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Fuzzy-PI Control of Grid Interact Three-Phase Voltage Source Inverter

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Abstract:

This work deals with control of Three Phase voltage source inverter connected to the grid under two main cases that is varying PV voltage and varying Grid Current. Fuzzy controller bring up to date the gain values of the Pi controller. The output of the Fuzzy PI controller are reference voltages to the pulse width modulation where reference voltage is compared with the carrier signal to generate the pulses to the Three Phase Inverter connected to the grid. Fuzzy-PI controller tracked the reference current with less time even though there are parameter changes that is in PV Input voltage and reference current than the conventional PI controller. It has given the fast transient response and zero steady state error with acceptable Total Harmonic Distribution value is achieved in grid current. Is Implemented in Mat-lab.

Keywords: Fuzzy-PI controller, Incremental conductance algorithm(IC), Three Phase Inverter.

INTRODUCTION

Renewable energy resources are an interesting alternative to that of the coal, diesel, petrol and nuclear energy sources because they can be used on a large scale without contaminating the environment. Photovoltaic (PV) power generation is a concept of converting solar energy into direct current using semi-conductor materials. A PV system includes a solar panel which consists of a number of solar cells which are used to generate the required Voltage, current and power [2, 8]. The generated power is sent through Maximum power point tracker (MPPT) using Incremental Conductance (IC) algorithm [5]. These renewable energies can be used efficiently with power electronic devices. When power electronic converters are placed in the control system, harmonics are generated due to the switching progression [1, 3, 4], which may cause harmonics in the distribution grid, so these harmonics should be reducible, which requires the usage of filters like "L, LCL, LC" has to make the THD in the Grid current should be less and also should satisfy the International standards.

Fuzzy Controller [7] is used to tune the gain of the PI controller for the adaptive controller has given the fast transient response and better performance under various parametric changes of three phase inverter connected to the Grid.

Among the various intelligent controllers fuzzy logic controller (FLC) is the simplest for inverter control. The FLC is better than the conventional controllers in terms of insensitivity to parameter changes and load variations, response time, setting time and robustness.

The simulation results verified the two cases:

Case 1. Variation of PV voltage

Case 2. Variation of Grid current

Therefore, in this paper a new fuzzy logic control strategy is developed for high performance control of grid-connected three phase photo voltaic inverter systems. Moreover, the inverter is feeding the demand of grid. The developed control system generates a Total harmonic distortion (THD) on both the cases. The THD of Grid Current under variation of PV Voltage is 2.48% and variation of Grid current is 4.07% both are acceptable by IEEE standards.

1. PV SYSTEM

Solar Energy is collected by photo voltaic effect called as photovoltaic cell and is considered as most suitable renewable resource due to abundance, and sustainability also counted as a strong alternate in place of fossil fuel. The photovoltaic system has a non-linear current-voltage and power-voltage characteristics that varies with Irradiance and Temperature. A Solar PV module can be a combination of solar cells arranged in Series, Parallel or both. The Solar cell is the basic unit of PV module. A PV Array is used to convert the light from the sun into DC current and Voltage. The Equivalent circuit of a PV cell is shown in figure (a). The current source Iph Represents the photo diode current. Rsh and Rs are the Shunt and Series resistance of the cell respectively.

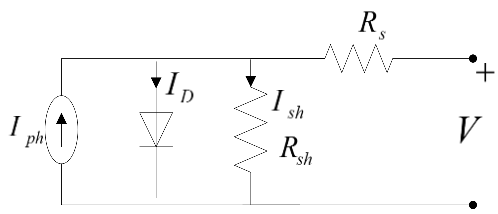

Figure 1. PV Module.

Generally the Value of Rsh is very large and that of Rs is very small hence they are neglected in order to simplify the analysis. In Practically, PV cells are combined in larger units known as PV modules and those modules are connected in series or parallel in such a way to generate PV arrays which will generate electricity in PV generation Systems

The module saturation current Io varies with the cell temperature, which is given by

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

Here, Tr -Nominal Temperature =298.15, Ego-Band gap energy of the semiconductor=1.1 ev.

The Current output of PV module is:-

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

Where $V_t = \frac{k*T}{q}$

$$I_{sh} = \frac{V*N_p/N_s + I*R_s}{R_{sh}}$$

Here Np: Number of PV modules Connected in Parallel

Rs : Series Resistance (Ω);

Rsh: Shunt Resistance (Ω);

Vt : Diode Thermal Voltage (V).

