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Solar PV Stand-Alone System Employing SEPIC and Single Phase Sine PWM Inverter

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ABSTRACT: This paper describes the simulation of 1KV solar PV standalone supplied SEPI (Single Ended Primary Inductor) converter for single phase SPWM inverter for household loads. The SEPI converter is controlled for extracting the maximum power from PV system and deliver the power to the DC link of single phase inverter. The Sinusoidal Pulse Width Modulation(SPWM) technique is used with the aim to reduce harmonics generated by inverter. Current standard needed that Total Harmonic Distortion(THD) should be minimum. A single phase SPWM signal is accomplished in order to produce output voltage which is closer to sine wave. The proposed system is implemented using MATLAB/Simulink R2019. The summation of LC filter helps in achieving a smooth sine wave and reduce voltage THD to 0.73% and current THD to 0.71%. The Simulation results emphasize the authenticity of the proposed technique in reducing in harmonic content and can be beneficial to improve power quality of the system.

KEYWORDS: PV Standalone , Single-Ended Primary Inductor Converter (SEPIC) , Perturb and Observe(P&O) , LC Filter, Unipolar PWM, Maximum Power Point Tracker (MPPT), Total Harmonic Distortion.

I. INTRODUCTION

The extensive usage of conventional fossil energy has resulted in depletion of fuel deposit and also disturbed the atmosphere giving rise to pollution and green house effect. Due to the non-renewable nature of fossil fuel energy, there appears the issue of energy scarcity. In order to replace the conventional fossil energy, it is essential to develop clean renewable energy. Among all the renewable energy sources, solar energy is one of the most promising as it much clean, inexhaustible and free to harvest. Photovoltaic cell technology plays an significant role on incorporate solar energy to the electrical systems[1]. Some of the advantages of the photovoltaic system are less routine maintenance, zero gas emission, single time investment and less operation charge.

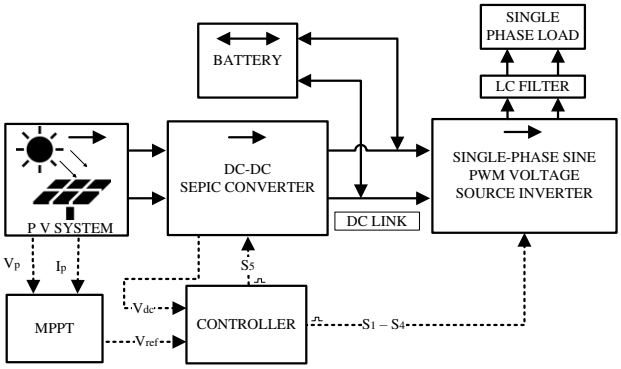

Figure.1: Block diagram of the proposed system.

Due to the non-linear characteristics of the current and voltage of the photovoltaic (PV) panel, a control algorithm is implemented called maximum power point tracking (MPPT) to harvest the maximum power from the PV panel. Over the last few years, various techniques have been implemented for MPPT, such as the Incremental Conductance(INC) method, Sliding mode control, Perturb and Observe(P & O) method, Modified P&O, Neural network control, Fractional short circuit, Fuzzy logic method, Adaptive Neuro fuzzy, Fractional order incremental conductance[2]-[9].The maximum power point is tracked by the DC-DC converter.

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Recently, SEPI-controllers has received an increasing attention because its output voltage may be either higher or lower than input voltage. Unlike fly back or Cuk topology, the output is not inverted. SEPIC controller can comprehensively control the maximum power point tracking (MPPT) converter, addressing maximum overshoot, settling time, rising time and steady-state error. Single-ended primary inductor converter (SEPIC) is able to deliver the needed input-to-output gain as a DC-DC converter. According to its duty cycle, SEPIC changes its output voltage. SEPIC has non-inverting output unlike buck and boost converter. Hence, it uses series capacitor to separate input from output. As MPPT tracks its maximum power through increasing/decreasing current and voltage, use of SEPIC converter is worthwhile as it increases or decreases voltage at current expenses. The block diagram of the proposed system scheme is shown in *Figure.1* The MPPT applied in the system use logics and control to know about the knee of MPP. In this paper, Perturb and Observe [P&O] method is employed due to its easy and simple performance. In this algorithm, the operating voltage of the system is change in a specified direction in accordance with the increase or decrease in power [10]-[13].

