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Performance Enhancement of Microgrid Using Fuzzy Controller Based Reconfigurable Inverter for Solar-wind Hybrid System

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Microgrid, solar-wind hybrid system, Inverter, harmonics, fuzzy controller

Abstract

This paper mainly concentrates on the new converter topology used for a solar hybrid energy generation for the Microgrid system. The Z source inverter is implemented for low distortion and low conductive losses. The reduced number components and switches are one of the main features of this circuit configuration. MATLAB Simulink simulation is performed for the new converter topology with and without fuzzy controller. This paper details to maximize the energy storage capacity with improved power quality. A single-phase inverter which is reconfigurable for a hybrid AC / DC powered grid is considered and the newly introduced single stage inverter converts the power from DC to DC and DC to AC. This inverter circuit has an advantage of reduced costs, size and losses. Using fuzzy logic based controller, the proposed inverter circuit is controlled to obtain crisp output values, thus reducing the harmonic profile by producing constant grid voltage and grid current. The inverter circuit has an impedance circuit which is not available in conventional circuits. The entire system is modeled in the MATLAB/Simulink software and the effectiveness of the system are analysed through the simulation results. The output voltage is increased with minimum sophistication using a fuzzy controller.

1. Introduction

In this contemporary century, the industrialised countries have demonstrated a great progress and increase in the production of electricity on a large scale as well as in the production of a Microgrid [1]. There has been a significant growth in both the potential and output of all renewable technologies, as well as an increase in the support provided by the government. When it comes to adding power to renewable sources, photovoltaic cells have had the greatest pace of growth ever. The unpredictable nature of renewable energy sources, on the other hand, creates substantial challenges for delivery-related devices in terms of stability and dependability. As a result of the transition that has taken place in the electrical supply business, the consumer has become an essential partner in the organisation. In order to reduce the amount of unpredictability that is associated with the generation of solar photovoltaic energy, many storage alternatives are utilized. Figure 1 depicts the grid-connected system that is connected to the wind-solar hybrid energy storage system. This system demonstrates the power generation that is accomplished through the combination of wind and solar energy with energy storage systems.

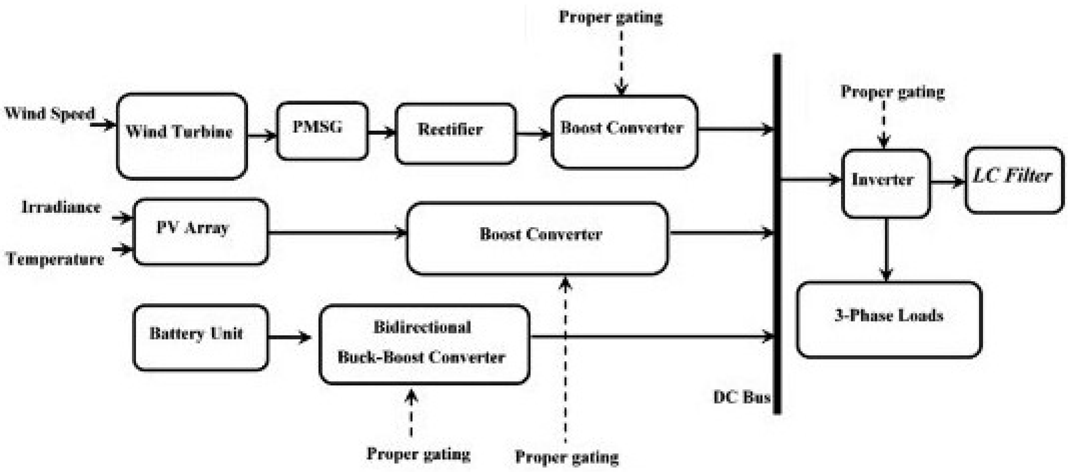


Fig. 1 *Wind-solar hybrid energy storage grid connected system*

The distribution sides are currently facing a significant challenge in terms of the minimising of harmonics. In order to address the harmonic problems and the methods that may be used to mitigate them, a number of research publications have been produced. The decrease of harmonics in distribution side systems that are based on solar inverters has been investigated in the literature [2-6]. According to reference [7], the utilisation of a photovoltaic–battery system results in an improvement in the system's stability on the distribution side. An inverter that is powered by solar energy is recommended for use in the process of charging an electric vehicle in the literature [8]. In reference [9-15], the advantages of DC micro grids as well as the problems that must be overcome when constructing a new home that is completely powered by DC microgrids were discussed. In addition, it has been determined, with the use of discernment concerning full buildings in the year 2040, that eighty percent of buildings are already in the process of being constructed currently. It is more important to recognise existing buildings in order to improve their performance than it is to construct a fresh new home in the District of Columbia. An investigation was conducted in reference [16] to examine the effectiveness of distributed secondary coordination control for microgrids.

Additionally, the inverter makes use of the additional DC link voltage, which is the maximum magnitude of the grid voltage [17]. This particular scenario calls for the completion of both the conversion and inversion processes. However, this will result in an increase in both the cost and the size. These issues can be avoided by utilising one-stage inverter technology, which are recommended in references [18-24].

