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A FUZZY CONTROLLED THREE PHASE GRID-TIED SPV SYSTEM WITH IMPROVED CPI VOLTAGE VARIATIONS

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ABSTRACT

This paper deals with a fuzzy logic controller (FLC) three phase two stage grid-tied SPV (solar photovoltaic) system. The first stage deals with boost converter with MPPT (Maximum power point tracking) procedure is used to extract maximum solar energy from SPV module and feed the DC link of PV inverter, whereas the second stage deals with two-level VSC (voltage source converter) enables PV inverter to feed the power to the main grid from boost converter. The proposed system uses an adaptive DC link voltage which is made adaptive in nature by adjusting reference DC link voltage according to CPI(common point of interconnection) voltage. The proposed MPPT technique provides better dynamic performance than the conventional MPPT technique under an abrupt change in voltage at CPI. The THD (total harmonics distortion) of the grid current is maintained under the limit of an IEEE-519 standard.

Keywords: Fuzzy logic controller, Adaptive DC link, MPPT, solar PV, and VSC.

1. INTRODUCTION

The electrical energy has a crucial part in the developed human race in the most recent century. The renewable energy sources such as sunlight based solar, wind, tidal and so on are few of such choices that can solve the issue of energy shortage. The cost fairness of any innovation is a prime factor for its business achievement. The SPV (Solar Photovoltaic) systems have been proposed long back yet the expenses of sun-powered boards have ruined the innovation for a long time but the costs of solar panels have hindered the technology for a long time, however, the SPV systems are reaching grid parity [1], [2].Moreover from available renewable sources, solar is an impressive alternative source to meet the required power demand towards rural electrification of residences and industries. The latest advance scenario in power converters [3-4] made the system very effective in MPPT and hence improves the overall efficiency. We can reduce the losses and increase the maximum utilization of the distribution system [5]. The SPV energy system can be operated in standalone mode with the storage system and in grid-tied mode [6-8]. If a problem occurred in the energy storage system then grid interfaced systems are more Advantageous than the standalone [9]. The initial investments for any plant installation are very high, so it is more important to extract maximum energy output from the installed plant. To achieve maximum energy several techniques are proposed as P&O, incremental conductance, particle swarm optimization (PSO) [10], An incremental conductance (InC) based MPPT technique is shown in [11]. The incremental conductance based MPPT is fast in response, accurate and easy in execution. The two-stage SPV generation system is used in many factors which are proposed in [12]–[14]. The first stage is a DC-DC converter supported with

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MPPT. The second stage is a grid-tied VSC (Voltage Source Converter) which gets input from boost converter and it gives output to feed the power into the distribution system. A single phase two stage grid-tied SPV system with adaptive DC link voltage is shown in [12]. Above that, a three-phase grid-tied SPV system is shown in [13]. The concept of a hybrid active power filter for reactive power compensation is shown in [14]. As in the proposed system with adaptive DC link voltage of VSC for CPI voltage variation.The control operation of the grid interfaced PV system is present in this system with a structure of DC link voltage for CPI associated with benefits. The DC link voltage is mainly used to reduce the switching losses and also high-frequency ohmic losses. The benefits of DC link voltage is also found under the nominal grid voltage condition in case of the worst scenario. The sudden change in insolation and its variation of CPI voltage is performed with this control system. This paper is organized as follows: the control approach is described with the help of MPPT, the boost converter, and the control of VSC and FLC (fuzzy logic controller) with its model design in section III. The simulation results were enclosed in section IV.

2. SYSTEM CONFIGURATION

The proposed system configuration is a two-stage grid-tied PV as shown in Fig.1. In the two-stage system, The first phase is a DC-DC boost converter which serves the purpose of MPPT, adapted to extract the maximum power point and the second stage is a two-level three phase VSC. The solar PV array is connected at the input of boost converter and the DC-DC boost converter's input is controlled to deliver maximum power at its output which is connected to DC link voltage of VSC. the DC link voltage can be varied by the VSC with reference to the CPI (common point of interconnection) voltage.

The ripple filter is connected to CPI to absorb high-frequency switching ripples generated by VSC with respect to its output terminals are connected to interfacing inductors and the ends of interfacing inductors are connected to CPI. The values of various components and parameters result in the performance of the SPV system to improve. The Total harmonic distortion (THD) of the grid current and voltage is maintained under IEEE-519 standards (less than 5%).