Inverter is a basic power electronic converter that converts DC power into AC power. The input of the DC can be taken from rectifiers or battery. According to their output waveform, the inverters can be classified into low distorted sine wave or quasi-wave, square wave .The square wave and quasi-square wave are restricted for low and medium power applications due to high value of total harmonic distortion (THD). The power from dc supply of SEPIC is fed to inverter to get ac output power. A battery is connected on DC link (between the Sepic Converter and Inverter). It is essential to control the magnitude and frequency of the sinusoidal ac outputs. This can be achieved by comparing sinusoidal wave having the same frequency as inverter output against triangular carrier wave. This technique is called sinusoidal pulse width modulation (SPWM). Among various PWM techniques, the Sinusoidal Pulse Width Modulation (SPWM) technique is the frequent one because of its simplicity and ease of implementation [14]-[19].

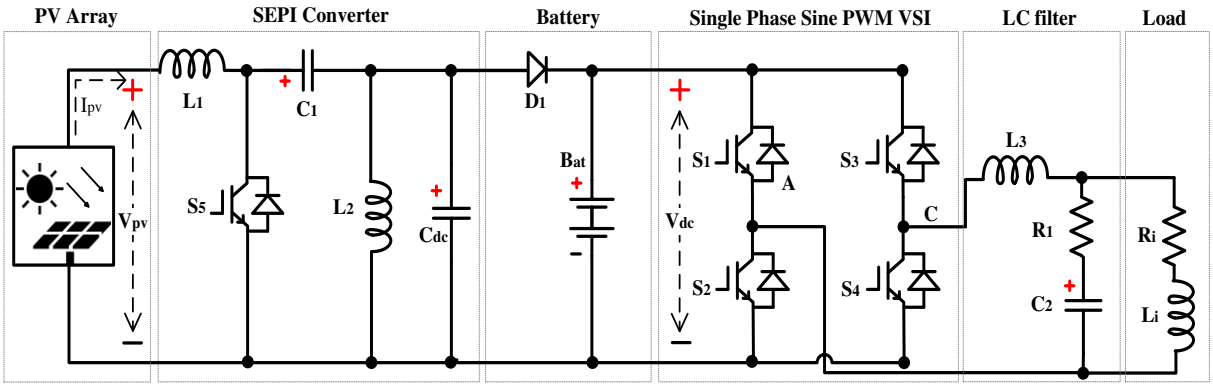

Figure.2: Solar PV Stand-Alone System Employing SEPIC and Single Phase Sine PWM Inverter.

In this paper, a standalone solar photovoltaic system and DC-DC SEPI-converter along with the single-phase SPWM voltage source inverter and its coordinated control is explain, Section II outlined the proposed system configuration. Section III describes the overall system control. The result analysis and discussion is contented in section IV and the conclusion is drawn in Section V.

II. PROPOSED SYSTEM CONFIGURATION

The block diagram of the proposed topology is shown in *Figure.2*.The system topology consists of a photovoltaic system, DC-DC SEPI-converter, battery, single-phase SPWM voltage source inverter and LC filter with single phase load. The SEPI-converter is used to boost the PV voltage and harvest the maximum power from the photovoltaic system. A MPPT controller is used for the SEPI-converter for generating the required gating pulses. The battery is connected to the DC link. Advantage of having battery at DC link, that it takes the over load power. Due to changes in the irradiations and temperature, SEPI-converter output power varies, to manages this variations and harvest the maximum power point tracking (MPPT) P&O technique is applied. The output of SEPI converter is fed to Single Phase SPWM VSI. The system will generate some harmonics component at the output terminals, so LC filter is used to filter the harmonics content.

