Reduction in THD for PV based Inverter System with PSO Technique using MATLAB/Simulation

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Abstract: The PV system exhibits a nonlinear power-voltage characteristic, its maximum power point (MPP) varies with irradiance and temperature. Under various conditions, it is possible to have multiple local maxima in some cases, but overall there is only one true MPP. This not only affects the power output of the PV systems, but also leads to complexity and reliability problems. Traditional methods are difficult to find the true MPP fast and accurately. Particle swarm optimization (PSO) is more suitable to reduce the steady state oscillations present in the current and voltage waveform at the output of the inverter. A modified soft computing technique called particle swarm optimization algorithm (PSO) is used to improve the switching of the inverter.This PSO based control algorithm alongwith PI controller is developed in MATLAB, which generates an error voltage and it is analysed using PSO based controller in order to improve the switching.In this paper PV system is analysed without using PSO as well as using PSO. It is concluded that while using PSO, improved current and voltage waveforms are observed which are responsible to reduce steady state oscillations in the system. FFT analysis is also done which shows that Total Harmonic Distortion (IEEE Std.519)with PSO based controller are within the acceptable limits defined by IEEE standards.It improves the reliability of the system.

Keywords: Boost Converter, Particle Swarm Optimization (PSO), Photovoltaic (PV), Solar Panel (SP).

Introduction

The global energy consumption is increasing everyday due to increased population and advanced technologies. But due to unreliable electrical system our country is facing severe power shortage problems. India and China are the two countries responsible for major consumption of energy. Due to Global warming concerns there is a strong need to deploy clean energy sources and implement energy efficient solutions to meet future energy demand. Energy engineers all over the world are focusing on solar projects to increase the generation capacity. A solar system is made up of solar modules. Number of cells combines to form a module and these modules are in turn connected to form the PV system. The output DC voltage of the panel is then converted to desirable AC voltage for feeding excess power to the grid [4]. Despite of advanced technologies, a grid connected PV system is always subjected to several complexities. Soft computing based algorithms were recently developed to improve the inverter switchingunder varying environmental conditions. The PSO [3] method is a simple and effective meta-heuristic approach for obtaining optimal solution.The proposed Particle Swarm Optimization algorithm (PSO) is a swarm behavior based technique and is relatively easier to develop.The proposed work concentrates on designing PSO based controller to enhance the switching performance of inverter.

This paper presents an intelligent approach to reduce THD with the benefits of technologies based on particle swarm optimization (PSO) algorithm.This PSO based control algorithm is developed in MATLAB which advances the voltage and current output of the inverter and reduces the Total Harmonic Distortions within the IEEE standards.

System Block Diagram

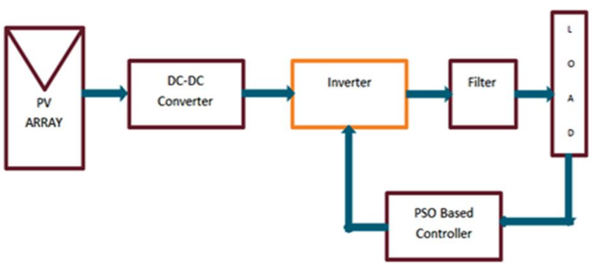

Figure 1. System Design

The basic design for the photovoltaic bridge inverter system to reduce THD and hence to improve power quality consists of the PV Array, DC-DC converter connected in a series, Inverter fed by PSO based controller, filter circuit, voltage and current sensors and the load. This model is known to have better accuracy when the irradiance varies slowly that allows for a more accurate prediction of PV system performance. The Peak Power tracker is a controlled DC/DC boost converter used by a photovoltaic power system. Output power from the solar panel is maximized by controlling the conversion ratio of the DC/DC converter to keep the solar panel operating at its MPP [1]. A DC-DC converter acts as an interface between the load and the module. The Boost mode of DC/DC converter is the most important type of switching regulator. The PSO based system uses an iterative approach to improve the switching of the inverter and hence constant current and voltage waveform over specified time interval.