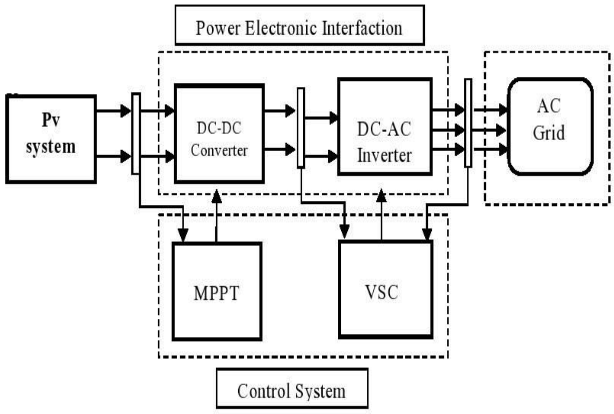

Figure-1. A grid-tied 3-phase solar PV system.

3. CONTROL APPROACH

The control of the system can be divided into two main parts, which are control of the boost converter and control of a grid-tied VSC. The input voltage of a boost converter is adjusted according to the MPPT algorithm and the output voltage of the boost converter, which is also the DC link voltage of VSC is kept adaptive according to CPI voltage condition. In overall, the proposed system is operated such that both the input and output voltages of boost converter are adjusted according to CPI.

A. Maximum Power Point Tracking

It is an effective method used for the MPPT in the solar PV system. We use the InC (incremental conductance) based MPPT algorithm. A range peak power voltage is known with the knowledge from fractional Voc MPPT, around 0.7Vocmax to 0.9Vocmax, where Voc describes open circuit voltage and Vocmax describes maximum open circuit voltage.The InC minimize the difference between the incremental conductance and the conductance offered by the PV array. the InC principle helps to estimate the reference PV array

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which is used to estimate the duty ratio of the boost converter. ΔIPV and ΔVPV are estimated as,

$$\Delta Ipv = Ipv(K) - Ipv(K-1) \qquad (1)$$

$$\Delta Vpv = Vpv(K) - Vpv(K-1) \qquad (2)$$

Where $I_{PV}(k)$ is the instantaneous sampled current and $V_{PV}(k)$ voltage of the solar array.

The governing equations for InC based MPPT algorithm are as it increments or reductions the voltage until the point that the most extreme power point (MPP) is come to. Not at all like with the P&O calculation, the voltage stays steady once MPP is come to.

$$Dref(K) = 1 - \frac{\text{Vpvrefn(k)}}{\text{Vdc(K)}} \qquad (3)$$

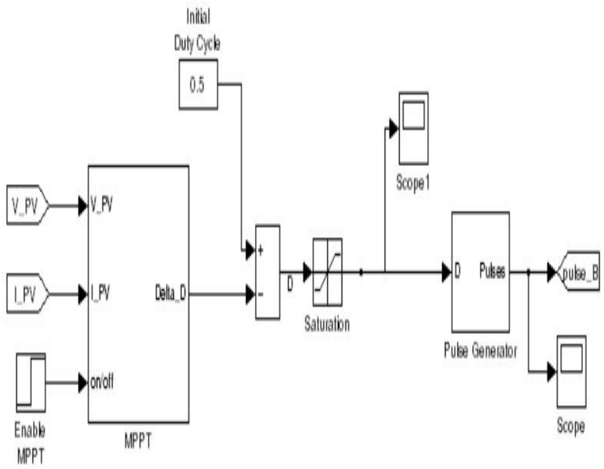

Figure-2. Simulink design of MPPT.

InC algorithm has many advantages over P&O and also it can track rapid change in solar insolation condition with higher accuracy over P&O. In the method of InC MPPT, the peak power of the system lies around 98%. The Flow chart of incremental conductance MPPT is shown below in Fig 3.