2. MAXIMUM POWER POINT TRACKER

Tracking the Maximum Power Point (MPP) of a photo voltaic (PV) is usually a major part of a PV System. The method vary in simplicity, complexity, sensors required convergence speed, cost, etc… In order to the continuously varying maximum power point of the solar array. The MPPT control topologies play an important role in PV module. The task of MPPT network in PV module system is to continuously tune the system so that it draws maximum power from the solar cell independent of weather or load conditions. The operation of the maximum power point tracker cannot be observed unless a varying matching network is used to interface the load to the PV array. Since obtaining unity power factor is important in grid interactive operation, the frequency and phase angle of line voltage should be strong-minded. Usually phase locked loop (PLL) circuits have been used to achieve information about the frequency and phase of the electric circuits. In grid interactive inverters, PLL circuits harvest synchronized current reference.

The maximum power tracking process makes use of an algorithm and an electronic circuitry. The process is based on principle of impedance matching between load and PV Module which is necessary for maximum power transfer. Coupling to the load for maximum power transfer may require either provide a higher voltage for higher current. MPPT is used along with DC-DC converter (step up/step down) serves the purpose of transferring maximum power from the solar PV module to the load. The duty cycle of DC-DC converter is changed with the load impedance as well as PV source is also varied and matched at the maximum point of power. The duty cycle of the converter is changing till the peak power is tracked.

The Incremental Conductance, the derivative of PV module conductance, is used to determine the maximum Operating point for power point (MPP).

The MPP can be calculated by using the relation between dI/dV and –I/V.

The equation of IC method is

$$\frac{dP}{dV} = \frac{d(V.I)}{dV} = I\frac{dV}{dV} + V\frac{dI}{dV} = I + V\frac{dI}{dV}$$

Maximum power point is obtained when:

$$dI/dV = 0$$

$$\frac{dP_{pv}}{dV_{pv}} = \frac{d(V_{pv} * I_{pv})}{dV_{pv}} = Vpv\frac{dI_{pv}}{dV_{pv}} + I_{pv} = 0$$

$$\frac{dP_{pv}}{dV_{pv}} = -\frac{I_{pv}}{V_{pv}}$$

On the left side of MPP, $\frac{dP_{pv}}{dV_{pv}} > 0$ if, $\frac{dI_{pv}}{dV_{pv}} > -\frac{I_{pv}}{V_{pv}}$

At MPP, $\frac{dP_{pv}}{dV_{pv}} = 0$ if, $\frac{dI_{pv}}{dV_{pv}} = -\frac{I_{pv}}{V_{pv}}$

On Right side of MPP, $\frac{dP_{pv}}{dV_{pv}} < 0$ if, $\frac{dI_{pv}}{dV_{pv}} < -\frac{I_{pv}}{V_{pv}}$

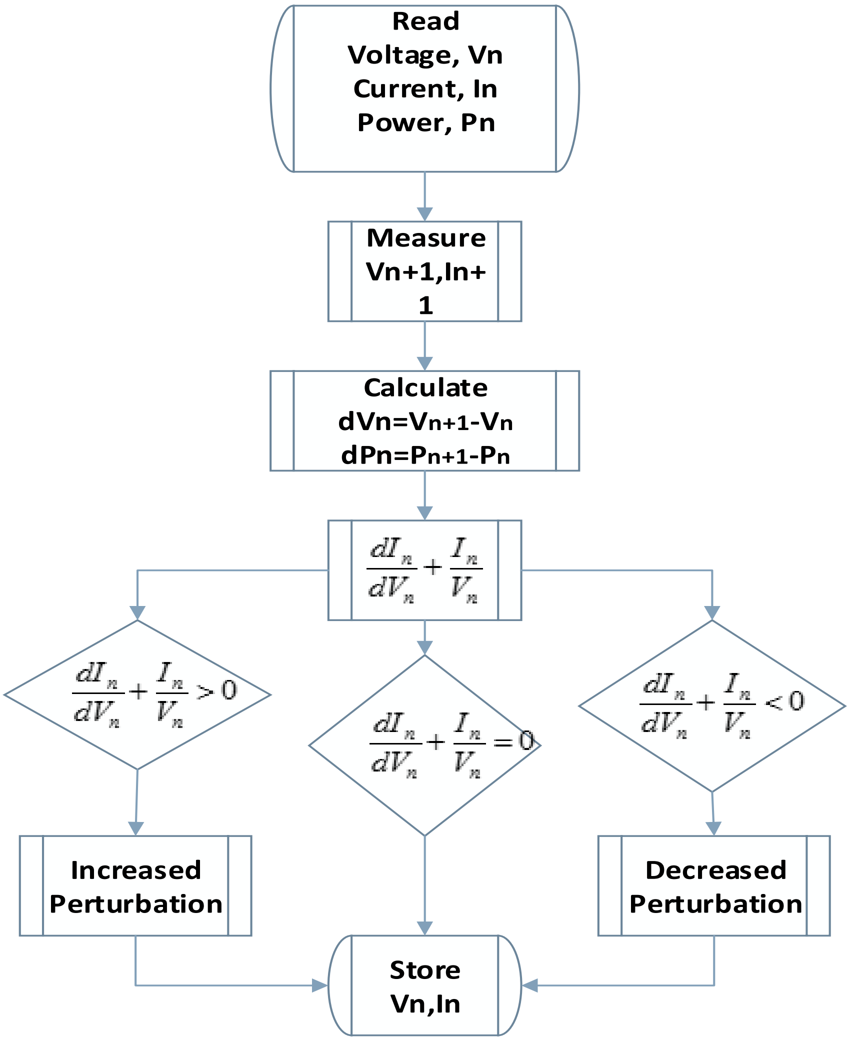

Figure 2. Algorithm of Incremental Conductance Method.