Photovoltaic System

PV systems offer consumers the ability to produce electricity from a clean, quiet and reliable source. These systems consist of photovoltaic cells that convert light energy directly into electrical energy. PV systems offer many advantages including the following: They are safe, clean and quiet to operate, they are very reliable, they practically do not require maintenance, they operate profitably in remote areas and for many residential and commercial applications, they are flexible and can be extended at any time to meet your electrical needsand give us greater autonomy, independence from mains and safeguard in case of failure.

Modelling of Solar Cell

The single diode model for solar cell is a very proper choice. Firstly, because most of the times results have a high degree ofdata uniformity secondly, as they are not too complex, it is relatively simple to implement and analyze them [7-8]. The equivalent circuit consists of a photocurrent, a diode, a parallel resistor expressing a leakage current, and a series resistor describing an internal resistance to the current flow, as shown in figure 2.

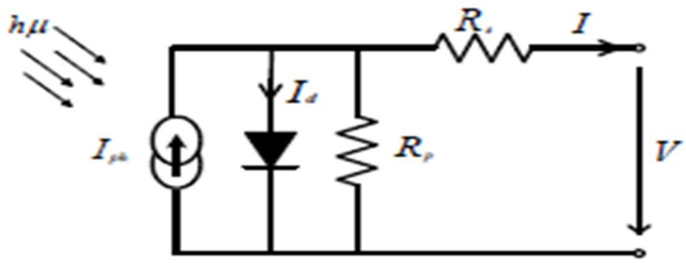

Figure 2.The Equivalent Circuit of Practical PV Cell

The characteristic equation I-V is given by:

$$I = Iph - Io\left[\exp\left(\frac{V+IRs}{AV}\right) - 1\right] - \frac{V+IRs}{Rp} \qquad (1)$$

Where, Iph: Photo generated current.
Io: Saturation current of diode.
Rs: Cell series resistance.
Rp: Cell parallel resistance.
A: Diode quality factor.
V: Thermal voltage.

Characteristics of Solar Cell

Several cells are connected in series forms a PV panel/module whereas several PV modules are linked together to form PV arrays. If panels are in series current through the cell is constant and voltage across it increases while on the other hand when panels are in parallel current through the cell increases and voltage remains constant. The I-V and P-V curve of a module is shown in the Figure 3.The output power of the panel increases as the module voltage increases, it reaches to a peak (called as peak power or maximum power point (MPP) in the module) and drops as the voltage approaches to the open circuit voltage. The peak power or MPP is defined at standard test condition (STC) of irradiation of 1000 W/m^2 and 25 degree C module temperature.

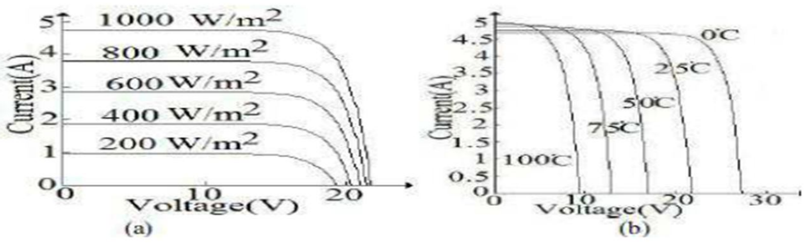

Figure 3. Waveforms showing the effect of (a) Radiation and (b) Temperature on I-V characteristics

