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An Improved PID and Repetitive Control for Single Phase Inverters of Photovoltaic Power System

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Abstract: Inverters, which are installed in photovoltaic (PV) power systems, are key devices to turn output direct current (DC) of PV arrays to alternative current (AC) with a specific waveform required by power load. With their widespread application and increasing large-scale of PV power systems in utility power network, the disturbances from load and line faults or external interferences often cause serious problems in inverters, operating in a safe and steady condition and inverters control problems on suppressing the disturbances have always been focused by the industry and academic circles. Many efforts and published contributions have been devoted to improve the flexible performance of PV-connected inverters. A technique to utilize favorable circumstances of proportional integral derivative (PID) and Repetitive Control (RC) controller implemented that helping PID controller diminishing mistake from last period while as yet utilizing PID controller for handling with noise and high error.

Keywords: *Renewable Energy Resources, DC Component, Total Harmonic Distortion (THD), Photovoltaic Power Systems, Repetitive Control.*

1. Introduction

Photovoltaic (PV) control frameworks, as a simple and accessible approach to use the sun oriented power, are most flowing, productive and advantageous to create control as contrasted and other sustainable renewable energy for instance wind, tide, biomass, hydro-control and so forth, which have shaped a domain well-disposed power industry and are given careful consideration. As of late, the demand of electric supply is expanding massively; in this way the vitality provided by photovoltaic systems to the electric grid is increasing high perceivability [1]. As a matter of first importance this paper sets up the conversion technique for single stage inverter of photovoltaic power system by utilizing the LC filter and endeavor to locate a novel strategy to control the framework with enhanced execution and strength. Besides the investigation will profound jump into a controlling component of PID and RC control to make the framework proficient. Repetitive Control (RC) is a viable and proficient method for following/dismissing periodic signal [2-4]. Performance of the RC plot has been estimated regarding Total Harmonic Distortion (THD) and steady state tracking error. Thirdly principle controller alongside an integrator is utilized into the feedback closed-loop system for achieving steady state error condition and reduced harmonics in output wave. At last the Experimental outcomes show that RC controller with relative controller essential subordinate is equipped for accomplishing a close to zero error steady-state error. The execution of the RC controller and power nature of the converter is estimated and exhibited as far as the THD. In our proposed strategy, THD % is decreased to a low dimension when contrasted with going before customary proposed strategies. The reenactment results affirm the legitimacy and noteworthiness of the proposed strategy.

Inverters are utilized to make single or three stage AC voltages from a DC supply. Inverters are utilized both in photovoltaic and in widespread universal power supply. High control methodologies should be exact, quick, robust and implementable for structuring of inverter system[6][7] A single phase stage inverter utilizing PWM rectifier has been simulated utilizing conventional proportional integral derivative with plugin repetitive control scheme[8]. Periodic control strategies, otherwise called learning control procedures, work over and over and reiteration empowers the framework to enhance following precision starting with one redundancy then onto the next [9].

A. Cataloging of PV Power System

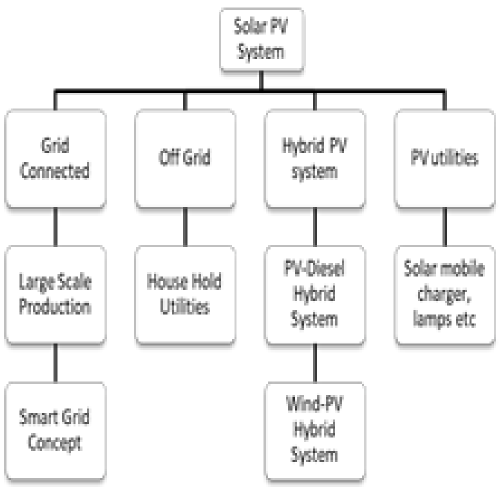

Figure 1: Cataloging of PV system

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As shown in figure 2, PV system can be categorized by various aspects but if classified primarily it classifies as follows.

