www.ijiarec.com

ISSN:2348-2079

MAR-2016

International Journal of Intellectual Advancements and Research in Engineering Computations

FUZZY CONTROL OF FOUR SWITCH THREE PHASE SEPIC BASED INVERTERS

[1]L.Malathi, [2]Prof.R.Yalini M.E.,(Ph.D).,

ABSTRACT

The four-switch three-phase (FSTP) SEPIC inverter with fuzzy controller has been proposed as an innovative inverter design to reduce the cost, complexity, size, and switching losses of the DC-AC conversion system. Fuzzy conroller can generate five different PWM pulses. A novel design for the FSTP inverter based on the topology of the single-ended primary-inductance converter (SEPIC). The proposed topology provides pure sinusoidal output voltages with no need for output filter. Compared to traditional FSTP inverter, the proposed FSTP SEPIC inverter improves the voltage utilization factor of the input DC supply, where the proposed topology provides higher output line voltage which can be extended up to the full value of the DC input voltage. Simulation model and experimental setup are used to validate the proposed concept. Simulations and experimental results show the effectiveness of the proposed inverter.

Key terms — Four-switch three-phase inverter (FSTP), SEPIC converter, Fuzzy Logic Controller (FLC).

INTRODUCTION

The conventional six switch three phase (SSTP) two level voltage source inverter (VSI) has wide spread industrial applications in different forms such as motor drives, renewable energy conversion systems, and active power filters. For some low power range applications, reduced switch count inverter topologies are considered to alleviate the volume, losses, and cost. Considering the above said factors three-phase inverter with only four switches has been implemented. Recently, the FSTP inverter has attracted the most interests regarding its performance, control, and application, the FSTP inverter has some advantages such as reduced cost and increased reliability due to the reduction in the number of switches, reduced conduction and switching losses by 1/3, where one entire leg is omitted, and reduced number of interface circuits to supply PWM signals for the switches. The FSTP inverter can also be utilized in fault tolerant control to solve the open/short circuit fault of the SSTP inverter. The proposed novel design of the FSTP inverter topology based on the single-ended primary inductance converter (SEPIC) is a fourth-order non linear system that is extensively used in step-down or step-up DC-DC switching circuits, photovoltaic maximum power point tracking and power factor correction circuits due to its promising features as the non-inverting output voltage buck-boost capability and lower input current ripple content. Although the proposed FSTP SEPIC inverter has not a voltage boost capability, it can produce an output voltage higher than that of the conventional FSTP VSI by a factor of two, which improves the voltage utilization factor of the input DC supply. Another attractive feature of the proposed SEPIC inverter is that the

---

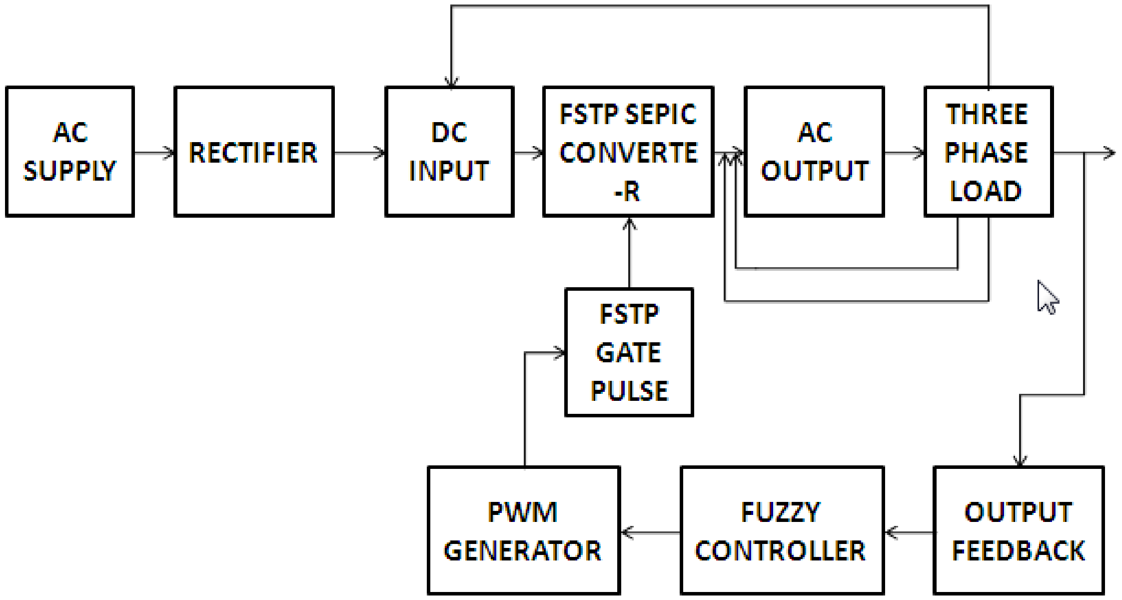
Author for correspondence:

[1]PG Scholar, Department of Electrical & Electronics Engineering, Power Electronics & Drives, Jayam College of Engineering & Technology, Dharmapuri, TN.

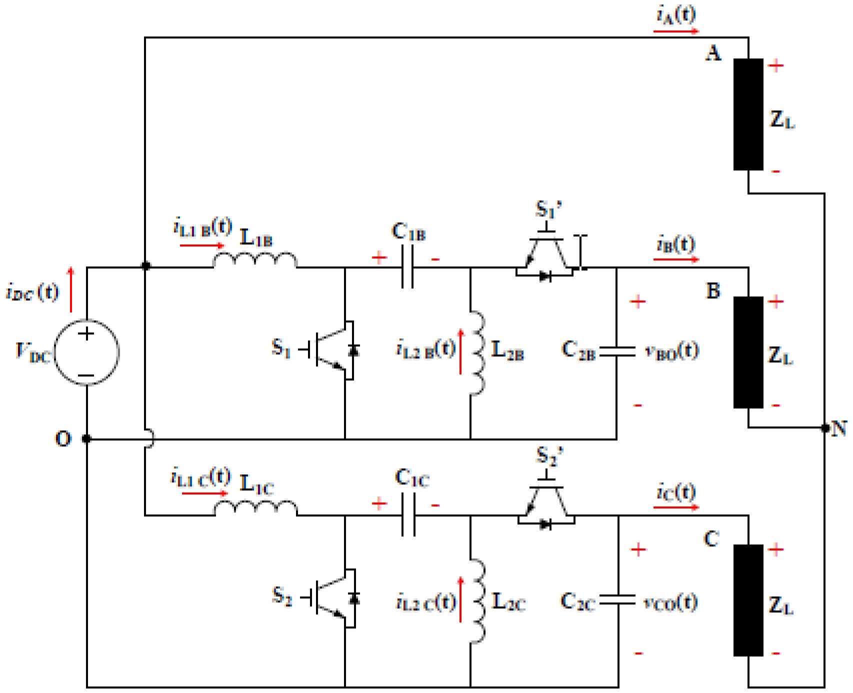
[2]Associate Professor, Department of Electrical & Electronics Engineering, Jayam College of Engineering & Technology, Dharmapuri, TN.

output voltage is a sinusoidal wave, therefore reducing the filtering requirements at the output stage. Also, there is no vital need to insert a dead-band between the same-leg switches, which significantly reduces the output waveform distortion and gain non-linearity.

