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Adaptive Fuzzy PI Current Control of Grid Interact PV Inverter

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ABSTRACT

Now a day's, Photo Voltaic (PV) power generation rapidly increasing. This power generation highly depending on the temperature and irradiation. When this power interface with grid through the voltage source inverter with PI controller. Its gains should be updated due to the parametric changes for the better performance. In This Work Fuzzy Controller updates the gains of the proportional integral (PI)s Controller under variable parametric conditions. the gaines of the PI Controller are updated based on the error current and change in error current through the fuzzy controller. The error current in direct and quadrature frame are the Inputs to the PI controller. The PI Controller generates the reference voltage to the pulse width modulation technique. Here reference voltage is compared with the carrier signal to generate the pulses to the 3-Ph Inverter connected to the grid. This controller has given well dynamic response with less steady state error and also given The less THD of the grid current compared to the PI and Fuzzy controller.It Is implemented and verified in MATLAB Simulink.

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1. INTRODUCTION

With development of renewable energy technologies, different inverter structures and control systems are investigated for renewable energy supplied inverters. In the old literature, PI or PID controllers are used to control the voltage source inverter (VSI) interact grid. PI controller with fixed gains for the fixed operating point provides an acceptable performance, but poor transient performance is obtained when the inverter operating point varies continuously is depending on the dynamics of the plant and also depending natural conditions such as solar radiation in case of the PV system and wind speed [1]. More ever voltage, frequency of the grid also may change and line impedance during the operation of the inverter [2]. Hysteresis current control has benefits of simple Implementation, robust structure, high stability, fast response, it has disadvantage of the variable switching frequency causes interference to communication lines, design of filter difficult, switching loss more [3-5].Studies on different topology in inverter such as multilevel inverter and HERIC inverters connected to the grid with linear control was used to achieve the high converter efficiency with minimizing the switching loss [6].Transformer less inverter topology are studied with linear controls and hysteresis control and dead beat control method to improve the efficiency of the single phase inverter connected to the grid. However, feed forward of the voltage and inverter current are used to improve the performance of the inverter connected to the grid when the delay in the control time and variations on passive elements values affect the deadbeat control were proposed [7]. Although, to improve dynamic response of the system line voltage feed forward is used, unwanted compensations increase the Voltage harmonics in the current waveform in this method. Recently, proportional resonant (PR) controllers [8-10] areused as current controller to achieve the unity power factor correction rectifiers connected to the grid. The PR controller has given the infinite gain at resonance frequency and zero steady state error. Whatever it is harmonic compensation of the PR controller is limited to low order current harmonic frequency is out of the band width of the system. But it has disadvantage that it needs the resonance frequency information is depending on the grid frequency in grid connected system which is variable [11].

So the operation of the grid connected inverter with linear control techniques with fixed gain is not given suitable performance with change in the system parameters. The grid connected inverter not only operates different circumstances and also meet the international standards [12-14]. Fuzzy logic control (FLC) is a non-linear which is used to updates the gains of the PI or PID controller has given the better performance with changing the parameter conditions and load disturbances [15-17]. Thus, FLC is used and given the better performance to control the plant with dynamic changes and grid interact inverter in variable wind energy applications and in FLC is used to extract the maximum power from PV panel [18-20].In fuzzy-PI controllers, fuzzy logic decides the gains of the PI controller according to operation point of the system is depending on the parameter changes [21-22].Fuzzy PI control makes the system insensitive to external circumstances changes are there in Renewable energy system like PV and Wind [23]. Since supply specifications and grid conditions are variable, adaptive control of the grid connected inverters is important to achieve requirements of the grid as well as consumers [24-25].

This paper is organised as Section 2 Describes the modeling of PV Array, Section 3 Describes the inverter and design of the LCL filter and Section 4 Presentes the design of the Adaptive Fuzzy PI controller. In Section 5 the Resultes And Discussion.

2. DESIGN OF THE PV ARRAY

Generally, A PV cell is a simple P-N junction diode which converts solar irradiation into electricity. PV cell is represented as a combination the current source (I_{pv}), shunt resistance (R_p), diode and a series resistance (R_s). In order to overcome the imperfections of PV single diode modeling at high voltages and low voltages, a two diode model of PV solar cell is considered is shown in the Figure 1 [3].

