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Harmonic Reduction in Inverter with Different Techniques Including Fuzzy Logic Controller

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Abstract: ***In recent years, the growing and widespread use of power electronic equipments by totally different segment of society is perceptible. But, these equipments present itself as nonlinear impedances in power system and generate harmonics with well-known adverse effects such as low power factor, electromagnetic interference, voltage variations resulting in flicker, etc resulting higher THD values. In the proposed paper, a comparative analysis of voltage T.H.D. has been carried out for Sine PWM inverter without filter, SPWM inverter with LC filter, fuzzy logic controlled SPWM inverter. An attempt is made to identify a control technique which permits higher harmonic reduction within the AC output voltage of the inverter. The realization and analysis of inverter circuits and various control techniques is done using MATLAB and Simulation.***

Keywords: Fuzzy logic, Inverter, LC Filter, Sine Pulse Width Modulation (SPWM), Total Harmonic Distortion (THD).

1. Introduction

INVERTER Converts DC power to AC power by switching the *DC input voltage* in a pre-determined sequence so as to generate AC voltage output. A Voltage source inverter (VSI) is a device which have stiff dc voltage supply at its input terminal. VSI are mostly used in adjustable speed drives (ASDs), uninterruptible power supplies (UPSs), static VAR compensators, flexible ac transmission systems (FACTSs), and voltage compensators and other industrial applications [3]. For economics reason and good performance, VSI's are often preferred over current source inverter (CSI) for flexible ac transmission (FACTS).The direct current in a VSI flows in either direction, so the converter valves used in it have to be bidirectional. MOFETs, IGBTs etc may have parallel reverse diode built in as a part of complete integrated device suitable for voltage source inverter. For sinusoidal ac voltage, the magnitude, phase and frequency should be controllable. VSIs are at the heart of applications requiring an AC supply from a DC source. So, it is needed that VSI design should be sturdy and efficient, as inverter failure can cause inconvenience in several production processes.

In order to own an approximate sine wave at output of the inverter terminal, a comparison has been created in this paper among different modulation technique of inverter. These techniques are explained one by one:

1.1 SPWM Inverter

SPWM inverter is Sinusoidal Pulse Width Modulated inverter. Pulse width modulated (PWM) inverters are among the most used power-electronic circuits in practical applications. They are capable of producing ac voltages of variable magnitude as well as variable frequency. As compare with square wave inverter the quality of SPWM inverter output is greatly enhanced. The PWM inverters are mostly used in adjustable speed ac motor drive loads where it is needed to feed the motor with V.V.V.F supply [1].

PWM inverters can be of single phase as well as three phase types. There are three types of PWM techniques, which differ from each other in their methods of implementation, and these techniques are as follow [1] :

a) Single pulse modulation
b) Multiple pulse modulation
c) Sinusoidal pulse modulation

However in all above techniques the aim is to generate a sinusoidal output voltage, but they differ from each other in the harmonic content in their respective output voltage[1].

Principle of Operation Of PWM Technique

In this method a fix DC input voltage is given to the inverter and a controlled AC output voltage is obtained by adjusting the on and off period of the inverter components. This is usually adopted method of controlling the output voltage and is termed as PWM control. PWM technique is known by constant amplitude pulses [1].The pulse width is however, modulated to obtain inverter output voltage control and to reduce its harmonic content. The harmonic content in sinusoidal pulse modulation is comparatively less than other two modulation.