BLOCK DIAGRAM



CIRCUIT DIAGRAM



SINGLE-ENDED PRIMARY-INDUCTANCE CONVERTER (SEPIC)

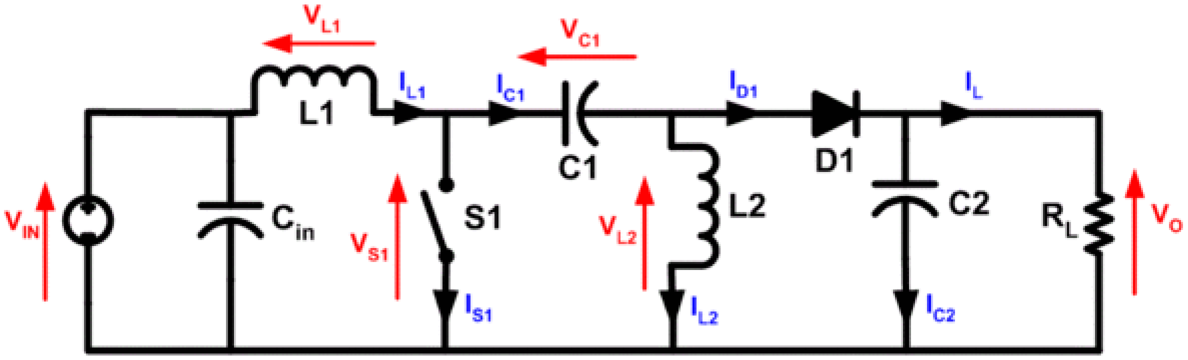


Figure 1: SEPIC Converter

Single-ended primary-inductance converter (**SEPIC**) is a type of DC-DC converter allowing the electrical potential (voltage) at its output to be greater than, less than, or equal to that at its input; the output of the SEPIC is controlled by the duty cycle of the control transistor. A SEPIC is essentially a boost converter followed by a buck-boost converter, therefore it is similar to a traditional buck-boost converter, but has advantages of having non-inverted output (the output has the same voltage polarity as the input), using a series capacitor to couple energy from the input to the output (and thus can respond more gracefully to a short-circuit output), and being capable of true shutdown: when the switch is turned off, its output drops to 0 V, following a fairly hefty transient dump of charge. SEPICs are useful in applications in which a battery voltage can be above and below that of the regulator's intended output. For example, a single lithium ion battery typically discharges from 4.2 volts to 3 volts; if other components require 3.3 volts, then the SEPIC would be effective.

WORKING OF SEPIC

The proposed FSTP SEPIC inverter consists of two SEPIC converters, and achieves DC–AC conversion as explained in Fig. 3.2.2 by connecting two phases of the three-phase load to the output of two DC–DC SEPIC converters which are sinusoidally modulated , while the third phase is directly connected to the input DC source. Both SEPIC DC-DC converters produce a DC-biased sinusoidal wave output, so that each converter produces a unipolar voltage. To generate three-phase balanced load voltages, the sinusoidal modulation of each converter is 120° shifted and the DC-bias is exactly equal to the input DC voltage. Since the load is connected differentially across the two converters and the DC input supply, thus, whereas a DC bias appears at each end of the load with respect to ground, the differential DC voltage across the load is zero and the voltage generated across the load is bipolar voltage, which necessitates the DC–DC SEPIC converters to be current bi-directional.

The bi-directional SEPIC converter includes DC input voltage , input inductor L_1 , two complementary bi-directional power switches S_1 and S_1^1 , coupling capacitor C_1 , output inductor L_2 and output capacitor feeding a load resistance R_0 . SEPIC operation core implies charging the inductors L_1 and L_2 during the ON state of the switching period taking the energy respectively from the input source and from the coupling capacitor C_1 , and discharging them simultaneously into the load through the bi-directional switch S_1^1 during the OFF state of the switching period. The output voltage of the SEPIC DC-DC converter may be less or more than the input voltage depending on the duty cycle. The relationship between the output and input voltages is as follows:

$$V_0 = D * V_{IN}/(1-D)$$

Where D is the duty cycle, while and are the input and output voltage of the converter respectively. The sinusoidal modulation of each SEPIC converter implies that the reference voltage of each converter with respect to the ground.

Although the FSTP SEPIC inverter can give an output line voltage up to a value equals the voltage of the input source. For successful DC-AC conversion, accurate selection of passive elements of SEPIC converter is necessary, and requires a knowledge of the instantaneous capacitors voltages and inductors currents. The voltage across the output capacitors has been given by (2). Based on the basics of DC-DC SEPIC converter, the average voltage across the coupling capacitor is equal to the input DC voltage, while the current through the output inductor is equal to the output load current.

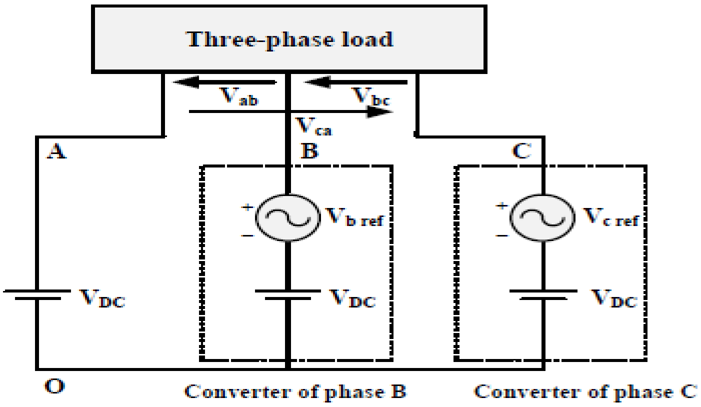
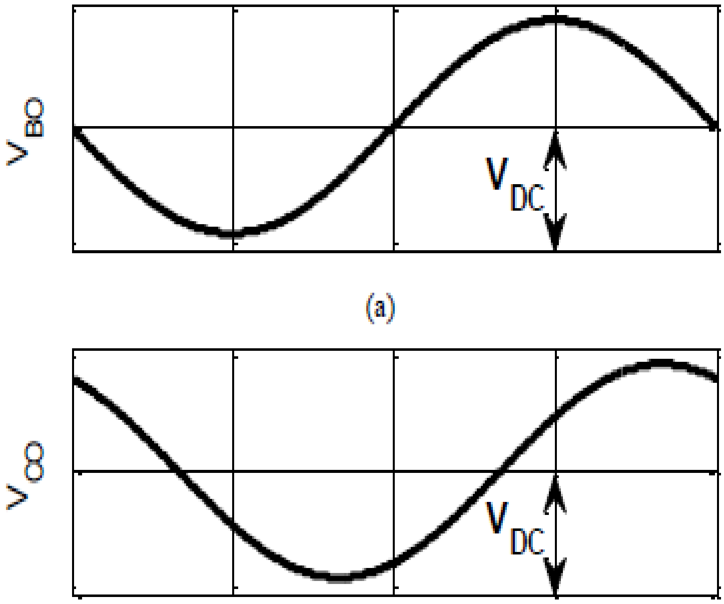


