



Current Control of Three Phase Grid – Connected PV Inverter Using Fuzzy Logic Controller

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Abstract- Distributed Generation (DG) is now widely employed in many electricity generation networks. It is mostly based on energy storage and renewable energy sources such as wind turbines (WT), photovoltaic cells (PV) and fuel cells to minimize pollution and greenhouse gas emissions. For large scale installations, a three phase power electronic inverter utilized to interface the source of renewable energy to the utility grid. The inverter and the associated control system are at the core of the energy conversion process and their operation is essential to inject high power quality, low harmonic distortion, current to the grid. For this reason international harmonic and power quality recommendations, such as IEEE Standard 519 and 1547, are often in place to limit the harmonic currents injected into the grid. Typically, 5% current total harmonic distortion (THD) limit is imposed. A Fuzzy controller is also implemented in this project in order to reduce the total harmonic distortion. In addition, the fuzzy and adaptive PR controller offers superior output power regulation, and improved power quality performance. Results are analyzed through MATLAB/SIMULINK environment

I. INTRODUCTION

Distributed Generation (DG) is now widely employed in many electricity generation networks. It is mostly based on energy storage and renewable energy sources such as wind turbines (WT), photovoltaic cells (PV) and fuel cells to minimize

pollution and greenhouse gas emissions [1]. For large scale installations, a three phase power electronic inverter utilized to interface the source of renewable energy to the utility grid. The inverter and the associated control system are at the core of the energy conversion process and their operation is essential to inject high power quality, low harmonic distortion, current to the grid [2]. For this reason international harmonic and power quality recommendations, such as IEEE Standard 519 and 1547, are often in place to limit the harmonic currents injected into the grid [3]. Typically, 5% current total harmonic distortion (THD) limit is imposed. Numerous inverter current control techniques have been proposed to achieve improved power quality waveforms.

The proportional-integral controller (PI controller) is perhaps the best understood and commonly applied control strategy. In three phase systems, the d-q rotating synchronous reference frame (SRF) approach, based on classic Park transformations, is often applied [4]. As a consequence of the shortcomings of the PI controller such as steady state output error when tracking sinusoidal reference signals [5], alternative control solutions have been presented. Of these, the Proportional Resonant (PR) controller has become a popular strategy in renewable energy applications. For example, in [6], the PR controller is successfully employed in the stationary reference frame of a three phase grid connected system. Significantly, the reported advantages of the PR controller include the capability to remove steady state errors when tracking AC signals by generating an infinite gain at a known resonant frequency of the controlled signal [7], and a highly attenuated gain at

other frequencies, such as the harmonic frequencies. Furthermore, the Park transformation is not necessary, and there is less cross coupling of the control axis, hence de-coupling strategies are not required [8]. As a result, in grid connected applications, significant reduction in the harmonic content of the controlled current is possible. Additional elimination of the harmonic content can be achieved by implementing Harmonic Compensation (HC) terms in parallel with the main control effort [9]. However, a sudden drop in the voltage could further increase the error between the reference signal and the controlled signal causing considerable deviation from its nominal value. The performance of the conventional PR controller will not keep up with the increase in the error which weakens the controller performance. To overcome this issue, this project presents an improvement in current control using a novel adaptive PR controller. It demonstrates and compares the performance of the adaptive PR controller during normal and abnormal grid voltage conditions. The proposed control technique is capable of providing low total harmonic distortion (THD) of the injected current even during the occurrence of abnormal grid conditions. The proposed method also achieves lower overshoot, settling time as well as steady-state error.

In addition, this project presents a simple method to decompose the voltage and the current into their positive and negative sequence components based on adaptive delayed filter with one-quarter period delay. The performance of the adaptive control strategy is verified by simulation. A three phase grid connected inverter is modeled and controlled using adaptive PR controller strategy based on the stationary reference frame point of view with space vector modulation technique (SVM). As a result, a phase locked loop (PLL) is used here in this control to detect the transformation angle and enhance the synchronization of the inverter output current with the grid voltages achieved. Two adaptive PR current controllers together with harmonic compensators are applied in the current controller. The control scheme does not have any coupling between active and reactive components, and the results show that it provides excellent dynamic response.