DC-DC Converter Topology

They are power electronic circuits that converts a dc voltage to a different dc voltage level. Generally switched mode DC-DC converters are used i.e. the use of a switch or switches for the purpose of power conversion can be regarded as an SMPS. In order to perform power conversion with highest possible efficiency, converter switches can be implemented using power MOSFET. A boost converter (step-up converter) is a power converter with an output DC voltage greater than its input DC voltage[12]. It is a class of switching mode power supply (SMPS) containing at least two semi-conductors switches (a diode and a transistor) and at least one energy storage element. Filters made of capacitors (sometimes in combinationwith inductors) are normally added to the output of the converter to reduce output voltage ripple. A boost converter is sometimes called a step-up converter since it "step-up" the source voltage. Since power ($P = VI$) must be conserved, the output current is lower thanthe source current. The boost converter has the same components as the buck converter, but this converter produces an output voltage greater than source."Boost" converters starttheir voltage conversion with a current flowing through the inductor (switch is closed). Then they close the switch leaving the current no other path to go than through a diode (functions as one way valve). The current then wants to slow really fast and the only way it can do this is by increasing it's voltage at the end that connects to the diode and switch. If the voltage is high enough it opens the diode, and one through the diode, the current can't flow back. This is the very basic concept of boost converter.Analysis of the boost converter originates by making these assumptions:

- The circuit is operating in the steady state. The inductor current continuous (always positive).
- The capacitor is very large and the output voltage is held constant at voltage Vo.
- This restriction will be relaxed later to show the effects of finite capacitance.
- The switching period is T the switch is closed for time DT and open for time (1-D)T.
- The components are ideal.

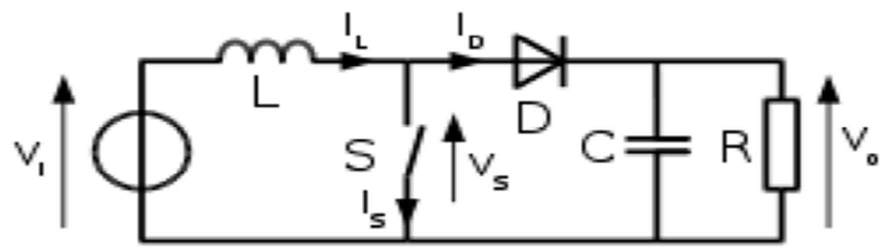

Figure 4. Boost Converter

Operating Principle

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current. When being charged it acts as a load and absorbs energy (somewhat like a resistor); when being discharged it acts as an energy source (somewhat like a battery). The voltage it produces during the discharge phase is related to the rate of change of current and not to the original charging voltage thus allowing different input and output voltages.

Particle Swarm Optimization

Particle swarm optimization (PSO) is a heuristic global optimization method put forward originally by Kennedy and Eberhart in 1995 (Kennedy J, Eberhart R, 1995). It is developed from swarm intelligence and is based on the research of bird and fish flock movement behavior. As far as particle swam optimization algorithm is concerned solution swarm is compared to the bird swarm, the birds moving from one place to another is equal to the development of the solution swarm, good information is equal to the most optimist solution and the food resource is equal to the most optimist solution during the whole course. The most optimist solution can be worked out in particle swarm optimization algorithm by the co-operation of each individual.The movement of particles impact by two variables, the P_{best} that used to store the best position of each particle as an individual best position and the G_{best} that found by comparing individual positions of the particle swarm and store it as best position of the swarm.[1]The particle swarm uses this process to move towards the best position and continuously it revise its direction and velocity by this way each particle quickly converge to an optimal or close to a global optimum. The standard PSO method can be defined by the following equations;

$$v_i(k+1) = wv_i(k+1) + c_1r_1(P_{best} - x_i(k)) + c_2r_2(g_{best} - x_i(k)) \quad (2)$$

$$x_i(k+1) = x_i(k) + v_i(k+1) \quad (3)$$

$i = 1,2,\_\_\_\_\_,N.$

where, $x_i$and v_i are the velocity and position of particle i, k represents the iteration number; w is the inertia weight; r_1,r_2 are random variables and their values are uniformly distributed between [0,1]; c_1 , $c_2$represents the cognitive and social coefficient respectively. $P_{besti}$is the individual best position of particle i, and g_{best} is the swarm best position of all the particles.

$$p_{besti} = x_{ik} \quad (4)$$

$$f(X_{ik}) > f(P_{besti}) \quad (5)$$

Where,$f$represents the objective function that should be maximized.