Figure 2 Basic approaches to achieve DC-AC conversion with four switches using two SEPIC DC-DC converters



(a)

(b)

Figure 2 a) reference output of the first converter

b) Reference output voltage of the second converter

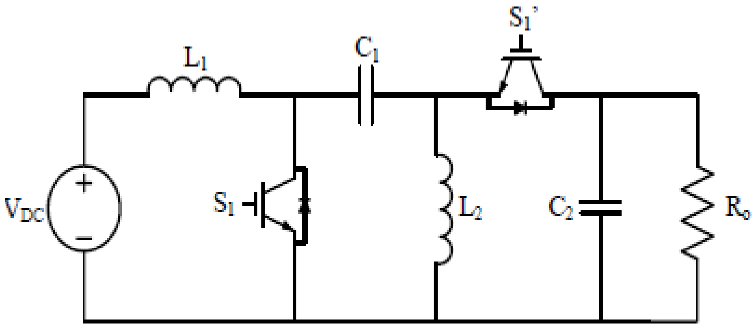


Figure 3 Bi-directional SEPIC converters

CONTROL STRATEGY

A robust control strategy is required to drive the proposed FSTP SEPIC inverter. This is due to the fact that the voltage of one of the three-output phases with respect to the common point is equal to the input DC voltage. Thus, any deviation in the output voltage of the two SEPIC DC-DC converters from the desired DC-biased sine-wave reference leads to a significant unbalance in the three-phase output line voltages.

A. SEPIC Modelling

To design a robust controller, a precise modeling is necessary. The conventional SEPIC converter has a complex model of fourth (4th) order, which is derived from the four passive components. This complex high-order system increases the difficulty of a precise model.

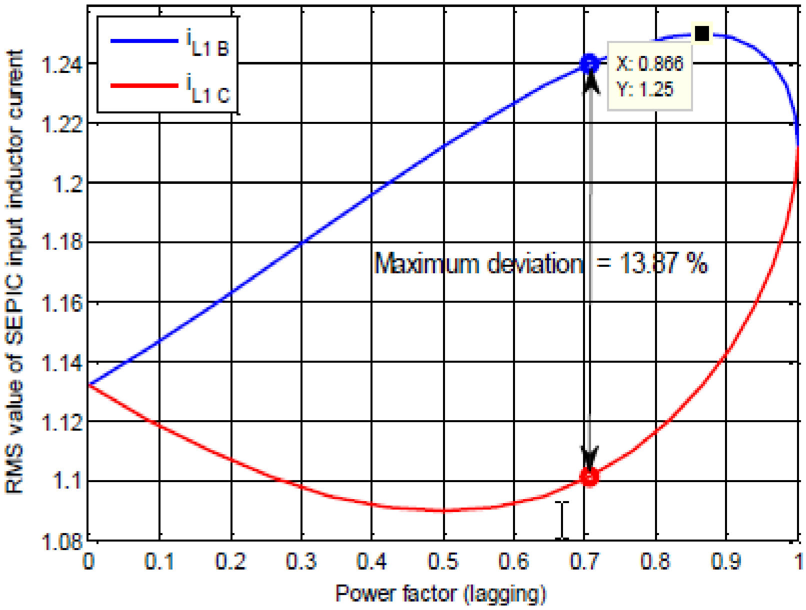


Figure 4 Normalized RMS value of input inductor current of each SEPIC converter at different lagging power factors

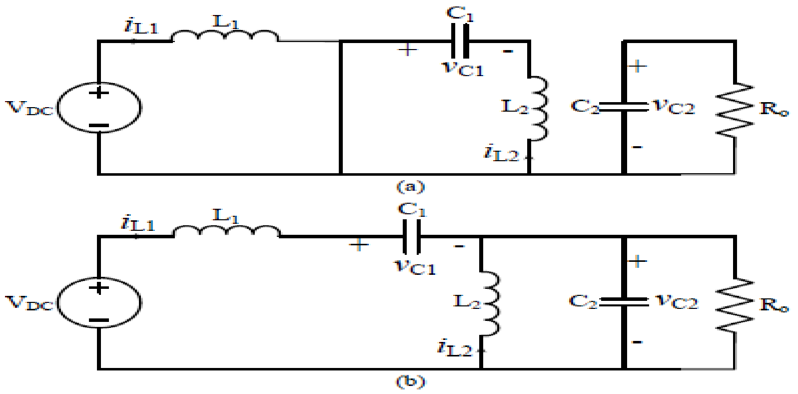


Figure 5 SEPIC equivalent circuits for a) switch on and b) switch off

CIRCUIT OPERATION

The SEPIC exchanges energy between the capacitors and inductors in order to convert from one voltage to another.

CONTINUOUS MODE

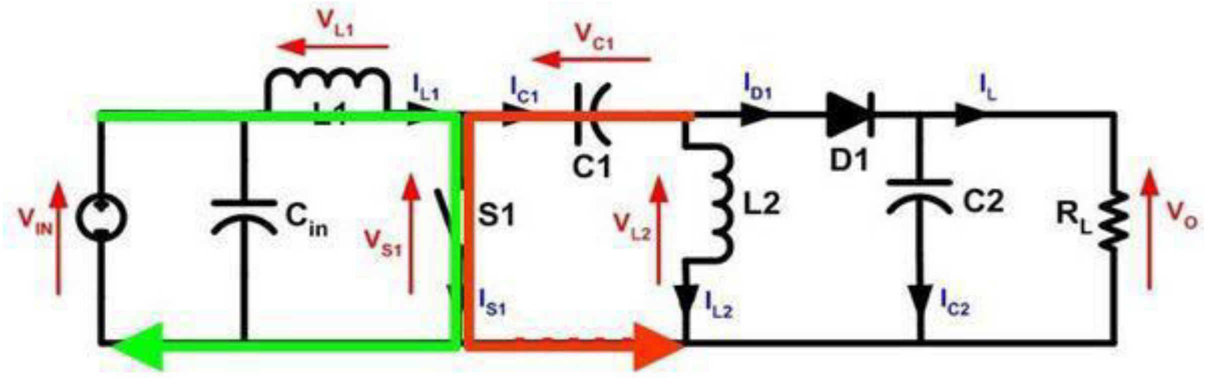


Figure 6 continuous modes at switch S_1 off

When switch S_1 is turned off, the current IC_1 becomes the same as the current IL_1, since inductors do not allow instantaneous changes in current. The current IL_2 will continue in the negative direction, in fact it never reverses direction. It can be seen from the diagram that a negative IL_2 will add to the current IL_1 to increase the current delivered to the load. Using Kirchhoff's Current Law, it can be shown that $ID_1 = IC_1 - IL_2$. It can then be concluded, that while S_1 is off, power is delivered to the load from both L_2 and L_1. C_1, however is being charged by L_1 during this off cycle, and will in turn recharge L_2 during the on cycle.

