Single-Phase Transformerless PV Inverter Under Partial Shading Conditions

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Abstract:- **The objective of this paper is to implement a single phase transformrless inverter under partial shading conditions.Transformerless photovoltaic (PV) systems are usedbecause they have many advantages (weight, size, efficiency, etc.). However, transformerless PV systems suffer from leakage current.Leakage current minimization is one of the most important considerations in transformerless photovoltaic (PV) inverters. Photovoltaic modules have relatively low conversion efficiency. Therefore Maximum Power Point Tracking (MPPT) is responsible for extracting the maximum possible power from the photovoltaic and feed it to the proposed topology via the single-ended primary-inductor (SEPIC) converter which provides a positive regulated output voltage from an input voltage that varies from above and below the output voltage.**

In this paper,proposes an improved Maximum Power Point Tracking of PhotoVoltaic system using a Modified Particle Swarm Optimization technique. This method has the ability to track the Maximum Power under partial shading condition. The advantage of this method is fast tracking speed, simple algorithm and reduced steady state oscillations, once the Maximum Power Point is located.The proposed system is modeled and simulated using MATLAB/Simulink software program.

Keywords- Transformerless PV inverter, Maximum Power Point Tracking (MPPT), Single-ended primary-inductor (SEPIC), A Modified particle swarm optimization (PSO), Partial shading condition.

I. INTRODUCTION

Photovoltaic (PV) power systems using solar energy are among the most used sources in the world. Most of the topologies for PV power systems use a transformer to isolate the PV panels from the grid. A transformer is classified as either line- or high- frequency depending on its position. The transformers block the injected current, although the line

frequency transformer has a larger size and weight. A high frequency transformer is used in PV systems
at some stages, decreasing the efficiency and making the entire system more complex. Topologies without a transformer generally have lower cost, smaller size, lighter weight and higher efficiency than topologies with transformers. However, some safety issues are caused by leakage capacitor CPV to ground,which is generated between the PV array terminals and the normally grounded frame.
It has been suggested in [1] a High Reliability and Efficiency Single-Phase Transformerless Inverter for Grid-Connected Photovoltaic Systems.This paper presents a high-reliability single-phase transformerless grid-connected inverter that utilizes superjunction MOSFETs to achieve high efficiency for photovoltaic applications. The proposed converter utilizes two split ac-coupled inductors that operate separately for positive and negative half grid cycles. This eliminates the shoot-through issue that is encountered by traditional voltage source inverters, leading to enhanced system reliability. Dead time is not required at both the high-frequency pulse width modulation switching commutation and the grid zero crossing instants, improving the quality of the output ac-current and increasing the converter efficiency. The split structure of the proposed inverter does not lead itself to the reverse-recovery issues for the main power switches and as such super junction MOSFETs can be utilized without any reliability or efficiency penalties.
It has been suggested in [2] transformerless PV inverters utilizing unipolar PWM control In order to minimize the ground leakage current and improve the efficiency of the converter system. The weighted California Energy Commission (CEC) or European Union (EU) efficiencies of most commercially available and literature reported single-phase PV transformerless inverters are in the range of 96–98%.

It has been suggested in [4] the modelling and controller design of the PV charger system implemented with the single-ended primary inductance converter (SEPIC). In modern age different portable electronic equipment have benefited from a power converter is able to achieve high efficiency with a wide input and output voltage ranges will be low. But conventional converters can’t maintain a wide operation range with high efficiency. These characteristics can be obtained in a single ended primary inductor converter (SEPIC). So SEPIC converter is used. The SEPIC converter is used in the proposed system.

Partial shading on a solar panel occurs when only a part of the panel’s surface is shaded. Partial shading on a solar panel string may occur when some panels are shaded and the others are fully illuminated.

When partial shading occurs in a small surface inside a cell group bypass diodes may not be able to protect the shaded cells. So, these solar cells are forced to operate with increased current, meaning that they will heat up. Then the lifetime of solar panel will be reduced.