- Stand-Alone PV system
- Grid-Tied PV system

B. Cataloging of PV Power System

A stand-alone, single-stage PWM inverter, associated with a non-linear load is appeared in Figure 3. In the block diagram, indicates the ostensible estimation of the dc bus voltage; Ln and Cn signify ostensible estimations of channel inductor and capacitor; Lr , Cr and Rr mean rectifier stack parameters (inductor, capacitor and resistor); vc and io speak to stack voltage and current; Vref(k) signifies the reference motion in the Kth inspecting moment. The RC controller guarantees high following precision. The goal of the RC controller is to follow a reference periodic signal within the sight of non-linear loads and parameter vulnerabilities. It is because of non-linear loads and parameter vulnerabilities, the output voltage of the inverter frequently experiences periodic errors, which are significant wellsprings of aggregate symphonious mutilation.

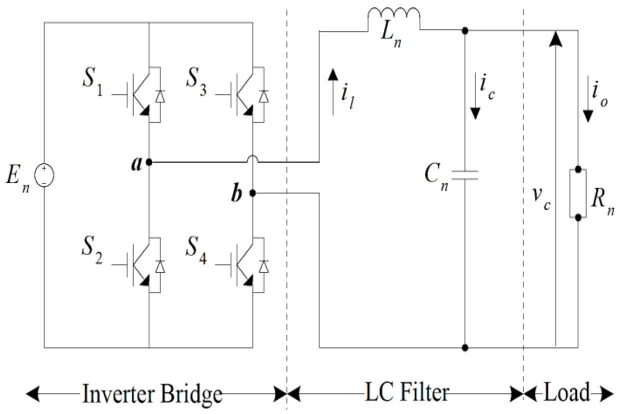


Figure 2: Single phase inverter model with LC filter

The state-space condition for the single-stage inverter framework progresses toward becoming:

$$\begin{bmatrix} \dot{v}_c \\ \ddot{v}_c \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ \frac{-1}{L_n C_n} & \frac{-1}{R_n C_n} \end{bmatrix} \begin{bmatrix} v_c \\ \dot{v}_c \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{L_n C_n} \end{bmatrix} v_{ab} \quad (1)$$

where v_{ab} is the PWM input voltage and for unipolar PWM pulse average value of $v_{ab} = E_n \Delta T$ results of discretization are shown here

$$x((k+1)T) \approx e^{AT} x(kT) + e^{AT/2} BE_n \Delta T \quad (2)$$

C. Proposed Control Method

In this section firstly described the schematic diagram of the proposed controller then followed with the block diagrams of each and every part of the controller, start with classical PID then Repetitive control then by combination of these two controllers for the single phase PWM inverter.

I. Schematic Diagram of Proposed Single-Phase PV Inverter System

Figure 4 depicts the complete schematic figure of the proposed system transformer less single-phase load connected inverter system. The PV array is connected to the Full-bridge inverter, and V_{out} is the bridge circuit output voltage of the inverter. The output current and voltage of the inverter can be adjusted by the PWM controller of the inverter. Proposed diagram shows the PWM full bridge inverter with LC filter and a resistive load R are considered as plant to be controlled. In this proposed schematic diagram the most usual load connected to the PWM inverter. As can be seen, because of diverse variety of loads, it is beyond the realm of imagination to expect to figure a general model to cover each sort of burdens. Anyway in this proposed structure, we characterize an ostensible load to drive the model and thinking about the heap varieties. For high-accuracy following of occasional reference inputs dependent on inside mode. A wide assortment of control system framework is managing periodic signals. These periodic signals either go about as a kind of perspective flag or unsettling influence. The control frameworks making do with intermittent signs can be disengaged into two orders: occasional signs with variable recurrence and settled recurrence intermittent signs. The variable frequency irregular signs may experience frequency varies as a result of the framework's inward characteristics or unordinary/unprecedented working. Repetitive control has been turned out to be a zero unfaltering state blunder answer for periodic signal with consistent frequency. In any case, execution of the Repetitive controller (RC) debases altogether when the frequency of the reference signal isn't actually known or shifts with time[16]. Repetitive control can be accomplished to pursue the ideal occasional unsettling influence. Be that as it may, the guidance began to work a large portion of a period later. At the point when the system loads happen non-intermittent variety, for example, step expanding, system dynamic performance is hard to meet the structure necessities.