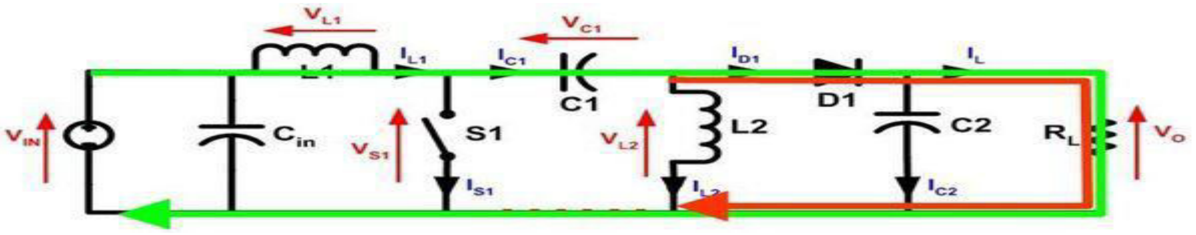


Figure 7 circuits for switch S_1 on

Because the potential (voltage) across capacitor C1 may reverse direction every cycle, a non-polarized capacitor should be used. However, electrolytic capacitor may be used in some cases because the potential (voltage) across capacitor C1 will not change unless the switch is closed long enough for a half cycle of resonance with inductor L2, and by this time the current in inductor L1 could be quite large. The capacitor CIN is required to reduce the effects.

The voltage drop and switching time of diode D1 is critical to a SEPIC's reliability and efficiency. The diode's switching time needs to be extremely fast in order to not generate high voltage spikes across the inductors, which could cause damage to components. Fast conventional diodes or Schottky diodes may be used.

The resistances in the inductors and the capacitors can also have large effects on the converter efficiency and ripple. Inductors with lower series resistance allow less energy to be dissipated as heat, resulting in greater efficiency (a larger portion of the input power being transferred to the load). Capacitors with low equivalent series resistance (ESR) should also be used for C1 and C2 to minimize ripple and prevent heat build-up, especially in C1 where the current is changing direction frequently.

FUZZY LOGIC CONTROLLER

BASIC PRINCIPLES OF FUZZY LOGIC

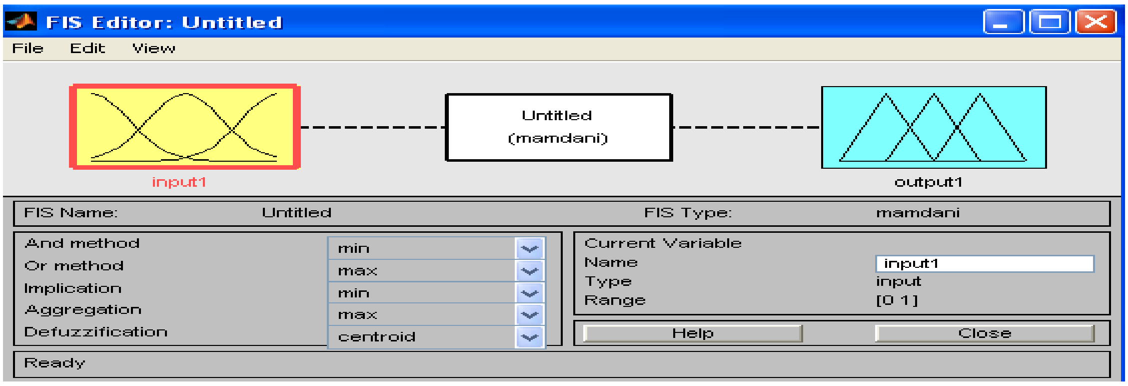
Fuzzy logic is a complex mathematical method that allows solving difficult simulated problems with many inputs and output variables. Fuzzy logic is able to give results in the form of recommendation for a specific interval of output state, so it is essential that this mathematical method is strictly distinguished from the more familiar logics, such as Boolean algebra. This paper contains a basic overview of the principles of fuzzy logic.

FUZZY LOGIC SYSTEM

Today control systems are usually described by mathematical models that follow the laws of physics, stochastic models or models which have emerged from mathematical logic. A general difficulty of such constructed model is how to move from a given problem to a proper mathematical model. Undoubtedly, today's advanced computer technology makes it possible; however managing such systems is still too complex.

These complex systems can be simplified by employing a tolerance margin for a reasonable amount of imprecision, vagueness and uncertainty during the modelling phase. As an outcome, not completely perfect system comes to existence; nevertheless in most of the cases it is capable of solving the problem in appropriate way. Even missing input information has already turned out to be satisfactory in knowledge-based systems.

Fuzzy logic allows to lower complexity by allowing the use of imperfect information in sensible way. It can be implemented in hardware, software, or a combination of both. In other words, fuzzy logic approach to problems' control mimics how a person would make decisions, only much faster.



FIS Name: Untitled
FIS Type: mamdani
And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid
Current Variable
Name: input1
Type: input
Range: [0 1]
Ready

Figure 8 Fuzzy logic analysis and control

The fuzzy logic analysis and control methods shown in Figure can be described as:

1. Receiving one or large number of measurements or other assessment of conditions existing in some system that will be analysed or controlled.
2. Processing all received inputs according to human based, fuzzy ”if-then” rules, which can be expressed in simple language words, and combined with traditional non-fuzzy processing.
3. Averaging and weighting the results from all the individual rules into one single output decision or signal which decides what to do or tells a controlled system what to do. The result output signal is a precise defuzzified value.

Fuzzy logic control system is created from four major elements presented on Figure: fuzzification interface, fuzzy inference engine, fuzzy rule matrix and defuzzification interface. Each part along with basic fuzzy logic operations will be described in more detail below.

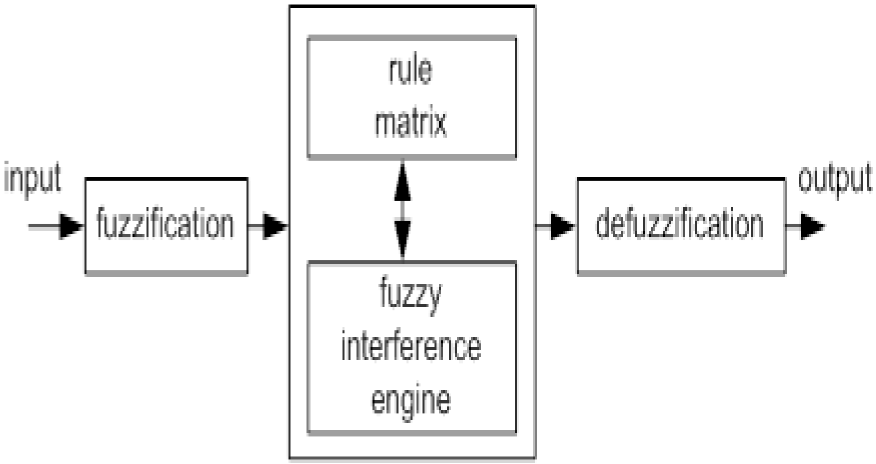


Figure 9 Fuzzy logic controller

FUZZY INTERFERENCE SYSTEM (FIS)

A fuzzy inference system (FIS) is a system that uses fuzzy set theory to map inputs (features in the case of fuzzy classification) to outputs (classes in the case of fuzzy classification). Some of the FIS types are

- MAMDANI METHOD
- SUGENO METHOD

MAMDANI METHOD

An example of a Mamdani inference system is shown in following figure. To compute the output of this FIS given the inputs, one must go through six steps:

1. Determining a set of fuzzy rules
2. Fuzzifying the inputs using the input membership functions,
3. Combining the fuzzified inputs according to the fuzzy rules to establish a rule strength,
4. Finding the consequence of the rule by combining the rule strength and the output membership function,
5. Combining the consequences to get an output distribution, and
6. Defuzzifying the output distribution (this step is only if a crisp output (class) is needed). The following is a more detailed description of this process.