Transformer-less inverters are discussed in reference [25], which pertains to this particular inverter topology. A discussion on the design of fuzzy logic controllers and their applications in electrical engineering may be found in references [25-30]. As may be seen in Figure 2, the RSC circuit schematic is presented.

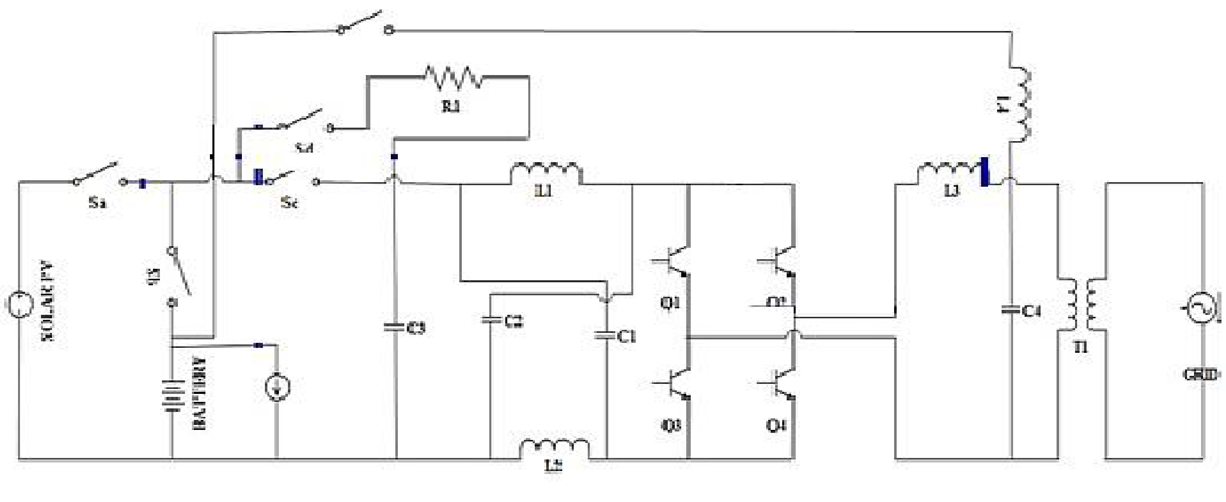
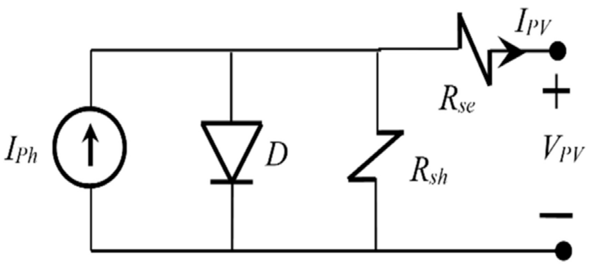


Fig. 2 *Proposed RSC circuit diagram*

Both the scale and the expenses of the converter will increase as a result of the battery. Consequently, the references [31] and [36] discussed the development of three-phase architecture of reconfigurable solar inverter and battery storage for the purpose of photovoltaic (PV) use. This gadget is suited for applications that involve wind farms and solar farms since it can be reconfigured. With the help of a fresh set of guidelines, this topology is examined and the findings are displayed. This study presents a single-phase single-level solar converter that is referred to as a reconfigurable solar converter (RSC). It is designed to be used in conjunction with energy storage devices in a microgrid that is powered by wind and solar energy.

Each and every component of this inverter system can be examined in a solar-powered home that incorporates both alternating current and direct current loads. The electrical additives and sensors are different from those described in reference [37], and the regular inductor is solely utilized for DC/DC operation. The difference in solar radiation is taken into account, and the performance of the solar photovoltaic battery is demonstrated. Within the context of this model, the circulation current is reduced as a result of the use of switches. An additional distinction is made between the control logic and the sampling of entire quantities in this paper.

In the second section, the mode of operation and assessment of the inverter are defined separately. The third section discusses the suggested converter update and the significant design requirements for upgrading to the proposed converter. Additionally, the fourth section verifies the presented topology with simulation results. Figure 3 depicts the equivalent circuit of a photovoltaic cell as well as the output power characteristic curve of the cell. This curve indicates
the maximum power output in the V-I plane.



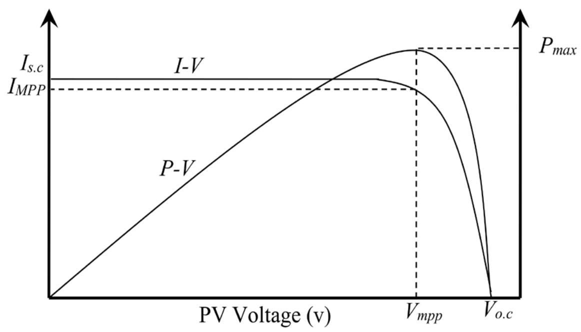


Fig. 3 *(a) Photovoltaic cell equivalent circuit; (b) output power characteristic curve*

2. Reconfigurable Solar Converter Topology

Reconfigurable fuzzy controlled solar inverter circuit diagram is shown in the Figure 2 and the cable specifications are greater for this scheme, although it will decrease the number of power conversion. Table.1 displays the operating modes of the proposed single-stage single phase converter. Furthermore, various modes of operations are given in Figs. 4-7.