In normal condition only one global peak is present in P-V curve. But in partial shading condition multiple peaks are present. It affect the output power of PV [7].

Maximum Power Point tracking (MPPT) that allows a PV array to deliver the maximum amount of power under varying under environmental condition. The point that gathers the power called the Maximum Power Point (MPP).

Over the years, various MPPT methods are proposed. For example, Perturb and Observe (P&O), Incremental and Conductance (I&C), Hill climbing (HC), Neural Network (NN) and Fuzzy Logic Controller (FLC).These methods are not suitable for partial shading condition. P&O, I&C and HC are very likely to lose its direction while tracking the true MPP. FLC and NN are effective with the nonlinear characteristics of the I-V curves, but they require more operations [7].

In order to get maximum power under partial shading condition, Particle Swarm Optimization (PSO) method is used.

II. PROPOSED METHOD

The proposed system consists of PV, SEPIC,Single phase Transformerless PV inverter. Fig.1 demonstrates the block diagram of proposed system.

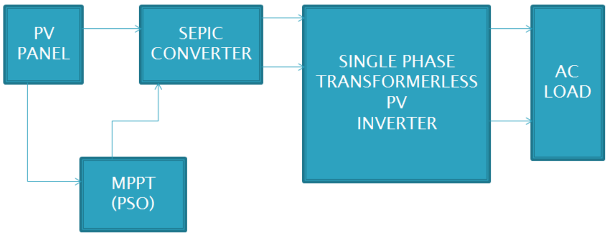

Fig.1 Block diagram of proposed method

The proposed method contains PV panel,SEPIC converter, single phase transformerless inverter.When no transformer is used in a grid-connected photovoltaic (PV) system, a galvanic connection between the grid and the PV array exists. In these conditions, dangerous leakage currents(common-mode currents) can appear through the stray capacitance between the PV array andthe ground.Maximum Power Point Tracking (MPPT) is responsible for extracting the maximum possible power from the photovoltaic and feed it to the proposed topology via the single-ended primary-inductor (SEPIC) converter which provides a positive regulated output voltage from an input voltage that varies from above and below the output voltage.

A. PHOTOVOLTAIC MODELING

A modeling PV module among various modeling methods of the PV module, the two-diode model, as depicted in fig.2. The output current of the module can be described

$$I = I_{PV} - I_{d1} - I_{d2} - \left(\frac{V+IR_S}{R_P}\right) \qquad (1)$$

Where

$$I_{d1} = I_{o1}\left[\exp\left(\frac{V+IR_S}{a_1 V_{T1}}\right) - 1\right] \qquad (2)$$

and

$$I_{d2} = I_{o2}\left[\exp\left(\frac{V+IR_S}{a_2 V_{T2}}\right) - 1\right] \qquad (3)$$

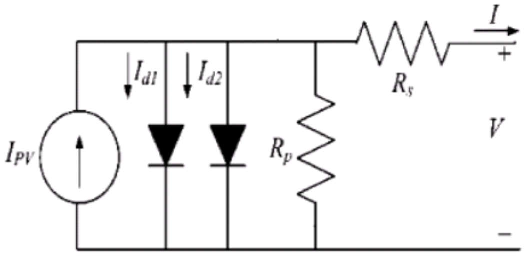

Fig.2 Two diode model of PV cell

where

- I_{PV} is the current generated by the incidence of light
- I_{o1} and I_{o2} are reverse saturation of diode 1 and diode 2, respectively. The I_{o2} term is introduced to compensate for the recombination loss in depletion region
- V_{T1} and V_{T2} (both equal to N_S k T/q) are thermal voltages
- N_S cells connected in series
- N_P cells connected in parallel
- q is the electron charge (1.60217646 x 10^{-19} C)
- k is the Boltzmann constant (1.3806503 x 10^{-23} J/K)
- T is the temperature of p-n junction in Kelvin
- Variables a_1 and a_2 represent the diode constants, respectively
- R_s is a series resistance
- R_p is a parallel resistance