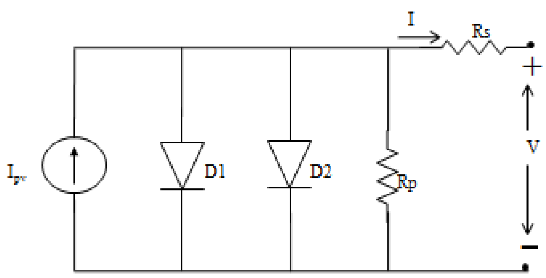

Figure 1. Two diode model of the PV Cel

The PV cells are connected in series (Ns× Np cells, where Np= 1) to produce the PV module. Basic equation that describes the current output of PV module using the two- diode model is given by equation. The PV cell voltage- current relationship in equation (1) is modified for PV module as [4-6].

$$I = NpIph - NpIo\left[\exp\left(\frac{N/V_s + I*R_s/N_p}{n*V_t}\right) - 1\right] - I_{sh} \tag{1}$$

In grid connected PV system, modules are configured in series- parallel structure with any number of PV modules (N_{ss} ×N_{pp} modules) to produce the PV array. Then the PV module voltage-current relationship in Equation (1) is modified for PV array and it is given by (2), [5].

$$I_o = I_{rs}\left[\frac{T}{T_r}\right]\exp\left[\frac{q*E_{go}}{nk}\left(\frac{1}{T} - \frac{1}{T_r}\right)\right] \tag{2}$$

Where I_{pv}, I_{o1}, I_{o2}, R_s are the parameters of the individual modules, N_s and N_p are the number of cells connected in series and parallel of module respectively, N_{ss} and N_{pp} are the number of modules connected in series and parallel respectively for array. In this work PV Array is designed using the KC200GT solar module. Its Parameters are given in the Table 1 [4].

Table 1. KC200GT PV Module Parameter

Parameter	Value
Maximum Voltage (V_m)	26.3V
Current at Maximum Power (I_m)	7.61A
Open Circuit Voltage (V_{oc})	32.9V
Short Circuit Current (I_{sc})	8.21A
Total No.of Cells in Series (Ns	54
Total No.of Cells in Parallel (N_p)	1
Temperature Coefficient of V_{oc}(K_v)	-123 mV/°C
Temperature Coefficient of I_{sc}(K_i)	3.18mA/°C
saturation current $I_{o1} = I_{o2}$	$1.045\times10-^{9}$A
R_p	415.405 Ω.
R_s	0.221 Ω.

3. THE THREE PHASE INVERTER

3-Ph Voltage source inverter connected to grid with LCL filter. Consisting the six switches as shown in the Figure 2. In this paper these switches are controlled with the help of the Adaptive fuzzy PI controller. Inverter output voltage is defined in terms of the switching states and input DC voltage. The magnitude of the output voltage is controlled by means of the modulation index of the PWM and frequency of the output voltage is equal to the frequency of the reference wave generated by the fuzzy controller.

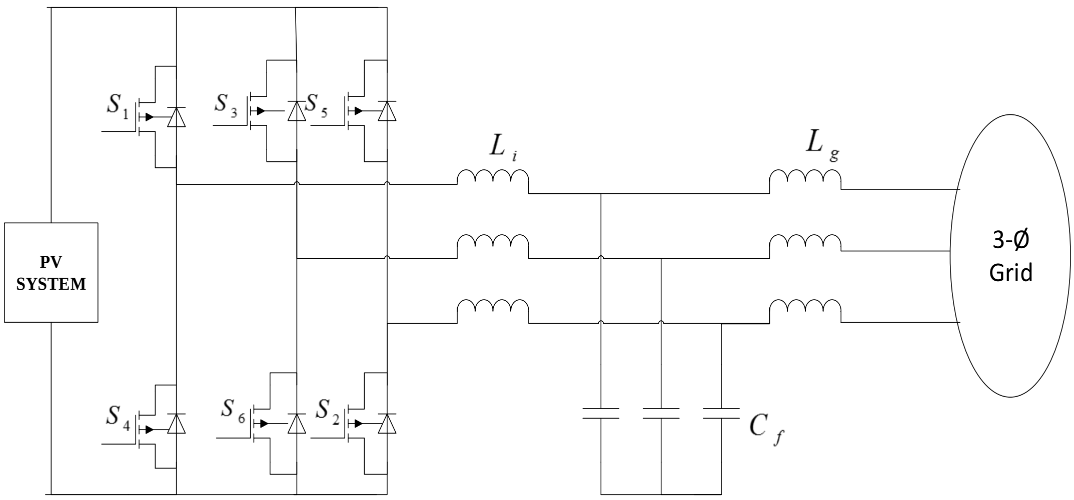

Figure 2. Three-phase grid connected PV inverter

Then, the output voltage 'V_i 'can be related to the switching state vector 'S 'and $V_{PV.}$

$$V_i = V_{PV}\ S \tag{3}$$

Where V_{PV} is the PV voltage after MPPT.