3. GRID INTERACTIVE FILTER

Grid interactive inverter is used to connect the PV system to the grid and to ensure more efficient operation by transferring efficient energy to the grid. Although these types of inverter have not been used for long times because of its Switching action. The first applications of the grid interactive inverters are based on inverters that were installed on motor drives without concern properties and characteristics of the RESs. Generally, power levels of these inverters are high.

The RES prices are tending to go down with increasing usage and interest on them. Moreover, because of the limitations of the International standards about the current harmonics, the usage of IGBT/MOSFET equipped grid interactive inverters at lower power levels instead of high power thyristor equipped grid interactive inverters is become common.

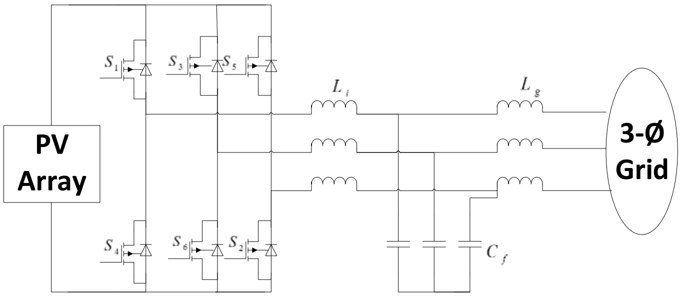

Figure 3. Three Phase Grid Interactive with PV Array.

The inverter output voltage becomes lower than grid voltage, and energy transfer does not happen. In this situation, a transformer is used to tie the inverter output voltage and grid voltage. Although some inverters contain high-frequency transformers embedded with DC-DC converters or DC-AC inverters. Some inverters use LFTs. Usage of LFT prevents DC current injection which is limited in IEEE and IEC standards, and causes saturation of distribution transformers. The low-sized high-frequency transformers cannot solve the DC injection problem. Moreover, it simplicities the grounding of RES.

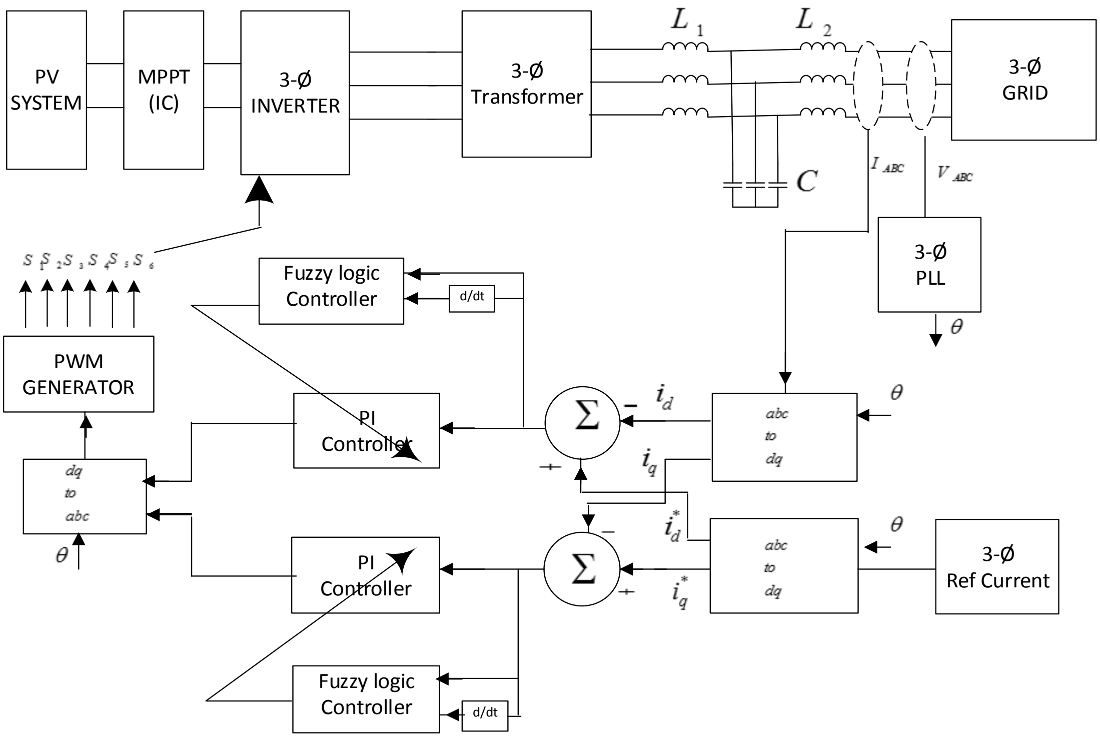

Figure 4. Schematic Diagram of Three Phase Inverter connected to Grid.