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III. SYSTEM CONTROL

1. DC-DC SEPI-CONVERTER USING MPPT CONTROL

A 1000 W PV panel with a peak output power at standard environmental conditions (1000 W/m2 @25 °C) is selected. The characteristics of PV is shown in *figure.3* PV modules (Zshine PV-Tech-ZXM6-60-265-M) with 4 module in series and 1 module is connected in parallel to assemble the PV panel of the relevant size. The short-circuit current, open-circuit voltage, MPPT voltage and current are shown in *Table I*. According to the MPPT, the voltage level increases or decreases. The PV voltage and current is fed to P&O block to achieve the maximum power point (MPP), output of P&O block is MPPT duty cycle, which is compare with the 10 KHz triangular carrier frequency. The output of the comparator is PWM pulse for switch S_5, as shown in *figure.4*. The ability to have an output voltage less than or greater the input voltage with no polarity reversal makes this SEPI-converter suitable for solar applications. The SEPI - converter is used as interface between PV system and single-phase SPWM inverter to give load impedance matching with PV system. SEPI-converter is an non-inverting converter can be used with buck mode or boost mode. The unique feature of SEPI-converter is that, it has a coupling capacitor, which offers isolation between the input side and output side. It can increase the output voltage to a appropriate value and is able to supply isolation route to isolate output and input terminal after terminating charging. SEPI-converter can also used for the low-power PV charger system due to having the characteristic of easy to drive switch and non-inverting polarity.

2. SINGLE PHASE SPWM INVERTER

In SPWM (Sinusoidal Pulse Width Modulation) technique , sinusoidal signal or reference signal is compared with the triangular signal or carrier signal using a device named comparator that produces the required gate signals for the inverter switches. The frequency of sinusoidal signal determines the inverter output frequency .The reference peak amplitude controls output voltage RMS value and modulation index (m_a). Carrier signal switching frequency determines the inverter switching frequency. A unipolar switching technique is implemented with single-phase inverter due to the advantage that its output voltage switches between two states can be negative or positive value of the applied voltage. In unipolar PWM technique, two sinusoidal waves having same frequency and magnitude are required with 180˚ out of phase shift from each other. This two sinusoidal signal are compared with a same triangular waves. By comparing the triangular signal and positive reference, switch S_1 gate signal are generated whereas gate signal of S_3 switch generates by comparing the phase shift of 180˚ with triangular signal and reference signal. Switch S_3 and switch S_4 are complementary of each other. Equivalently switch S_1 is complementary to switch S_2, as shown in *figure.5*.

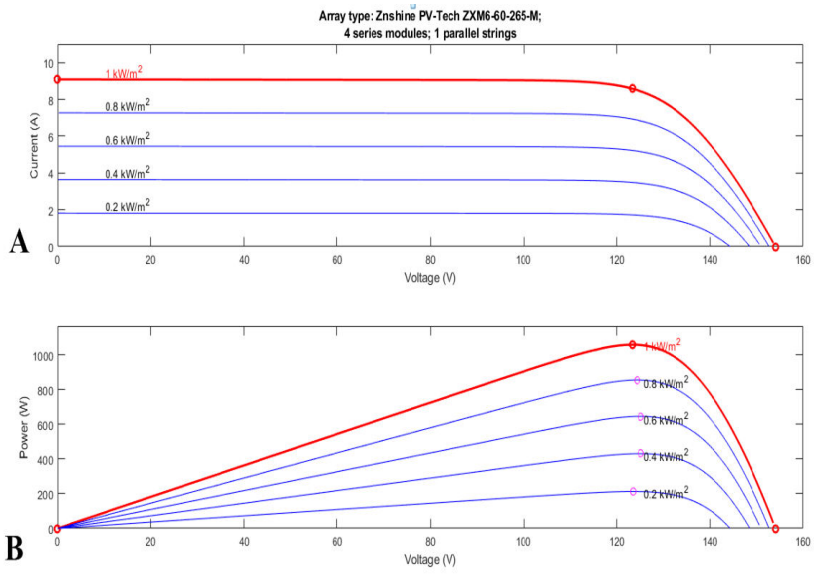

Figure.3: PV Characteristics plots for different irradiations. (a) V-I plot, (b) P-V plot.

