Z Source Inverter for Photovoltaic System with Fuzzy Logic Controller

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ABSTRACT

In this paper, the photovoltaic system is used to extract the maximum power from sun to get the dc voltage. The output dc voltage is boost up into maximum voltage level by using the SEPIC converter. This converter voltage is fed to Z source inverter to get the AC voltage. The Z source inverter system can boost the given input voltage by controlling the boost factor, to obtain the maximum voltage. PWM technique which is used as to given the gating pulse to the inverter switches. Modified system is very promising for residential solar energy system. In stand-alone systems the solar energy yield is matched to the energy demand. Wherever it was not possible to install an electricity supply from the mains utility grid, or desirable, stand-alone photovoltaic systems could be installed. This proposed system is cost-effective for photovoltaic stand-alone applications. This paper describes the design of a rule based Fuzzy Logic Controller (FLC) for
Z Source inverter. The obtained AC Voltage contains harmonics of both odd and even harmonics of lower and higher order. Higher order harmonics are eliminated with the help of Filters. Here the impedance network act as a filter to reduce the lower order harmonics obtained in the system. So with the help of FFT analysis this value is obtained to be 15.82%.

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1. INTRODUCTION

Renewable energy is generated from natural resources such as water, sunlight, wind, rain, tides, geothermal sources and biomass sources as energy crops. Renewable energy sources are continually and naturally replenished in a short period of time. In contrast, fuels such as coal, oil, and natural gas are non-renewable. Once a deposit of these fuels is depleted it cannot be replenished – a replacement deposit must be found instead. Both renewable and non-renewable energy sources are used to generate electricity, power vehicles, and provide heating, cooling, and light.

Renewable sources of energy vary widely in their cost-effectiveness and in their availability across the world. Although water, wind, and other renewable sources may appear free, their cost comes in collecting, harnessing, and transporting the energy so that it can do useful work Photovoltaic (PV) systems can be grouped into stand-alone systems and grid connected systems. In stand-alone systems the solar energy yield is matched to the energy demand. Since the solar energy yield often does not coincide in time with the energy demand from the connected loads, additional storage systems (batteries) are generally used. In upcoming years, in the long term it is expected that ever-increasing numbers of stand-alone systems will be installed, especially in developing countries. Small individual power supplies for homes known as solar home systems. The first cost-effective applications for photovoltaic were stand-alone systems. Wherever it was not possible to install an electricity supply from the mains utility grid, or desirable, stand-alone photovoltaic systems could be installed. The range of applications is constantly growing.

Figure 1 shows the standalone system with converters and inverters. Normally the photovoltaic cells are used to produce minimum voltage. The DC-DC converters are boost the voltage to low level voltage to high level voltage. In the figure 1 the SEPIC converter is used to boost the voltage up to maximum level. The SEPIC converter's popularity is due to its ability to operate from an input voltage that is greater or less than the regulated output voltage. This capability allows it to be used in many non-isolated applications such as automotive, medical, security systems, and LED lighting. Once the choice is made to use a SEPIC, you need to decide if you want to use a dual-winding inductor or two separate inductors. A single-coupled inductor is often selected due to its reduced component count and lower inductance requirement compared to using two single inductors.

In the late nineties, Fang Zheng Peng popularized the concept of the Z-Source Converters, which employ a unique impedance network (or circuit) to couple the Converter with the main circuit and then fed to the power source. They provide unique features that cannot be obtained in the traditional voltage-source and current-source converters which use capacitor and inductor, respectively. The conceptual and theoretical barriers and limitations of the traditional voltage-source converter and current-source converter are overcome by the Z-source converter providing a novel power conversion concept that can be applied to all dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion.

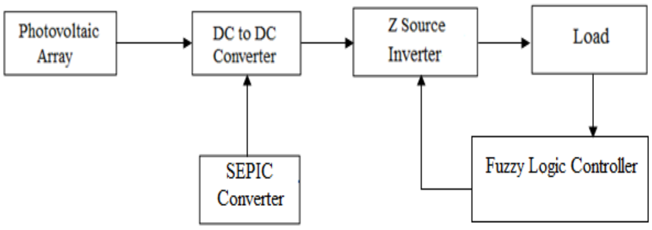

Figure 1. Proposed diagram for standalone system

2. PHOTOVOLTAIC SYSTEM

A photovoltaic (PV), or solar electric system, is made up of several photovoltaic solar cells. An individual PV cell is usually small, typically producing about 1 or 2 watts of power. To boost the power output of PV cells, they are connected together to form larger units called modules. Modules, in turn, can be connected to form even larger units called arrays, which can be interconnected to produce more power, and so on. In this way, PV systems can be built to meet almost any electric power need, small or large. The modules or arrays does not represent an entire PV system. y. PV systems may also include batteries. These items are referred to as the *balance of system* (BOS) components. Combining modules with BOS components creates an entire PV system. This system is usually everything needed to meet a particular energy demand, such as powering a water pump, the appliances and lights in a home, or all the electrical requirements of a community.