4. DESIGN OF LCL FILTER

At the output of the inverter generally use the L, LC, LCL filter. To reduce the switching harmonics, L filter is used to provide 20db attenuation. Switching frequency should be high. If PWM is operated at low switching frequency the magnitude of the L filter becomes very high and it becomes expensive to provide same attenuation. Generally, LC filter are used in uninterruptible power supply applications. Variation of the resonance frequency with line impedance limits the usage of the grid interact systems. Thus LCL Filter is Chosen, in this study. The transfer function of the LCL filter is

$$Gi(S) = \frac{I_{inv}}{U_{inv}} = \frac{1}{L_i S} \frac{(S^2 + 1/L_g C_f)}{(S^2 + L_1 + L_2 / L_i L_g C_f)}$$

I_{inv} is the inverter output current, U_{inv} inverter output voltage, L_i inverter side inductance, L_g is the grid side inductance, C_f filter capacitance. The resonance frequency of the Filter can be calculated

$$F_r = \frac{1}{2\Pi} \sqrt{(L_i + L_g) / L_i L_g C_f}$$

LCL filter has Advantage such it requires the low reactive power it provides 60db attenuation over resonance frequency. By allowing the low switching frequencies, the components values of LCL filter are determined based on the switching frequency, line frequency, inverter output power, current, and Impedance values.
Resonance frequency of the LCL filter can be calculated using

$$10 f_g \le f_r \le f_{sw} / 2$$

5. DESIGN OF FUZZY-PI CONTROLLER

The main fundamentals that makes up a FLC system are

1. The Fuzzifier unit at the input terminal
2. Knowledge based (Rule base) and Inference engine
3. The defuzzifier at the output terminal.

In FLC- based control system, the required variables are the input and output variables'.

1. The inputs to the FLC are the parameters (or) variables of the process to be controlled which depends on the application.
2. Normally an error and its rate of change are chosen for the input variables and the change of Gains are selected as the output variables.
3. An error in discrete time is the difference between the desired output or reference, r(k), and the process output variable, y(k). The current sample of error, e(k) and the change of error Δ e(k)

4. These variables universal discourse, which are normalized to fit into the interval value between -1 and +1, require five membership functions as shown in figure.

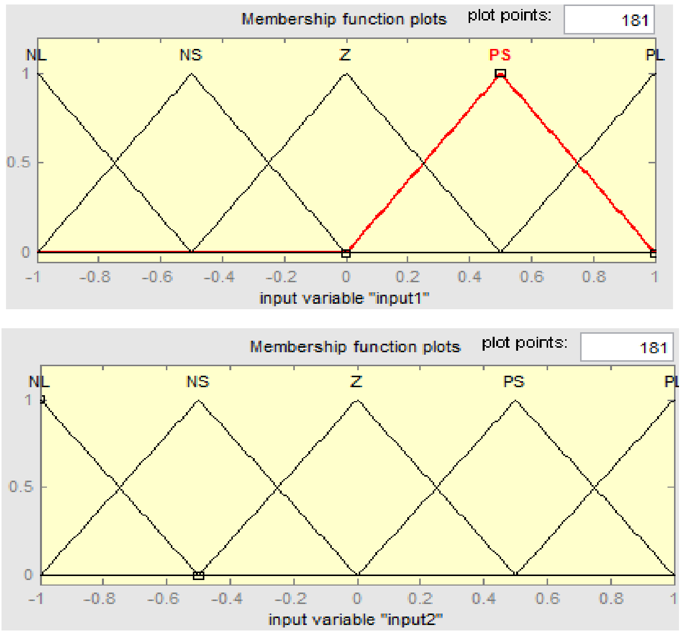

Figure 5. Input membership functions of e & Δe.