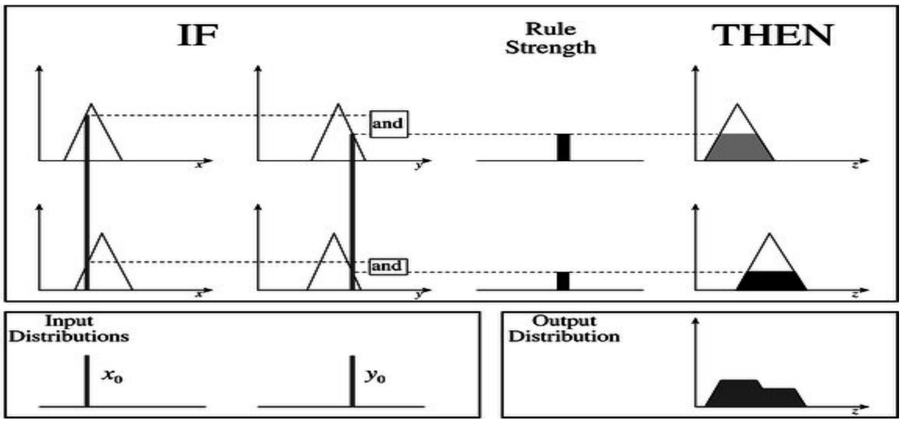


Figure 10 A two input, two rule Mamdani FIS with crisp inputs

CREATING FUZZY RULES

Fuzzy rules are a collection of linguistic statements that describe how the FIS should make a decision regarding classifying an input or controlling an output. Fuzzy rules are always written in the following form:

If (input1 is membership function1) and/or (input2 is membership function2) and/or then (output_n is output membership function_n).

For example, one could make up a rule that says:

If temperature is high and humidity is high then room is hot.

There would have to be membership functions that define what we mean by high temperature (input1), high humidity (input2) and a hot room (output1). This process of taking an input such as temperature and processing it through a membership function to determine what we mean by "high" temperature is called fuzzification and is discussed in section . Also, we must define what we mean by "and" / "or" in the fuzzy rule. This is called fuzzy combination.

FUZZIFICATION

The purpose of fuzzification is to map the inputs from a set of sensors (or features of those sensors such as amplitude or spectrum) to values from 0 to 1 using a set of input membership functions. In the example shown in their are two inputs, x_0 and y_0 shown at the lower left corner. These inputs are mapped into fuzzy numbers by drawing a line up from the inputs to the input membership functions above and marking the intersection point.

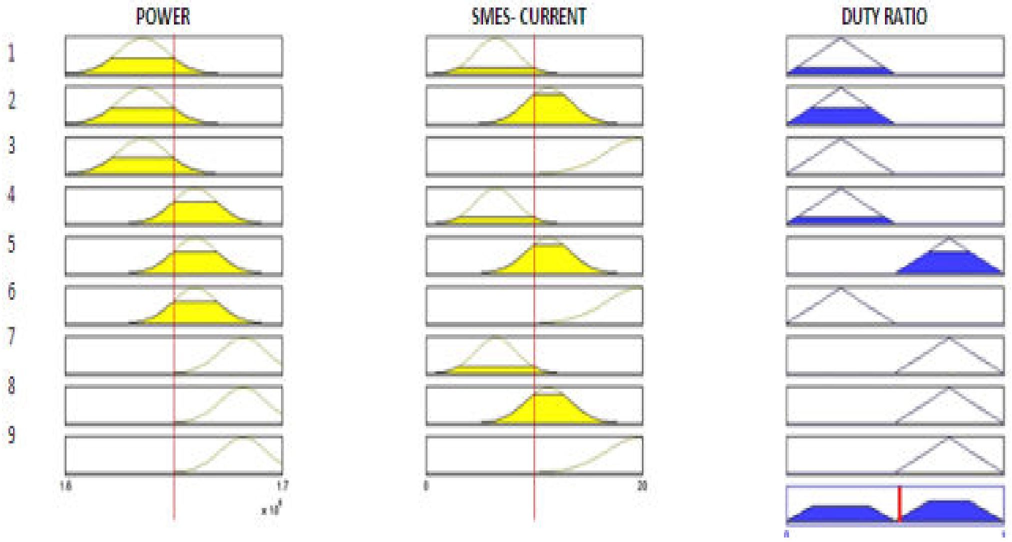
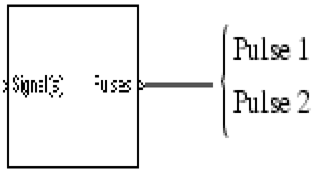


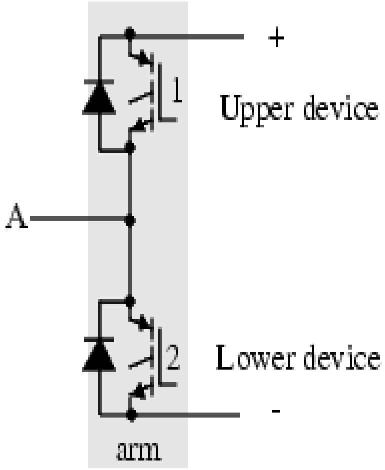
Figure 11: Duty ratio for chopper from fuzzy logic controller

PWM GENERATOR

The PWM generator block can be used to fire the self-commutated devices (FETs, GTOs, IGBTs or MOSFETs) of single-phase, two-phase, three-phase, or a combination of two three-phase bridges. The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast rate. The longer the switch is on compared to the off periods, the higher the total power supplied to the load. The number of pulses generated by the PWM generator block is determined by the number of bridge arms that have to be controlled:

Two pulses are generated for one-arm bridge. Pulse 1 fires the upper device and pulse 2 fires the lower device.





Total harmonic distortion is a complex and often confusing concept to grasp. However, when broken down into the basic definitions of harmonics and distortion, it becomes much easier to understand. Imagine a power system with an AC source and an electrical load.

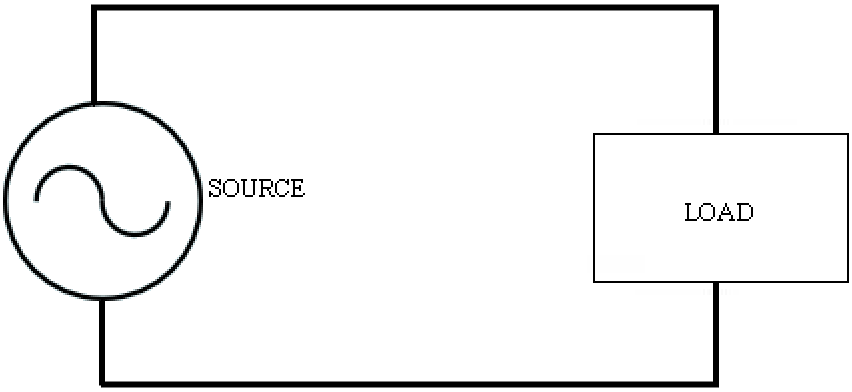


Figure 12 Power System with AC source and electrical load

Now imagine that this load is going to take on one of two basic types: linear or nonlinear. The type of load is going to affect the power quality of the system. This is due to the current draw of each type of load. Linear loads draw current that is sinusoidal in nature so they generally do not distort the waveform (Figure 2). Most household appliances are categorized as linear loads. Non-linear loads, however, can draw current that is not perfectly sinusoidal (Figure 3). Since the current waveform deviates from a sine wave, voltage waveform distortion is created.