In recent years, there has been a rapid increase in the number of grid connected three phase inverter systems being connected to the distribution network. As a result, the need for high quality, low harmonic distortion, current injection into the grid is essential. To achieve this, careful consideration of the inverter controller is necessary. Many control methods are based on the traditional proportional-integral controller (PI), or the more recently adopted Proportional Resonant controller (PR). This project presents a new technique of minimizing the error of the current control in a three phase grid connected inverter using a readily implementable Adaptive Proportional Resonance controller. A Fuzzy controller is also implemented in this project in order to reduce the total harmonic distortion. In addition, the fuzzy and adaptive PR controller offers superior output power regulation, and improved power quality performance.

II. LCL Filter Design

Fig.1 shows a three-phase grid connected inverter with a third order LCL filter. The LCL filters improve the power quality of the current injected to the grid compared to lower order L and LC filters

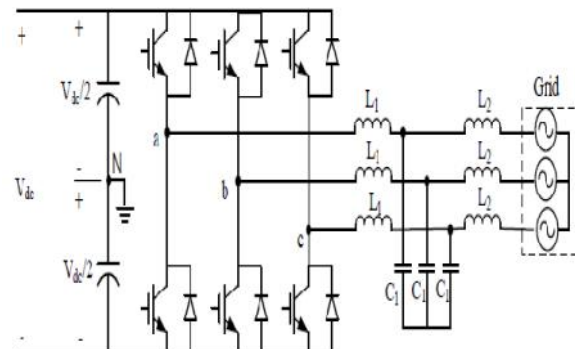


Fig.1 Three phase inverter connected with LCL filter

The differential equation representing of the LCL filter can be found from the single phase equivalent circuit in Fig.2. Here, the filter is defined by the inverter-side inductor L_1 , filter capacitor C_1 , grid side inductor L_2 , and the resistive elements represent the ohmic losses in the passive components.

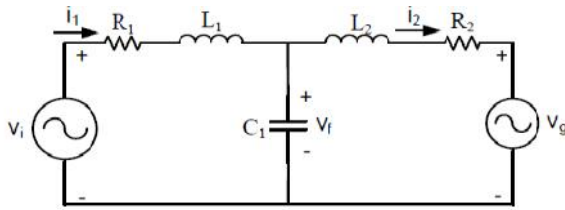


Fig.2 Equivalent circuit of single phase LCL filter

Since SVM is used in this system, the LCL filter is designed in the stationary reference frame () using space vectors to make it easier and more convenient. By applying Kirchhoff's voltage and current laws, the following equations can be used to represent the voltages and currents within the circuit of Fig.2 [11]. Inverter vector equations, dc voltage, capacitor voltage and LCL filter current equations are given by project [1].

III. Control Scheme

In this work, the applied control system is a cascaded system with an inner current control loop controlled by an outer voltage control loop. The block diagram of the adaptive PR current control scheme is presented in Fig.3. The system consist of PV array with maximum power point comprised of dc-dc converter following by three phase dc-ac inverter [3, 4]. The voltage control loop comprises of two PI regulators; one for the dc link voltage control and the other for the grid voltage control. The measured dc voltage is compared with the reference dc voltage