The overall block diagram of the system is given in the Figure 3. The fuzzy controller is used to update the gains of the PI Controller for the Parametric Changes. The PI controller processes the Error in current and generates the reference Voltage.The reference voltage is input to the PWM operation.Generates the switcheing signal to the 3-Ph Inverter. In this work frequency modulation index is taken as the 200.The magnitude of the output voltage is controlled by voltage modulation Index. It is dependeing on the error in Current.

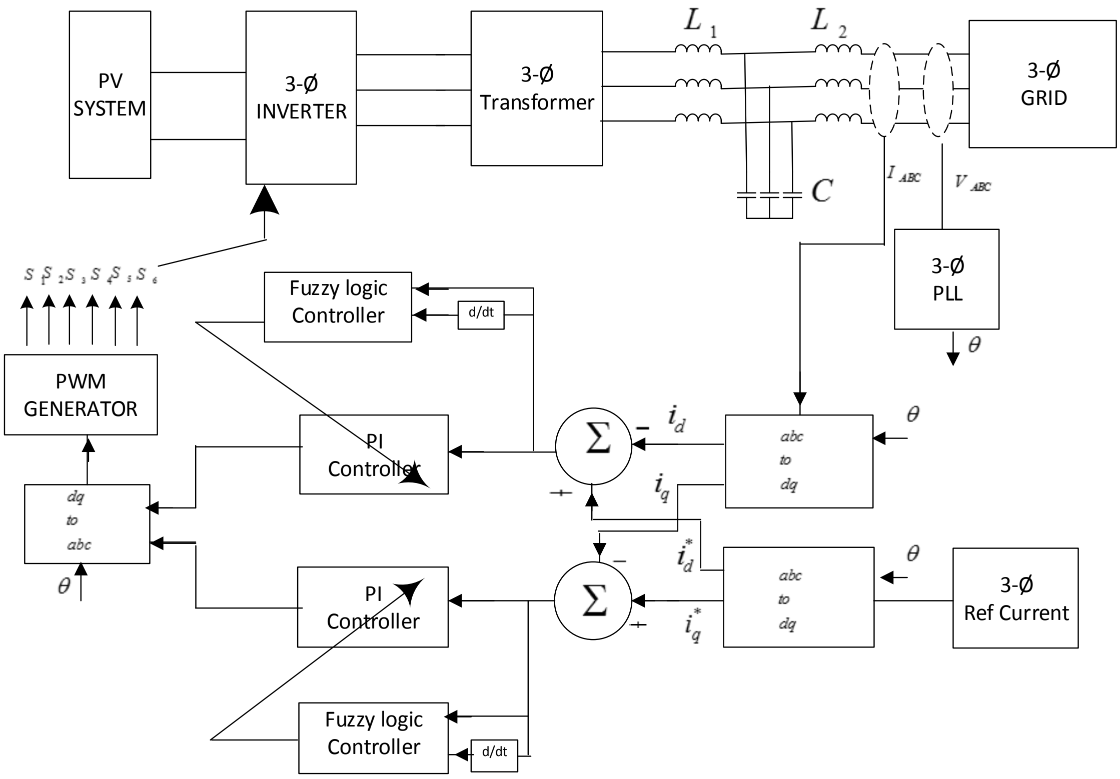

Figure 3. Overall Block Diagram of the PV Inverter Connected to the grid with Adaptive Fuzzy PI Controller

Table 2. Parameter of the System

Variable	Speed (rpm)
PV Voltage	600 V
Grid Voltage	415V L-L (rms)
Grid Frequency	50Hz
Inverter Side Inductance(Li)	3mH
Grid Side Inductance(Lg)	2.2mH
Filter Capacitor(Cf)	0.015µF
Carrier Frequency	10KHz

4. DESIGN OF THE FUZZY PI CONTROLLER

The Architecture of thefuzzy controller is shown in Figure 4. It has three units Fuzzifier unit, Interface unit and Defuzzifier at the out terminal. It has input and output variables. Error and change in error currents are inputs whereas proportional gain (Kp) and Integral gain (K_I) are the output variable [19-21]. The error in current and change in error currents are defined in Equation (4) and Equation (5). Change in error current means difference between the present error current and previous error current value. Which are defined in (4) & (5) respectively. In this work input five membership levels are defined as Negative Large (NL2), Negative Small (NS1), Zero (Z), Positive Small (PS1), Positive Large (PL2) and for output membership function three levels are defined as Large (L2), Medium (M1), Small (S0) which are used to build input and output membership functions and Based on the rule matrix's table foroutput variable K_i and K_p are given in Table 3 & Table 4 [23], [24]. The membership fuction of the input and output varibles are shown in Figure 5 to Figure 8. Three Dimentinal variation of the Fuzzy Inputs (I_d&Iq) and outputs $K_I$and Kp are shown in Figure 9 and Figure 10 [25].