`In standard PSO method the converge criterion are either locating to optimal solution or reaching the maximum number of iterations. However in PV systems the fitness value is not constant as it changes with the weather condition and load. Therefore, the PSO must be reinitialized and search again for a new to search the new MPP when the PV module output changed for this application the proposed PSO algorithm is reinitialized whenever the following functions are satisfied;

$$\frac{p_i(k+1) - p_i(k)}{p_i(k)} > \Delta p \quad (6)$$

This algorithm can be used to work out the complex optimist problems. Due to its many advantages including its simplicity and easy implementation the algorithm can be used widely in the fields such as function optimization, the model classification etc.

Particle Swarm optimization Application to Improve Inverter Switching

Particle Swarm Optimization is an optimization method that tries to improve the particle solution with respect to given measure of quality. These particles moves around the search space according to position and velocity. Each particle is influenced by its own best position and velocity.InPSO, particles are randomly initialized at different positions followed by position update based on new velocity, previous best positions and distance to P_{best} to G_{best}. Search process is continued till optimum value is obtained. As the particles, approach to MPP they get closer to G_{best} position. Correspondingly, P_{best} factor and G_{best} factor in velocity term moves towards zero [2]Eventually, zero velocity is obtained and duty cycle remains almost unchanged under this condition PV system reaches MPP. PSO is useful to enhance the switching of bridge inverter in partial shading conditions. PSO can be used in conjunction with PI controller in which error voltage generated is compared with PI controller which helps to get constant output waveforms of current and voltage at the output of the inverter and hence ultimately improve the power quality by reducing THD within acceptable standards defined by IEEE. PSO search starts with random initial guess and it is possible to explore the search region with continuous updation of duty cycle which helps in reduction in steady state oscillations around MPP.Main feature is that absence of steady state oscillations at MPP and ability to improve inverter switching for extreme environmental conditions. Drawback is its initial duty cycle selection. If duty cycle values are not within well-defined limits and algorithm takes more no. of iterations to obtain the global maximum. This causes reduction in power output. Therefore it is necessary to specify limits of initial duty cycle.

Algorithm for PSO Implementation

Step 1 -Set the number of particles and searching parameters along with the limit for position and velocity

Step 2 - Randomly initialize Position and velocity of each particle.

Step 3 - Compute the fitness value of each particle.

Step 4 - The particle having the best fitness value is set as G_{best} (Global Best).

Step 5- Update the position and velocity of each particle with respect to the G_{best}.

Step 6- Repeat Step 3 & 4 till the optimum solution is reached.

Step 7- G_{best} at the end of the last iteration gives the optimized value.
Step 8- Compute the Duty-cycle using the given formula.D= $\frac{1}{1+\sqrt{\frac{Rin}{Rout}}}$.

MATLAB/Simulation

The algorithm and simulation circuits are developedinMATLABsoftware. The efficiency is tested using different number of swarms and iterations. PSO traps the global optimal value when radiation levelis different due to environmental conditions.
Implementation of MPPT based photovoltaic converter without using PSO and using PSO is carried out in MATLAB software. It consists of PV array, a DC/DC boost converter and Inverterfed PSO based control algorithm via PI controller and a RL load.PV array generates PV voltage V_{PV}which acts as a controlled voltage source for boost converter. The DC/DC boost converter consists of MOSFET switch, an inductor L of 0.1mH, Capacitor connected across PV array to reduce fluctuations in generated PV voltage. The switch was controlled by a Pulse width modulation (PWM) technique with switching frequency of 20kHz.

