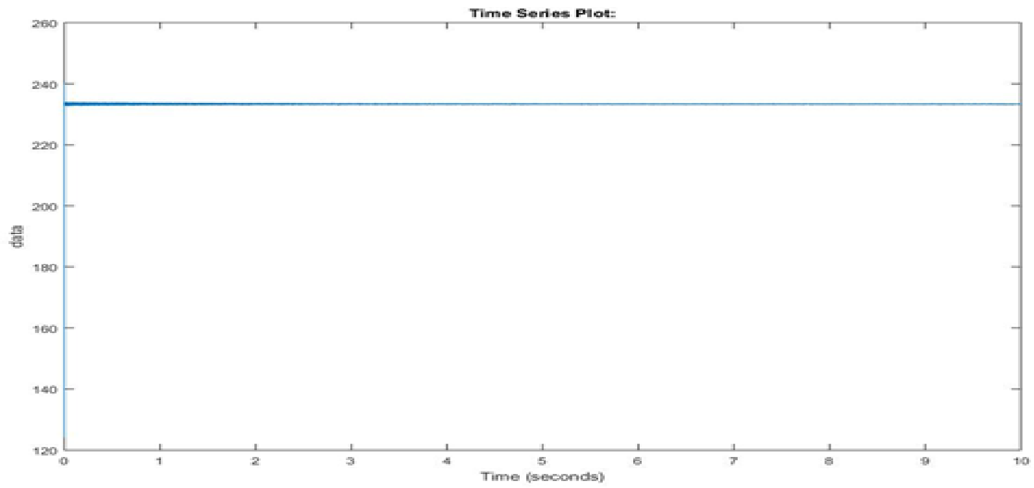


Figure 17: DC Link Voltage Waveform for proposed system

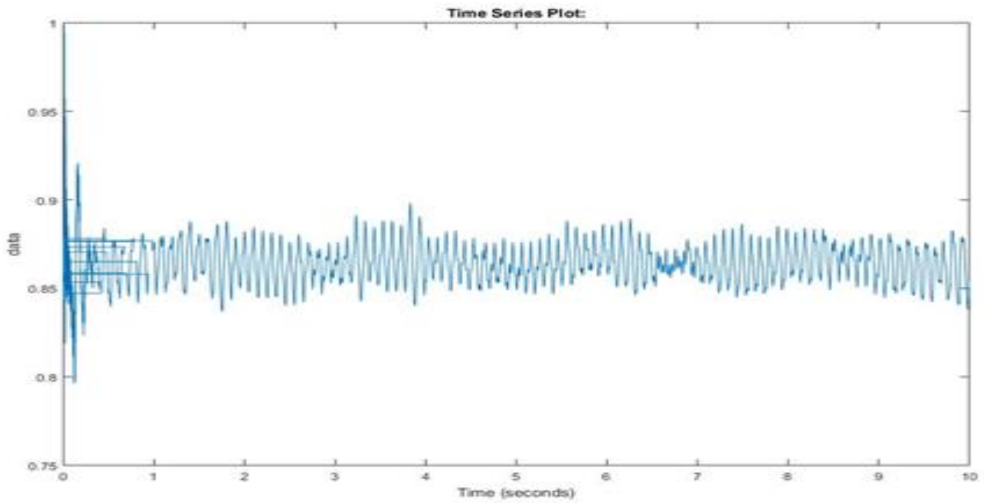


Figure 18: Power factor correction (PFC) waveform

Table 3: Comparison table of proposed fuzzy logic and without fuzzy logic

Parameters	With FUZZY	Without FUZZY
PV output power(w)	520	520
PV output voltage(V)	150	150
Wind output power	170	170
Wind output voltage	50	50
DC output voltage	257	248
Battery voltage	257.1	257.1
Power Factor	0.8806	0.874

5. Conclusion

An innovative integration of solar energy system and wind energy from grid connected PMSG proposed multi connected to the rectifier to rectify AC input in this work. The -input KY converter for hybrid photovoltaic and wind power system extract as much renewable energy as possible by utilizing the fuzzy logic controller. The experimental results demonstrate the total power, real power, reactive power, THD, wind and PV system voltage and current power factor, battery voltage and current, and the DC link voltage and the comparative analysis provide the performance of the proposed work.

CONFLICT OF INTEREST

There is no conflict of interest in this paper regarding publication.

REFERENCES

[1]. Buticchi, Giampaolo, Emilio Lorenzani, and Giovanni Franceschini. "A five-level single-phase grid-connected converter for renewable distributed systems." IEEE Transactions on Industrial Electronics Vol. 60, no. 3, pp: 906-918, 2013.

[2]. Jiang, Wei, and Babak Fahimi. "Multiport power electronic interface—concept, modeling, and design." IEEE Transactions on Power Electronics Vol. 26, no. 7, pp: 1890-1900, 2011.

[3]. Shamsi, Pourya, and Babak Fahimi. "Dynamic behavior of multiport power electronic interface under source/load disturbances." IEEE Transactions on Industrial Electronics Vol. 60, no. 10, pp: 4500-4511, 2013.

[4]. Chen, Wu, Alex Q. Huang, Chushan Li, Gangyao Wang, and Wei Gu. "Analysis and comparison of medium voltage high power DC/DC converters for offshore wind energy systems." IEEE Transactions on Power Electronics Vol. 28, no. 4, pp: 2014-2023, 2013.