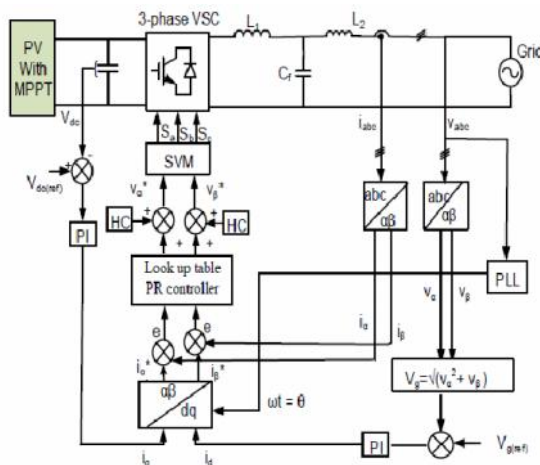


Fig.3: Adaptive PR controller in stationary Reference control

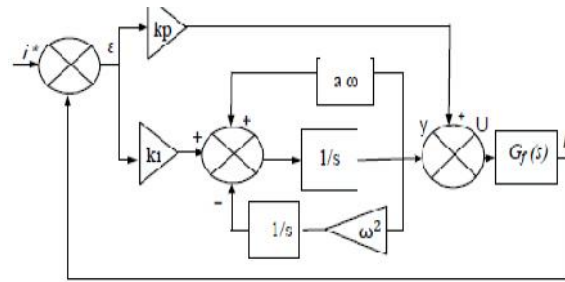


Fig.4: Controller diagram of PR Controller

The measured voltage is converted to the synchronous reference frame, and the q-component, v_q is compared with the reference v_q^* which is equal to zero and controlled by a PI controller. The nominal grid frequency is added to the output of the PI controller, and the sum is integrated to obtain the grid voltage angle .

IV. BRIEF OF THE INSTANTANEOUS POWER THEORY

As the name implied, the instantaneous power theory is based on a definition of instantaneous real and reactive powers in time domain. It is very useful not only in the steady-state but also in the transient state analysis for both three-phase systems with or without a neutral conductor. To illustrate the theory, let consider a set of instantaneous three phase quantity, for example $a v$, $b v$ and $c v$. It starts with transforming a set of three-phase variables in the abc into 0 coordinates. This transformation is so-called as the Clark transformation as described follows.

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$

..... (1)

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

..... (2)

In three-phase, three-wire systems, there is no zero sequence components. If $0 v$ and $0 i$ are both neglected, instantaneous voltage, v , and current phasors, i , can be defined from their corresponding instantaneous and components as follows

$$v = v_\alpha + jv_\beta \dots\dots\dots (3)$$

$$i = i_\alpha + ji_\beta \dots\dots\dots (4)$$

From (3) and (4), instantaneous complex powers, s , can be defined as the product of the instantaneous voltage phasor and the complex conjugate of the instantaneous current phasor given in (5).

$$s = vi^* = (v_\alpha + jv_\beta)(i_\alpha - ji_\beta) = p + jq \dots\dots\dots (5)$$

Where,

$P = v_\alpha i_\alpha + v_\beta i_\beta$ is the instantaneous active power

$q = v_\beta i_\alpha - v_\alpha i_\beta$ is the instantaneous reactive power

The instantaneous complex power is useful. It can be applied for transient or steady-state analysis. The following equation is a compact form for the instantaneous real and reactive power definition and its inversion.

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \dots\dots\dots (6)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix}$$

..... (7)

$$p = \bar{p} + \tilde{p} \dots\dots\dots (8)$$

$$q = \bar{q} + \tilde{q} \dots\dots\dots (9)$$

V.FUZZY CONTROLLER

INTRODUCTION:

The word Fuzzy means vagueness. Fuzziness occurs when the boundary of piece of information is not clear-cut. In 1965 Lotfi A. Zahed propounded the

fuzzy set theory. Fuzzy set theory exhibits immense potential for effective solving of the uncertainty in the problem. Fuzzy set theory is an excellent mathematical tool to handle the uncertainty arising due to vagueness. Understanding human speech and recognizing handwritten characters are some common instances where fuzziness manifests.

Fuzzy set theory is an extension of classical set theory where elements have varying degrees of membership. Fuzzy logic uses the whole interval between 0 and 1 to describe human reasoning. In FLC the input variables are mapped by sets of membership functions and these are called as “FUZZY SETS”.

Fuzzy set comprises from a membership function which could be defines by parameters. The value between 0 and 1 reveals a degree of membership to the fuzzy set. The process of converting the crisp input to a fuzzy value is called as “fuzzificaton.” The output of the Fuzzier module is interfaced with the rules. The basic operation of FLC is constructed from fuzzy control rules utilizing the values of fuzzy sets in general for the error and the change of error and control action. Basic fuzzy module is shown in fig.5 The results are combined to give a crisp output controlling the output variable and this process is called as “DEFUZZIFICATION.”