Implementation of MPPT based photovoltaic converter without PSO

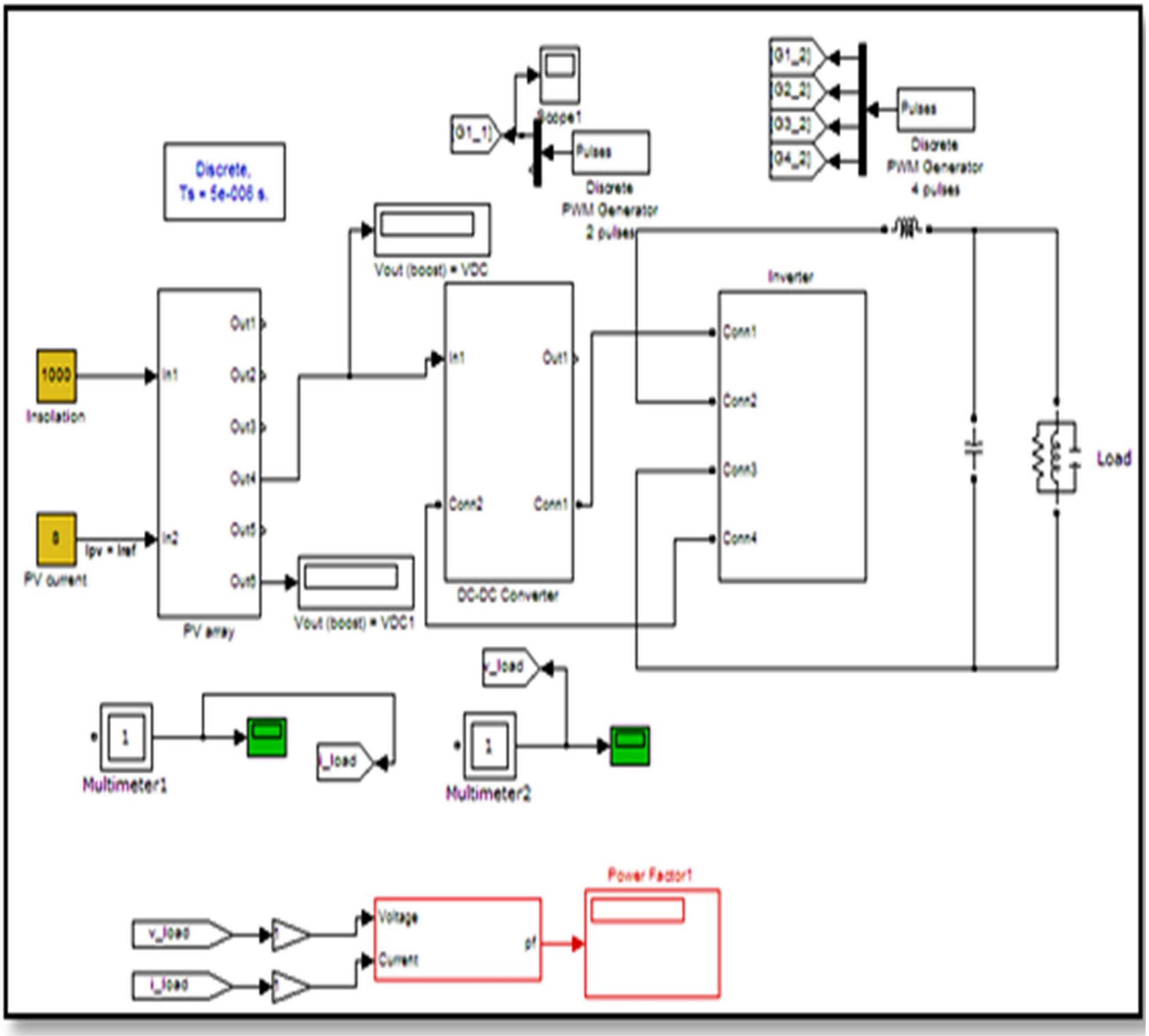

Figure 5. MATLAB/Simulation for Implementation of PV based converter system without PSO