[5]. Hui, Joanne, Alireza Bakhshai, and Praveen K. Jain. "A hybrid wind-solar energy system: A new rectifier stage topology." In Applied Power Electronics Conference and Exposition (APEC), 2010 Twenty-Fifth Annual IEEE, pp. 155-161. IEEE, 2010.

[6]. Hwu, K. I., and W. C. Tu. "Voltage-boosting converters with hybrid energy pumping." IET Power Electronics Vol. 5, no. 2, pp: 185-195, 2012.

[7]. Hwu, K. I., and W. Z. Jiang. "Voltage gain enhancement for a step-up converter constructed by KY and buck-boost converters." IEEE Transactions on Industrial Electronics Vol. 61, no. 4, pp: 1758-1768, 2014.

[8]. Banaei, Mohammad Reza, Hossein Ardi, and Amir Farakhor. "Analysis and implementation of a new single-switch buck–boost DC/DC converter." IET Power Electronics Vol. 7, no. 7, pp: 1906-1914, 2014.

[9]. Radhika, S., BS Manikanda Prabhu, and G. Irusapparajan. "Introduction to KY converter for voltage ripple reduction: a technological literature survey." pp: 217-221, 2013.

[10]. Hwu, K. I., and Y. T. Yau. "A KY boost converter." IEEE Transactions on Power Electronics Vol. 25, no. 11, pp: 2699-2703, 2010.

[11]. Olalla, Carlos, Daniel Clement, Miguel Rodriguez, and Dragan Maksimovic. "Architectures and control of submodule integrated DC–DC converters for photovoltaic applications." IEEE Transactions on Power Electronics Vol. 28, no. 6, pp: 2980-2997, 2013.

[12]. Oucheriah, Said, and Liping Guo. "PWM-based adaptive sliding-mode control for boost DC–DC converters." IEEE Transactions on Industrial Electronics Vol. 60, no. 8, pp: 3291-3294, 2013.

[13]. Hwu, K. I., and Y. T. Yau. "KY converter and its derivatives." IEEE Transactions on Power Electronics Vol. 24, no. 1, pp: 128-137, 2009.

[14]. Abrishamifar, Adib, Ahmad Ahmad, and Mustafa Mohamadian. "Fixed switching frequency sliding mode control for single-phase unipolar inverters." IEEE Transactions on Power Electronics Vol. 27, no. 5, pp: 2507-2514, 2012.

[15]. Chen, Zengshi. "PI and sliding mode control of a Cuk converter." IEEE

Transactions on power electronics Vol. 27, no. 8, pp: 3695-3703, 2012.

[16]. Rahavi, JS Anu, T. Kanagapriya, and R. Seyezhai. "Design and analysis of interleaved boost converter for renewable energy source." In Computing, Electronics and Electrical Technologies (ICCEET), 2012 International Conference on, pp. 447-451. IEEE, 2012.

[17]. Shin, H-B., J-G. Park, S-K. Chung, H-W. Lee, and T. A. Lipo. "Generalised steady-state analysis of multiphase interleaved boost converter with coupled inductors." IEE Proceedings-Electric Power Applications Vol.152, no. 3, pp: 584-594, 2005.

[18]. Aby, Jilu Rose, and Teenu Techela Davis. "High Voltage Gain KY Converter with Microinverter for Micro source Application. “International Advanced Research Journal in Science, Engineering and Technology” Vol. 2, Issue 10, October 2015.

[19]. Pugazhendiran, P., and J. Baskaran2 R. Vinothini. "A Step-Down And Step-Up Dc-Dc Voltage Converter Combining KY And SR Buck Converters. “International Journal of Technology and Engineering System(IJTES), Vol. 5,No.2, pp 1-7, 2013.

[20]. Kurniawan, Adi, Eko Haryanto, and A. A. Masroeri. "A neural network based maximum power point tracker with KY converter for photovoltaic system on a moving vehicle." In Advanced Mechatronics, Intelligent Manufacture, and Industrial Automation (ICAMIMIA), 2015 International Conference on, pp. 117-120. IEEE, 2015.

[21]. Hwu, K. I., and Y. T. Yau. "Two types of KY buck–boost converters." IEEE Transactions on Industrial Electronics Vol. 56, no. 8, pp: 2970-2980, 2009.

[22]. Venkatanarayanan S., Jeyalakshmi G., “Analysis of Integrated SEPIC & KY Converter for Solar Energy Conversion with MPPT Controller,” in International Conference on Innovations in Engineering and Technology (ICIET’14), Vol. 3, Special Issue 3, March 2014.

[23]. Zhang, Ying, Dan Li, Hao Lu, Shiquan Fan, Zeqiang Chen, Yan Wang, and Li Geng. "Analysis and Implementation of a High-Performance-Integrated KY Converter." IEEE Transactions on Power Electronics Vol. 32, no. 12, pp: 9051-9064, 2017.

[24]. Radhika, S., R. Rajalakshmi, and D. Venkatesan. "Reduction of VR using Pi and FLC in a buck-boost converter by SR buck–KY boost converter." (2017).

[25]. Hwu, K. I., and T. J. Peng. "A novel buck–boost converter combining KY and buck converters." IEEE Transactions on power electronics Vol. 27, no. 5, pp: 2236-2241, 2012.

[26]. Elmas, Cetin, Omer Deperlioglu, and Hasan Huseyin Sayan. "Adaptive fuzzy logic controller for DC–DC converters." Expert Systems with Applications Vol. 36, no. 2, pp: 1540-1548, 2009.