Photovoltaic (PV) cells convert sunlight directly to electricity. Fabricated from a wide variety of materials using many different processing techniques, these devices are used for terrestrial power generation, as well as commercial, military, and research space power applications. PV cell characterization involves measuring the cell's electrical performance characteristics to determine conversion efficiency and critical equivalent circuit parameters. A PV cell may be represented by the equivalent circuit model shown in Figure 1, consisting of a photon current source (IL), a diode, a series resistance (r_s), and a shunt resistance (r_{sh}). The series resistance (r_s) represents the ohmic losses in the front surface of the cell and the shunt resistance (r_{sh}) represents the loss due to diode leakage currents. The conversion efficiency (η) is defined as:

$$\eta = \frac{P_m}{P_{in}} = efficiency \quad (1)$$

where P_{in} is the power input to the cell, Voc is the open circuit voltage, I_{sc} is the short circuit current, and I_m and V_m are the maximum cell current and voltage respectively at the maximum power point, $P_m = I_m V_m$.

Conversion Efficiency

Current-voltage (I-V) relationships, which measure the electrical characteristics of PV devices, are depicted by *I-V curves*. These I-V curves are obtained by exposing the cell to a constant level of light while maintaining a constant cell temperature, varying the resistance of the load, and measuring the current that is produced. On an I-V plot, the vertical axis refers to current, and the horizontal axis refers to voltage. The actual I-V curve typically passes through two significant points:

- The *short-circuit current* (I_{sc}) is the current produced when the positive and negative terminals of the cell are short-circuited and the voltage between the terminals is zero, which corresponds to a load resistance of zero.
- The *open-circuit voltage* (V_{oc}) is the voltage across the positive and negative terminals under open-circuit conditions when the current is zero, which corresponds to a load resistance of infinity.

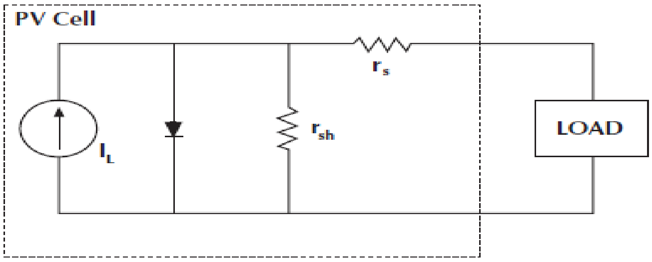

Figure 1. Equivalent circuit model of a photovoltaic cell

3. SEPIC CONVERTER

The single-ended primary-inductance converter (SEPIC) is a DC/DC-converter topology that provides a positive regulated output voltage from an input voltage that varies from above to below the output voltage. Figure 2 shows a simple circuit diagram of a SEPIC converter, consisting of an input capacitor, C1; an output capacitor, C3; coupled inductors L1 and L2; coupling capacitor, C2; a power MOSFET, S; and a diode, D1. Figure 3 shows the SEPIC operating in continuous conduction mode (CCM). S is on in the top circuit and off in the bottom circuit.

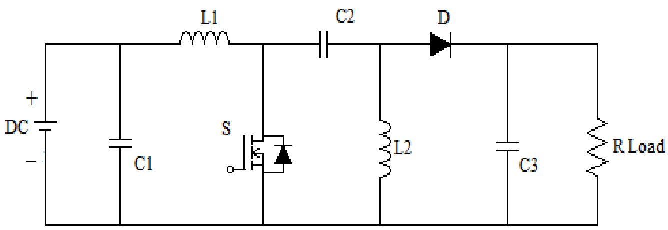

Figure 2. Circuit diagram of SEPIC converter

A) Operating modes of SEPIC Converter

Mode 1: The primary MOSFET (S) turns on during time D. With input voltage imposed across the primary winding, current ramps in the positive direction. The secondary winding also has the input voltage across it due to the 1:1 turn ratio of the coupled inductor. The coupling capacitor then charges to a DC voltage equal to V in. Current flow in both windings is through Switch(S)-to-ground, with the secondary current flowing through the capacitor.