Table 1 *ON and OFF states of the reconfigurable solar converter*

Different Modes	ON state switches	Off state switches
PV-Grid	S_a ,S_c ,S_d	S_b, S_e
PV-Battery- Grid	S_a ,S_b ,S_c ,S_d	S_e
PV- Battery	S_a ,S_c ,S_e	S_b , S_d
Battery - Grid	S_b ,S_c	S_a , S_d ,S_e

2.1 Mode-1

The operation of mode 1 is depicted diagrammatically in figure 4, which contains the information. Whenever this mode is employed, the photovoltaic (PV) system is connected to the grid in a manner that is direct. Because it makes use of a fuzzy logic controller, the solar panel is able to collect the maximum amount of power that is possible as a result of this. It is through the utilisation of the inverter that the photovoltaic (PV) system is brought into synchronisation with the grid.

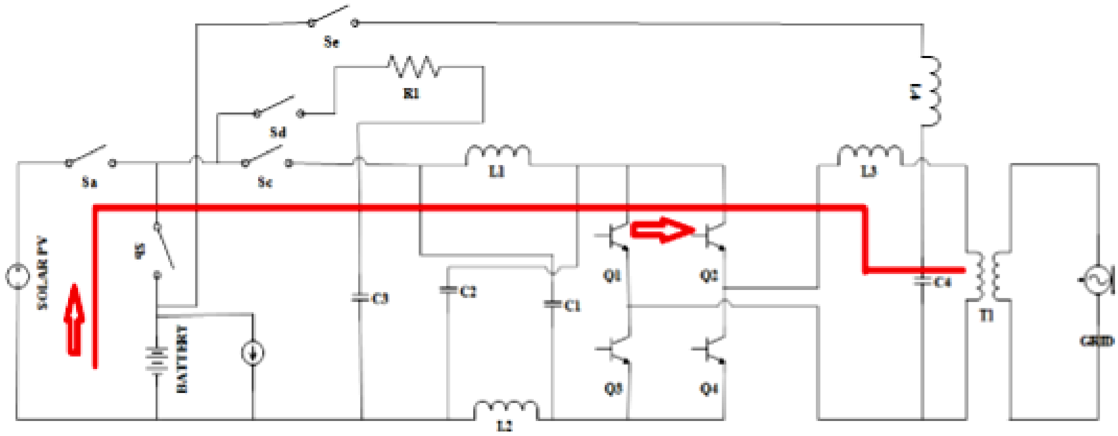


Fig. 4 *Mode.1-PV to grid*

2.2 Mode-2

Figure 5 is a visual representation of the second configuration of the operational system. The load is split between the solar photovoltaic system and the battery that is connected to the grid while the system is operating in this mode of operation. It is necessary to engage this mode in circumstances where the amount of electricity generated by solar photovoltaic (PV) systems is insufficient owing to external factors. One of the challenges that are linked with this technology is that the voltage of the PV system and the voltage of the battery must be balanced at all times. Additionally, this must be done continuously.

2.3 Mode-3

As may be seen in Figure 6, the DC/DC functioning of the topology that was only recently proposed is displayed. In order to achieve the objective of charging the battery, this topology employs the converter in the capacity of a chopper. An extra inductor can be utilised in order to accomplish the goal of achieving a further reduction in the ripple of the charging current. Additionally, in the event that there is an excess of energy, it is utilised during the nighttime hours for the purpose of charging the battery. This is done in the event that there is a surplus of energy.