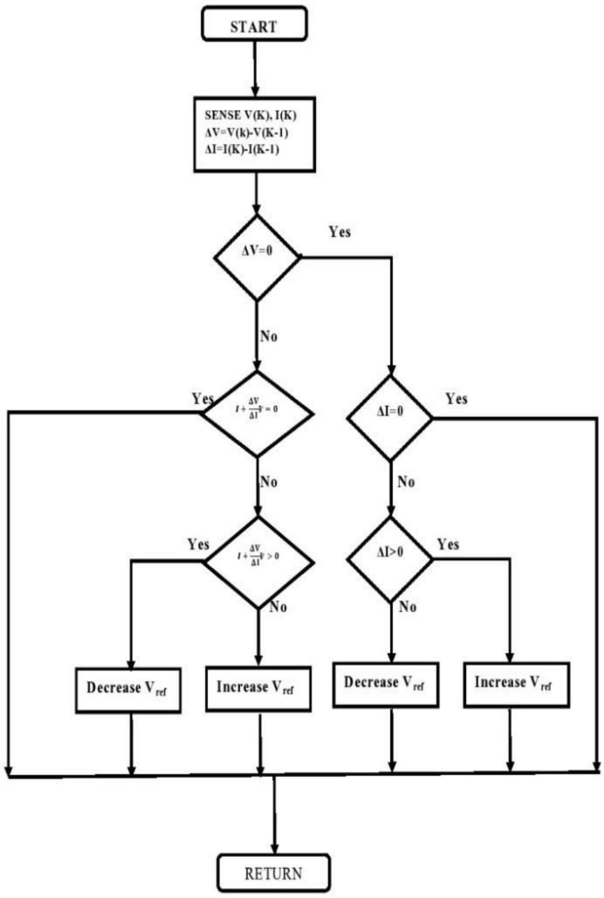

Figure-3. Incremental Conductance algorithm

B Boost Converter

A Boost converter is a switch mode power supply (SMPS) DC to DC converter in which the output voltage is greater than the input voltage. It is also called a step-up converter. The name boost converter comes from the fact that equivalent to step up transformer the input voltage is stepped up to a level greater than the input voltage. The main working principle of the boost converter is that the inductor in the input circuit resists sudden variations in input current. When the switch is OFF the inductor stores energy in the form of magnetic energy and discharges it when the switch is closed. The capacitor in the output circuit is assumed large enough that the time constant of the RC circuit in the output stage is high. The large time constant compared to the switching period ensures a constant output voltage Vo(t) = Vo(constant).

The boost converter is used to adjust the output voltage to the tolerated level and the duty

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cycle is generated by the FLC. A basic construction of a boost converter is shown in fig.4, which consists of main components like inductor L, the input voltage Vin, switch S, diode d, capacitor C, load R, and duty cycle D

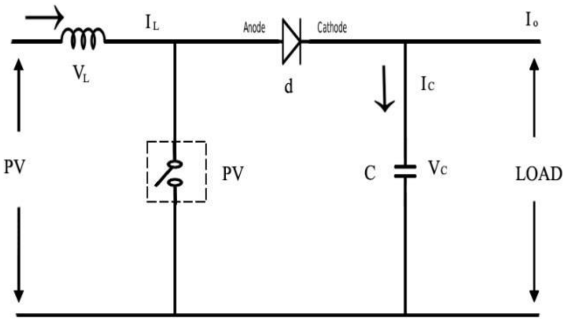

Figure-4.The equivalent circuit of the boost converter

C. Control Algorithm for VSC

The main operation of the VSC control algorithm is to govern the DC link voltage also by maintaining an almost unity power factor at the utility grid which is feed from the solar system. It injects the extracted power from the solar system into the utility grid. The appropriate reference grid currents are estimated to control the output currents of VSC (or grid currents), and their amplitude multiplied with in-phase unit vectors to hang onto the balanced system. The CPI line voltages, DC link voltage, and grid currents are sensed for the control purpose. Whereas CPI line voltages are Vsab and Vsbc, DC link voltage is VDC, and grid currents are iga and igb. The control of the grid current mainly depends on DC link voltage which should be higher than the amplitude of line voltage, with respect to CPI.The reference DC link voltage is maintained constant at 10% greater than the reference voltage, with the drop across switches, interfacing inductor, resistance of interfacing inductor and proper current control under DC link voltage dynamic. The output voltage variation is kept at ±15% tolerance of the three-phase main supply. In this fuzzy logic controller is deployed to control the DC link voltage to the reference CPI voltage.