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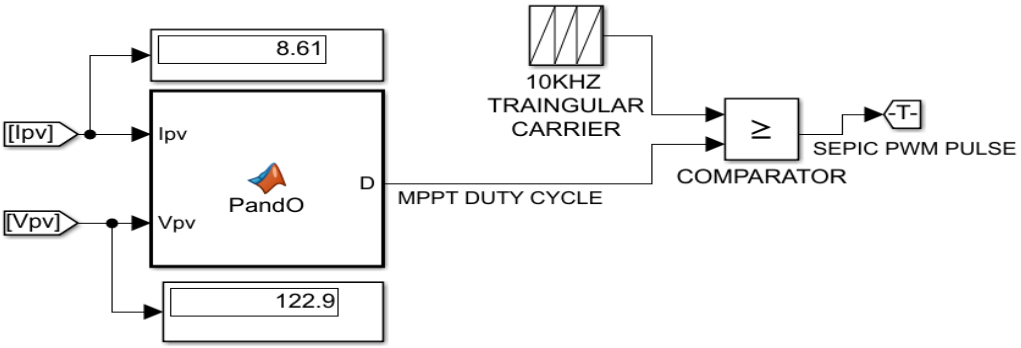

Figure.4: P&O based MPPT controller.

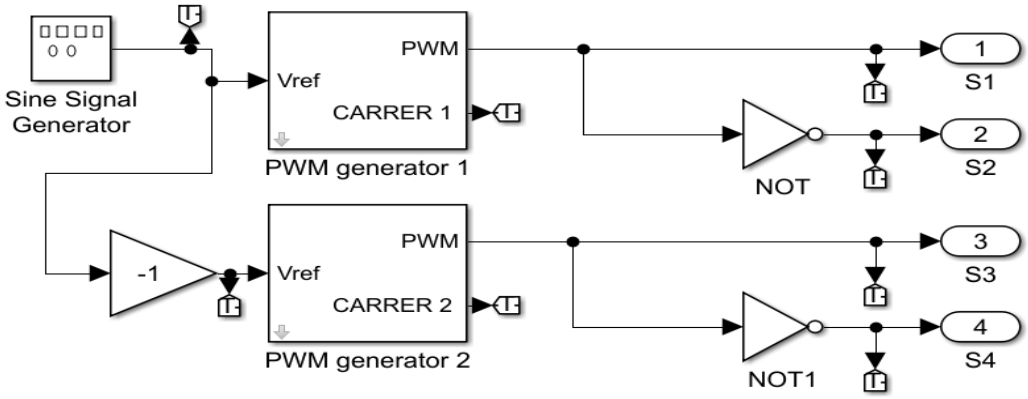

Figure.5: Single phase SPWM Inverter control technique.

IV. SIMULATION RESULTS AND DISCUSSIONS

The model of solar PV stand-alone system employing SEPIC and single phase sine PWM inverter is developed using MATLAB/ SIMULINK R2019, as shown in *figure.8*. The simulation specifications are tabulated in *Table I.* The proposed control strategy is implemented on standalone dc-dc SEPI-converter and SPWM inverter system having resistive inductive load of 105.8 Ω, 1 mH and constant power load of 1K Watt for a solar irradiation of 1000 W/m^2.