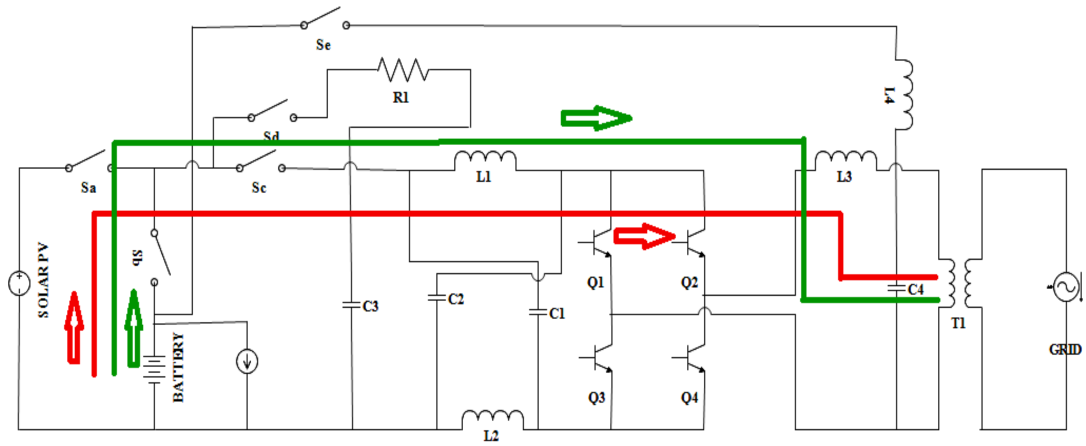


Fig. 5 *Mode.2 mode PV-battery to grid*

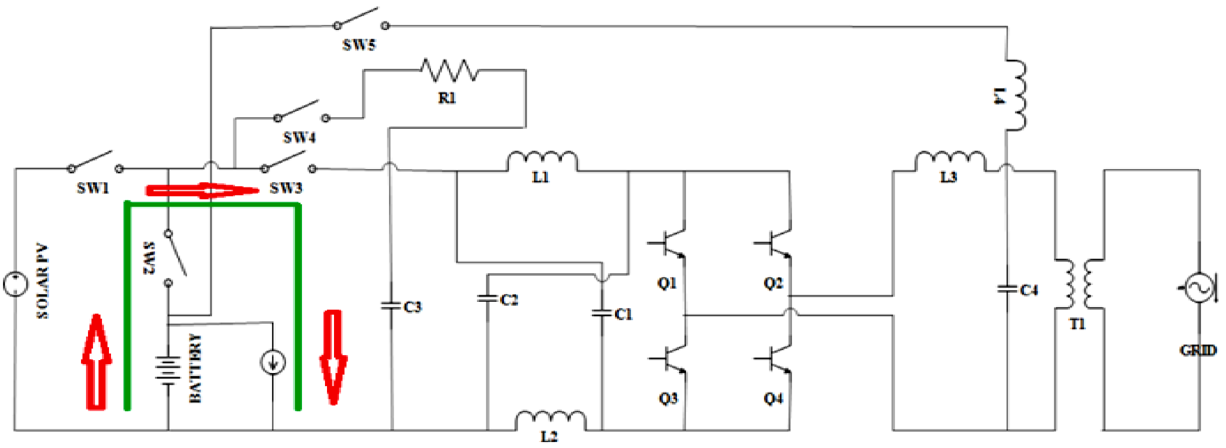


Fig. 6 *Mode.3-PV to battery charging*

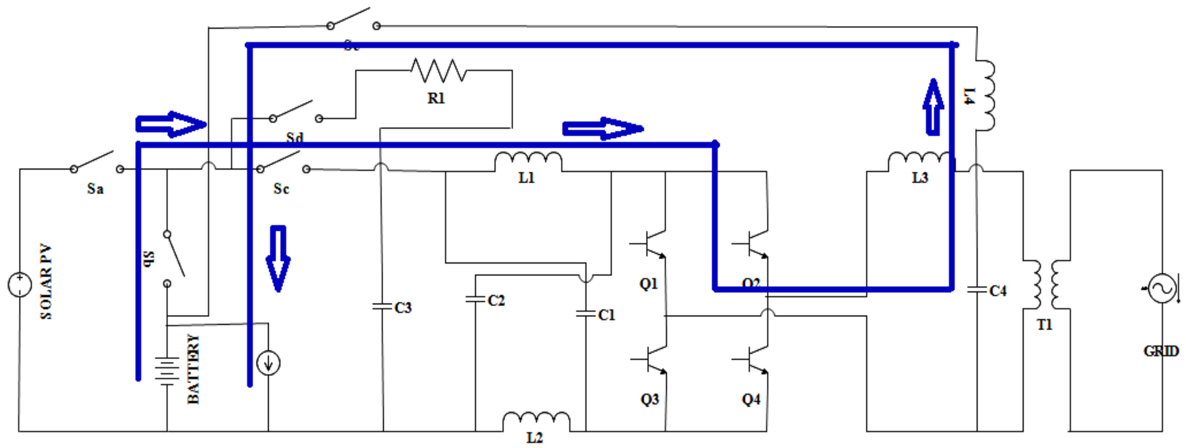


Fig. 7 *Mode.4-battery to grid*

2.4 Mode-4

The grid is able to make use of the energy that is stored in the battery during the nighttime or when there is no solar radiation present, as demonstrated in Figure 7. This is a possibility. It is the responsibility of the inverter to ensure that the terminals receive a constant supply of electricity from the battery. As a result of this, it is feasible for this to be precise and beneficial throughout the process of enhancing the quality of the electricity.

3. Proposed Reconfigurable Solar Converter Control

The drawbacks of the long-established V-source and I-source converters can be overcome by use of a Z-source power converter. In this topology a distinctive impedance network is united with the inverter circuit. The Z-source circuit is a Two-port network that comprises of inductor and capacitor that are connected in zigzag configuration is brought into play, coupling the inverter to the DC source. The voltages are enhanced with shoot through states by use of the impedance network. The output control and harmonic content is also improved by use of the impedance network.

Use of the Z-source inverter not only reduces the volume and cost but also reduces the no. of active devices. The entire system efficiency is significantly improved by the use of this inverter. Switches used in the converter will be used to achieve the combination of active devices and anti-parallel diode.

The simulations of proposed single-phase inverter topology with four different modes are carried out using MATLAB / Simulink modal. Among the four modes, PV to grid is the first mode of operation in which the power is directly fed to the grid from PV system without connecting the battery. Then in the second mode the PV charges the DC voltage in battery using chopper circuit. In the third and fourth modes, the battery power and the direct PV power are fed to the grid using inverter and chopper circuit configuration. The proposed converter configuration is tested by analysing the simulation results.