$$ei(k) = I_r(k) - I_g(k) \quad (4)$$

$$\Delta ei = ei(K) - ei(k-1) \quad (5)$$

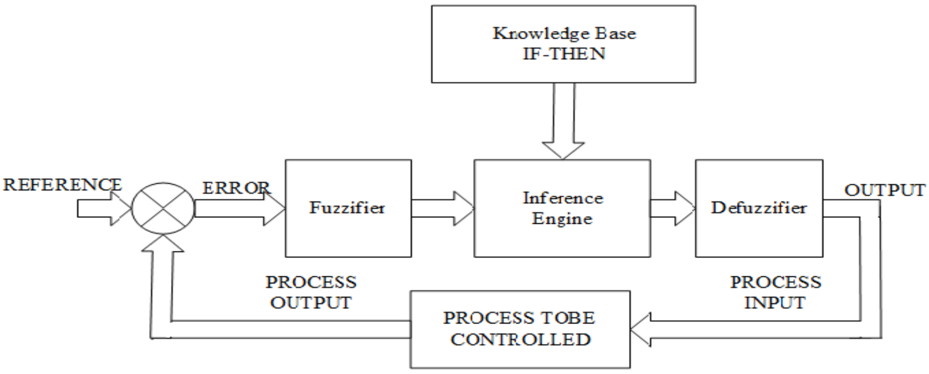

Figure 4. Architecture of the Fuzzy controller

Membership functions for Error Current (I_d& I_q)

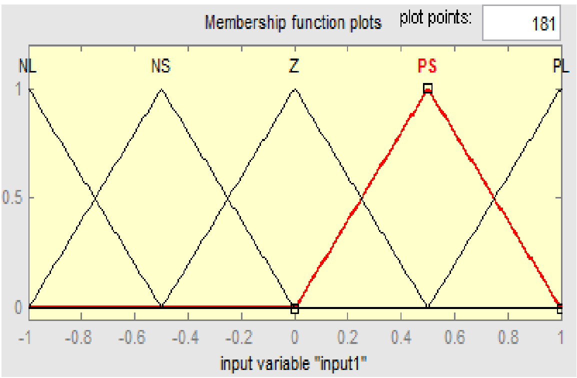

Figure 5. Membership functions of error in currents (I_d& I_q)

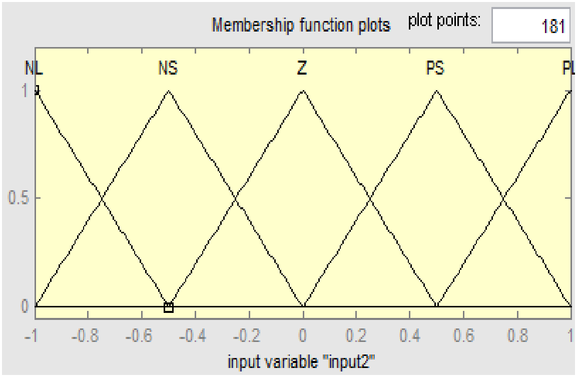

Figure 6. Membership functions of change in error (I_d& I_q)

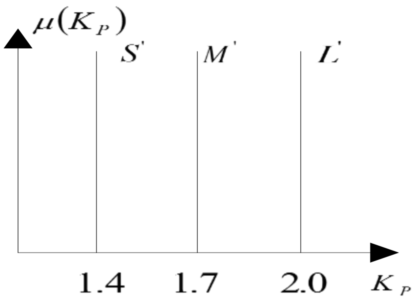

Figure 7. Membershipfunction of the output (K_i)

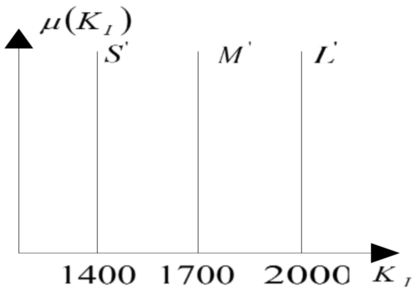

Figure 8. Membership function of the output (K_p)

Table 3. Rule Matrices table for Kp output Variable

Output (K_P)		Error(e)				
		NL2	NS1	Z	PS1	PL2
Change In Error(ce)	NL2	L2	L2	M1	M1	S0
	NS1	L2	L2	M1	S0	S0
	Z	M1	M1	M1	M1	M1
	PS1	S0	M1	M1	M1	L2
	PL2	S0	S0	M1	L2	L2

Table 4. Rule Matrices table for Ki output Variable

Output (K_i)		Error(e)				
		NL2	NS1	Z	PS1	PL2
Change In Error(ce)	NL2	S0	S0	M1	L2	L2
	NS1	S0	S0	M1	L2	L2
	Z	M1	M1	M1	M1	M1
	PS1	L2	L2	M1	S0	S0
	PL2	L2	L2	M1	S0	S0