The proposed PID-RC Controller installed together for controlling of the single phase PWM inverter. By implementing the model of periodic signal generating periodic in the closed loop system, an efficient and accurate asymptotic tracking characteristic is achieved. It is comparatively a simple learning control method designed specifically for this purpose. In view of its high accuracy, basic execution and low reliance on the execution of framework parameters, tedious control is considered as the primary strategy to manage occasional exogenous signs. The repetitive operation of trajectory control can diminish the tracking error to the lower level. The PID control lags behind in some issues like signals overshooting, deadbeats, and periodic tracking errors, so for achieving better results PID adds with improved technology introduced by the internal mode principle RC technique. The asymptotic tracking of reference signals and rejection of distortion harmonics are realized by RC in the closed loop system.

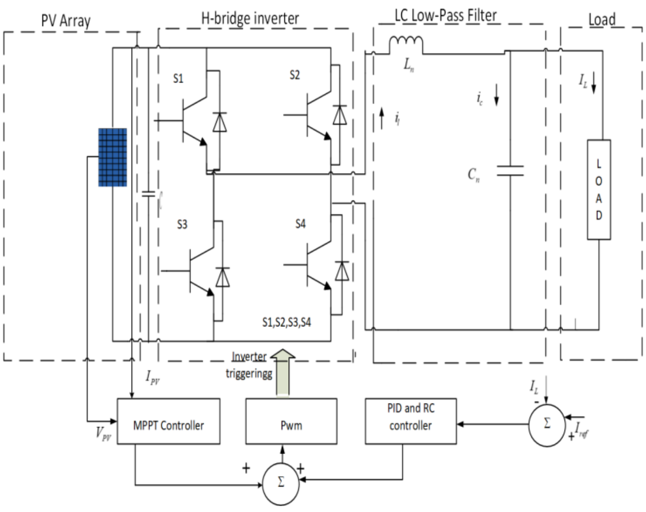


Figure 3: Proposed schematic diagram

For convenience, from the previous section the discrete transfer function of the PWM inverter can be obtained

$$G_p(z) = C_d(zI - A_d)^{-1}B_d \tag{3}$$

$$G_p(z) = \frac{b_1 z + b_2}{z^2 + a_1 z + a_2} \tag{4}$$

II. Repititive Control Model

Repetitive control based on the internal mode principle, a tracking method in which the control variables track the reference signals if there are nonlinear loads still the system performs good results with lowest harmonic distortion which can't be achieved with only PID controller [10]. The given below figure 4 shows the algorithm inside the RC controller, where k_r an error gain for RC controller needs to be fine-tuned. The output which is coming from the RC controller adds with the present error.

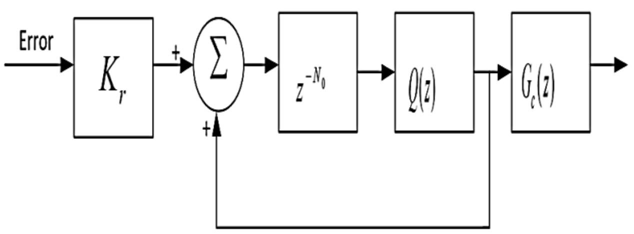


Figure 4: Repetitive controller

To minimize the tracking error and suppressing the total harmonic distortion the control law in similar way as presented by Zhi-xiang Zou in [11].

$$G_{rc}(z) = K_r \frac{Q(z)z^{-N_0}}{1 - Q(z)z^{-N_0}} G_c(z) \tag{5}$$

If we take $Q(z) = 1$, $K_r = 1$ and $G_c(z) = 1$ then it reduced to the one as shown below in figure 6. Repetitive controller that regards as periodic waveform generator that is inserted in closed loop central system and from regulate this wave from the closed loop feedback controller and hence minimized the periodic errors, the two things that repetitive system control ensure are the stability and the rejection of harmonics as listed also in [7-9].