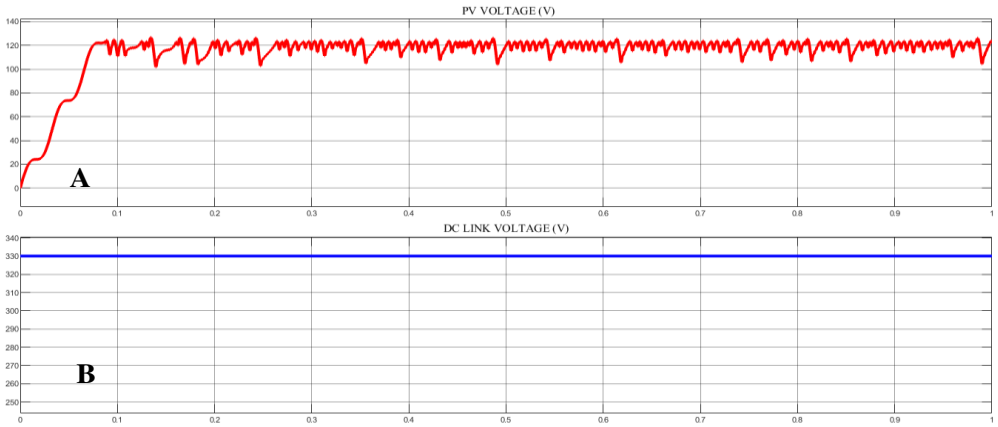

Figure.6: Waveform of (a) PV voltage and (b) DC link voltage (SEPIC output voltage).

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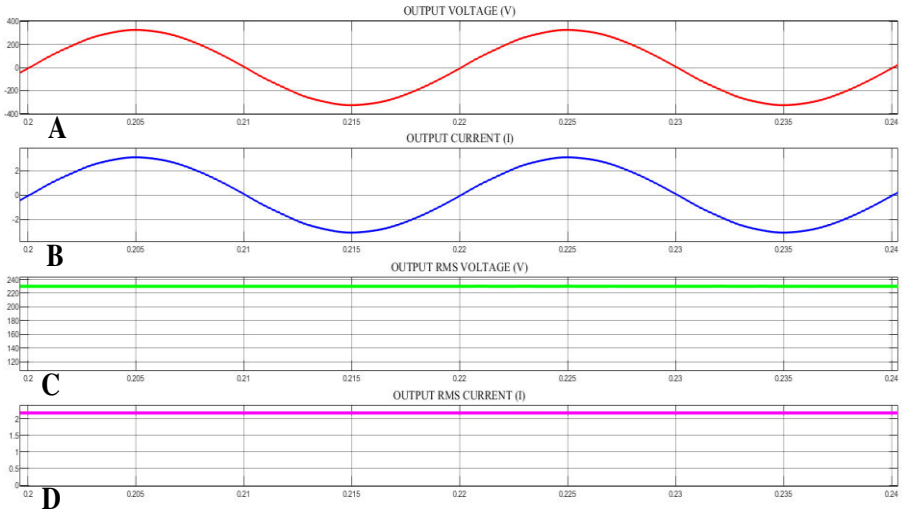

Figure.7: SPWM Inverter output waveform (a) output voltage, (b) output current, (c) output rms voltage, (d) output rms current.

The PV System is fed to SEPI-converter to boost the PV voltage and harvest the maximum power through MPPT, A PV system of 120V is fed to SEPI-converter, the output of SEPI boost converter is 330V, as shown in *figure.6*, a battery of 330V is connected between DC link, a sine PWM inverter is control by SPWM pulses and, there reference, carrier, PWM pulses are shown in *figure 9(a-h),* the harmonics content of inverter are filter using LC filter, a 1 KW load is connected on inverter , the modulated output of inverter is 230 V_{rms}, are shown in *figure.7(c).*

The FFT analysis of inverter is done in the Simulink to determine the THD from the modulation index (M_a) of 0.98 are 0.73% THD and 0.71% THD for output voltage and current respectively. As results are shown in *figure.10-11.*