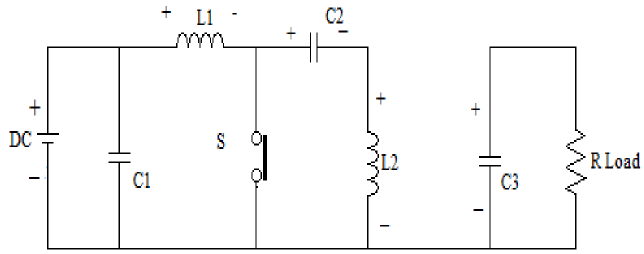

Figure 3. SEPIC Converter Current Flow During Switch(S) On-Time

Mode 2: During the off time (1-D period) polarities across both windings reverse to maintain current flow. The secondary winding voltage is clamped to V out (ignoring the diode drop), and sources current through D1 and into the output. The primary winding voltage is also clamped to V out, while current flows through the capacitor, D1 and into the output. With V out impressed across both windings, and the coupling capacitor held to a constant voltage of V in, the FET sees a potential equal to V in + V out during this period. It is interesting to note that while the coupling capacitor maintains a DC voltage across it; both sides are switching and AC current flows through it. The output capacitor filters this large pulsating current and provides a DC output voltage.

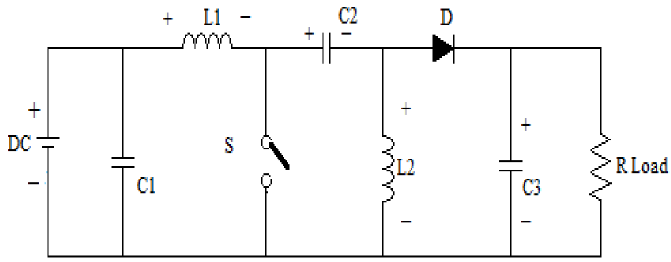

Figure 4. SEPIC Converter Current Flow During Q1 Off-Time

4. INVERTER

An inverter is an electric device that converts DC to AC, the converted AC can be at any required voltage and frequency with the use of switching device and control circuits. Solid state inverters have no moving parts and are used in a wide range and application, from small switching power supplies in computers, to large electric utility high voltage dc applications that transport bulk power. Inverters are commonly used to supply AC power from DC sources such as solar panel or batteries. Inverters are used in various applications such as induction motor drives, UPS, standby power supplies, induction heating etc. Normally they are used for high power applications.

A) Principle

- The output voltage waveform of the inverter can be square wave, quasi-square wave or low distorted sine wave. The output voltage can be controlled (i.e. adjustable) with the help of drives of the switches.
- The pulse width modulation (PWM) techniques are most commonly used to control the output voltage of inverters. Such inverters are called PWM inverters. The output voltage of the inverter contains harmonics whenever it is non-sinusoidal. These harmonics can be reduced by using proper control schemes.
- The inverters can be classified as voltage source inverters or current source inverters. When input DC voltage remains constant, then it is called Voltage Source Inverter (VSI) or Voltage Fed Inverter (VFI). When input current is maintained constant, then it is called Current Source Inverter (CSI) or Current Fed Inverter (CFI). Sometimes, the DC input voltage to the inverter is controlled to adjust the output. Such inverters are called variable DC link inverters.

B) Z Source Inverters

Z source inverter operated with the combination of VSI(Voltage Source Inverter) and the CSI(Current Source Inverter). Normally the traditional inverters convert the DC voltage in to AC voltage.