The Dc link voltage is brought to the low pass filter to suppress the noise produced in the system and the difference between VDC-ref and VDC is input to the fuzzy logic controller. The output of the controller is the loss component of grid currents. Which are estimated as,

$$I_{loss}(k)=I_{loss}(k-1)+K_p\{v_e(k)-v_e(k-1)\}+K_i v_e(k) \quad (4)$$

The PV feedforward term is estimated to provide a fast dynamic response for the change in solar insolation.The PV power changes immediate effect can be observed

Which is estimated as,

$$I_{PVg} = (2P_{PV}) / (3V_Z)$$

$$P_{PV} = V_{PV} * I_{PV} \quad (5)$$

The grid currents are expected coming out of CPI. With consideration of the direction of current losses are assumed. The amplitude of grid current ($I_{rg}=I_{loss}-I_{PVg}$) is multiplied with the unit vector of the same phases to reference grid currents. With the reference and grid currents, the output of the current controller is the switching pulses to the VSC.

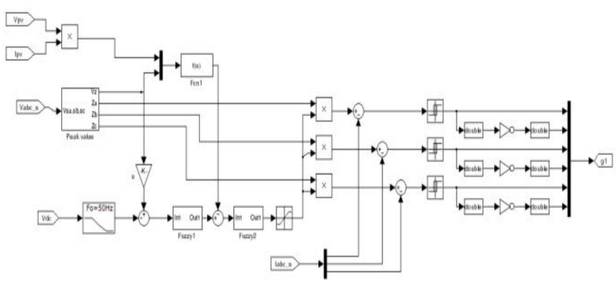

Figure-5.The equivalent Design of VSC

D. Fuzzy logic controller

The fuzzy logic controller (FLC) mainly consists of two inputs in it namely error and change in error, the error is obtained by comparing the reference input signal with an output signal which is checked with respect to time that is called as a change in error. The functioning of FLC consists of four chief essentials in the structure as fuzzification, inference mechanism, rule base, and defuzzification. When these inputs are given to the fuzzy logic controller then fuzzy logic controller decided what would be the output of this controller using fuzzy rules which are settled by fuzzy controller designer. Similarly, the fuzzy logic controller output is given to the output of VSC.

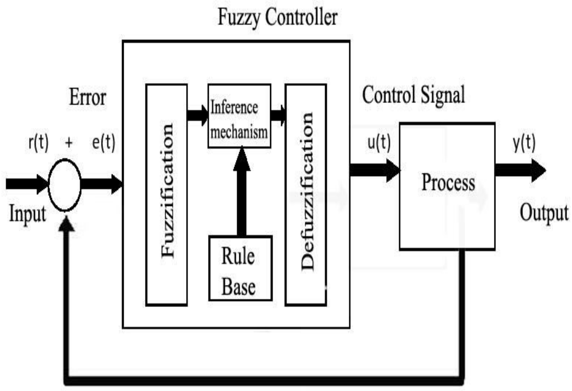

Figure-6. Fuzzy logic control Circuit

The fuzzification component consists of two supplementary components that are called membership function and labels. The fuzzy logic controller converts input data or variable data into fuzzy membership functions according to user-defined chart. The Membership functions differ as Triangular, Gaussian, Trapezoidal, and Generalized Bell in addition to Sigmoid.The inference mechanism component of the fuzzy logic control system consists of fuzzy rules which are settled by the controller designer shown in figure 6. Based on these fuzzy rules, the controller decided the output of the fuzzy logic controller. This is the main perceptive control of this system. The rule base is used to govern the output variable. The rule base is based on the IF-THEN rule with an exact condition and conclusion, characterized by the matrix table. Error and change in error are the two variables filled along the axes. An extreme operation is defined by the output of the membership function in the rule base. The fuzzy rule base is typically changed by the change in inputThe defuzzification component of fuzzy logic converts which controls the non-fuzzy value by defuzzification of the fuzzy set as the fuzzy data values into real life data values after examining the fuzzy rules but these real-life data values depend upon the Defuzzification method. The duty cycle is obtained as the output of FLC, which is used to control the boost converter operation. Different methods are used for the Defuzzification process such center of gravity (SOG), smallest of maxima (SOM), mean of maxima (MOM) and weighted average method. Each method has different advantages and disadvantages. These methods are set by the controller designer. FLC has more benefits as Low-cost executions founded on cheap sensors, low- resolution analog-to-digital converter. the I/O variables are expressed in seven grammatical labels such as negative large (NL), positive large (PL), negative medium (NM), positive medium (PM), zero (Z), negative small (NL) and positive small (PL). If the E is NL and 6E is NL, the duty cycle is PL, such that the duty cycle is largely increased and a similar manner for all the membership functions.

