Design and Analytical Comparison of Various Controllers Used in PWM Inverter

Romya Bhatnagar¹, Malik M. Anwer² & Manish³
¹,³Department of Electronics & Communication, ²Department of Electrical & Electronics, ABES Engineering College, Ghaziabad, U.P.
E-mail: romya_a1@yahoo.com.au

ABSTRACT

This paper presents the analytical comparison of different types of controllers which analyze the Total Harmonic Distortion (THD) at the output of the Pulse Width Modulated inverters. Harmonics are the basic and old problems which continue to affect the performance of the power systems in various applications depending upon the types of loads (linear & non-linear). Thus, there is need to limit such kind of distortion. So, in this paper PID control and Fuzzy logic control mechanism is presented for the modifications of the controllers’ structure. This paper proposes the utilization of fuzzy logic to analyze, compare and diagnose harmonic distortion indices in a power system with other controllers.

Index terms: Fuzzy Logic Controller, Membership functions, PWM (pulse width modulation) inverters, PID controllers, THD, model.

I. INTRODUCTION

For the DC–AC conversion, a full-bridge PWM inverter is employed. A filter is used to obtain the sinusoidal waveform from the PWM inverted pulse waveform. Still the desired output is not obtained which means harmonic contents are there in high proportionate [1]. For that new technologies using various controllers are to be applied. Conventional closed loop control scheme employs PID controller to achieve the desired output. The PID controller requires quite a large bit of tuning to obtain fast and dynamically acceptable response. The design of the controller parameters requires the complete mathematical model of the system, which includes linearization over a limited operating region.

Recently, fuzzy logic controllers are gaining momentum in many applications. In this paper, a controller based on fuzzy set theory [2] is proposed. Unlike its counterpart, the PID controller no detailed mathematical model or linearization about an operating point is required by the fuzzy logic controller. Superiority of FLC’s over the conventional controllers can be considered as it can work with imprecise inputs, can handle nonlinearity and it is more robust than conventional nonlinear controllers [3][4]. Also, each rule addresses a wider scenario of operating conditions and ensures the same performance even with change in temperature, variation in system parameter with aging or with change in operating conditions. That’s why comparison is made in this paper between two types of controllers to judge various parameters including Total Harmonic Distortion (THD).

This paper explores the potential and feasibility of fuzzy logic control schemes that are suitable for harmonic current mitigation and inverter voltage control to improve the performances. The performance of fuzzy controller is evaluated through computer simulations under steady state and transient conditions. The results show that, the proposed mechanism with fuzzy logic controller is capable of providing sinusoidal source voltage(s) with low harmonic distortion.

II. HARMONIC DISTORTION IN POWER SYSTEM

In most power systems certain loading conditions can cause harmonic distortion to the associated voltage waveform, which may adversely affect certain types of connected load [5]. When an electrical load is connected to an AC electricity source, it will draw current. For some types of load, the current drawn is also a sine wave. These loads are called linear loads, and the current
drawn may be in phase with the supply voltage (resistive loads), or may lead the voltage (capacitive loads) or may lag the voltage (inductive loads). For other types of load, however, the current drawn by the load may not be sinusoidal. That is, the input current waveform carries a number of harmonics. These are referred to as non-linear loads [6].

A common type of non-linear load is a rectifier, which uses diodes or silicon controlled rectifiers (SCRs) to convert the incoming AC to direct current (DC). Such rectifiers may be found in many power conversion devices, including the input circuit of AC or DC motor drives, battery chargers, UPS systems, etc. These harmonic distortions, by Fourier analysis, are components that have frequencies that are integer multiples of the fundamental frequency [5].