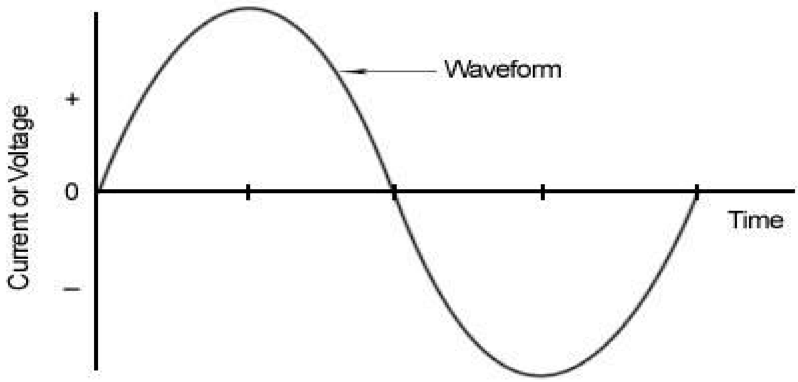


Figure 13 Ideal Sine wave

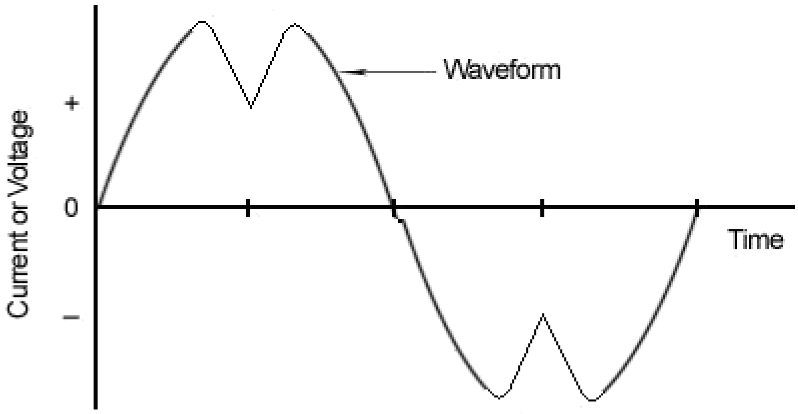


Figure 14 Distorted Waveform

As can be observed from the waveform in Figure 3, waveform distortions can drastically alter the shape of the sinusoid. However, no matter the level of complexity of the fundamental wave, it is actually just a composite of multiple waveforms called harmonics. Harmonics have frequencies that are integer multiples of the waveform's fundamental frequency. For example, given a 60Hz fundamental waveform, the 2nd, 3rd, 4th and 5th harmonic components will be at 120Hz, 180Hz, 240Hz and 300Hz respectively. Thus, harmonic distortion is the degree to which a waveform deviates from its pure sinusoidal values as a result of the summation of all these harmonic elements. The ideal sine wave has zero harmonic components. In that case, there is nothing to distort this perfect wave. Total harmonic distortion, or THD, is the summation of all harmonic components of the voltage or current waveform compared against the fundamental component of the voltage or current wave:

$$\mathrm{THD} = \frac{\sqrt{(V_2^2 + V_3^2 + V_4^2 + \cdots + V_n^2)}}{V_1} * 100\%$$

The formula above shows the calculation for THD on a voltage signal. The end result is a percentage comparing the harmonic components to the fundamental component of a signal. The higher the percentage, the more distortion that is present on the mains signal.

SIMULATION AND RESULTS

MATLAB

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation.

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar non-interactive language such as C or FORTRAN

MODELING AND SIMULATION

Matlab has several auxiliary Toolboxes distributed by Math works, Inc., which are useful in constructing models and simulating dynamical systems. These include the System Identification Toolbox, the Optimization Toolbox, and the Control System Toolbox. These toolboxes are collections of m-files that have been developed for specialized applications. There is also a specialized application, Simulink, which is useful in modular construction and real time simulation of dynamical systems.

The simulation circuit for the proposed system is given below.

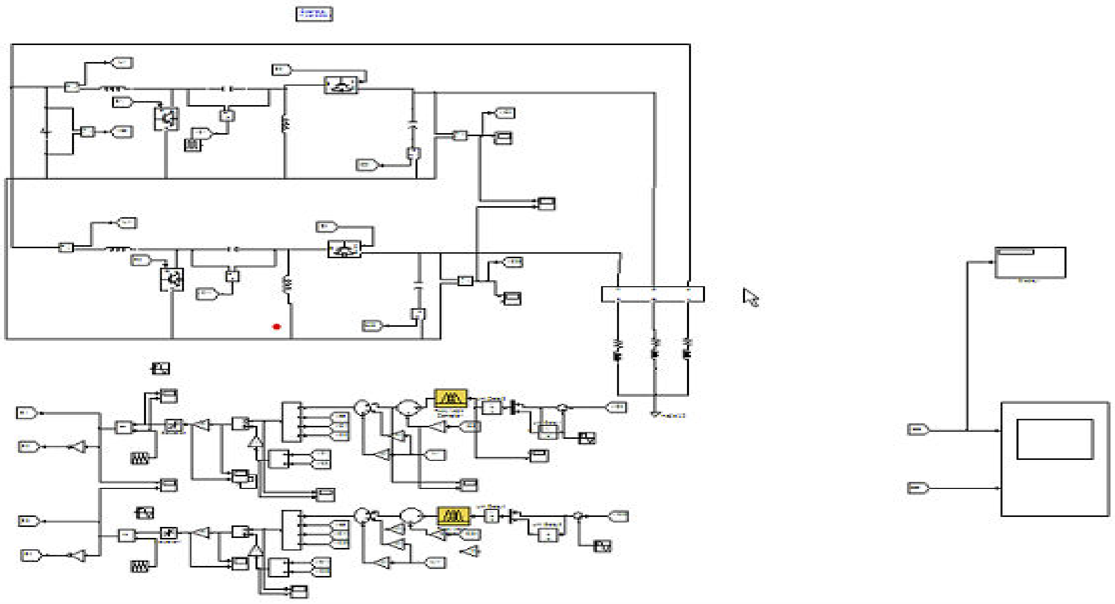


Figure 15 Simulation circuit diagram

Simulations were performed by using MATLAB/SIMULINK to verify that the fuzzy controller can be practically be implemented in a FSTP SEPIC INVERTER. Fuzzy controller gets the output feedback from the load and gives the information to the PWM generator. The PWM generator gives the gate pulse to the FSTP SEPIC inverter.