TABLE.I. FUZZY RULE BASE TABLE

E/ ΔE	NL	NM	NS	Z	PS	PM	PL
NL	PL	PL	PL	PL	NM	Z	PL
NM	PL	PL	PM	PL	PS	Z	Z
NS	PL	PM	PS	PS	PS	Z	Z
Z	PL	PM	PS	Z	NS	NM	NL
PS	Z	Z	NM	NS	NS	NM	NL
PM	Z	Z	NS	NM	NL	NL	NL
PL	Z	Z	NM	NL	NL	NL	NL

4. SIMULATION RESULTS

The solar PV system is modeled for 100kW under the sudden change in insolation from 1000W/m^2 to 500W/m^2 at a temperature of 25^{o}C connected to the 25kV utility grid through boost converter and VSC. Where the boost converter is step-up the voltage from 450V to 724V and fed to

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VSC. The three-level VSC regulates the DC bus voltage at 724V DC and converts to 723V AC with a unity power factor. During the operation of 1000W/m^{2,} the system will work under steady state condition with balanced and sinusoidal grid current. At t = 0.3 s, the solar irradiation is decreased to 500W/m^2 which effects the PV current tends to decrease led to PV power also. The proposed system helps to maintain a better dynamic response for the sudden change in solar insolation. The simulation results of three-phase AC voltage (V_{abc}), three-phase AC current (I_{abc}), DC link voltage (V_{DC}), PV array voltage (V_{PV}), PV array current (I_{PV}) and PV array power (P_{PV}) using InC MPPT based grid-tied SPV system using Fuzzy logic controller (FLC) are measured as given below.

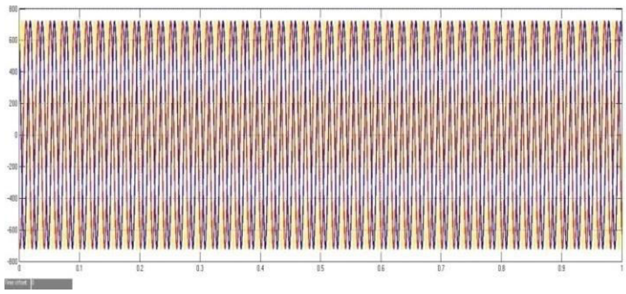

Figure-7. Simulation result Three phase AC voltage (V_{abc})

The grid Voltage and current can be modified with the help of the VSC controller in which the voltage of V_{abc} is observed as 723V of three phase AC voltage and I_{abc} is observed as 72A at the Insolation 1000 W/m^2 until t=0.3s, at the time t=0.3s when insolation decreased from 1000W/m^2 to 500W/m^2 the three phase current is measured as 36A. The sudden change in insolation is maintained with a better dynamic response shown in fig 7&8.

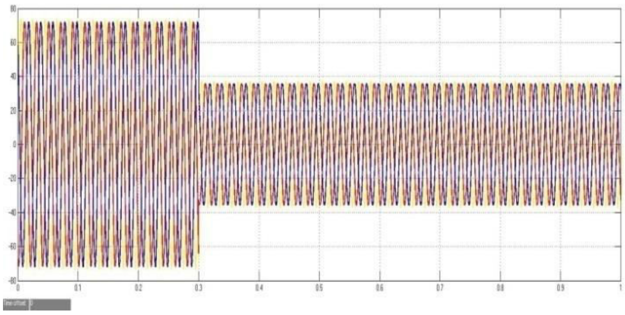

Figure-8. Simulation result Three phase AC
current (I_{abc})

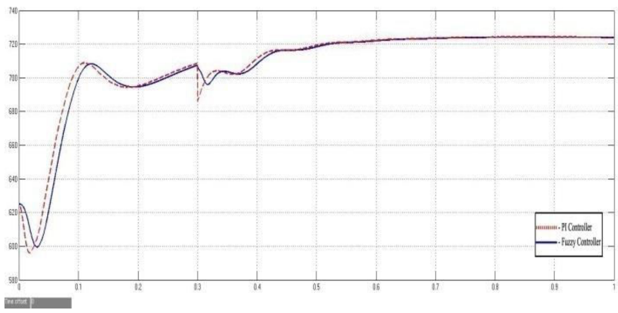

Figure-9. Simulation result of DC link voltage (V_{DC})

The second stage operation of the proposed system is a VSC controller with the help of DC link voltage which is measured as 724V of DC supply. The Fig 9 shows the DC link voltage with PI controller and modified Fuzzy controller. In this fuzzy is has more dynamic response the PI controller. The based grid-tied solar PV system are shown in Fig.10-12. PV array voltage (V_{PV}), PV array current (I_{PV}) and PV array power (P_{PV}) are shown respectively.