B. MODELING OF PV ARRAY

A large PV power generation system, the modules are configured in a series- parallel structure (i.e., N_{SS} x N_{PP} modules), as depicted fig.3.

$$I = N_{PP}\{I_{PV} - I_0(I_p + 2)\} - (V + IR_s\Gamma / R_p\Gamma) \qquad (4)$$

Where

$$I_p = \exp\left(\frac{V+IR_S\Gamma}{V_T N_{SS}}\right) + \exp\left(\frac{V+IR_S\Gamma}{(p-1)V_T N_{SS}}\right) \qquad (5)$$

and $$\Gamma = \frac{N_{SS}}{N_{PP}} \qquad (6)$$

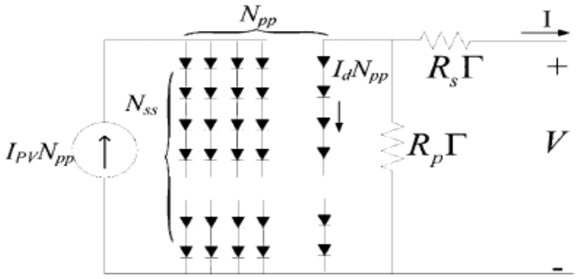

Fig.3 Series parallel combination of PV array

C.PV ARRAY UNDER PARTIAL SHADING CONDITION

Normally, numbers of PV modules are connected in series or parallel to form a PV array and the power of the PV array is the combination of the power derived from each PV module. In fig.4, there are two series connected PV modules and one of the PV modules is partially shaded. The shaded module will become power consumer and dissipates heat [6].

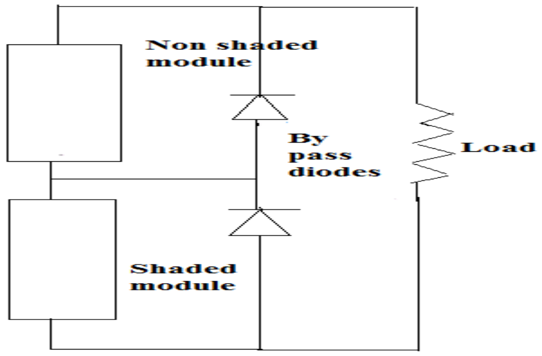

Fig.4 PV array under partial shading condition

If the operating current of the PV array that consists of these two series connected PV modules is at I_a, then the shaded PV module is forced to operate at the reverse biased region. Therefore, it acts as a load instead of a power source. In long term conditions, the shaded PV module will be damaged due to the localized power dissipation. Hence, the bypass diodes as shown in fig.4 are added to protect the PV modules from self-heating during partial shading.

Under uniform insolation, the bypass diodes are reverse biased and have no impact. When the PV module is shaded, the bypass diode across the PV module is forward biased and the current passes through the diode instead of the PV module. However, there is a disadvantage of using the bypass diodes where there will be multiple peaks that appear in the *P-V*curve during partial shading conditions [6].

D. A MODIFIED PARTICLE SWARM OPTIMIZATION ALGORITHM

In case of slow variation in the solar insolation, a proper initialization of duty cycles in PSO is very critical. In this case a change in duty cycle from the previous one should be small to track the MPP [3].

Thus, due to initialization, when the change in the duty cycle is large, the particles will have to search a large area of the *P−V* curve. However, MPP will still be tracked at the expense of large fluctuations in the operating point. Consequently, certain amount of energy will be wasted during the exploration process. However, the large change in the duty cycles does not allow for the duty cycles to follow the new MPP very accurately [3].

On the other hand, a large change in the operating point can also occur due to a large change in insolation, for example, during the partial shading condition. In this case, if the change in the duty cycle is small, the convergence toward the MPP could be slow [3]. This could be more critical for the case of partial shading. As duty cycles are not allowed to explore a larger area of the P−V curve, the final MPP could settle at a local instead of global peak.