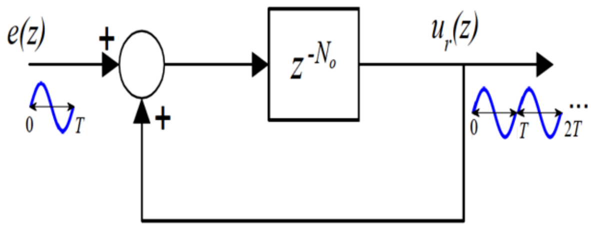


Figure 6: Standard memory loop in discrete domain of RC.

III. Proposed PID-Repetitive Control

The combined PID and RC used in so many control techniques such as scanning probe microscopes SPMs in [12]. For positioning of the SPMs it should follow a periodic trajectory to sort out a discrete repetitive controller is proposed with the PID controller. By implementing the model of periodic signal generating periodic in the closed loop system, an efficient and accurate asymptotic tracking characteristic is achieved [13-15]. It is comparatively a simple learning control method designed specifically for this purpose. Because of its high precision, simple implementation and low dependence on the performance of system parameters, repetitive control is considered as the main method to deal with periodic exogenous signals. The repetitive operation of trajectory control can reduce the tracking error to the lower level.

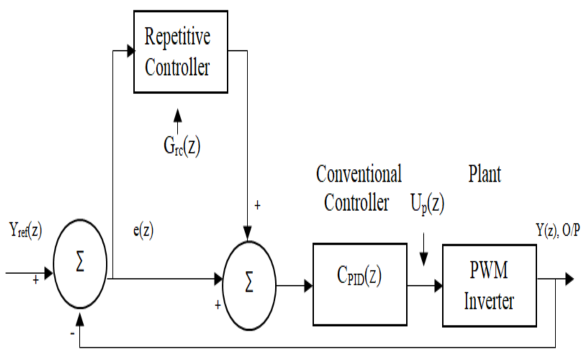


Figure 7: proposed control system

R (z), $y(z)$ and $E(z)$ represent input, output and error signal. $Q(z)$ is a filter which enhances system stability. It can be expected that the asymptotic tracking of exogenous periodic signals can be realized by implementing model expressions in the closed loop system. The system under this controlling technique called the repetitive control system. The controller is considered to be a simple learning control because control input is computed using information from the error signals of the previous period. This is the reason sending the set points to RC controller for testing the conceptual Repetitive controller design[17][18] ,these set points are arranged themselves in the form of step function with accordingly reference to the sine wave symmetry, so it tracks our reference signal which is sine wave signal. When the signal interference is periodic, it enhances the exactness of the consistent state reaction of the control framework and comprises of the consonant parts of regular crucial frequencies [19]. The detailed mechanism system shown below, the detailed of each part is shown figure 7.

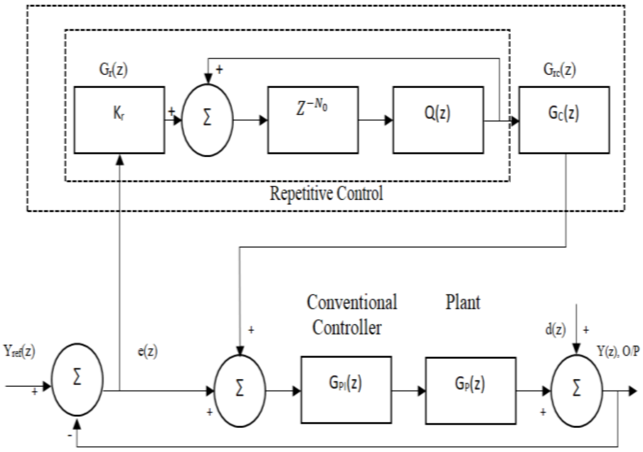


Figure 7: Controller design for given system with external disturbance

The total control mechanism has shown in detailed. From figure 7 the transfer functions from $y_{ref}(z)$ and $d(z)$ to $y(z)$ in the overall closed loop system, are:

$$\frac{y(z)}{d(z)} = \frac{\left(1+G_{PI}(z)G_p(z)\right)^{-1}\left(1-z^{-N_0}Q(z)\right)}{1-z^{-N_0}Q(z)\left(1-k_rG_c(z)H(z)\right)} \quad (6)$$

$$\frac{y(z)}{y_{ref}(z)} = \frac{\left(1+G_{rc}(z)\right)G_{PI}(z)G_P(z)}{1+\left(1+G_{rc}(z)\right)G_{PI}(z)G_p(z)} \quad (7)$$

$$H(z) = \frac{G_{PI}(z)G_p(z)}{1+G_{PI}(z)G_p(z)} = \frac{z^{-d}B^+(z^{-1})B^-(z^{-1})}{A(z^{-1})} \quad (8)$$

So as to accomplish zero-stage remuneration, the Compensating filter $G_c(z)$ should be the correct backwards of (1.8) however basically it is difficult to accomplish the correct converse of the framework because of parameter vulnerabilities and elements of the framework, general $G_c(z)$ the can be picked as:

$$G_c(z) = \frac{z^d A(z^{-1})B^-(z^{-1})}{B^+(z^{-1})b} \quad (9)$$

$$C(z) = \frac{U_P(z)}{e(z)} = C_{PID}(z)(1+G_{rc}(z)) \quad (10)$$

Now the equation 1.10 becomes after putting the value of $G_{rc}(z)$:

$$C(z) = \frac{U_P(z)}{e(z)} = C_{PID}(z)(1+K_r\frac{Q(z)z^{-N_0}}{1-Q(z)z^{-N_0}}G_c(z)) \quad (11)$$

IV. Stability Analysis

The Consequently zero tracking error in close-loop is safeguarded if the nearby close-loop is steady. This will add to a superior yield for rehashed forms as clarified and investigated with mathematical modeling of plant. The investigation is to test blend of PID controller and RC controller module in a framework and measure FFT range, SNR (signal to noise ratio) and contrast the outcome and typical PID controller as examined with simulations results in next section. This will add to a superior yield for repeated process. The closed loop system is stable if the table following conditions are fulfilled:

- The closed loop system $G(z)$ is stable.
- The system with the controller is steady if every basic establishment of the denominator (1.6) lies within the unit circle.

These conditions are fulfilled by proposed design of $G_c(z)$ and $G_X(z)$ which are described as follows:

- Condition 1: it is prudent to structure the controller with an adequately sufficiently high enough robustness.
- Condition 2: There is no issue with the causality of $H(z)$.

The RC controller learns from the output of the PID controller, the errors of the previous and current periods. As a result of learning, the RC controller can help the PID controller to learn the error of the previous time period, if there is no noise in the system, and then the error of the next time period will be reduced. For this reason, this controller does not require more time to fine-tune k_p, k_i and k_d in the PID controller, and it is easy to fine-tune Kr in the RC controller mode only. So, over all control system is: For PWM inverter in discrete form:

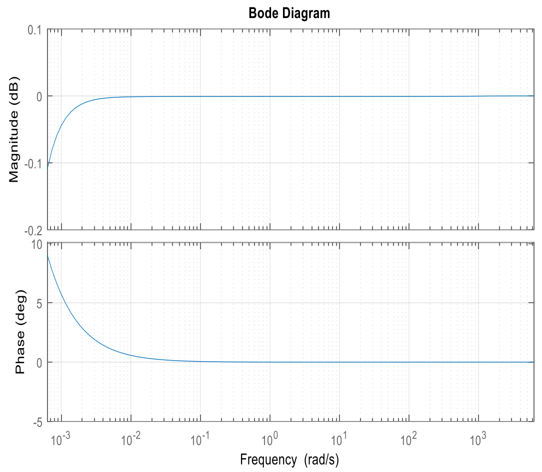
$$G_P(z) = \frac{b_1z+b_2}{z^2+a_1z+a_2} \quad (12)$$