Table 2 *Specifications of reconfigurable converter*

Devices	Value
Battery	390V,10Ah
Capacitors(C1,C2)	1000µF
Inductors(L1)	1mH
Switching frequency	50Hz
Resistor(R1)	1 Ω

Table 3 *PV panel specifications*

Devices	Value
No. of cells in a module	36
O.C voltage(V)	22.09
S.C current(A)	8.36
Number of series-connected module	14
Number of parallel-connected module	20
Resistance in Series (Ω)	0.18
Resistance in parallel (Ω)	360

The various rating of the system is being specified the radiation is kept at 120W/m^2 with the temperature of about 25^{0}C. Grid, PV to battery to grid, PV to battery charging and finally battery to grid is also analysed.

3.1 Fuzzy Speed Controller

Fuzzy logic is a mathematical tool to simulate neural networks. A fuzzy logic controller (FLC) has a set of rules, which is used to determine the final control action. The diagrammatic illustration of the FLC system is depicted in Fig.8. It consists of inference, rule base and defuzzification. The speed error (*e(k)*) and previous state error (*de(k)*) are the 2 inputs to the FLC and Fig. 9 and 10 depicts the corresponding membership function. The rules are designed, and framed a matrix as shown in Table 4. The FLC rule base of a system is denoted by:
If '*e(k)*' is 'PL' and '*de(k)*' is 'Z' then '*c*' is 'PS'.

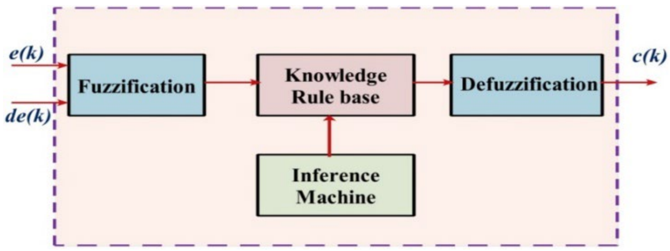


Fig. 8 *General FLC rule base system*

Int. Journal of Integrated Engineering Vol. 16 No. 7 (2024) p. 162-175

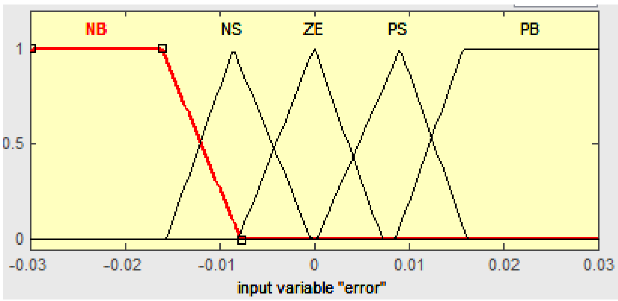


Fig. 9 *Input variable (error)*

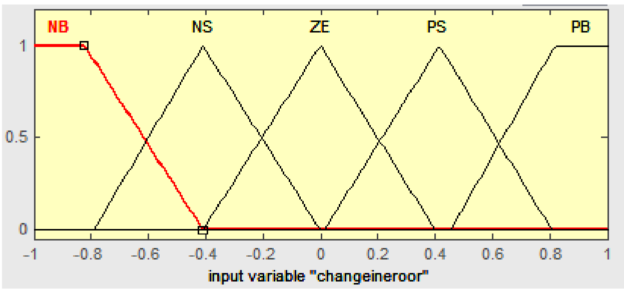


Fig. 10 *Input variable (change in error)*

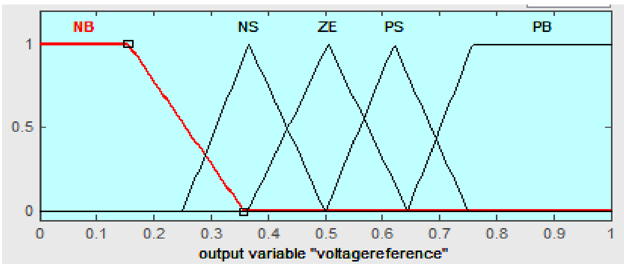


Fig. 11 *Output variable (voltage reference)*

The defuzzification is used to convert the output variables from inference value to crisp. Numerous defuzzification procedures are presented in literature. Conversely, the crisp values are calculated by applying center of gravity and hence centroid method is taken into account for the controller design. There are two input variables they are Error e(k) and change in error de(k) and the output variable is chosen as (u) and the diagrammatic representation is shown in Figure 9-11. The membership function is triangular type.

Table 4 *Fuzzy rule base*

	Error *(e)*					
Previous state error *(de)*		NL	NS	Z	PS	PL
	NL	NL	NL	NS	NS	Z
	NS	NL	NS	NS	Z	PS
	Z	NS	NS	Z	PS	PS
	PS	NS	Z	PS	PS	PL
	PL	Z	PS	PS	PL	PL

4. Simulation Results

The converter off state is labeled as Mode-0. As similarly, solar panel to grid is Mode1, solar PV panel/battery to grid is Mode-2 and solar PV panel to power unit charging is Mode-3. In order to avoid the avalanche current, a small limiting resistor of 2 KΩ is connected in series with the DC link capacitor.