Principle of Operation of Sinusoidal Pulse Modulation (SPWM)

In this method of modulation, several pulses in each half cycle are used. In SPWM, pulse width is a sinusoidal function of the angular position of the pulse in a cycle. For realizing SPWM, a high-frequency carrier wave V_c is compared with a sinusoidal reference wave V_r of desired frequency. The intersection of V_c and V_r waves determine the switching instants and commutation of modulated pulse. The carrier wave and reference waves are mixed in a comparator. The comparator output is high only when sinusoidal wave have higher magnitude than triangular wave. The comparator output is then processed in a trigger pulse generator [1]. Fig1 shows sinusoidal pulse modulation. Among all PWM techniques, sinusoidal pulse width modulation (SPWM) is the most popular as it has many advantages [7], best being the linearity in controlling the fundamental component

1.2 Fuzzy Logic Controlled SPWM Inverter:

Fuzzy Logic: Fuzzy logic concept has been into existence since 1965 and was disclosed by Lofti A. Zadeh. As the complexity of the system increases, it becomes difficult to make a precise statements about the behavior of that system, eventually arriving at a point of complexity where the fuzzy logic method born in humans is the only way to get at the problem. The base of this theory lies in making the membership function. Dr. Zadeh proposed the set membership idea to make suitable decision whenever uncertainty occurs [4].

Fuzzy Logic Controller (FLC): The most significant application area of fuzzy logic has been in control field. Fuzzy control includes fans, complex aircraft engine, helicopter control, missile guidance, and other industrial processes. The basic concept behind FLC is to utilize the expert knowledge and experience of human operator for designing a controller for controlling an application process whose input output relationship is given by a collection of fuzzy control rules using linguistic variables instead of a complicated dynamic model. The fuzzy control rules are basically IF-THEN rules. The linguistic variables, fuzzy control rules and fuzzy appropriate reasoning are best utilized for designing a controller. The main components of FLC are: Fuzzifier, Fuzzy knowledge base ,Fuzzy rule base , an inference engine and a defuzzifier. It include the membership function defining the input variables to the fuzzy rule base and the output variable to the plant under control. The inference engine is the head of an FLC system, and it possess the capability to simulate human decisions by performing approximate reasoning to achieve a desired control strategy[4].

The defuzzifier converts the fuzzy quantities into crisp quantities from an inferred fuzzy control action by inference engine. The processes are described in detail below:

Fuzzification: Fuzzy logic uses linguistic variables instead of numerical variables. Generally one of the input to the FLC is error between reference signal and output signal is used as NL (Negative Large), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium) and PL (Positive large)[4].In this process conversion of numerical variable (real number) into a linguistic variable (fuzzy number) is done.

Rules Elevator: Humans explain their actions and knowledge using linguistic rules and fuzzy logic works to represent this knowledge on computers. There are three principal ways to obtain these rules:

1 .Human experts provide rules
2. Data driven: here rules are formed by training methods
3. Combination of 1 and 2.

The first way is the ideal case for fuzzy systems. Although the rules are not precise, they contain important information about the system. In practice human experts may not provide a sufficient number of rules and especially in the case of complex systems the amount of knowledge may be very small. Thus the second way must be used instead of the first one (provided the data is available). The third way is suits when some knowledge exists and sufficient amount of data for training is available. In this case fuzzy rules are taken from experts. Rules provided by the expert's form an initial point for the training and thus exclude the necessity of random initialization and diminish the risk of getting stuck in a local minimum. Fuzzy rules define the connection between input and output fuzzy linguistic variables and they can be seen to act as associative memories. Resembling inputs are converted to resembling outputs.

Rules have a structure of the form:
IF (antecedent) **THEN** (consequent)
The basic fuzzy set operations needed for evaluation of rules are AND (∩), NOT (−) and OR (∪).[4]

Membership Function: The membership function defines all the information contained in a fuzzy set. The membership value ranges in the interval [0,1]. Triangular membership function is used to represent the input and output variables

Defuzzification: It is a mapping process from a space of fuzzy control actions defined over an output universe of discourse into a space of crisp control actions. Centroid method of defuzzification [2] is used in this paper. Fuzzy model for harmonic distortion is shown in later pages.