PSO is a stochastic, population-based EA search method, modelled after the behaviour of bird flocks. The PSO algorithm maintains a swarm of individuals (called particles), where each particle represents a candidate solution. Particles follow a simple behaviour; emulate the success of neighbouring particles and its own achieved successes [6]. The position of a particle is,therefore, influenced by the best particle in a neighbourhood P_{best} as well as the best solution found by all the particles in the entire population G_{best} . The particle position X_i^k is adjusted using,

$$X_i^{k+1} = X_i^k + \varphi_i^{k+1} \qquad (7)$$

Where the velocity component $\Phi_i$represents the step size. The velocity is calculated by

$$\varphi_i^{k+1} = w\,\varphi_i^k + c_1 r_1\{P_{besti} - X_i^k\} + c_2 r_2\{G_{best} - X_i^k\} \qquad (8)$$

Where wis the inertia weight, c_1 and c_2 are the acceleration coefficients, $r_1, r_2 \in U(0, 1)$, P_{besti} is the personal best position of particle *i*, and G_{best} is the best position of the particles in the entire population.

$$d_i^{k+1} = d_i^k + \varphi_i^{k+1} \qquad (9)$$

However, for the case of PSO, resulting perturbation in the present duty cycle depends on P_{besti} and G_{best} . If the present duty cycle is far from these two duty cycles, the resulting change in the duty cycle will also be large, and vice versa. Therefore, PSO can be thought of as an adaptive form of HC. In the latter, the perturbation in the duty cycle is always fixed but in PSO it varies according to the position of the particles. With proper choice of control parameters, a suitable MPPT controller using PSO can be easily designed.

To illustrate the application of the PSO algorithm in tracking the MPP using the direct control technique, first a solution vector of duty cycles with N_P particles is determined,

$$X_i^k = d_g = [d_1, d_2, \ldots\ldots d_j]$$
$$j = 1, 2, 3 \ldots\ldots N_P \qquad (10)$$