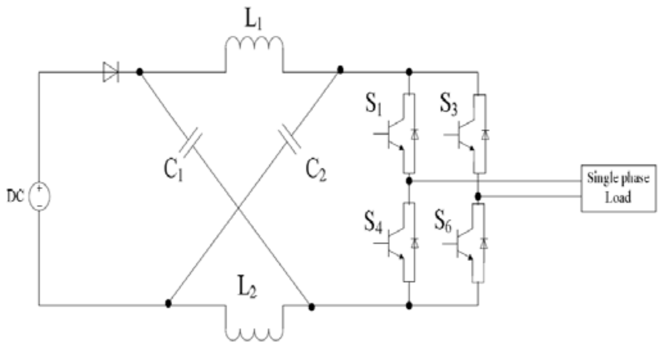

Figure 5. Basic circuit of Z source inverter

Z source inverter not like the traditional inverter it is buck or boost the voltage at the maximum level. The impedance network is connected which is used to boost the voltage to maximum level and it act as a filter. The structure is as shown in Figure 5. Z-source inverters are single-stage electronic power converters which have both voltage-buck and boost capabilities. A Z-source inverter is proposed, which can operate at wide range load (even no-load) with small inductor, eliminating the possibility of the dc-link voltage drops, and simplifying the inductor and controller design. The Z-source inverter is a buck–boost inverter that has a wide range of obtainable voltage. The traditional V- and I-source inverters cannot provide such feature. This shoot-through zero state is forbidden in the traditional V-source inverter, because it would cause a shoot-through. The shoot-through zero state, which can be generated by seven different ways: shoot-through via any one phase leg, combinations of any two phase legs, and all three phase legs. The Z-source network makes the shoot-through zero state and non shoot through switching state is possible. This shoot-through zero state provides the unique buck-boost feature to the inverter.

C) Inductor selection

During traditional operation mode, when there is no shoot-through, the capacitor voltage is always equal to the input voltage; therefore, there is no voltage across the inductor and only a pure dc current going through the inductors. The purpose of the inductor is to limit the current ripple through the devices during boost mode with shoot-through. The average current through the inductor is

$$I_L = \frac{P}{V_{in}} \quad (8)$$

During shoot-though, the inductor current increases linearly, and the voltage across the inductor is equal to the voltage across the capacitor; during non-shoot-through modes (six active modes and the two traditional zero modes), the inductor current decreases linearly and the voltage across the inductor is the difference between the input voltage and the capacitor voltage.

$$L_1 = L_2 = \frac{f_{sw} V_c}{\Delta I_L} \quad (9)$$

D) Capacitor Selection

The purpose of the capacitor is to absorb the current ripple and maintain a fairly constant voltage so as to keep the output voltage sinusoidal. During shoot-through, the capacitor charges the inductors, and the current through the capacitor equals the current through the inductor. Therefore, the voltage ripple across the capacitor can be roughly calculated by

$$C_1 = C_2 = \frac{I_{av} f_{sw}}{\Delta v_c} \quad (10)$$

5. FUZZY LOGIC CONTROLLER

The fuzzy logic controller (FLC) requires that each control variables which define the control surface be expressed in fuzzy set notations using linguistic labels. A fuzzy logic system consists of three main blocks: fuzzification, inference mechanism, and defuzzification. The following subsections briefly explain each block, and characterize them with regard to the type of fuzzy system we used.

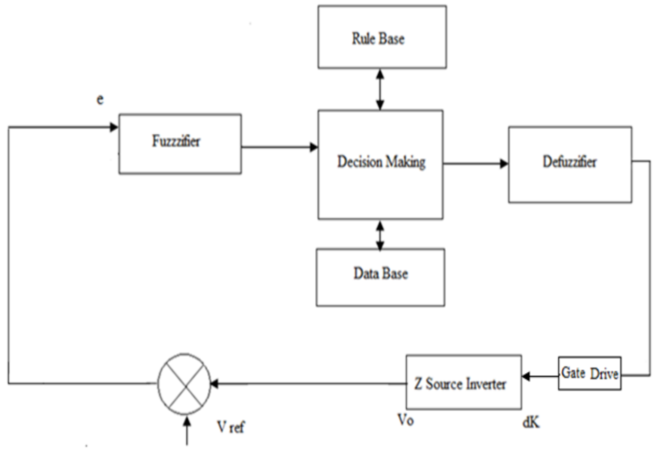

Figure 6. Block diagram of a conventional FLC

A) Fuzzification

Fuzzification is a mapping from the observed numerical input space to the fuzzy sets defined in the corresponding universes of discourse. For each input and output variable selected, we define two or more membership functions (MF), normally three but can be more. We have to define a qualitative category for each one of them, for example: low, normal or high. The shape of these functions can be diverse but we will usually work with triangles and trapezoids (actually usually pseudo-trapezoids) . For this reason we need at least three (for triangles) or four (for trapezoids) points to define one MF of one variable.