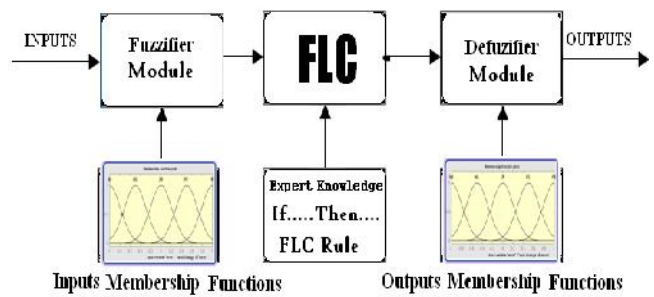


Fig.5: block diagram fuzzy logic.

VI.SIMULINK DESIGN AND RESULTS

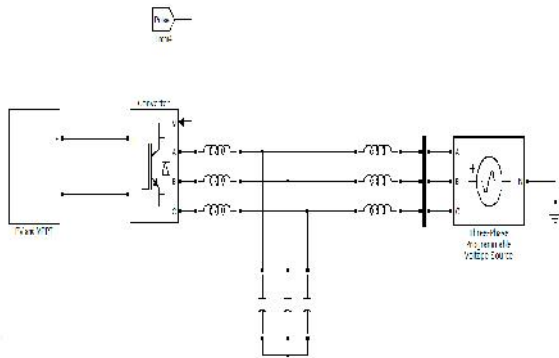


FIG 6: Simulink Block Diagram.

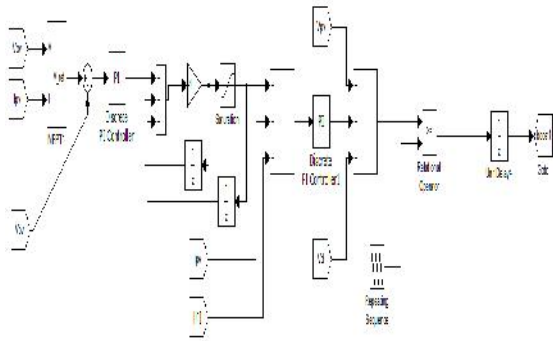


FIG 7:Boost Converter Control Circuit Diagram.

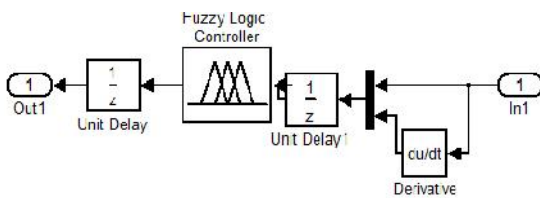


FIG 8:Fuzzy Logic Controller Diagram.

Simulation Results:

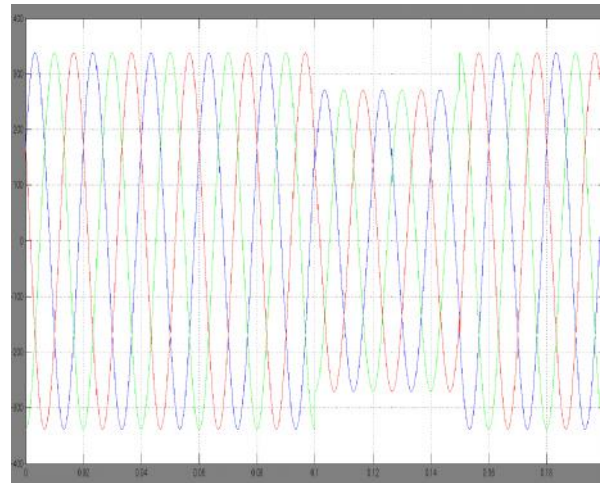


Fig9:Three phase voltage waveform

Fig. 9 and 10 shows the simulation results of the three phase voltage and current. Fig.9 shows the three phase voltage waveform.