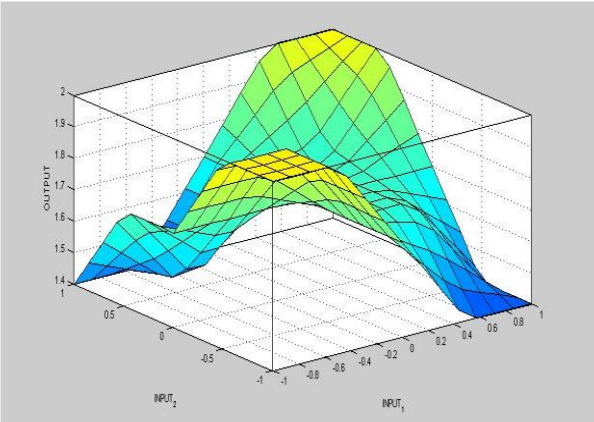

Figure 9. Three dimensional variation of the Fuzzy inputs and output Kp

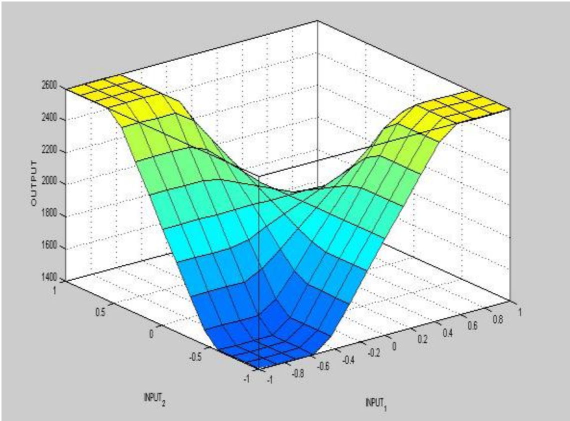

Figure 10. Three dimensional variation of the Fuzzy inputs and output K_I

Three Dimensional variation of the Fuzzy inputs (Id & Iq) and outputs K_I and Kp are shown in Figure 9 and Figure 10.

The K_p and K_i taken from fuzzy logic controller is given to PI controller. The schematic diagram of PI controller is shown in Figure 11. The K_p and K_i values multiplied with error and are sent to zero order hold and discrete time integrator.

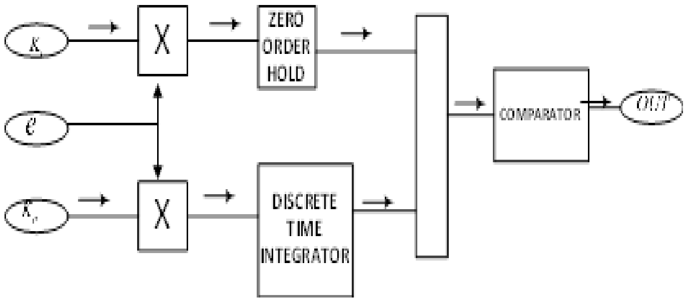

Figure 11. Schematic Diagram of PI Controller

5. SIMULATION RESULTS

5.1. Case Study 1: Change in Reference Current

The above mentioned system parameters in Table 4 are considered to study the adaptive fuzzy current controller makes the inverter to tracks the change in reference current at fixed DC input voltage. Here temperature and irradiation in the nature is considered as constant to get the constant DC Voltage to the inverter as shown in Figure 12. Here changes in reference current is considered at 0.5 sec from 4A to 6A as shown in Figure 17 causes to change the PV current supllied to the Inverter as shown in Figure 13. Inverter output voltage is shown in Figure 14. The variation of the K_p and K_i values due to change in reference current are shown in Figure 15 and Figure 16. Grid current followes the reference current with less transient behavier and zero steady state error even though change in reference Current as shown in Figure 18. Total Harmonic Distortion of the Grid current is less the 5% as shown in the Figure 19.