Implementation of MPPT based photovoltaic converter with PSO

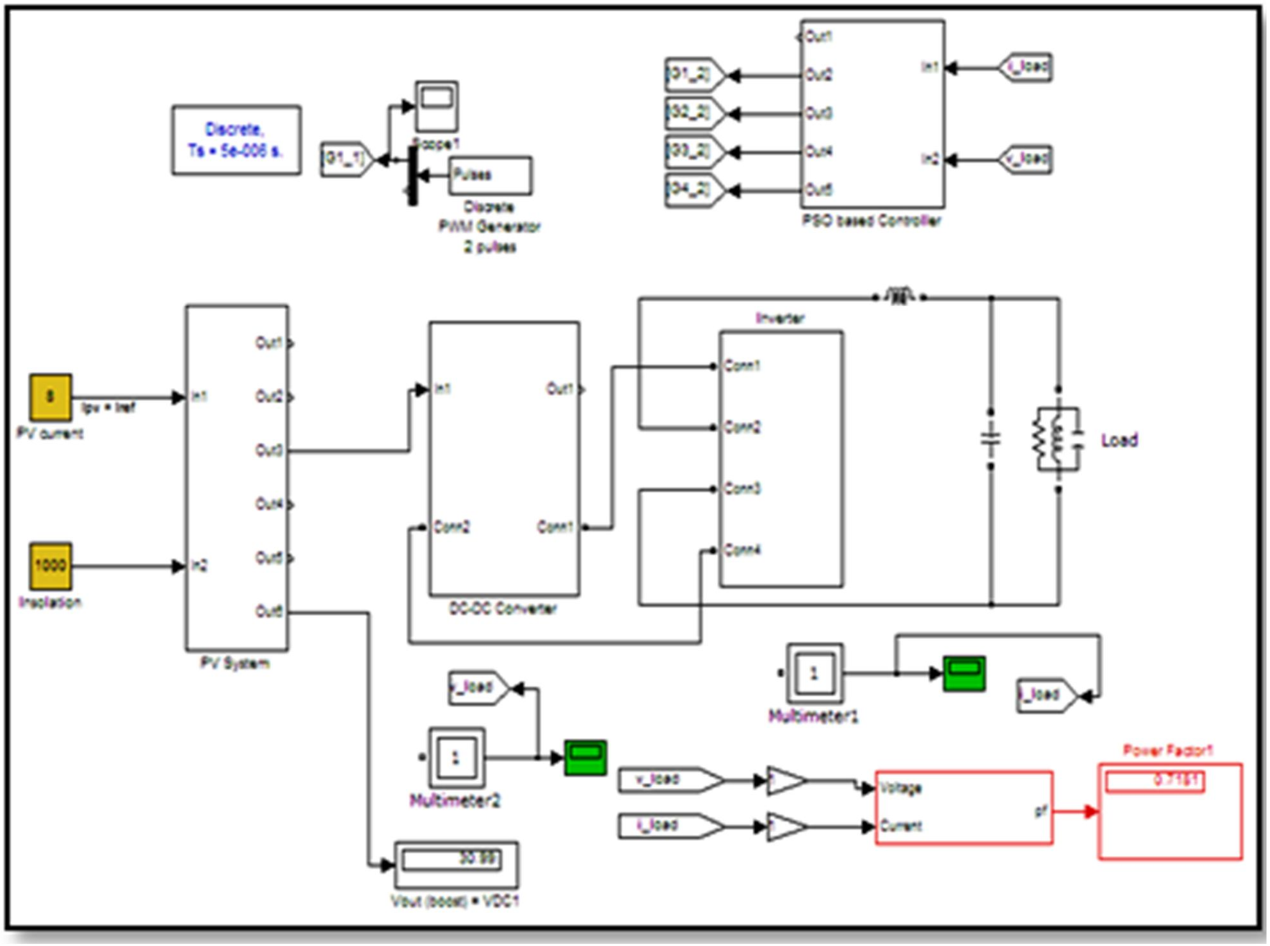

Figure 6. MATLAB/Simulation for Implementation of PV based converter system using PSO

Results and Discussion

Fig.7 and Fig.8shows the respective current and voltage waveform without using PSO while Fig.9 and Fig.10 shows the current and voltage waveform using PSO. From this it is concluded that current and voltage waveform shows somewhat peaks during the specified time interval i.e. output power varies do not remains constant. Hence they are responsible for complexities in the load fed by this model. On the other hand, it is observed that if we model and simulate the photovoltaic system with PSO control technique, resultant current and voltage waveform obtained shows steady state value for both current and voltage ultimately output power remains constant over the specified time interval.