The Figure 2 shows the Mode-0 to Mode-1 operation of proposed inverter. Inverter is turned ON from off state and later an interval of time; it is connected with the grid.

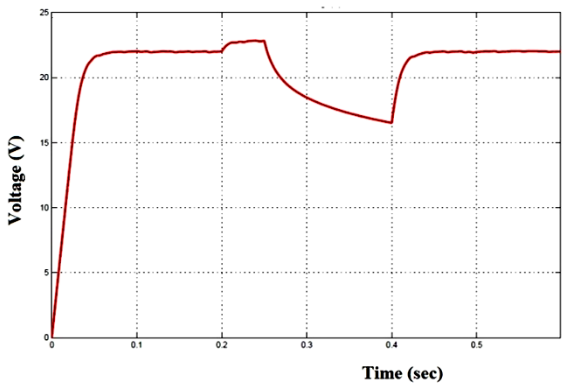


Fig. 12 *Solar panel output voltage waveform with variation in the irradiation*

From the Figure 12 it is observed that, the panel produces the voltage that reaches the constant value with in a small interval and Figure 13 shows that the current produced by the panel with the specified irradiation and temperature.

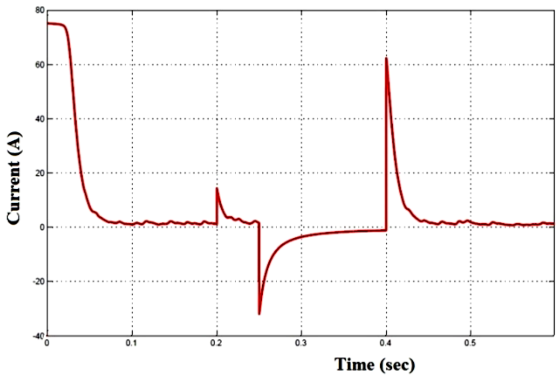


Fig. 13 *Solar panel output current wave form with variation in the irradiation*

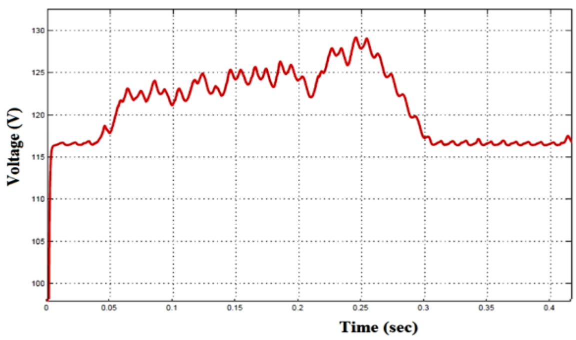


Fig. 14 *DC link voltage waveform for variation in the PV irradiation*

The output voltage obtained from the solar panel is input to the chopper. Figure 14 depicts the output voltage of the chopper circuit for variable PV irradiation. This variable output voltage obtained from the chopper is connected as input source for the inverter circuit through the DC link.

Due to the variations in the irradiation, the voltage obtained at the output terminal is also variable. This variable alternating supply will damage the electrical equipment and the power supply is not with constant magnitude. Figures 13 and 14 reveal the performance of the inverter circuit.

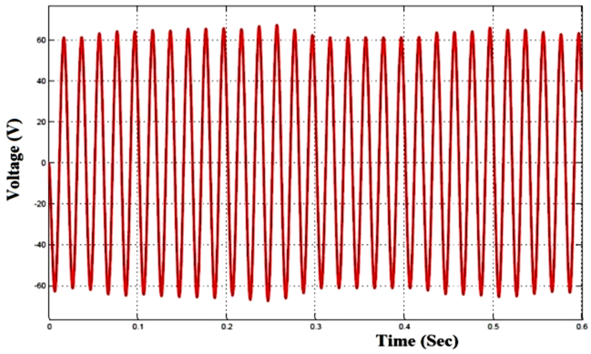


Fig. 15 *Inverter output voltage for the variations in PV irradiation*

This variable output voltage is converted to constant voltage with the help of FLC. The fuzzy controller is located in between the solar panel and chopper system. The voltage at output terminal is sensed and compared to the ref. voltage. The e(k) signal and de(k) in error signal will act as the input to the FLC. The output of the FLC is given to the control circuit in order to modify the width of the pulse given to the chopper switch. By modifying the pulse width; the output voltage of the chopper is maintained at constant value.