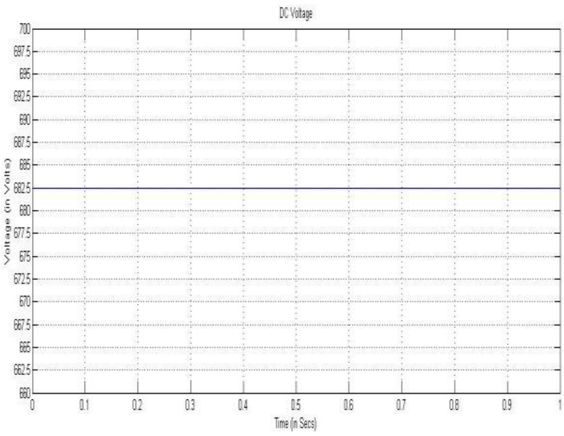

Figure 12. PV Output Voltage

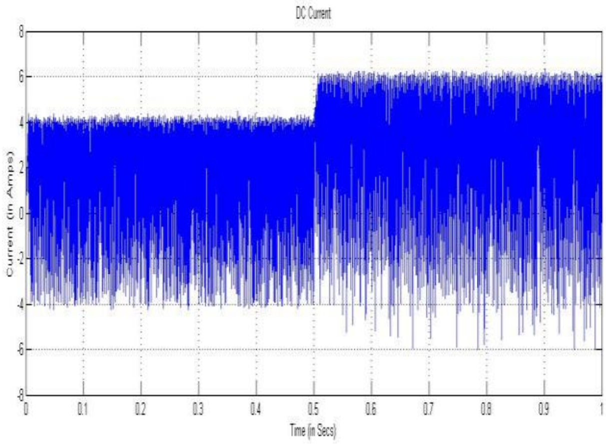

Figure13. PV Current

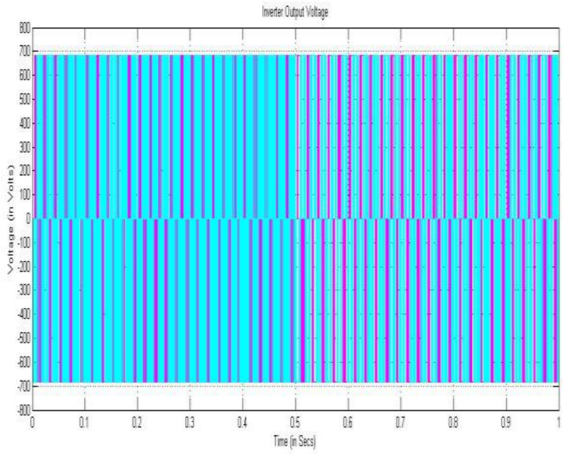

Figure14. Inverter Output Voltage

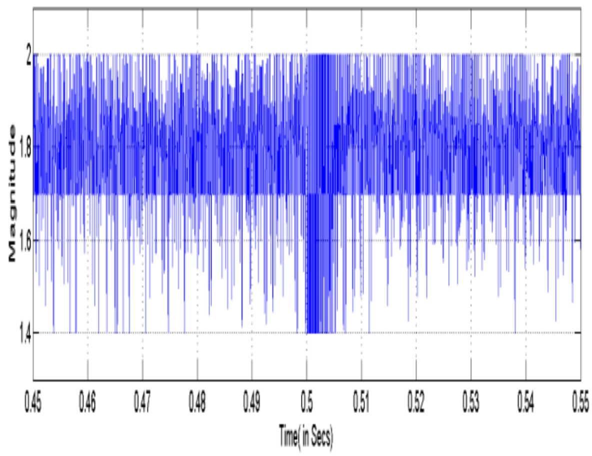

Figure 15. Variation of the Proportional Gain (K_p)

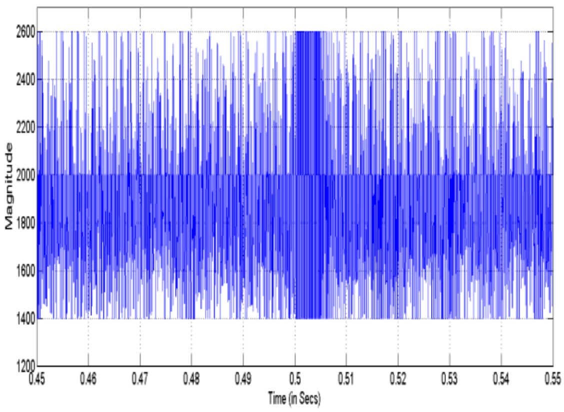

Figure 16. Variation of the Integral Gain (K_i)