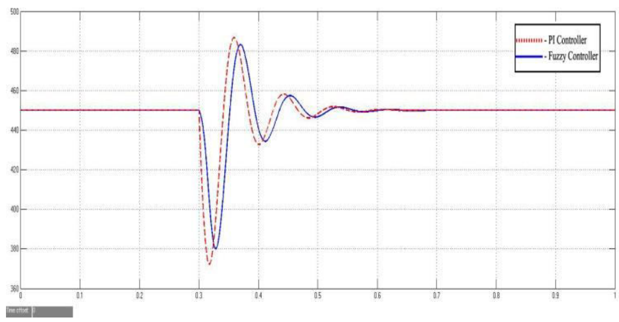

Figure-10. Simulation Result of PV array voltage (V_{PV})

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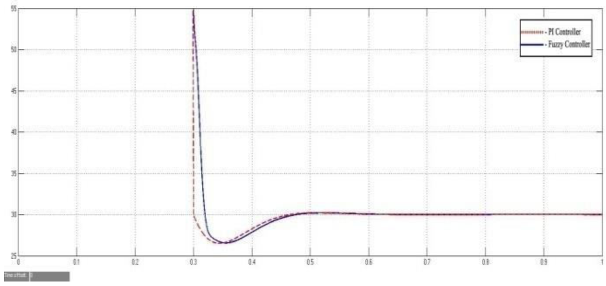

Figure-11. Simulation result of PV array current (I_{PV})

The economized THD (Total Harmonic Distortion) of the grid current is found around 2.44% (within the limit of an IEEE-519 standard of 5%) when compared with PI controller based system of 10.96%. Fig.13.

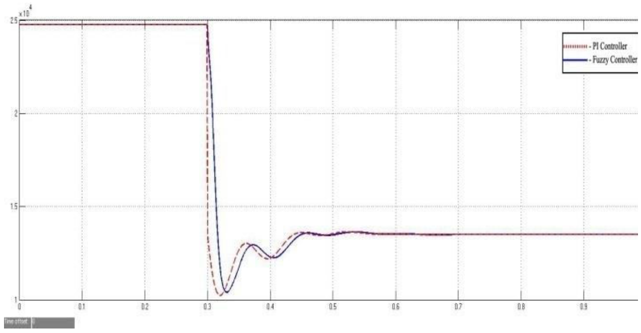

Figure-12. Simulation result of PV array power (P_{PV})

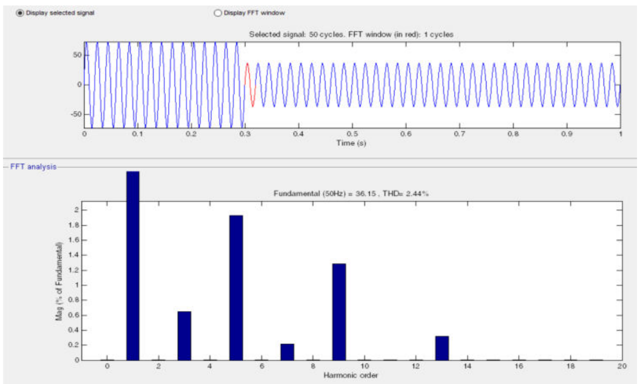

Figure-13. % of total harmonic distortion (THD)

5. CONCLUSION

The fuzzy logic controller (FLC) base three-phase grid-tied SPV system technique is proposed with the help of two stages, the first stage is InC based MPPT algorithm which is used to control the boost converter under various irradiation and temperature conditions. The second stage is the DC link voltage which is used to control the VSC with reference to the CPI (common point of interconnection) voltage which helps to reduce the switching losses. The performance is Improved and the THDs of the grid currents and voltages are found less than 5% (within IEEE – 519 standard).

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