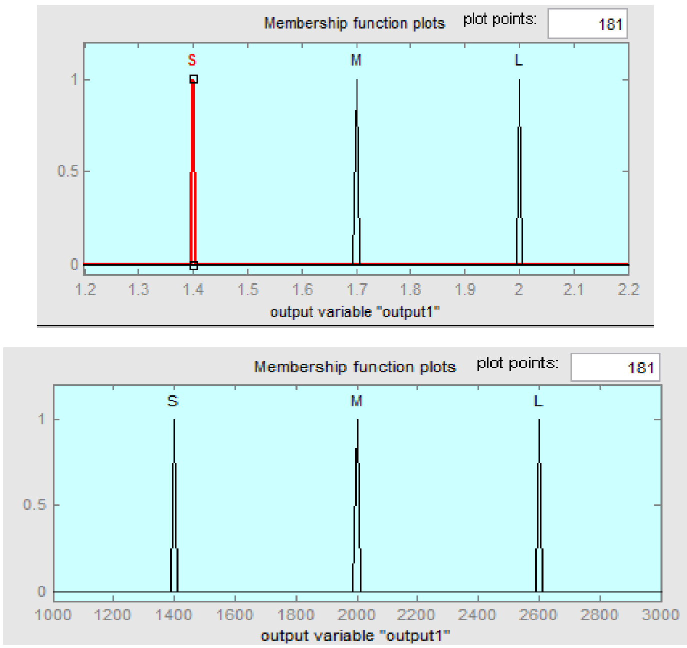

Figure 6. Output Membership functions of Kp and Ki.

6. SIMULATION RESULTS

The proposed FUZZY-PI controlled grid interactive is simulated using MATLAB/Simulink. To obtain the grid voltage, grid current, reference current, a PLL is used. The FLC determines the Kp and Ki gains of the PI controller. The simulation results are as follows

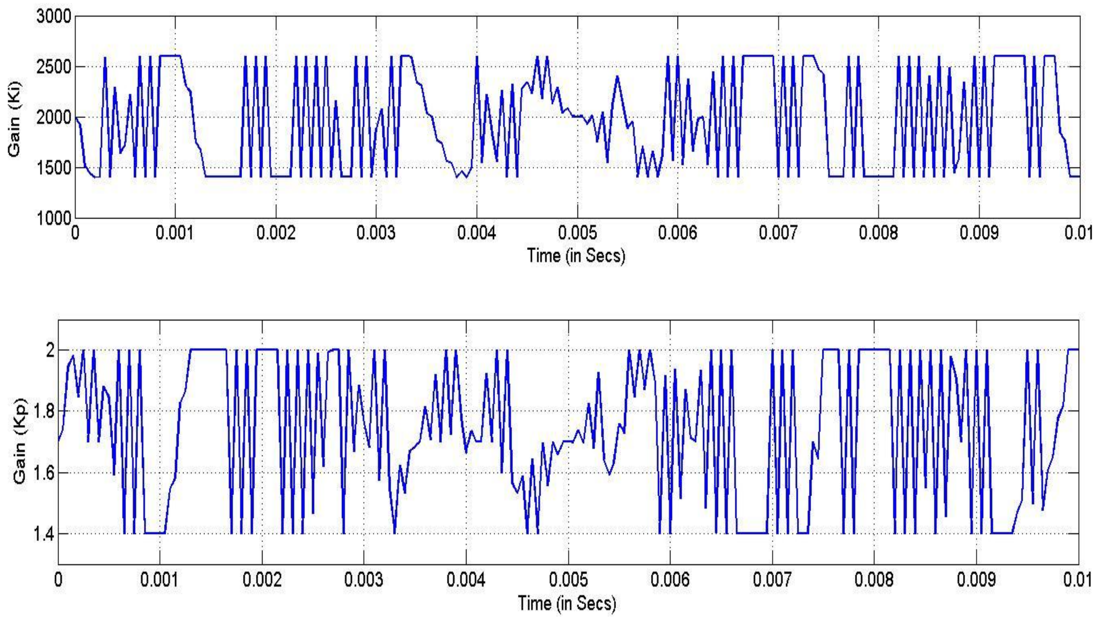

Figure 7. Fine-tuning of Kp & Ki.

6.1. Variation of PV Voltage

Here the temperature varies with respect to time when temperature changes the voltage across the PV module changes. Here are the results of Grid current, Inverter voltage when PV Voltage differs.

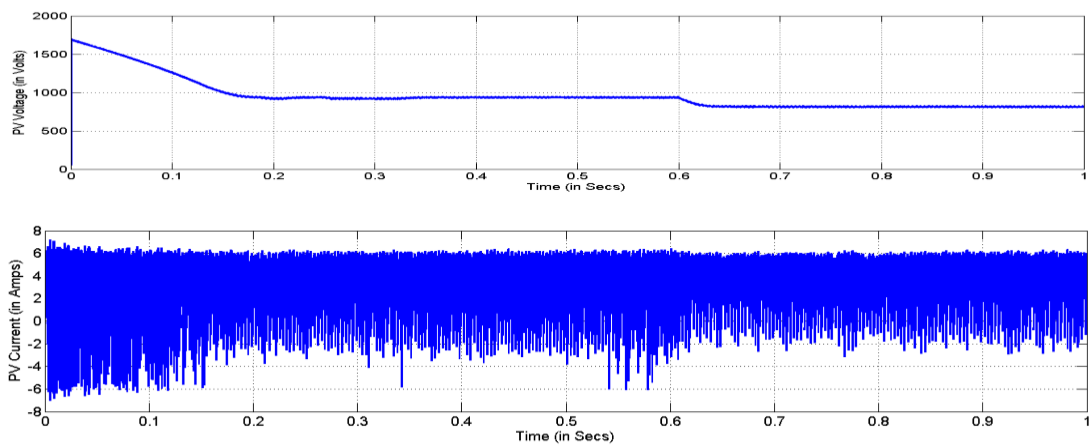

Figure 8. PV Voltage & PV Current.