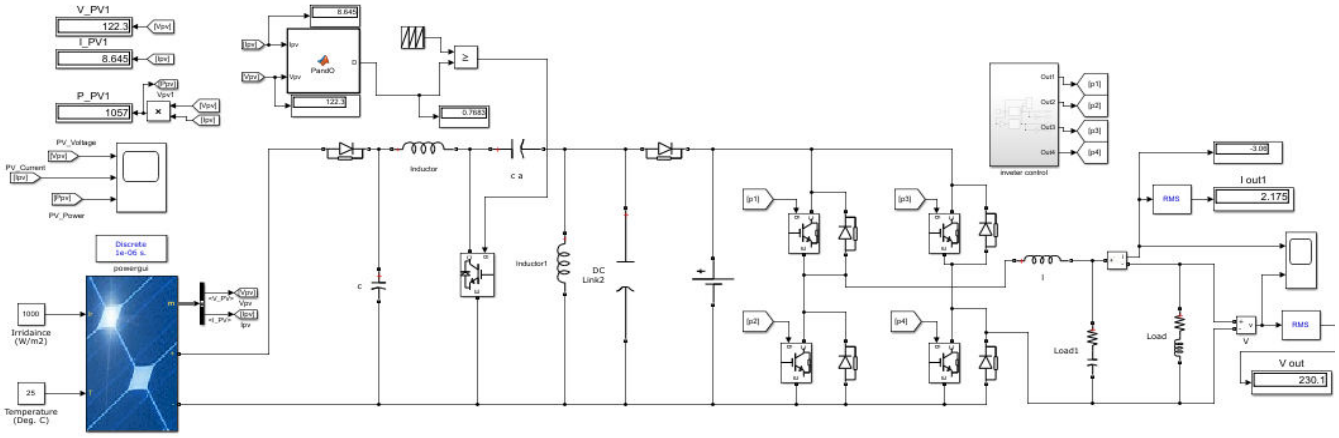

Figure.8: Simulink model of proposed topology.

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Table- I: Simulation parameters

	Parameters	Value
PV ARRAY	Znshine-PV-tech-ZXM6-60-265-M	
	Open circuit voltage (Voc)	38.5 V
	Short-circuit current (Isc)	9.07A
	Voltage at maximum power point (Vmp)	30.84 V
	Current at maximum power point (Imp)	8.59 A
	Maximum power/module	246.91 W
	Cells per module	60 Ncell
	Temperature coefficient of open circuit voltage	-0.32 %/deg.C
	Series modules	4
	Parallel modules	1
SEPIC	Capacitor, C_1	3 mF
	Inductor, L_1	9 mH
	Inductor, L_2	9 mH
	Sepic switching frequency	10 KHz
	DC-link voltage, (V_{dc})	330 V
	DC-link Capacitor, (C_{dc})	20 µF
	Battery voltage, (V_{bat})	330 V
INVERTER	Inverter amplitude modulation ratio, m_a=0.98/1	0.98
	Inverter frequency modulation ratio, m_f=5000/50	100
	Filter capacitor, (C_2)	20 µF
	Filter inductor, (L_3)	5 mH
	Inverter output voltage	230 V_{rms}
	RL Load, (R_i, L_i)	105.8 Ω, 1 mH