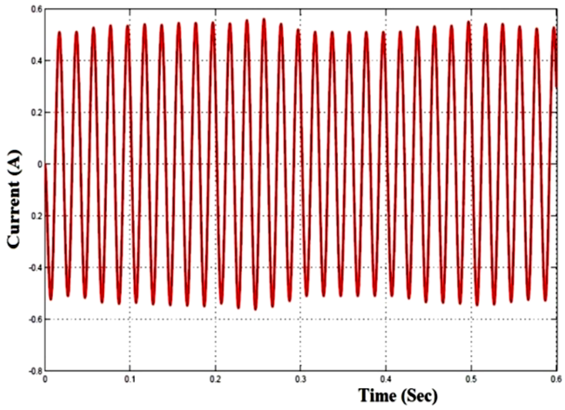


Fig. 16 *Inverter output current waveform for the variations in PV irradiation*

Afterwards, the constant dc voltage is connected to the inverter system. Figure 15 shows the output voltage of the chopper circuit.

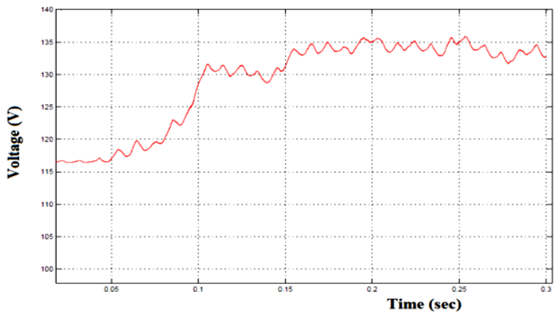


Fig. 17 *Dc link voltage wave for without fuzzy controller*

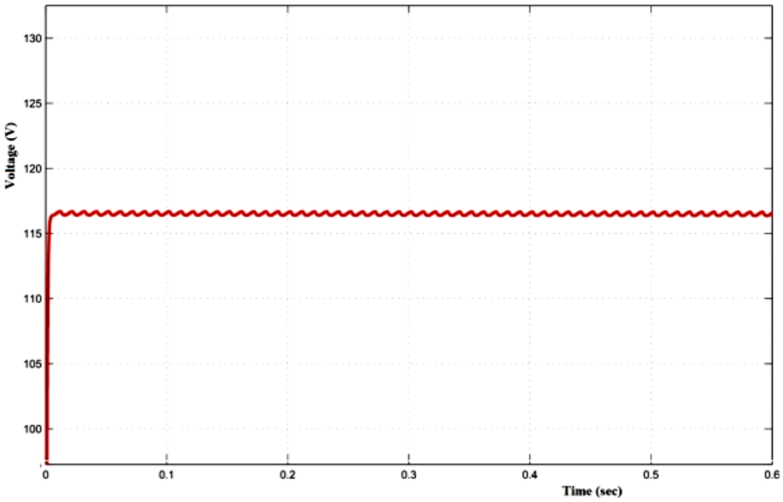


Fig. 18 *Dc link voltage waveform with fuzzy controller*

Figure 18 shows the Dc link output voltage with fuzzy controller. Figure 19(a) – (c) gives the inverter output voltage and total harmonic distortion for both with and without fuzzy controller. Figure 19 and 20 are obtained by operating the switches according to Mode 2.