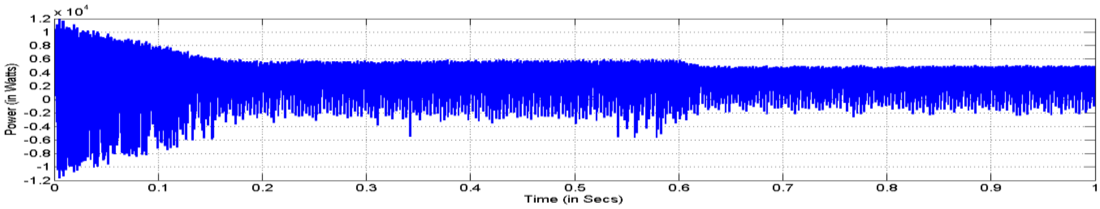

Figure 9. Maximum power at MPPT.

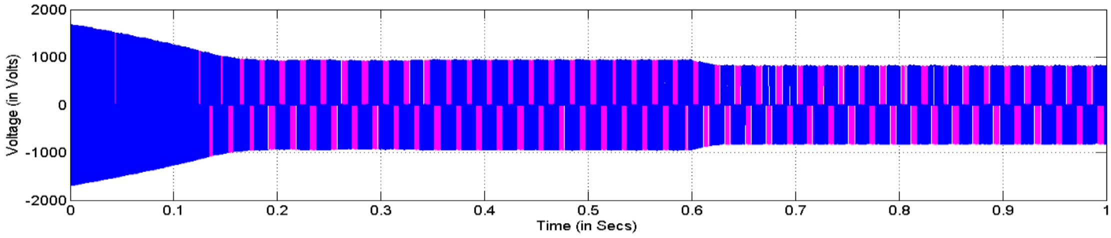

Figure 10. Inverter Output Voltage.

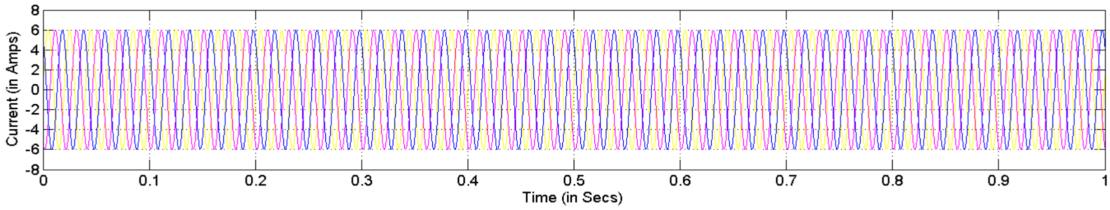

Figure 11. Reference Current.

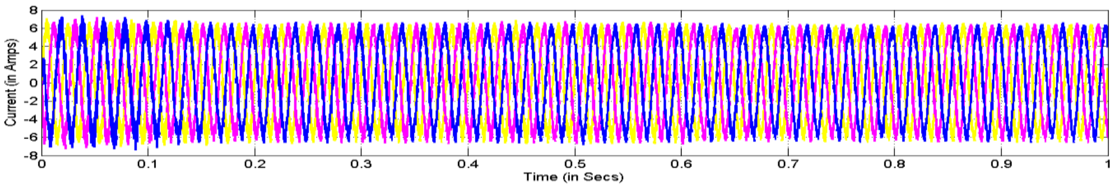

Figure 12. Grid current.

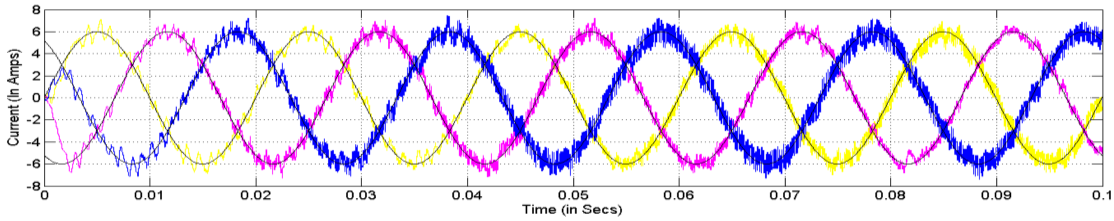

Figure 13. Comparison of Grid Current with Reference Current.