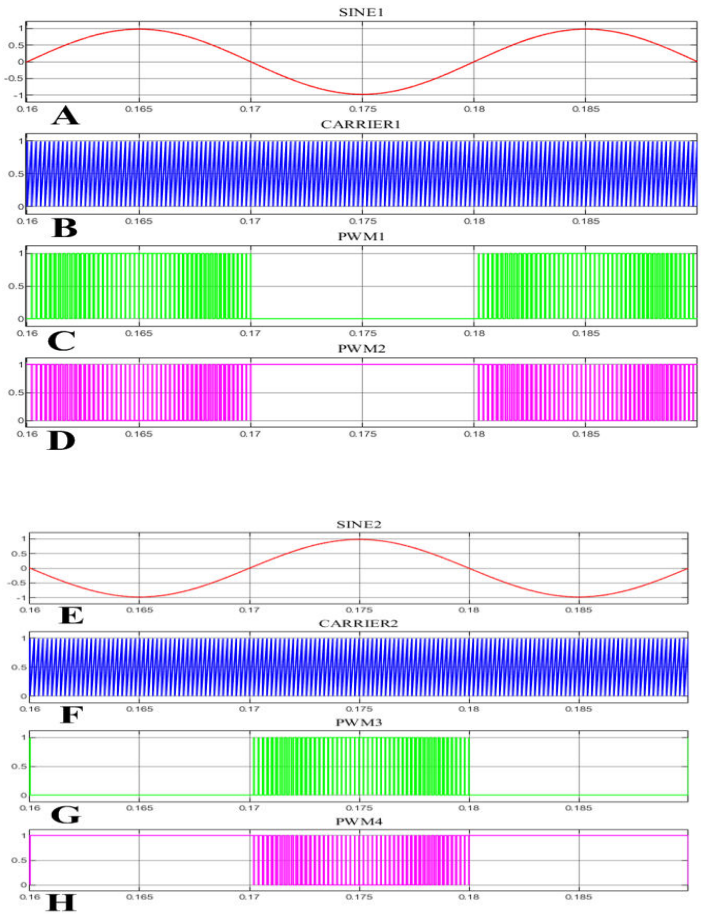

Figure.9: (a) sinusoidal reference wave, (b) carrier frequency wave, (c) SPWM for switch S_1, (d) SPWM for switch S_2, (e) 180° phase shift sinusoidal reference wave, (f) carrier frequency wave, (g) SPWM for switch S_3, (h) SPWM for switch S_4.

The simulated results shows that unipolar SPWM inverter is easy to filter. THD of filtered voltage for propose topology is below 5% as recommended by IEEE Standard-519.

V. CONCLUSION

The Solar PV Standalone system based SEPI-converter fed single phase SPWM inverter for household system has been modelled and controlled. The MPPT based P&O technique is implemented for SEPI-converter. The proposed system provides energy efficient solution and good stability for solar irradiation. The single phase SPWM inverter using proposed SPWM control technique with LC filter benefits in generating a smooth sinusoidal output voltage having lower harmonics. Hence, the proposed SPWM technique reach the permitted standard THD requirement for advanced performance of power quality .

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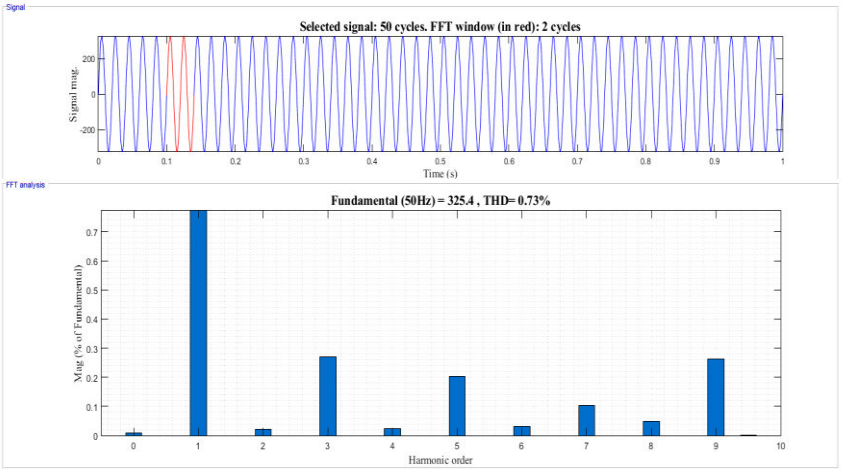

Figure.10: Output voltage FFT analysis with m_a=0.98 is 0.73% THD.

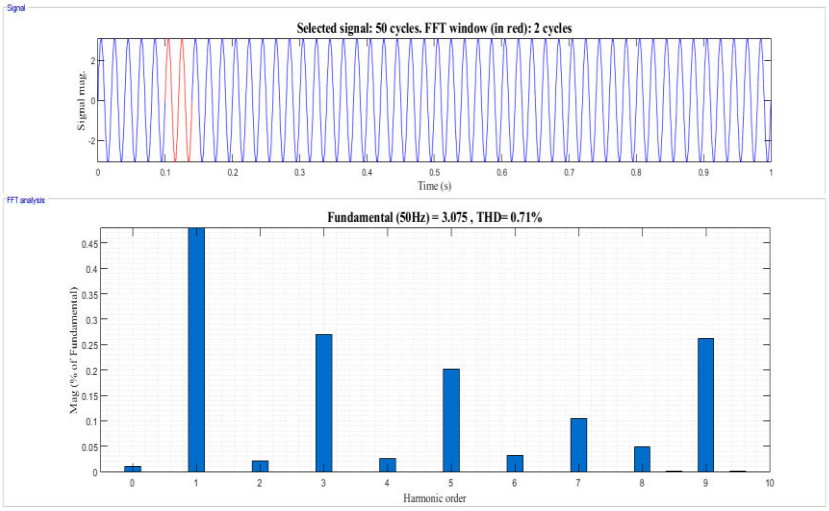

Figure.11: Output current FFT analysis with m_a=0.98 is 0.71% THD.