B) Rule Base

Once the input and output variables and MF are defined, we have to design the rule-base (or decision matrix of the fuzzy knowledge-base) composed of *expert* IF <antecedents> THEN <conclusions> rules. These rules transform the input variables to an output that will tell us the risk of operational problems (this output variable, risk of a problem, also have to be defined with MF, usually low, normal and high risk). Depending on the number of MF for the input and output variables, we will be able to define more or less potential rules. The easier case is a rule base concerning only one input and one output variable.

C) Defuzzification

The fuzzy set representing the controller output in linguistic labels has to be converted into a crisp solution variable before it can be used to control the system. This is achieved by using a defuzzifier. Several methods of defuzzification are available. Of these, the most commonly used methods are i) Mean of Maxima (MOM) and ii) Centre of Area (COA). Most control applications use the COA method. This method computes the centre of gravity of the final fuzzy space (control surface) and produces a result which is sensitive to all the rules executed. Hence, the results tend to move smoothly across the control surface.

6. PWM TECHNIQUES

The output voltage of the inverter needs to be varied as per load requirement. Whenever the input DC varies, the output voltage can change. Hence these variations need to be compensated. In case of motor drives the ratio of voltage to frequency [v/f] is maintained constant. The output voltage and frequency of the inverter is adjusted to keep V/F constant. Similarly, in UPS the output voltage of inverter is to be regulated. These all the reasons indicate that the output voltage of inverter is to be controlled. The pulse width modulation (PWM) techniques are mainly used for voltage control. These techniques are most efficient and they control the drives of the switching devices. The technique differs from each other in the harmonic content in their respective output voltage. Thus the choice of PWM technique depends on permissible harmonic content in the inverter output voltage.

A) Sinusoidal PWM

The sinusoidal pulse width modulation (PWM) is mostly used in converters and inverters. The width of each pulse is weighted by the amplitude of sine wave at that instant. Sine wave is the reference wave and the triangular wave is the carrier wave. The widths of pulses depend upon the amplitude of the sine wave. If amplitude is increased, widths increase. The rms value of output voltage of the inverter depends upon width of the pulses. These widths depend upon modulation index. The modulation index controls toe output voltage of the inverter.

B) Simple Boost PWM (SB-PWM)

For control of shoot-through duty ratio, two straight lines equal to, or greater than, the peak value of the reference signal, are used. When the carrier signal is greater than the upper straight line or lower than the bottom straight line, then circuit turns into shoot-through state; else, it operates like a traditional carrier-based PWM.

7. SIMULATION RESULTS

In the simulation block diagram, PV Cell is designed for 45V DC shown in figure 7. The SEPIC converter is applied to the photovoltaic cell system. Output voltage of the converter is obtained as a DC voltage. Depending upon the R value the voltage varies proportionally. The obtained dc voltage 90V is fed into the inverter to obtain the AC voltage. The output voltage of SEPIC converter is shown in figure 8. In SEPIC converter sinusoidal pulse width modulation technique is used. In the Z Source inverter impedance network act as filter and also boost the voltage up to maximum level. From the Z Source inverter to get the output voltage of 230V AC is show in figure 7. By using FFT analysis, THD of the circuit is calculated. The Bar graph using FFT analysis is shown in figure 9. IGBT is used as switch and the output of the converter is connected to an impedance network for boosting purpose which in turn is connected to a single phase Z Source inverter. Z source inverter naturally generates the output AC voltage always higher than the input DC voltage depending on the duty cycle produced by simple boost pulse width modulation technique. Reduction of THD shows the reduction in Harmonics obtained. The simulation of the complete system is carried out in the MATLAB/SIMULINK software environment.