Description Of Fuzzy Logic Controlled SPWM Inverter: The model is implemented in MATLAB/Simulink using the fuzzy logic toolbox [5]. This toolbox allows for the creation of input membership functions, output membership functions and fuzzy control rules. The system which is implemented in simulink required two inputs voltage error (V_e) and change in voltage error (V_{ce}). These two inputs will then be combined by the multiplexer and processed by a fuzzy logic controller whose output is a degree of correction. The degree of correctness is decoded into one of the output variables namely small, average, large. The output of the FLC is then again compared with modulation signal. Modulation signal here is a sine wave of magnitude ranging -1 to +1. Three membership functions are assigned for both input and output. Figure3 shows the membership functions for input and output variables. Triangular membership function is used to represent the input and output variables. With two input variables and with three labels for each variable there are 9 input label pairs. The rule table relating each of the 9 input pairs to the respective output label is given in Table1 [2]. Simulation of this system is shown in the later pages.

Table 1: Membership Rules

V_E \ V_{CE}	N	Z	P
N	S	A	L
Z	S	A	L
P	S	A	L

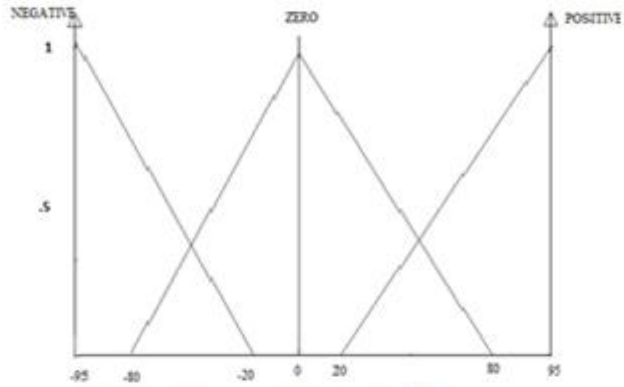

FIGURE 1(a): Error Input Membership function

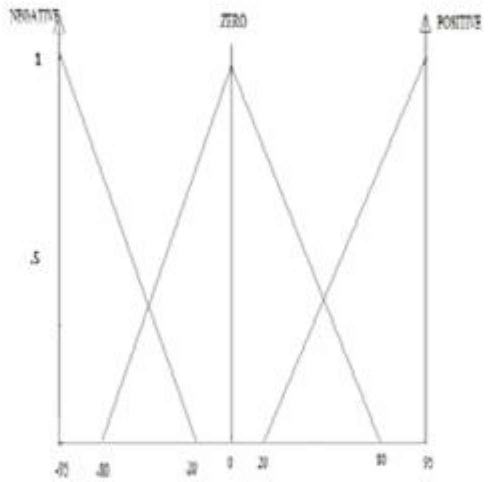

Figure 1(b): Error Change Input Membership Function

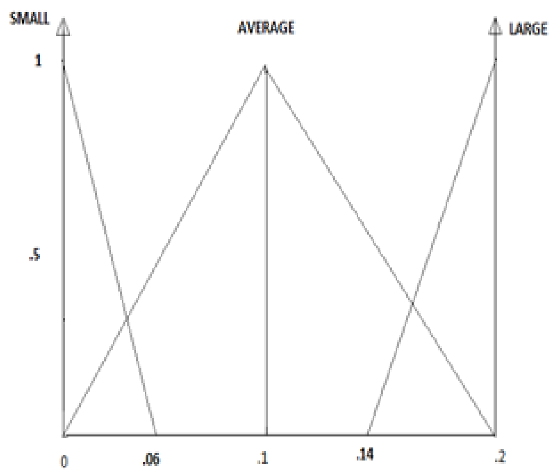

Figure 1(c) Output Membership Function

Harmonics In Power System And Total Harmonic Distortion (THD)[1]: *Harmonics* are voltages or currents having frequencies which are integer multiples of the fundamental frequency. Harmonic distortion levels are described by the complete harmonic spectrum with magnitudes and phase angles of each individual harmonic component. It is common to use a single quantity, the *total harmonic distortion* (THD), as a measure of the effective value of harmonic distortion. Non-linear loads represent a large percentage of the total loads. Under these conditions, THD may become very high and therefore dangerous for the system. Fourier Series is a tool for harmonic distortion analysis[6].