For Repetitive Control:

$$G_c(z) = \frac{z^d A(z^{-1})B^-(z^{-1})}{B^+(z^{-1})b} \quad (13)$$

$$G(z) = \frac{b_1z+b_2}{z^2+a_1z+a_2}\,\frac{z^d A(z^{-1})B^-(z^{-1})}{B^+(z^{-1})b} \quad (14)$$

Zero following error in closed-loop is safeguarded if the closed-loop system is steady. In the PID-RC controller, RC controller helping the PID controller to take in the error from the last period which will be prepared to limit the error of the following time frame. The RC controller gains from the yield of the PID controller, the errors of the past and current periods. In view of taking in, the RC controller can help the PID controller to take in the errors of the previous time period, on the off chance that there is no clamor in the system, and, the error of whenever period will be decreased.



(a) $e(z)/y_{ref}(z)$

Figure 8: Magnitude and phase characteristics of the closed loop system

D. Simulations and Results

For simplicity, in the realization of the hardware, it needs to test the circuit, prior to performing error checking and programming test. In order to improve our control strategy, the legitimacy and effectiveness of the system as a whole stimulated in the MATLAB/Simulink version 8.5 R2016a. The adoption of Windows 10 ultimate with 64-bit and Intel Dual Core 2.1 GHz processor operating system with 8 GB of RAM for evaluation results. The research work is based on the modeling and simulations for the proposed controlling technique. Finally the MATLAB simulation results were compared to show the effectiveness of this work.

I. SIMULATION PARAMETERS

Table 1: Simulation Parameters

System setup		
Voltage	E_n	100V
Voltage out	V_{out}	220V
Output filter resistance	R	1Ω
Filter inductor	L_n	5mH
Triangular generator frequency	F	$10e^3$
Filter coefficient	N	100
Reference sine wave frequency	f	2*pi*50
Proportional gain	K_P	0.9
Integral gain	K_i	0.1
Derivative gain	K_d	0.5
RC Controller gain	K_r	0.1
Non-linear load resistance	R_r	20Ω
Capacitor	C_n	20 µF

II. PROPOSED SIMULINK DIAGRAM

The complete Simulink diagram of our proposed method is illustrated in the Figure 9

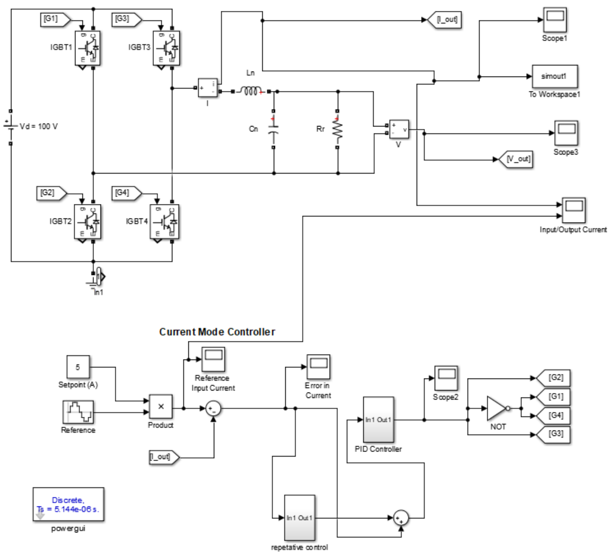


Figure 9: Simulink model of the proposed scheme

III. Performance Evaluation

The proposed single inverter comprises of full extension DC-AC module, line frequency transformer, and a nonlinear load repaying module. A LC channel is set in the yield of DC-AC module to get the sinusoidal voltage. The conventional PID to control the output current of the PWM inverter, study analysis and the output results shows that the waveforms are distorted and not properly tracked according to the reference current and have so many distortions and spikes in the resulted output waveform it also has the DC component. A smooth waveform is required with minimal total harmonic distortion.