III. INTRO TO PID CONTROLLER

By the basics of control system, the general way to adjust the controlling process for measuring and calculating in such a way to generate the least error in the practical operations. For that, it seems to be good to apply PID controllers as it contains the Proportional gain, Integral gain and Derivative gain [3]. The following section describes the ideal parallel or non-interacting form of the PID controller.

\[ u(t) = M \ V(t) = K_p \ e(t) + K_i \int_0^t e(t) \, dt + K_d \frac{de}{dt} \]

where

1. \( K_p \): Proportional Gain - Larger \( K_p \) typically means faster response since the larger the error, the larger the Proportional term compensation. An excessively large proportional gain will lead to process instability and oscillation [9].

2. \( K_i \): Integral Gain - Larger \( K_i \) implies steady state errors are eliminated quicker. The trade-off is larger overshoot: any negative error integrated during transient response must be integrated away by positive error before we reach steady state [9].

3. \( K_d \): Derivative Gain - Larger \( K_d \) decreases overshoot, but slows down transient response and may lead to instability due to signal noise amplification in the differentiation of the error.

The following figure shows a block diagram of the PID Controller for pure sine wave Inverter that we want to implement.

![PID Controller Diagram](image)

Figure 1: Ideal parallel or non-interacting form of the PID controller.

In a PID control scheme, the manipulated variable (MV). Hence:

\[ M \ V(t) = P_{out} + I_{out} + D_{out} \]

where \( P_{out} \), \( I_{out} \), and \( D_{out} \) are the contributions to the output from the PID controller from each of the three terms, i.e. Proportional Term, Integral Term, Derivative Term.

The final form of the PID algorithm is:

IV. INTRO TO FUZZY LOGIC

The ideas behind fuzzy logic have been around since 1965 when they were introduced by Lofti A. Zadeh. Fuzzy logic, however, has not been widely used since 1965; it has only gained popularity in the last 20 years, meaning that there are many new applications of fuzzy logic [4]. The idea of fuzzy sets is that the members are not restricted to true or false definitions. A member in a fuzzy set has a degree of membership to the set. For example, the set of temperature values can be classified using a bivalent set as either hot or not hot. This would require some cut-off value where any temperature greater than that cut-off value is ‘hot’ and any temperature less than that value is ‘not hot’. If the cut-off point is at 50°C then this set does not differentiate between a temperature that is 20°C and a temperature of 49°C. They are both ‘not hot’ [2].
If a fuzzy set were to be used in this situation each member of the set, or each temperature, would have a degree of membership to the set of hotness. The function that determines this degree of membership is called the fuzzy membership function (Figure 3).

![Figure 3: Fuzzy membership function for hotness](image)

There is countless different membership function topologies that can be used; the most common are triangular, Gaussian and sigmoidal. This function is a sigmoidal function. The attributes of the membership function can be modified based on the desired input [5]. If the relevant temperature range was between 20 and 60 degrees, for example, and more weight was needed for higher temperatures then an appropriate membership function can be determined. The determination of this function is dependent on the desired weighting of the input.

V. FUZZY LOGIC CONTROL

The basic fuzzy logic control system is composed of a set of input membership functions, a rule-based controller, and a defuzzification process.

![Figure 4: Structure of fuzzy logic](image)

The fuzzy logic input uses member functions to determine the fuzzy value of the input. There can be any number of inputs to a fuzzy system and each one of these inputs can have several membership functions. The set of membership functions for each input can be manipulated to add weight to different inputs. The output also has a set of membership functions. These membership functions define the possible responses and outputs of the system [4]. The fuzzy inference engine is the heart of the fuzzy logic control system. It is a rule based controller that uses If-Then statements to relate the input to the desired output [4]. The fuzzy inputs are combined based on these rules and the degree of membership in each function set. The output membership functions are then manipulated based on the controller for each rule. Several different rules will usually be used since the inputs will usually be in more than one membership function. All of the output member functions are then combined into one aggregate topology. The defuzzification process then chooses the desired finite output from this aggregate fuzzy set. There are several ways to do this such as weighted averages, centroids, or bisectors. This produces the desired result for the output.

