International Journal for Modern Trends in Science and Technology
Volume: 03, Issue No: 05, May 2017
ISSN: 2455-3778
http://www.ijmtst.com

Design and Analysis of Boost Converter Based PSO Method for MPPT Extraction in Photovoltaic System

T.Pavithra

Department of EEE, Mount Zion College of Engineering and Technology, Pudukkottai, Tamilnadu, India.

To Cite this Article
T.Pavithra, "Design and Analysis of Boost Converter Based PSO Method for MPPT Extraction in Photovoltaic System", *International Journal for Modern Trends in Science and Technology*, Vol. 03, Issue 05, May 2017, pp. 114-122.

ABSTRACT

In this paper, Developments in global policies have seen the push for greater use of renewable energy sources. Particle Swarm Optimization based Maximum Power Point Tracking (MPPT) algorithm for solar panel is proposed. The solar panel is modeled and analyzed in MATLAB/SIMULINK. The Solar panel can produce maximum power at a particular operating point called Maximum Power Point (MPP). To produce maximum power and to get maximum efficiency, the entire photovoltaic panel must operate at this particular point. This proposed method has the ability to track the MPP for the extreme environmental condition, e.g., large fluctuations of insolation and partial shading condition. The algorithm is simple and can be computed very rapidly. To optimize the utilization of large arrays of photovoltaic modules, maximum power point tracker (MPPT) is normally employed in conjunction with the power converter (dc–dc converter and/or inverter). However, due to the varying environmental condition, namely temperature and solar insolation, the power–voltage characteristic curve exhibits a maximum power point (MPP) that varies nonlinearly with these conditions—thus posing a challenge for the tracking algorithm.

KEYWORDS *— Photovoltaic, Particle swarm optimization, Open circuit voltage(VOC), Short circuit current(ISC).*

I. INTRODUCTION

Energy is a universal and fundamental quantity that describes fundamental physical interactions [1]. Energy is usually considered to be localized, that is to say distributed in space and time, either in a body or in a force field. It can be redistributed, subject to the principle of causality [2]. There are many forms of energy [3]. They include the kinetic energy of a moving object, the radiant energy carried by light and other electromagnetic radiation, the potential energy stored by virtue of the position of an object in a force field such as a gravitational, electric or magnetic field, and the microscopic kinetic and potential energies of the disordered motions of the particles making up matter [4]. Renewable energy resources exist over wide geographical areas, in contrast to other energy sources, which are concentrated in a limited number of countries. Rapid deployment of renewable energy and energy efficiency is resulting in significant energy security, climate change mitigation, and economic benefits [5]. A non-renewable resource (also called a finite resource) is a resource that does not renew itself at a sufficient rate for sustainable economic extraction in meaningful human time-frames [6].

Photovoltaic's (PV) is a method of generating electrical power by converting sunlight into direct current electricity using semiconducting materials that exhibit the photovoltaic effect. A photovoltaic system employs solar panels composed of a number of solar cells to supply usable solar power. Power generation from solar PV has long been seen as a clean sustainable energy technology which draws upon the planet's most plentiful and widely distributed renewable energy source – the sun. The direct conversion of sunlight to electricity occurs without any moving parts or environmental emissions during operation. It is well proven, as photovoltaic systems have now been used for fifty years in specialized applications, and grid-connected PV systems have been in use for over twenty years.

With current technology, photo voltaics recoup the energy needed to manufacture them in 1.5 (in Southern Europe) to 2.5 years (in Northern Europe) [7,8]. It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Solar cells are the building blocks of photovoltaic modules, otherwise known as solar panels [9]. In contrast, a solar thermal collector supplies heat by absorbing sunlight, for the purpose of either direct heating or indirect electrical power generation from heat. A "photo electrolytic cell" (photo electrochemical cell), on the other hand, refers either to a type of photovoltaic cell (like that developed by Edmond Becquerel and modern dye-sensitized solar cells), or to a device that splits water directly into hydrogen and oxygen using only solar illumination [10].

A solar cell converts the radiant energy of sunlight into electrical energy that can then be used to light a bulb or power a computer. The generic name for a device which converts energy from one form to another is a transducer [11]. Conversions to thermal energy (thus raising the temperature) from other forms of energy, may occur with essentially 100% efficiency (many types of friction do this) [12]. Conversion among non-thermal forms of energy may occur with fairly high efficiency, though there is always some energy dissipated thermally due to friction and similar processes. Sometimes the efficiency is close to 100%, such as when potential energy is converted to kinetic energy as an object falls in vacuum, or when an object orbits nearer or farther from another object, in space [13]. This letter therefore proposes a hybrid power control concept with the objective to improve the thermal performance and increase the utilization factor of PV inverters. It has the following Features:

1. A constant power generation (CPG) control mode is activated by using a direct power control when the dc power from PV panels reaches to a specific limit, the value of which Depends on the trade-offs of thermal loading (therefore lifetime Of switching devices, PV inverter utilization factor, and annual Energy yield under yearly mission profiles (i.e., solar irradiance And ambient temperature). It should be noted that the selection of this power limit is different from those in and as discussed above.
2. The RPPT mode is active when the dc power is below the specific power level. The proposed RPPT-CPG control Concept allows a reduction of required power ratings of PV Inverters and also a reduction of junction temperature peaks and Variations on the power devices (i.e., an extended lifetime) Meanwhile, it could contribute to the system level Power management to some extent, due to its role in smoothing and limiting the power fed into the grid [14]. However, the following steps describes characteristics of MPPT using GA & PSO methods.