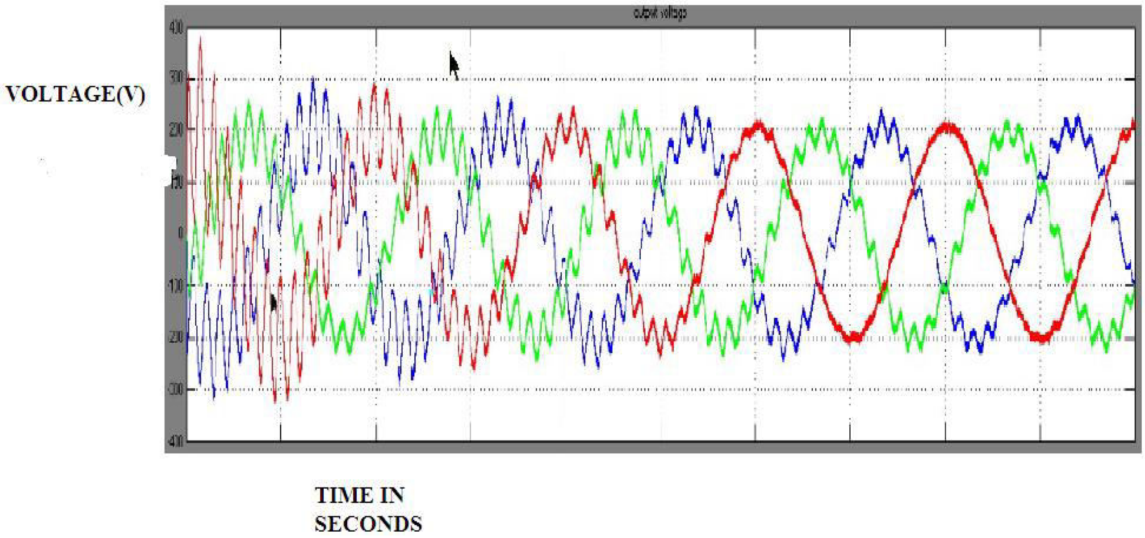


Figure 16 Output voltage waveform

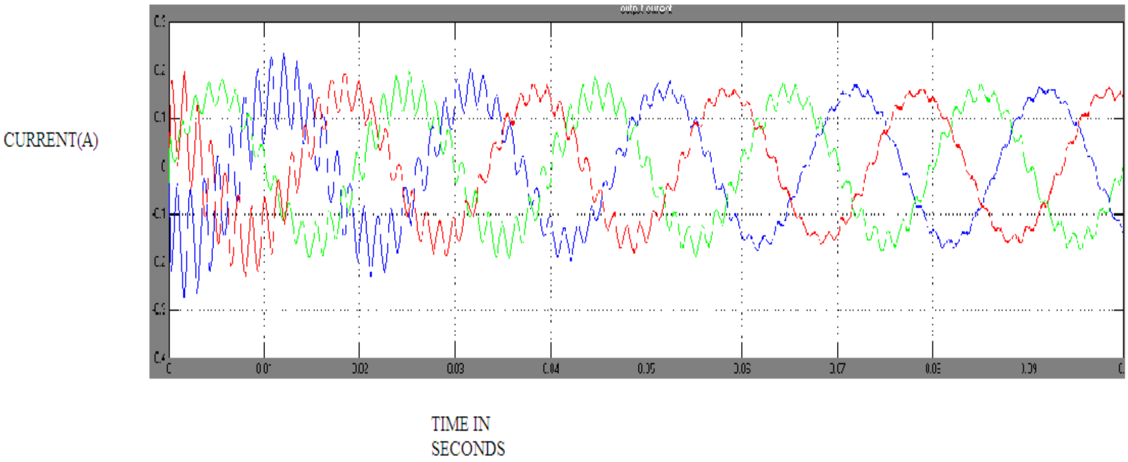


Figure 17 Output current waveform

The output voltage and current waveforms are found to be less distorted and with reduced fluctuations. The waveforms are found to be sinusoidal so that reduced number of filters used.

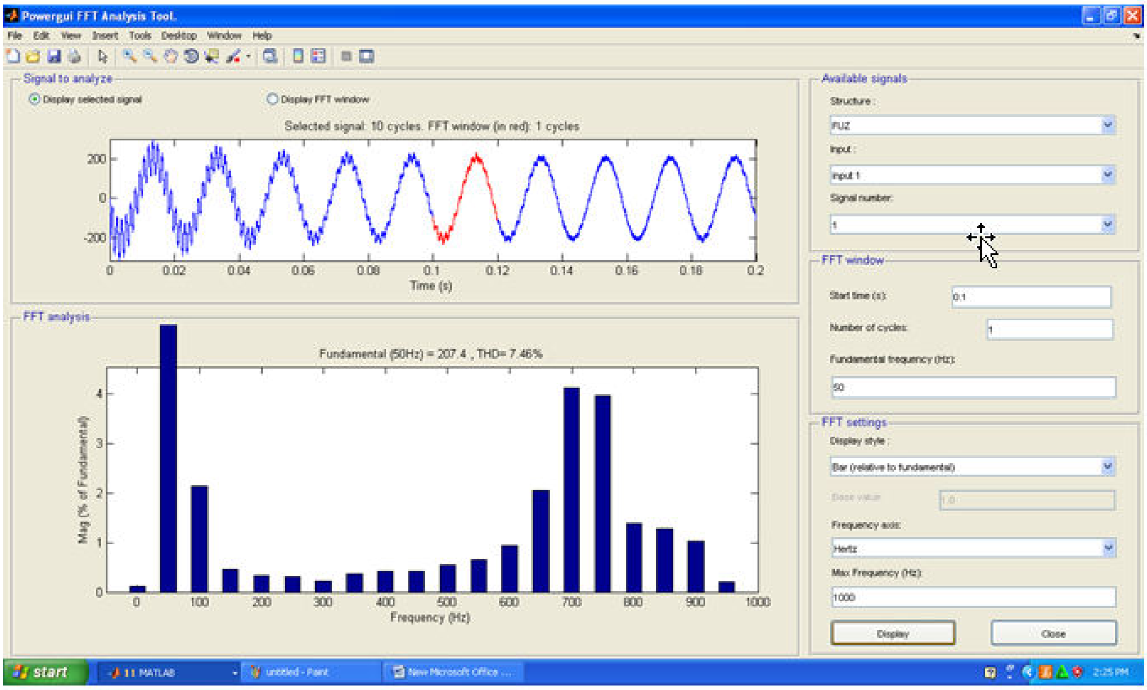
Moreover FFT analysis of the simulation is produced by power gui. The input is given as voltage and after the scope is ready the power gui operates and gives the FFT analysis for both single phase and three phase.

Now the total harmonic distortion value can be viewed theoretically. It will be found less compared to the other controllers used.