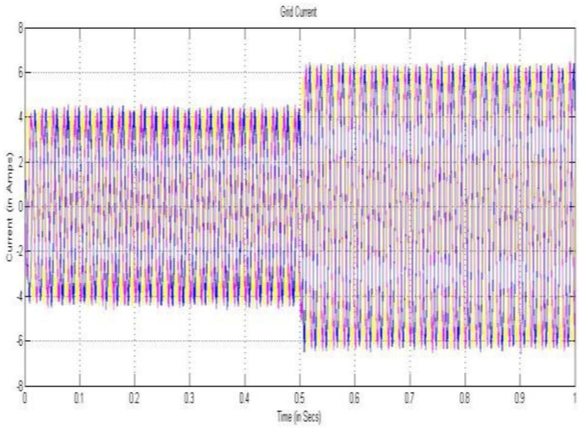

Figure 17. Referance Current

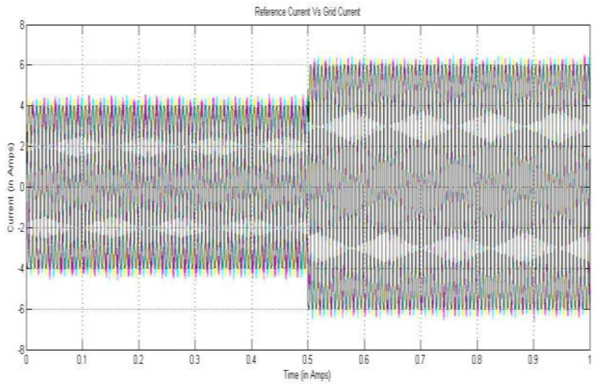

Figure 18. Referance Current & Grid Current

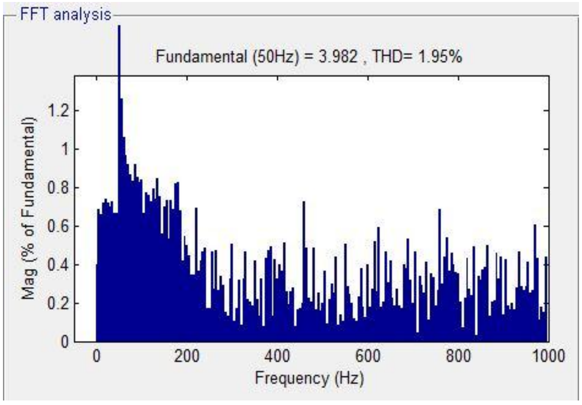

Figure 19. THD analysis of the Grid Current

5.2. Case Study 2: Change in DC Voltage

Same system parameters are considered to study weather adaptive fuzzy current controller makes the inverter to track the reference current if there is change in DC input voltage. Here change in irradiation is considered to change the DC Voltage from 0.5 Seconds and PV Currents are shown in Figure 20 and Figure 21 respectively. The constant grid current is considered as 5A shown in Figure 25. The variation of the K_p and K_i values which are updated by fuzzy controller due to change in DC input voltage as shown in Figure 23 and Figure 24. Total Harmonic Distortion of the Grid current is less the 5% as shown in the Figure 27.

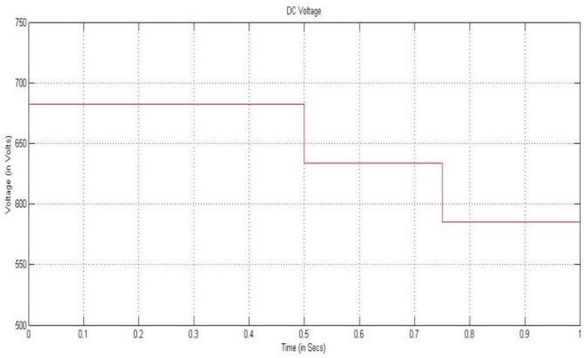

Figure 20. Change in PV Voltage

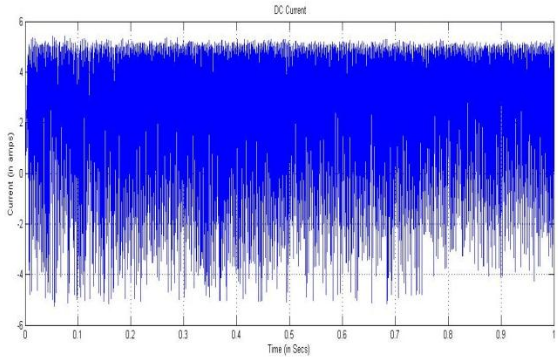

Figure 21. PV Current

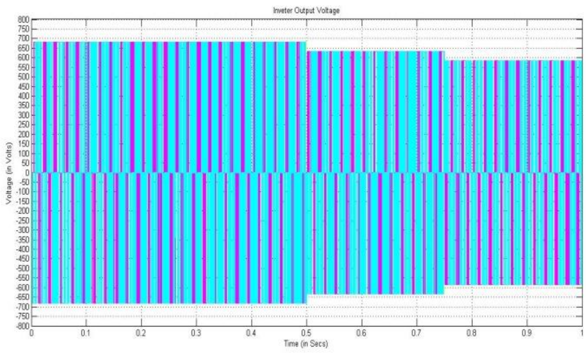

Figure 22. Inverter Output Voltage

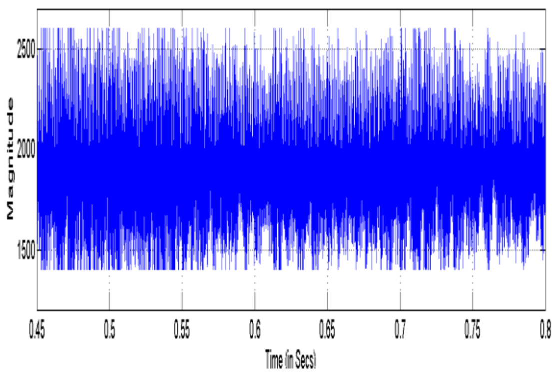

Figure 23. Variation of the Integral Gain (K_i)