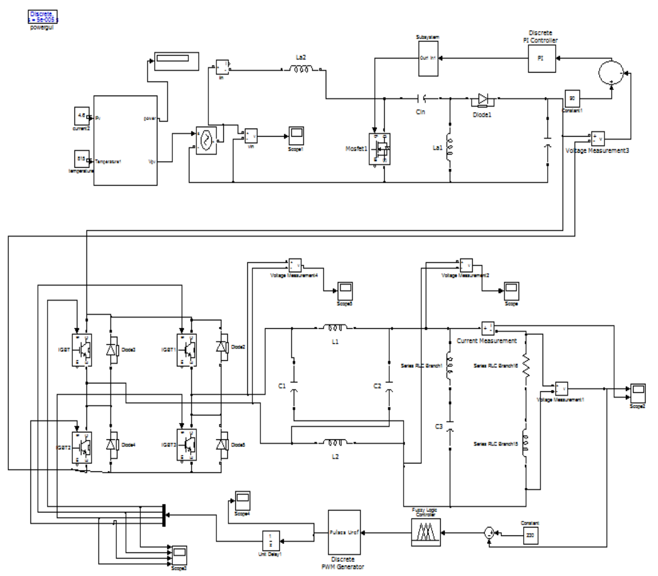

Figure 7. Simulation diagram of proposed system

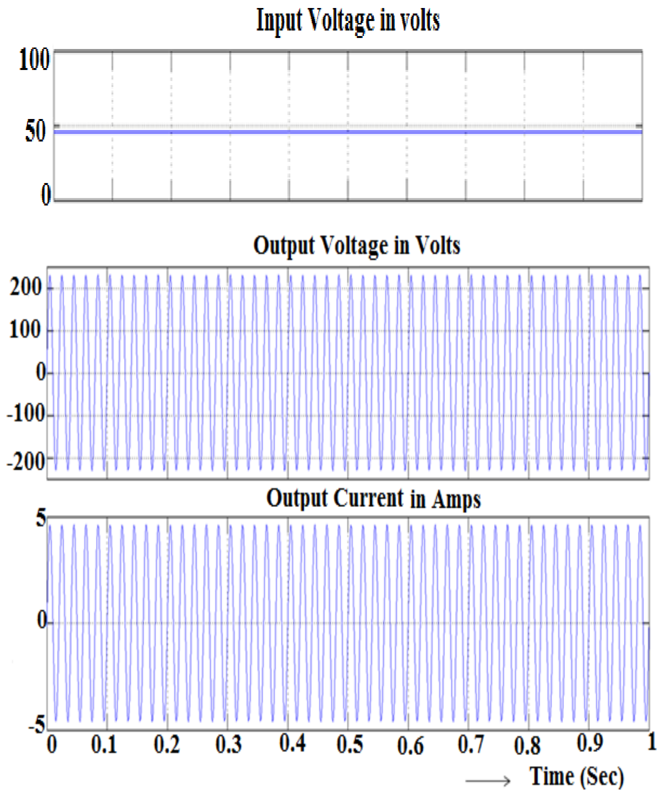

Figure 8. Output waveform of proposed system

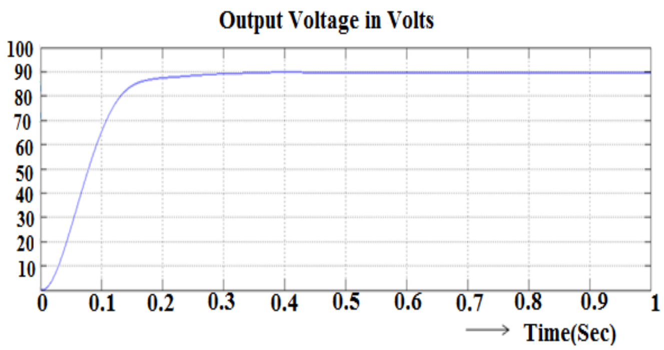

Figure 9. Output Voltage of SEPIC Converter

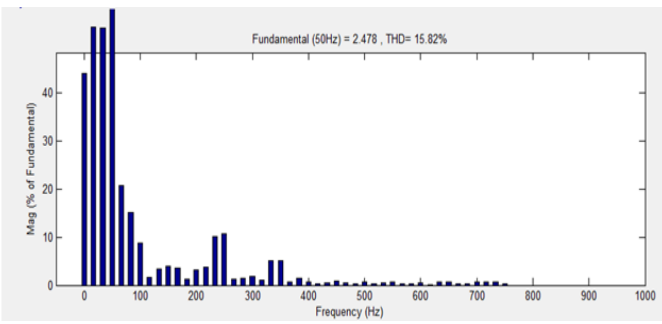

Figure 10. Bargraph using FFT analysis

8. CONCLUSION

In this paper, PV system along with SEPIC converter and Z source inverter with FLC has been proposed and implemented. This standalone system shows the proposed PV array to extract the maximum power from the solar energy sources. The SEPIC converter is applied to the PV cell system to obtain the DC voltage. The DC voltage is fed into the single stage Z Source inverter has both voltage buck and boost capabilities due to its unique LC impedance network to obtain the voltage level of 230V AC. By using the FLC intelligent technique, the harmonics are much reduced. Its performance satisfies the electric power generation with improved system efficiency. The MATLAB/SIMULINK software is used for controller design and simulation of the entire system.

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