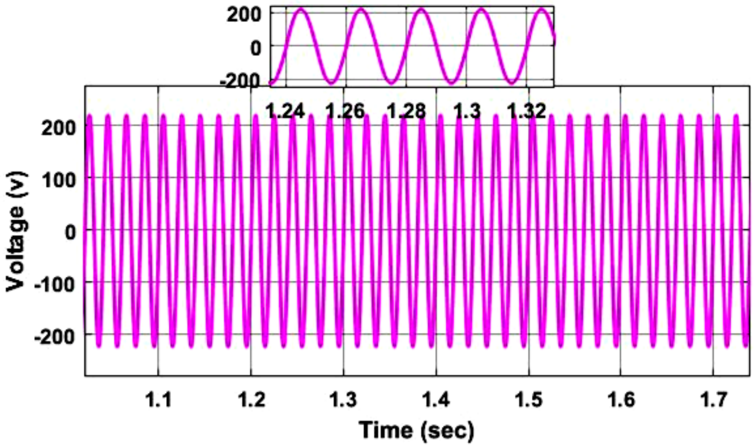


Fig. 19 *(a) Inverter output voltage with fuzzy controller*

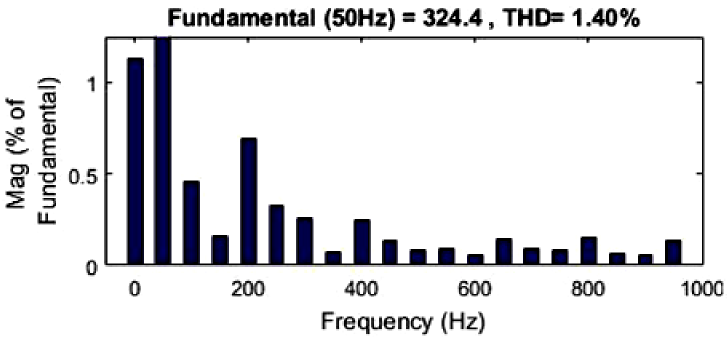


Fig. 19 *(b) %THD of inverter output voltage with fuzzy controller*

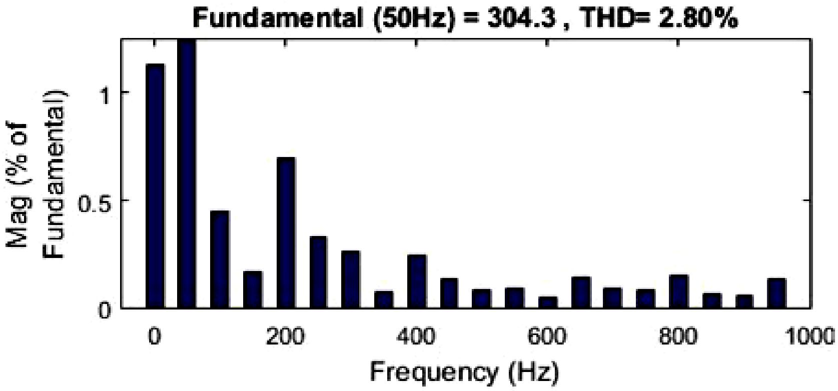


Fig. 19 *(c) %THD of Inverter output voltage waveform without fuzzy controller*

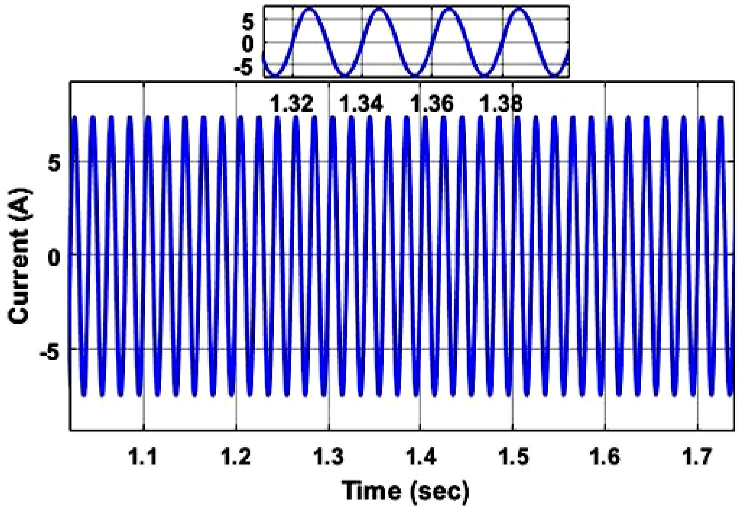


Fig. 20 *Inverter output current waveform with fuzzy controller*

In mode 3, the solar PV system is eliminated and battery is used to supply the grid. Therefore, the implementation of RSC as their solar converter configuration is possible and the feeder may achieve a significant reduction in harmonics. Reduction of such harmonics also helps in reducing the power of distortion.

It is evident from Table 5 that the fuzzy controller helps to lower the system's harmonic distortion. A comparison between the three settings with and without fuzzy controllers has been made. As it stands, the fuzzy controller has decreased the overall harmonic distortion. With a fuzzy controller, the overall harmonic distortion has been decreased.

Table 5 *THD Comparison in inverter output voltage*

Mode of operation	Inverter output Voltage (% THD)	
	Without Fuzzy controller	With Fuzzy controller
PV-Grid	3.1%	1.90%
PV-Battery- Grid	2.8 %	1.4%
Battery – Grid	2.6%	1.6%

5. Conclusion

This study is primarily concerned with the newly created converter topology that is utilised for the generation of solar hybrid energy for the Grid system application. This is the key emphasis of this study. The application of the

Z source inverter allows for the achievement of minimal distortion as well as low conductive losses. One of the most prominent qualities of this particular configuration of the circuit is the reduced number of components and switches that are present. When it comes to the new converter system, simulations are carried out both with and without the fuzzy controller. An increase in the overall efficiency of the system has been brought about as a consequence of the implementation of reconfigurable inverters for photovoltaic systems. When thinking about the hybrid system, the most important thing to take into consideration is the quality of the power. During the course of this study, the converter is created in such a way that the total harmonic distortion (THD) is contained within the control, and it displays the efficiency of the system that was presented. The findings of the simulation indicate that the grid's output voltage and current have been enhanced as a result of increased dependability and a reduction in total harmonic distortion (THD) of less than three percent. This improvement was brought about by the reduction in THD. Taking this into consideration, the converter topology is also advantageous in terms of reducing significant quantities of harmonics in the residential feeders of the smart grid that will be installed in the future.

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We express our sincere gratitude to Dr. J.Surya Kumari for her invaluable guidance and encouragement throughout this research. We extend our heartfelt thanks to our co-authors, M A Nabi and Dr.J Surya Kumari for their significant contributions, particularly M A Nabi efforts in data collection and manuscript preparation. Special thanks to the Department of Electrical and Electronics Engineering at G Pullaiah College of Engineering and technology for providing the necessary resources. We also acknowledge the support of our colleagues and fellow researchers. Finally, we are grateful to our families for their unwavering support and understanding.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper is as follows: ***study conception and design****: M.A.Nabi, J.Surya Kumari;* ***data collection****: M.A.Nabi;* ***analysis and interpretation of results****: M.A.Nabi, J.Surya Kumari;* ***draft manuscript preparation****: M.A.Nabi, J.Surya Kumari. All authors reviewed the results and approved the final version of the manuscript.*

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