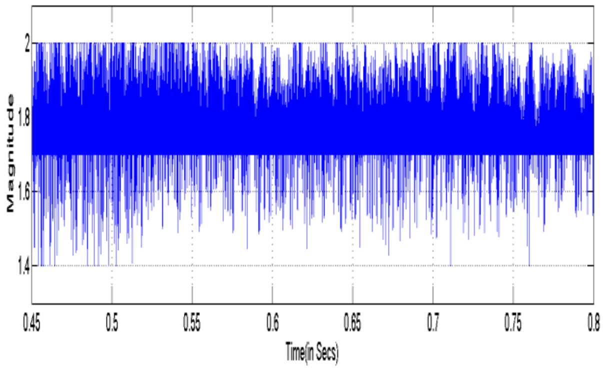

Figure 24. Variation of the Proportional Gain (K_p)

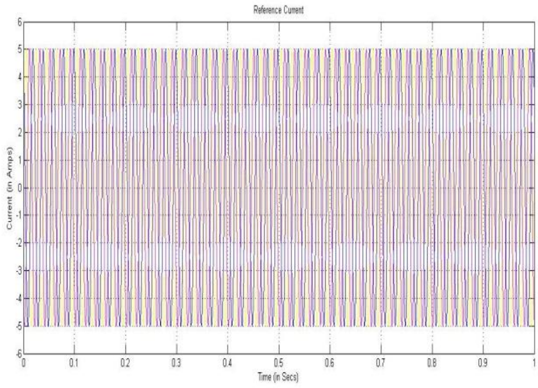

Figure 25. Grid Current

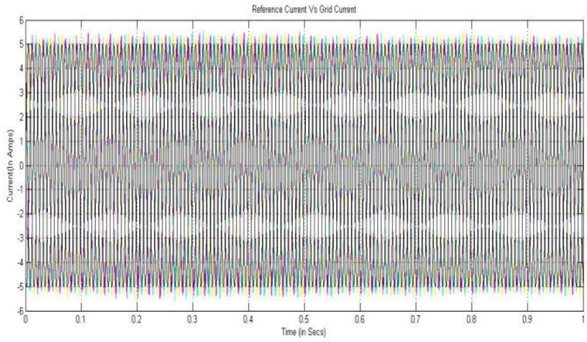

Figure 26. Referance Current & Grid Current

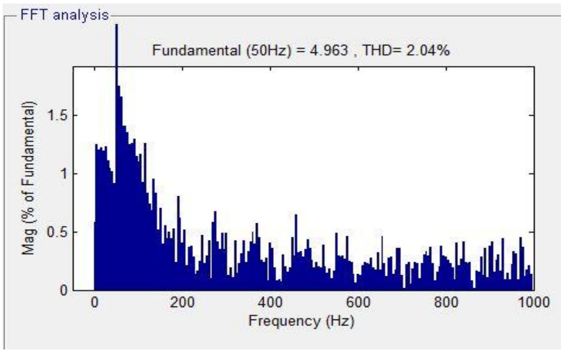

Figure 27. THD Analysis of the Grid Current

The THD values of the Grid Currents with PI Controller, Fuzzy controller and Fuzzy PI current controllers are given in the Table 5. Adaptive Fuzzy Controller improved the quality of the grid current.

Table 5. Comparision of the Controllers

Currents	With PI THD%	With FLC THD%	With Fuzzy-PI THD%
4A	4.81	5.28	4.71
5A	4.01	4.27	3.54
6A	3.59	4.66	2.98
7A	4..80	4.79	2.57
8A	5.80	7.58	2.42
9A	5.50	6.63	2.16

6. CONCLUSION

In this work adaptive Fuzzy PI current controller is implemented for the grid connected 3ph PV inverter under different parametric conditions. When there is change in PV voltage and reference current. The Fuzzy controller updates the gains of the PI controller so that grid current traces the references Current with less transient behavior, zero steady state error and low THD value of the Grid current compared to the PI Controller, Fuzzy controller. It is implemented and verified in Matlab-Simulink.

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