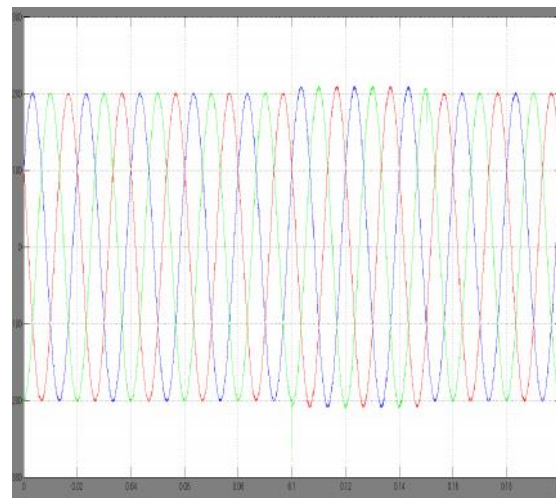


Fig10:Three phase voltage waveform

It can be seen that the voltage drops when a voltage sags happens in the system at 0.1 sec until 0.15 sec. Fig.10 shows three phase current waveform. It is clear that the current

has increased when the sudden voltage occur at 0.1 sec in order to balance the active power transfer from the PV source. Fig.13 shows the stationary reference frame (alpha) current waveform and Fig.14 shows the stationary reference frame(beta) current waveform for conventional PR

controller. They show significant deviation when variation in the current waveform.

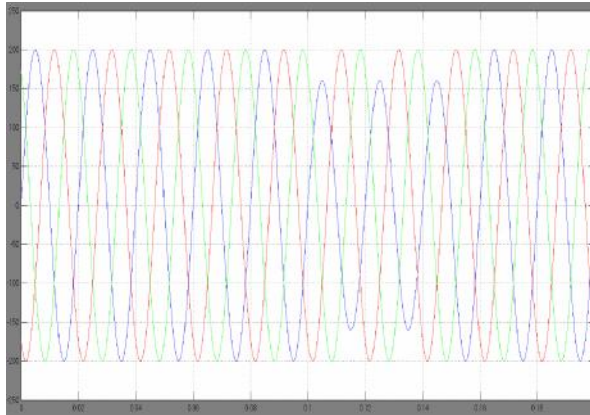


Fig11:Simulation Waveform for unbalanced grid condition : three phase voltage waveform

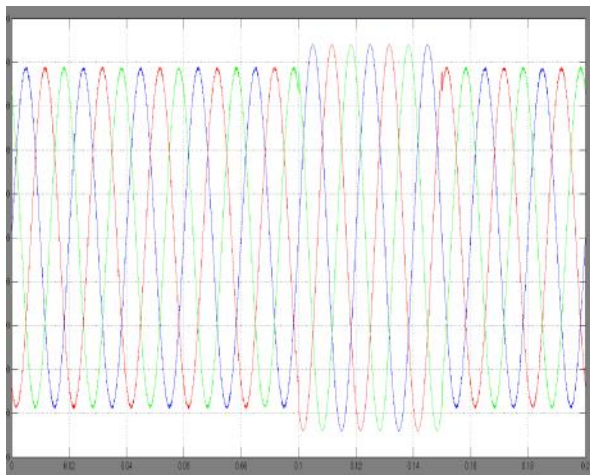


Fig12:Simulation Waveform for unbalanced grid condition : three phase current waveform

Fig.13 and Fig.14 show the stationary reference frame alpha and beta current waveform respectively. The measured current following the reference current which they point out that the fuzzy controller works effectively when there is change in the grid conditions. However, in the case of unbalanced voltage sag the fuzzy controller achieves better dynamic response. Fig.11 and 12 shows the three phase voltage and current waveform respectively; note the reduction in the overshoot characteristics and the recovery time to achieve steady state. It is clear that the adaptive

controller can better compensate the unbalanced current. It can be shown that this is due to the adaptive and fuzzy controllers improved ability to regulate the positive and negative sequence components.