The objective function is defined as,

$$P(d_i^k) > P(d_i^{k-1}) \qquad (11)$$

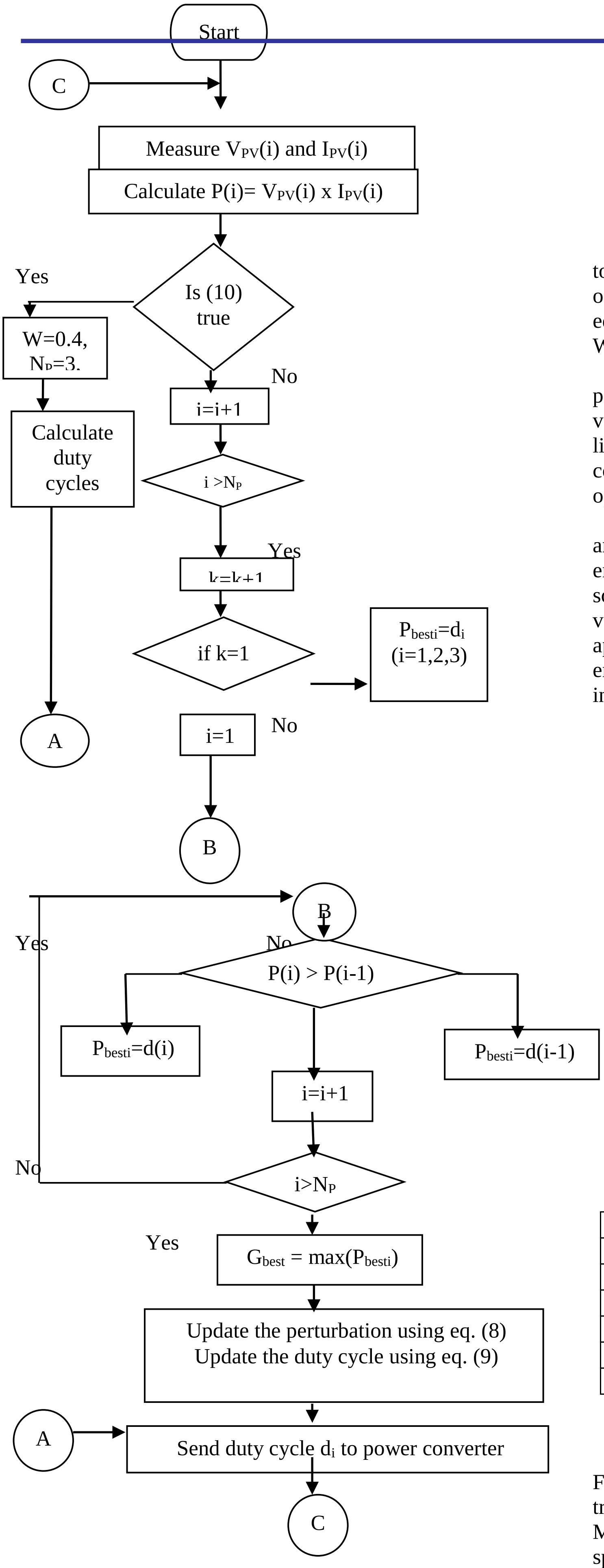

Fig.5 Flowchart of the proposed method

III. SINGLE ENDED PRIMARY INDUCTORCONVERTER

Single Ended Primary Inductor Converter (SEPIC) is a DC to DC converter and is capable of operating in either step up or step down mode and widely used in battery operated equipment by varying duty cycle of gate signal of MOSFET. We can step up or step down voltage [4].

The advantage of this converter is it provides a positive regulated output voltage from an input voltage that varies from above to below the output voltage. It act as both like a buck and boost converter. It also has minimal active components, a simple controller that provides low noise operation [4].

When switch Q_1 is turned on, current I_{L1} increases and the current I_{L2} increases in the negative direction. The energy to increase the current I_{L1} comes from the input source. Since Q_1 is a short while closed, and the instantaneous voltage V_{CS} is approximately V_{IN}, the voltage V_{L2} is approximately $-V_{IN}$. Therefore, the capacitor C_S supplies the energy to increase the magnitude of the current in I_{L2} and thus increase the energy stored in L_2 .

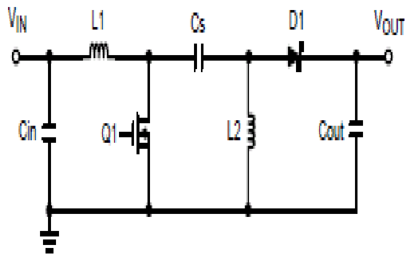

Fig.6Circuit diagram of SEPIC converter

When switch Q_1 is turned off, the current I_{CS} becomes the same as the current I_{L1}, as the inductors will not allow instantaneous changes in current. Current I_{L2} will continue in the negative direction, in fact it never reverse direction.

TABLE 1
DESIGN SPECIFICATION

Parameters	Value
L1	47e-6 H
L2	1e-6 H
C_{IN}	2000e-6 F
C_{OUT}	2000e-6 F
C_S	1e-6 F
Type of switch used	IGBT

IV. PROPOSED TOPOLOGY

Fig. 7 shows the circuit diagram of the proposed transformerless PV inverter, which is composed of six MOSFETs switches (S1–S6), six diodes (D1–D6), and two split ac-coupled inductors *L*1 and *L*2 . The diodesD1–D4

perform voltage clamping functions for active switches S1–S4. The ac-side switch pairs are composed of S5, D5 and S6, D6 , respectively, which provide unidirectional current flow branches during the freewheeling phases decoupling the grid from the PV array and minimizing the CM leakage current.
The proposed inverter topology divides the ac side into two independent units for positive and negative half cycle. In addition to the high efficiency and low leakage current features, the proposed transformerless inverter avoids shoot-through enhancing the reliability of the inverter. The inherent structure of the proposed inverter does not lead itself to the reverse recovery issues for the main power switches and as such superjunction MOSFETs can be utilized without any reliability or efficiency penalties.