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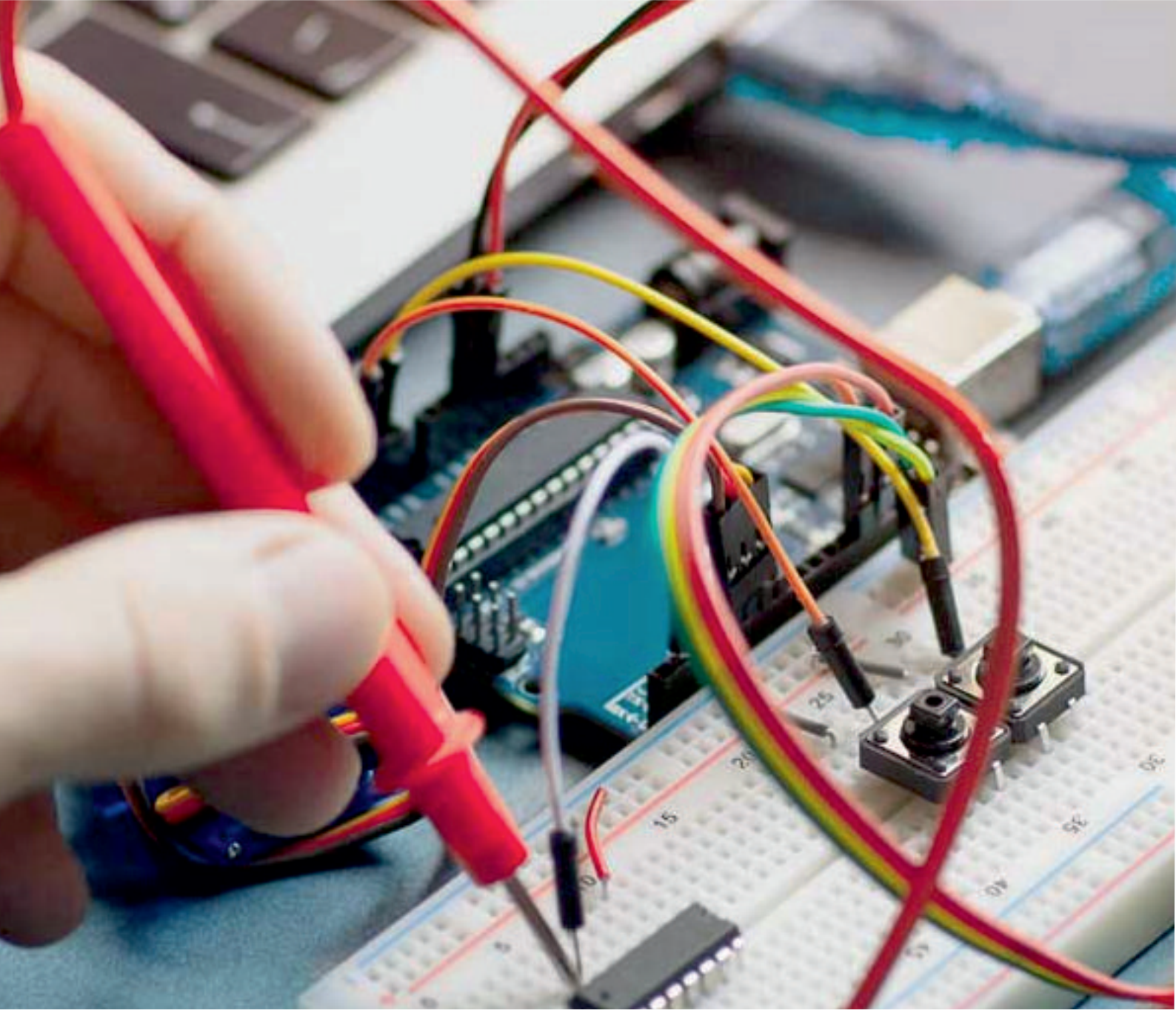

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