The line frequency transformer is associated with the opposite end of LC channel. This structure prompts great voltage measure at LC channel yield. So as to figure the yield current esteem and the THD, the FFT investigation is performed utilizing MATLAB recreation test which is appropriately structured and the outcomes check the practicality, upgraded execution and enhanced effectiveness of the proposed control technique. Our proposed model simulation result shown below and total harmonic distortion is shown in figure 11.

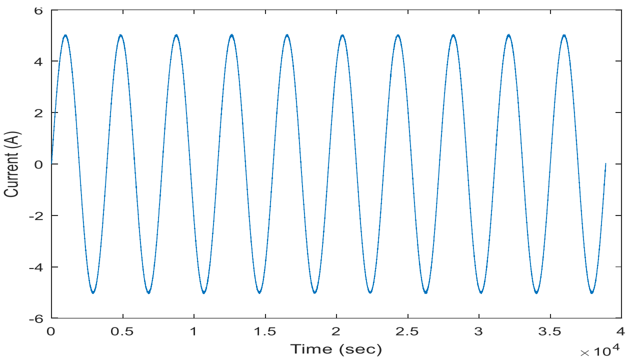


Figure 10: Output current wave form of proposed scheme

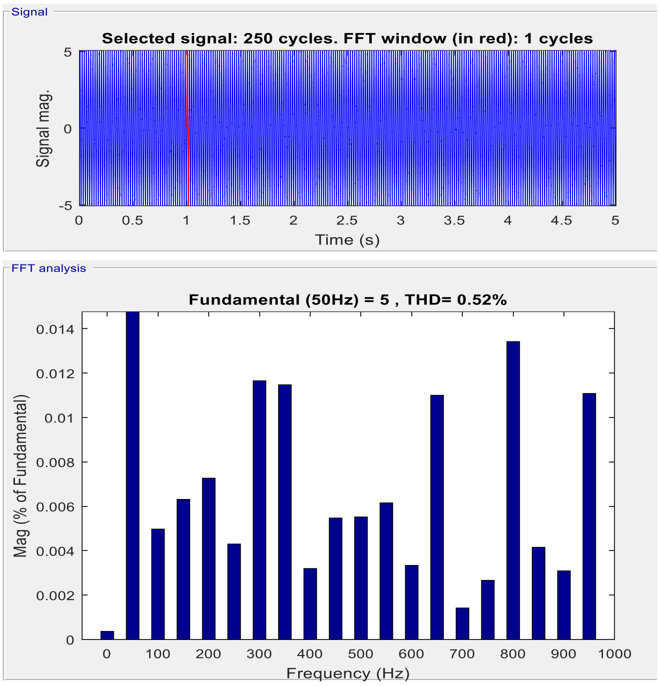


Figure 11: FFT analysis of proposed scheme

IV. Comparison with other methods

A Comparison has been made with customary PID controller for controlling of the inverter yield current. The execution of the framework is thought about based on lattice associated inverter yield current and the FFT range investigation, which is clarified in the following area with reenactment results.

Table 2: Comparison of techniques using conventional and proposed scheme

Technique	DC component	THD %
PID controller	0.15	0.89
PI controller	0.02	2.06
PID-Repetitive Controller	0.025	1.15
With proposed scheme	0.001	0.52

5. Conclusion

In this paper, the main focuses on the research work done in this thesis and the content of the research, research direction and scientific research plans. In this thesis transformer less single-phase photovoltaic system with improved control strategy discussed. The design depends on the model of PID-RC controller in the inverter system feedback closed loop control, so as to accomplish the zero relentless state error to stifle the dc infusion in single-stage photovoltaic inverter with low THD. The control framework has been reenacted in MATLAB-SIMULINK programming copying, and our control model of the recreation results confirms a straightforward and compelling approach to accomplish results. The proposed scheme can effectively improve the performance by considering the tradeoff between the performance and computational complexity. The main time consume in testing and evaluation and then fixing the errors and designing parameters for fruitful results. The proposed control model allows harmonic mitigation, and the grid current THD value is decreased to 0.52%.

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