Fig. 8 illustrates the PWM scheme for the proposed inverter. When the reference signal *V*control is higher than zero, MOSFETs S1 and S3 are switched simultaneously in the PWM mode and S5 is kept on as a polarity selection switch in the half grid cycle; the gating signals G2, G4 , and G6 are low and S2, S4 ,and S6 are inactive. Similarly, if the reference signal –*V*control is higher than zero, MOSFETs S2 and S4 are switched simultaneously in the PWM mode and S6 is on as apolarity selection switch in the grid cycle; the gating signals G1, G3 , and G5 are low and S1, S3 , and S5 are inactive[1].

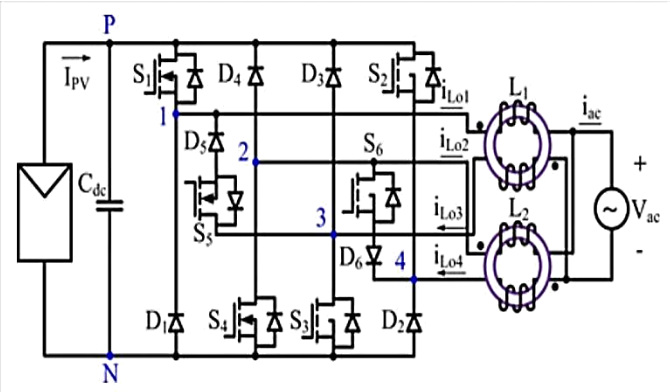

Fig.7 Circuit diagram of Proposed Transformerless PV inverter

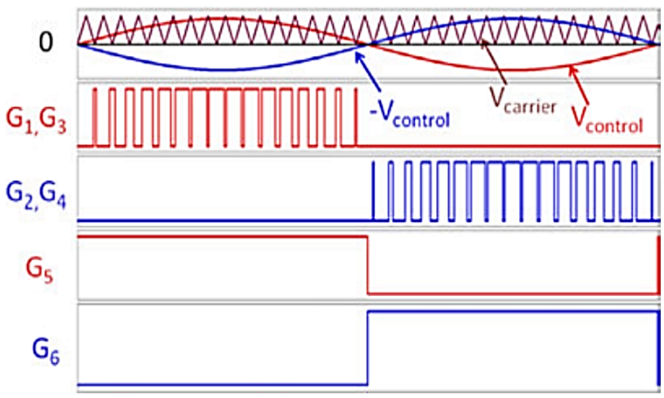

Fig.8 Gating signals of the proposed transformerless PV inverter

V. SIMULATION RESULTS

Modelling and simulation of proposed system has been carried out in MATLAB- SIMULINK.