Fourier Series

$$a_o = {}^{1}/_{(\pi)} \int_0^{2\pi} \{f(u)d\theta\}$$

$$a_n = {}^{1}/_{(\pi)} \int_0^{2\pi} \{f(u)\cos(n\theta)\,d\theta\}$$

$$bn = {}^{1}/_{(\pi)} \int_0^{2\pi} \{f(u)\sin(n\theta)d\theta\}$$

From Fourier analysis it is observed that

- Harmonic decreases with a factor of (1/n).
- Even harmonics are absent
- Nearest harmonics is the 3rd harmonic. If fundamental is 50Hz, then frequency of nearest harmonic is 150Hz.

2. Simulation Results Of Above Explained Modulation Techniques

2.1 Simulation results of SPWM inverter for Resistive load is shown in fig 2 (a),fig 2(b), fig 2(c)

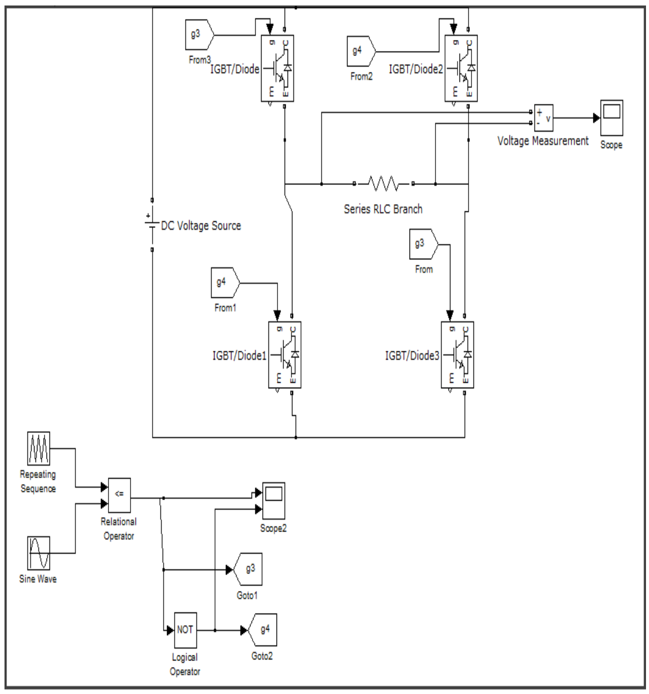

Figure 2(a): Represent Simulation Model Of SPWM Inverter

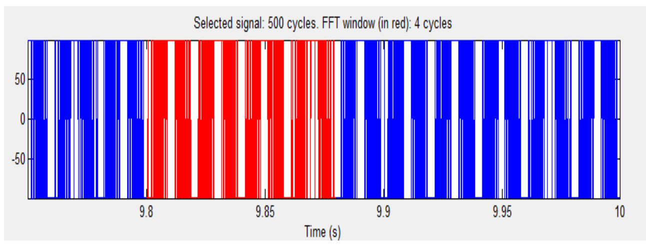

Figure 2(b): Voltage Waveform Of SPWM Inverter

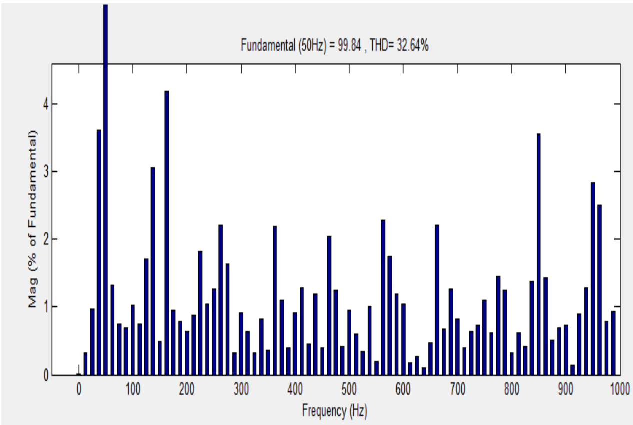

Figure 2: FFT Analysis Of SPWM Inverter