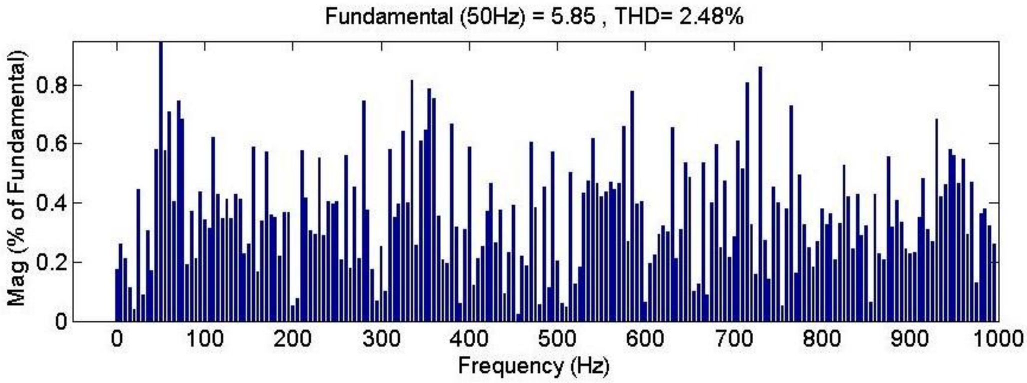

Figure 14. Total harmonic distortion.

6.2. Variation of Grid Current

Whenever sudden change in current the system can able to withstand the variations of different currents. Here the reference current varies from 4A to 6A. The variation in other parameters as shown below

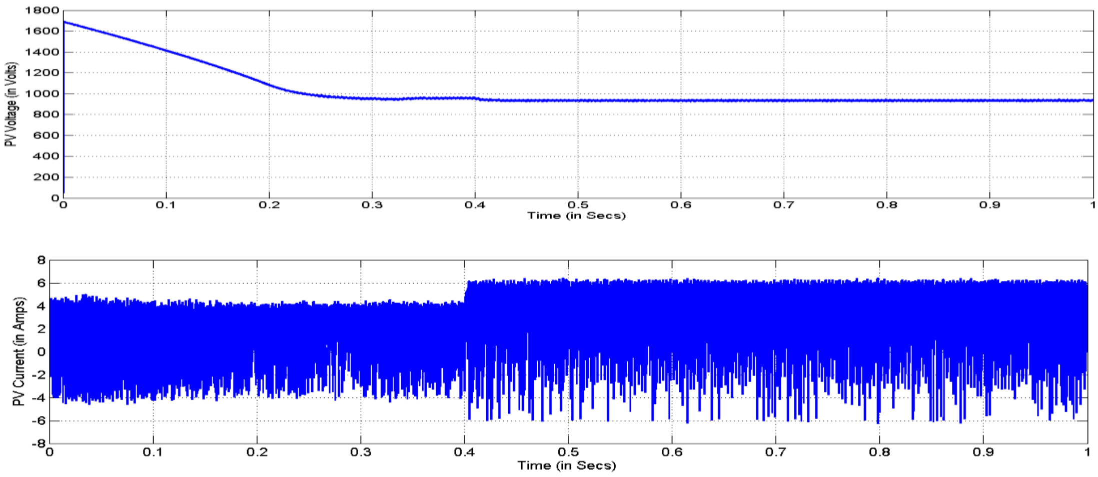

Figure 15. PV Voltage & PV Current.

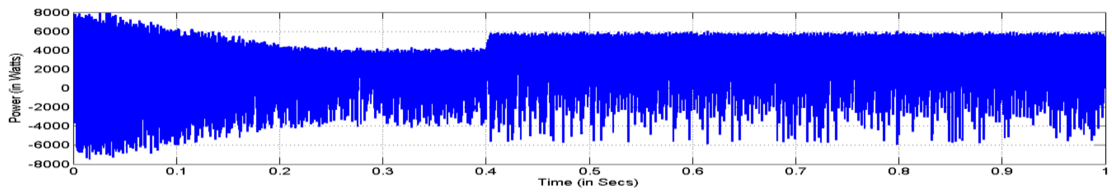

Figure 16. Maximum Power at MPPT.

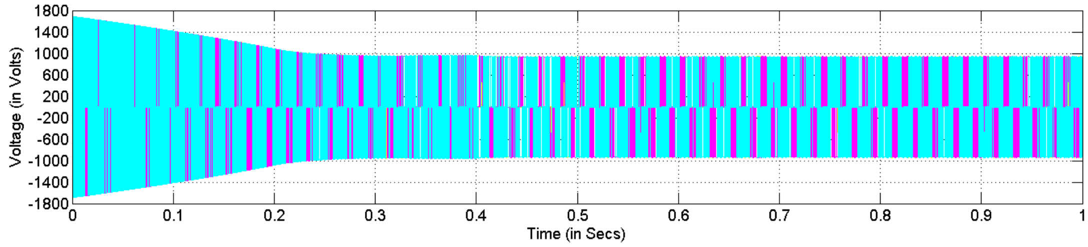

Figure 17. Inverter Output Voltage.