FFT ANALYSIS RESULTS

FFT Analysis:

1. Fuzzy With Single phase analysis:



● Display selected signal ○ Display FFT window

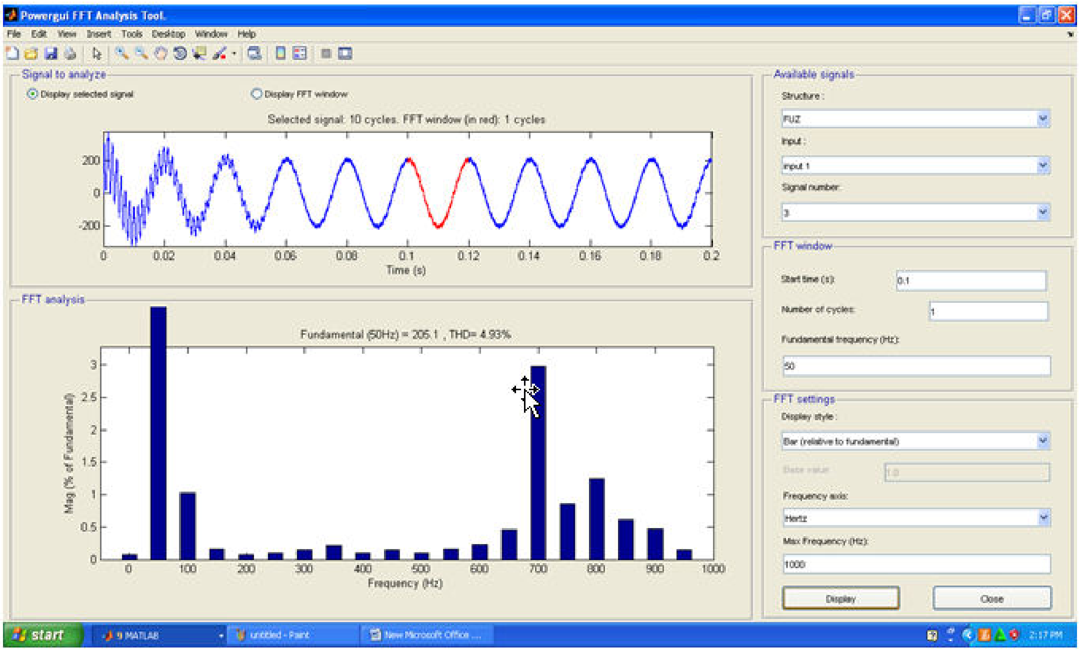
Selected signal: 10 cycles. FFT window (in red): 1 cycles

Fundamental (50Hz) = 207.4 , THD= 7.46%

Structure : FUZ
Input : input 1
Signal number: 1
Start time (s): 0.1
Number of cycles: 1
Fundamental frequency (Hz): 50
Display style : Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

Figure 18 Fuzzy with single phase analysis

2.Fuzzy With Three Phase Analysis:



● Display selected signal ○ Display FFT window

Selected signal: 10 cycles. FFT window (in red): 1 cycles

Fundamental (50Hz) = 205.1 , THD= 4.93%

Structure : FUZ
Input : input 1
Signal number: 3
Start time (s): 0.1
Number of cycles: 1
Fundamental frequency (Hz): 50
Display style : Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

CONCLUSION AND FUTURE ENHANCEMENTS

A DC-AC four-switch three-phase SEPIC-based inverter is proposed as a novel design. The proposed inverter improves the utilization of the DC bus by a factor of two compared to the conventional four-switch three-phase voltage source inverter. Also, it can produce three-phase output voltages that are sinusoidal waves with reduced no. of output filter. Unlike conventional four-switch three-phase inverter, the proposed inverter does not suffer from the problems of voltage fluctuation across the DC link split-capacitors, as the third phase load current is directly drawn from the DC source without circulation in any passive component. A fuzzy controller with fixed switching frequency was designed and applied to the proposed SEPIC inverter. It was found that the total harmonic distortion is reduced and also the voltage fluctuations are reduced. Simulation and experimental results verified the performance of the proposed inverter with the recommended control strategy.

REFERENCES

[1] H. W. V. D. Broeck and J. D. V. Wyk, “A comparative investigation of a three-phase induction machine drive with a component minimized voltage-fed inverter under different control options,” IEEE Trans. Ind. Appl., vol. IA-20, no. 2, pp. 309–320, Mar. 1984.

[2] M. B. de R. Correa, C. B. Jacobina, E. R. C. da Silva, and A. M. N. Lima, “A general PWM strategy for four-switch three-phase inverters,” IEEE Trans. Power Electron., vol. 21, no. 6, pp. 1618–1627, Nov. 2006.

[3] M. N. Uddin, T. S. Radwan, and M. A. Rahman, “Fuzzy-logiccontroller-based cost-effective four-switch three-phase inverter-fed IPM synchronous motor drive system,” IEEE Trans. Ind. Appl., vol. 42, no. 1, pp. 21–30, Jan./Feb. 2006.

[4] C.-T. Lin, C.-W. Hung, and C.-W. Liu, “Position sensorless control for four-switch three-phase brushless DC motor drives,” IEEE Trans. Power Electron., vol. 23, no. 1, pp. 438–444, Jan. 2008.

[5] J. Kim, J. Hong, and K. Nam, “A current distortion compensation scheme for four-switch inverters,” IEEE Trans. Power Electron., vol. 24, no. 4, pp. 1032–1040, Apr. 2009.

[6] C. Xia, Z. Li, and T. Shi, “A control strategy for four-switch three-phase brushless DC motor using single current sensor,” IEEE Trans. Ind.Electron., vol. 56, no. 6, pp. 2058–2066, Jun. 2009.

[7] S. B. Ozturk,W. C. Alexander, and H. A. Toliyat, “Direct torque control of four-switch brushless DC motor with non-sinusoidal back EMF,” IEEE Trans

Power Electron., vol. 25, no. 2, pp. 263–271, Feb. 2010.

[8] K. D. Hoang, Z. Q. Zhu, andM. P. Foster, “Influence and compensation of inverter voltage drop in direct torque-controlled four-switch three-phase PM brushless AC drives,” IEEE Trans. Power Electron., vol. 26, no. 8, pp. 2343–2357, Aug. 2011.

[9] Tzann-Shin Lee; Jia-Hong Liu, "Modeling and Control of a Three-Phase Four-Switch PWM Voltage-Source Rectifier in d-q Synchronous Frame," IEEE Trans. Power Electron., vol.26, no.9, pp.2476-2489, Sept. 2011.

[10] R. Wang, J. Zhao, and Y. Liu, “A comprehensive investigation of four-switch three-phase voltage source inverter based on double fourier integral analysis,” IEEE Trans. Power Electron., vol. 26, no. 10, pp. 2774–2787, Oct. 2011.

[11] Wen Wang; An Luo; Xianyong Xu; Lu Fang; Thuyen Minh Chau; Zhou Li, "Space vector pulse-width modulation algorithm and DC-side voltage control strategy of three-phase four-switch active power filters," Power Electronics, IET , vol.6, no.1, pp.125-135, Jan. 2013.

[12] Narimani, Mehdi; Moschopoulos, Gerry, "A method to reduce zero-sequence circulating current in three-phase multi-module VSIs with reduced switch count," Applied Power Electronics Conference and Exposition (APEC), 2013 Twenty-Eighth Annual IEEE , vol., no., pp.496-501, 17-21 March 2013.