VI. THE HARMONIC DISTORTION PID MODEL

This model for the harmonic distortion diagnostic using conventional controller such as PID controller is implemented in MATLAB by self-designing the PID controller [3] according to the usage. This tool allows for different values of the proportional, integral, derivative gains to generate several output values. To implement this system in Simulink, the system will need to have only single input: the harmonic contained voltage error. This input will then be processed by designed PID controller block that will correct the given error.
The fuzzy model for the harmonic distortion diagnostic is implemented in MATLAB using the fuzzy logic toolbox. This toolbox allows for the creation of input membership functions, fuzzy control rules, and output membership functions [7]. To implement this system in Simulink the system will need to have only single input: the harmonic contained voltage error. This input will then be processed by a fuzzy logic controller that will output a degree of correction. This degree of correctness is decoded into one of the output: low, medium, high. A simple single-variable diagnostic system was created as shown in Figure 6.

The voltage input is a random distribution in the range of 0 to 0.1 given in figure 7.

Fuzzy membership sets are designed for the input to the fuzzy logic controller which is the degree of error. The fuzzy system used will be a mamdani system [4], and the centroids method for defuzzification. The input membership function for harmonic error will have three different membership functions: low, medium and high.

The harmonic error membership functions define anything from 0 to .4 as low, using a triangular function. Anything from 0.1 to 0.9 is medium, and anything from 0.6 to 1 is high.

The output has three membership functions: low, medium & high. The fuzzy rules are in the form of if-then statements. These statements look at both inputs and determine the desired output. The rules defined for this system are in Table 1 below:

<table>
<thead>
<tr>
<th>If error difference is:</th>
<th>Then correction is:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>
These rules are the defining elements of this system. They determine the output based on the input.

VIII. SIMULATION

The simulink model is developed for the above cases and hence the output waveforms are shown over here for both controllers. First case is for the conventional controller named PID and the load current and voltage waveforms are shown below:

![Figure 11: PID controller waveforms](image)

Second case is of the fuzzy logic controller and below the output current and voltage waveforms are presented:

![Figure 12: Fuzzy Controller waveforms](image)

IX. SIMULATION RESULTS

In this section, the comparison between the simulated outputs of both the systems in case of PID controller and Fuzzy Logic Controller are shown graphically. Here the PWM inverter output can be taken as both voltage and current depending upon the type of the source of the inverter as: voltage source inverter (VSI) or current source inverter (CSI). The Total Harmonic Distortion (THD) is calculated using FFT analysis tool which is the provided in simulink model in the form of powergui.

Generally the best and worst cases counted for the Total harmonic Distortion is from 1% to 13%. But in this system tremendous results have been shown with comparison in between the controllers. Firstly, the simulation results are shown for PWM inverter using feedback loop for PID controller, when simply considering the values of $K_p, K_i, K_d=1$, in terms of THD for both current and voltage across the load.

![Figure 13: Fundamental PID controller voltage output](image)

The value of THD in voltage across load is 0.55% and in current across load is 3.70% at 50 hertz frequency within the range of 1000 Hz.

Secondly, the simulation results are shown for PWM inverter using feedback loop for Fuzzy Logic controller in terms of THD for both current and voltage across the load.

![Figure 14: Fundamental PID controller current output](image)
The value of THD in voltage across load is 0.20% and in current across load is 1.55% at 50 hertz frequency within the range of 1000 Hz.

X. CONCLUSION

From the review, the conclusion has been reached to the fact that there are several different aspects to be taken into account for designing the single input fuzzy controller for showing through calculation, the better results over the various conventional controllers like P, PI, PID etc.

This paper has presented the absolute analysis for the total harmonic distortion for single phase PWM inverters using different controllers. The simulated systems indicate the potential for using such a procedure for studying complex systems and performing a meaningful evaluation and/or analysis of the impact of harmonic distortion on a power system for uninterruptable supply.

REFERENCES