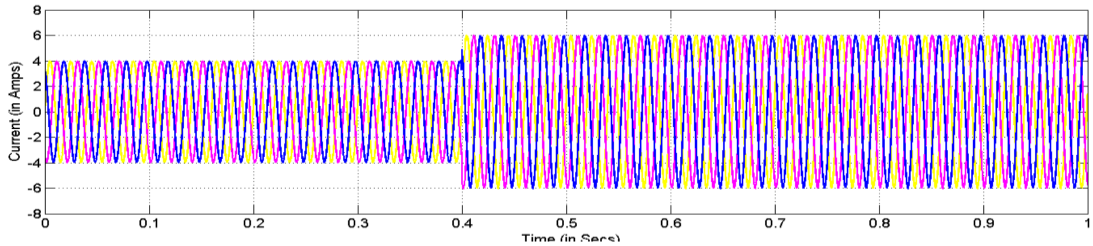

Figure 18. Reference Current.

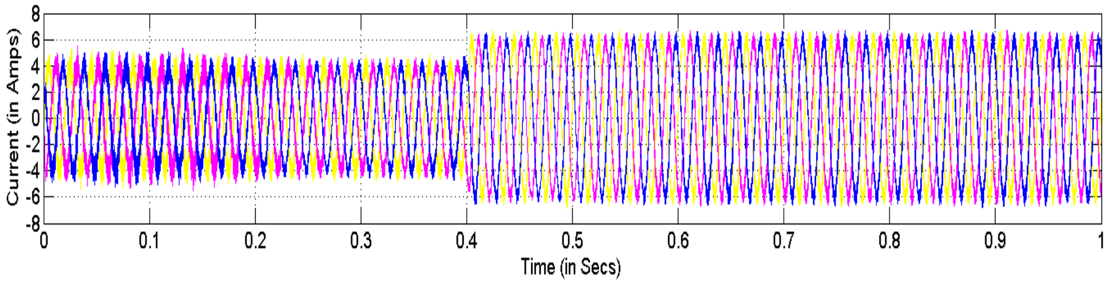

Figure 19. Grid Current.

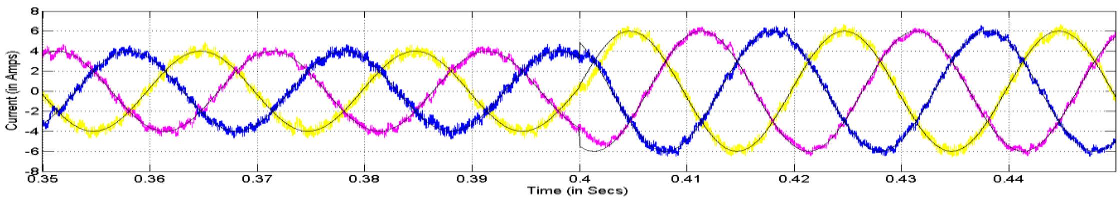

Figure 20. Comparison of Grid Current with Reference Current

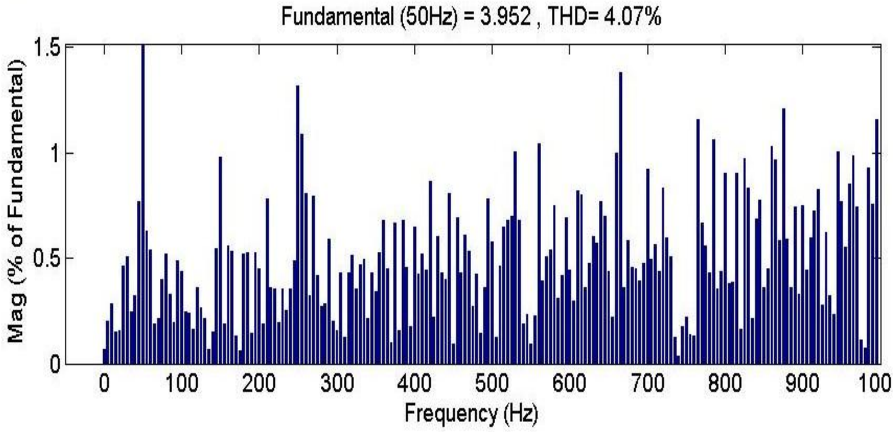

Figure 21. Total Harmonic Distortion.

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7. CONCLUSION

The above two cases shows the variation of PV Voltage and Variation of Grid Current. The variations in the system are tracked by the FUZZY-PI Controller. The Total Harmonic Distortion (THD) of the Grid current under both the cases are 2.48% and 4.07% respectively and is acceptable by IEEE standards.

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