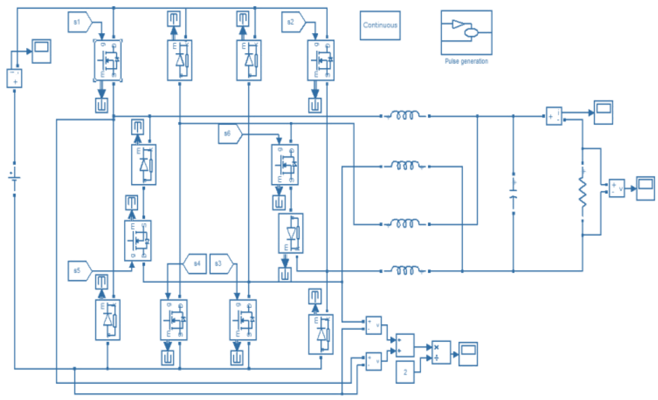

Fig.9.Simulation circuit of proposed system

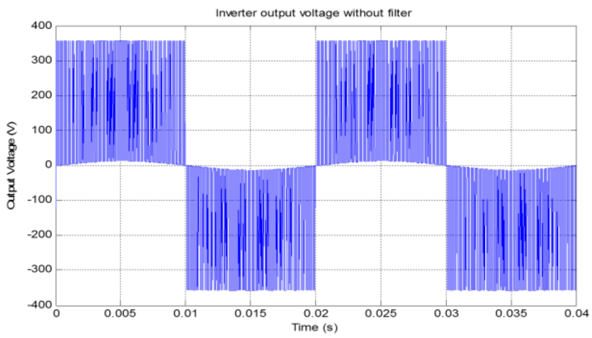

Fig.9.Output voltage of PV inverter without filter

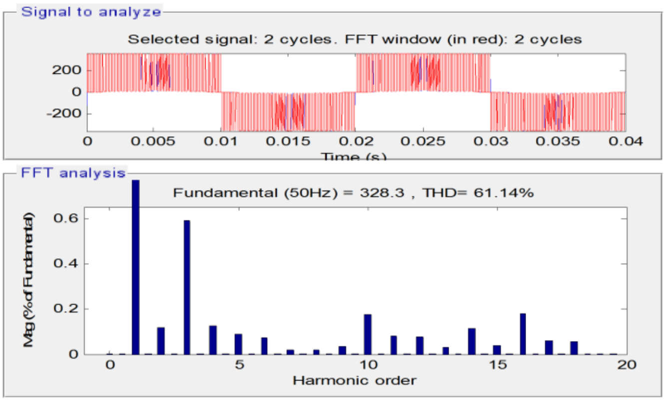

Fig.10.THD analysis of PV inverter without filter

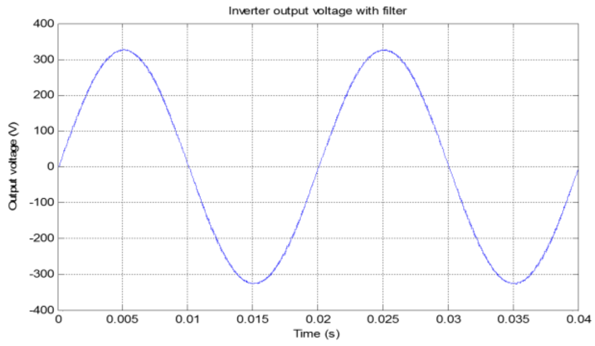

Fig.11. Output voltage of PV inverter with filter

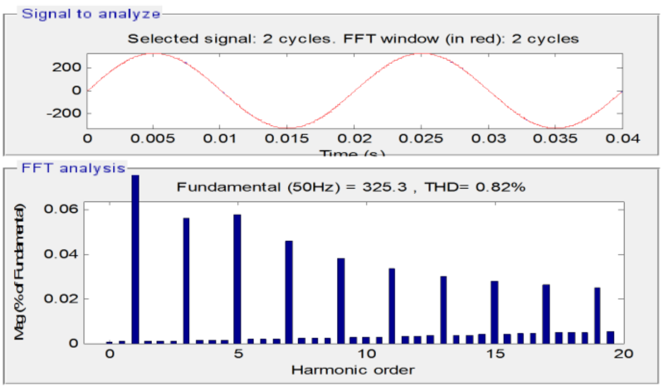

Fig.12. THD analysis of PV inverter with filter

VI. CONCLUSION

In this paper, presented a single-phase PV inverter without a transformer generally have lower cost, smaller size, lighter weight and higher efficiency than topologies with transformers.The configuration is suitable for PV application because of low conversion efficiency. By inserting the filter circuit the THD value can be reduced.Here proposes a Modified Particle Swarm Optimization (PSO) with the capability of direct duty cycle is used to track the MPP of a PV system under partial shading condition. It gives the best result under partial shading condition.

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