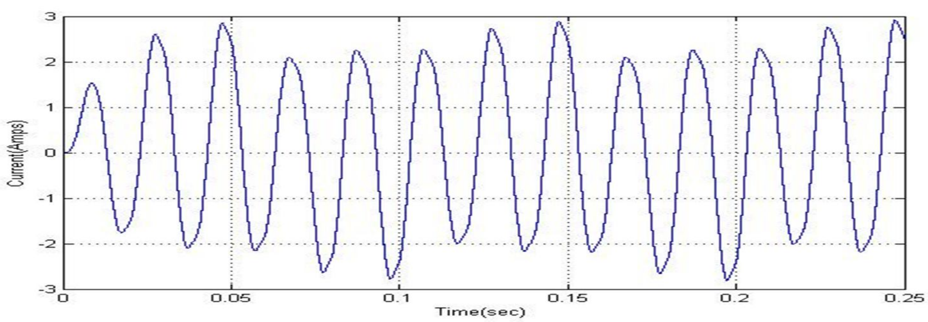

Figure 7.Current Waveform without using PSO

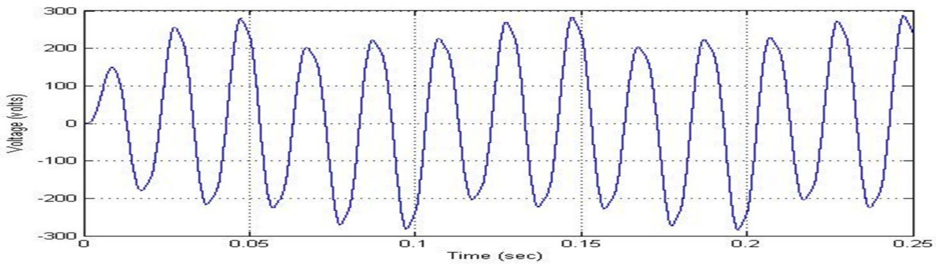

Figure 8.Voltage Waveform without using PSO

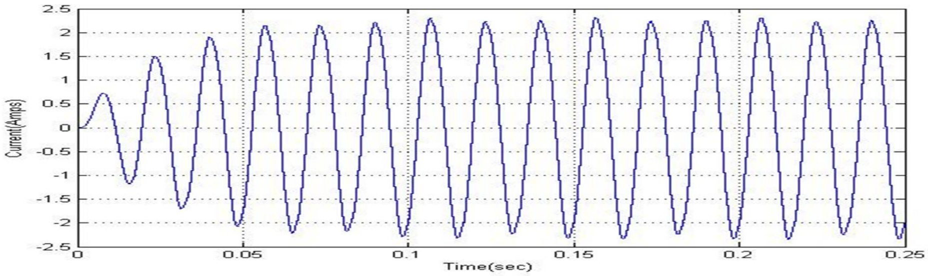

Figure 9.Current Waveform using PSO

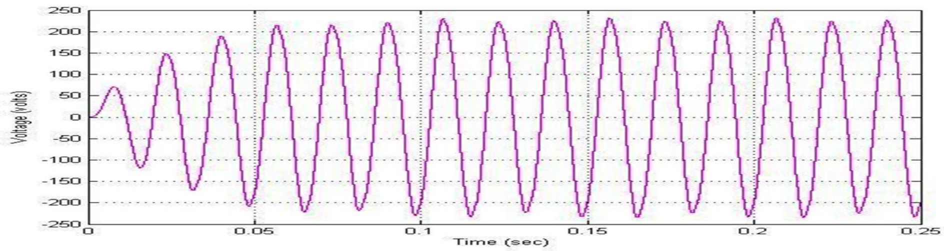

Figure 10.Voltage Waveform using PSO

Alongwith waveform analysis FFT analysis is also done. From Fig.11 results obtained are such that we get the Total Harmonic Distortions are 21.80% for PV system without using PSO while from Fig.12, it is clearly observed that Total Harmonic Distortions are within IEEE standards 2.80 % only.