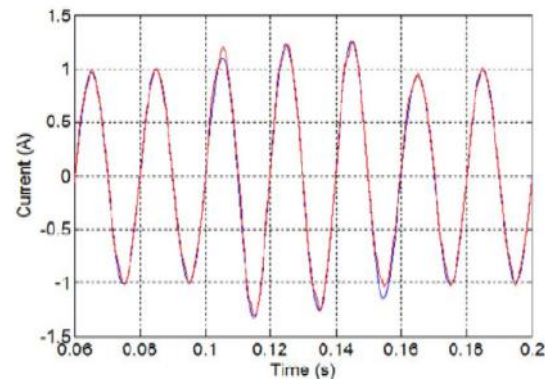
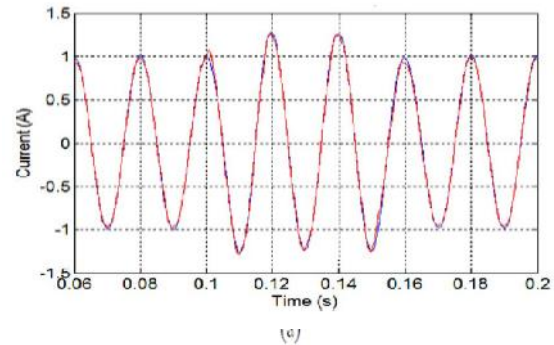
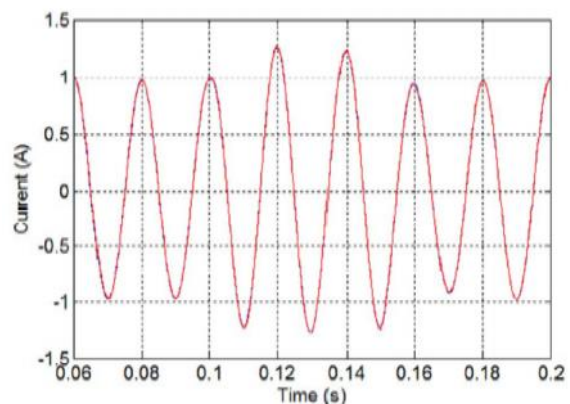


FIG 13: Simulation Waveforms for Conventional PR controller i-alpha and i-beta.



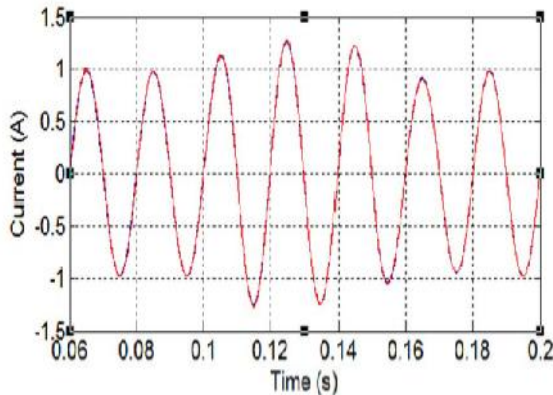


FIG 14: Simulation Waveforms for Adaptive PR controller i-alpha and i-beta

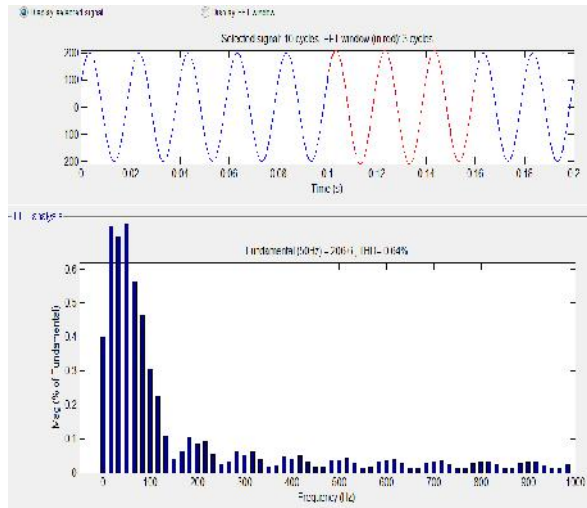


FIG15: Total Harmonic Distortion

CONCLUSION

This thesis has considered the impact of an adaptive PR current controller and fuzzy controller scheme of a three phase grid connected inverter. In particular, this work has shown the performance of the adaptive PR controller compared with the conventional PR controller which is popular in grid connected inverters. Simulation studies confirm that the adaptive PR controller demonstrates better performance under normal and abnormal operating conditions. There is no steady state error output, and the harmonic content of the current waveform is very low. A Fuzzy controller is also implemented in this

project in order to reduce the total harmonic distortion. In addition, the fuzzy and adaptive PR controller offers superior output power regulation, and improved power quality performance. Overall, it can be concluded that the adaptive PR and fuzzy controllers are better suited in the event of grid faults, or operation in weak grid environments, compared to fix gain controllers.

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