2.2 Simulation diagram of **fuzzy controlled SPWM inverter** and its simulation result is shown in fig3 (a) ,fig 3(b), fig 3(c).

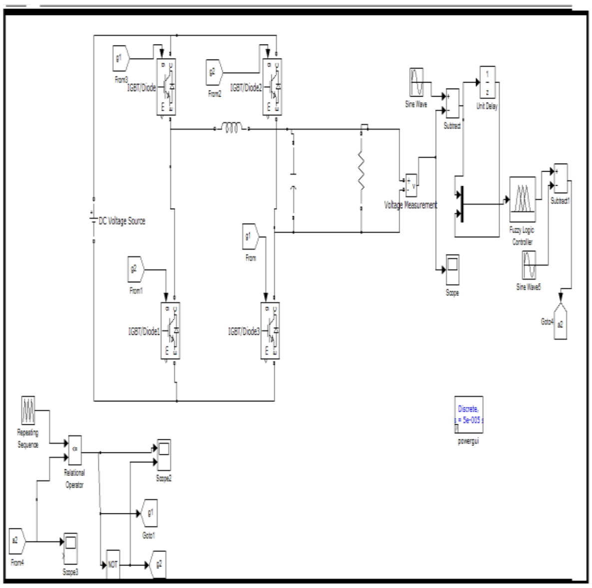

Figure 3(a): Represents Simulation Model Of Fuzzy Controlled SPWM Inverter

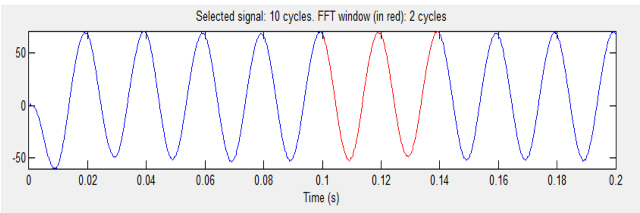

Figure 3(b): Represents Voltage Waveform Of Fuzzy Controlled SPWM Inverter

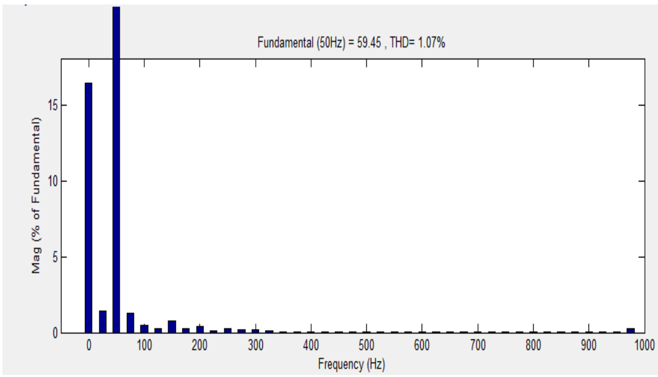

Figure 3: Represents FFT Analysis Of Fuzzy Controlled SPWM Inverter

3. Conclusion

This paper shows the comparative analysis of THD and fundamental component in different modulation technique of inverter and results are as

Inverter Modulation Technique	*THD(%)*
• Square Wave Inverter With Pwm Technique	32.64
• Square Wave Inverter With Fuzzy Controlled Spwm Technique	1.07

From above discussion it is concluded that SQUARE WAVE INVERTER WITH FUZZY CONTROLLED SPWM TECHNIQUE HAVE HIGHEST THD REDUCTION**.**

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