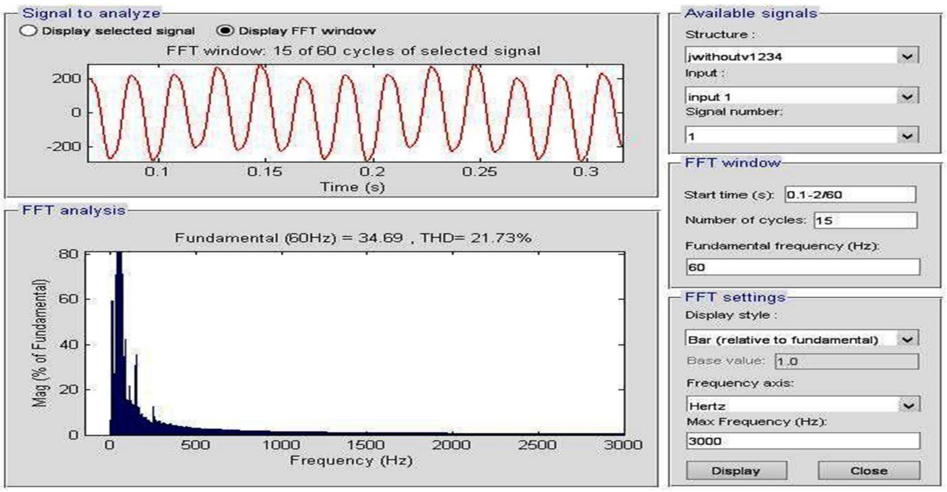

Figure 11.FFT Analysis without using PSO

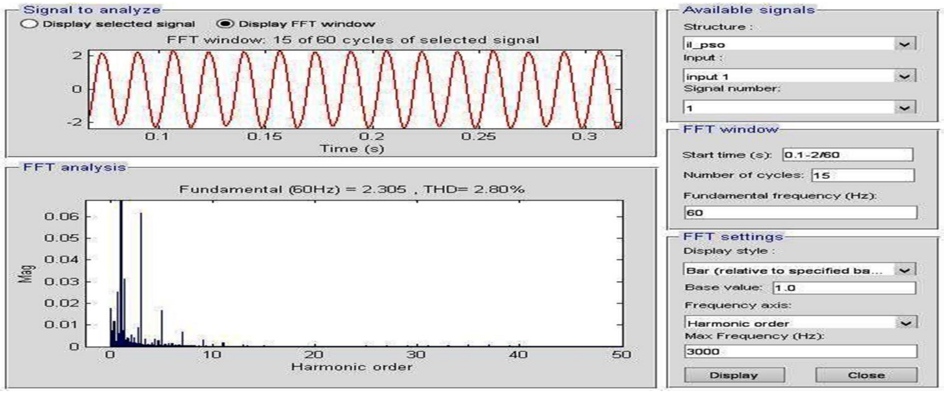

Figure 12.FFT Analysis using PSO

Conclusion

From the proposed model it is concluded that this PV system is used to reduce THD and hence eventually to improve the power quality. It consists of simple digital controller called as PSO based controller capable of improving the inverter switching which help the overall system to satisfy anytype of load demand over a specified time period without failure.Addition to this it also reduces the THD. If comparison of inverter output with and without particle swarm optimization is carried out then the results show that particle swarm optimization technique gives better results. Hence PSO technique can be employed forphotovoltaic system to reduce THD within acceptable limits.Finally, this improves the reliability of the system. This system is not only able to improve switching of the inverter under extreme environmental conditions but also reduces steady state oscillations at MPP which results in stability of the system. However, keeping low THD values on a system ensures us the proper operation of equipment and a longer equipment life span.

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