II. PV SYSTEM MODELLING

2.1 Photovoltaic cell

A photovoltaic cell or photoelectric cell is a semiconductor device that converts light to electrical energy by photovoltaic effect. If the energy of photon of light is greater than the band gap then the electron is emitted and the flow of electrons creates current. However a photovoltaic cell is different from a photodiode. In a photodiode light falls on n-channel of the semiconductor junction and gets converted into current or voltage signal but a photovoltaic cell is always forward biased.

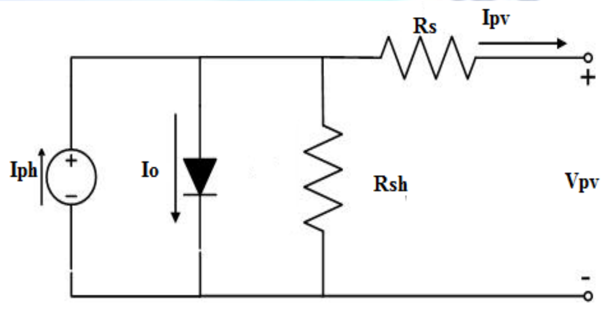

Fig.1. Solar cell equivalent electrical circuit.

2.2 PV module

Usually a number of PV modules are arranged in series and parallel to meet the energy requirements. PV modules of different sizes are commercially available (generally sized from 60W to 170W). For example, a typical small scale desalination plant requires a few thousand watts of power. A PV array consists of several photovoltaic cells in series and parallel connections. Series connections are responsible for increasing the voltage of the module whereas the parallel connection is responsible for increasing the current in the array the most important component that affects the accuracy of the simulation is the PV cell model. Modeling of PV cell involves the estimation of the I-V and P-V characteristics curves to emulate the real cell under various environmental conditions. An ideal solar cell is modeled by a current source in parallel with a diode.

2.3 PV modelling

Typically a solar cell can be modeled by a current source and an inverted diode connected in parallel to it. It has its own series and parallel resistance. Series resistance is due to hindrance in the path of flow of electrons from n to p junction and parallel resistance is due to the leakage current. When irradiance hits the surface of solar PV cell, an electrical field is generated inside the cell. As seen in Fig.3 this process separates positive and negative charge carriers in an absorbing material (joining p-type and n-type). In the presence of an electric field, these charges can produce a current that can be used in an external circuit. This generated current depends on the intensity of the incident radiation. The higher the level of light intensity, the more electrons can be unleashed from the surface, the more current is generated.

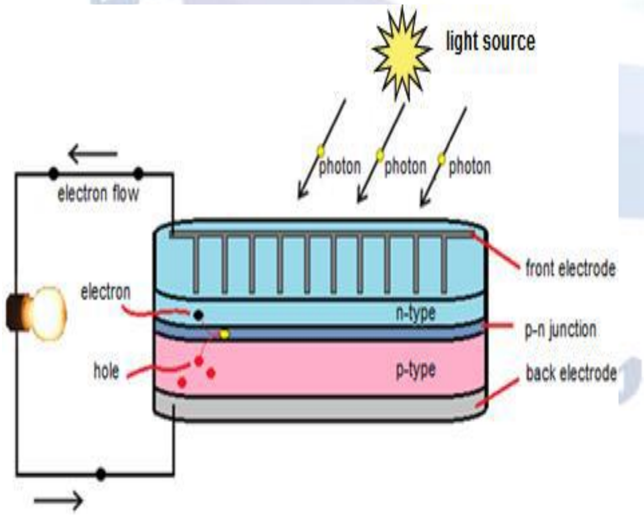

Fig.2. Schematic cross-section of a typical solar cell.

.

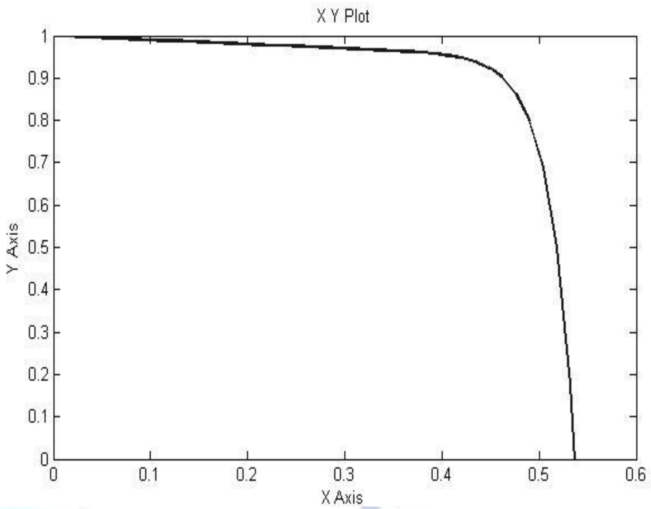

Fig.3. I-V curve of PV cell.

A bridgeless boost converter is widely used in advantages of reduced input current ripple, but its output voltage should be higher than the peak voltage of the input voltage relatively low output voltage of PFC converters is required in many applications such as low-voltage switched-mode power supplies. PFC buck converters are more suitable for these applications due to their low output voltage. A bridgeless buck converter was proposed in . Like conventional PFC buck converters, the output voltage of the converter proposed in and is lower than the peak value of the input voltage.

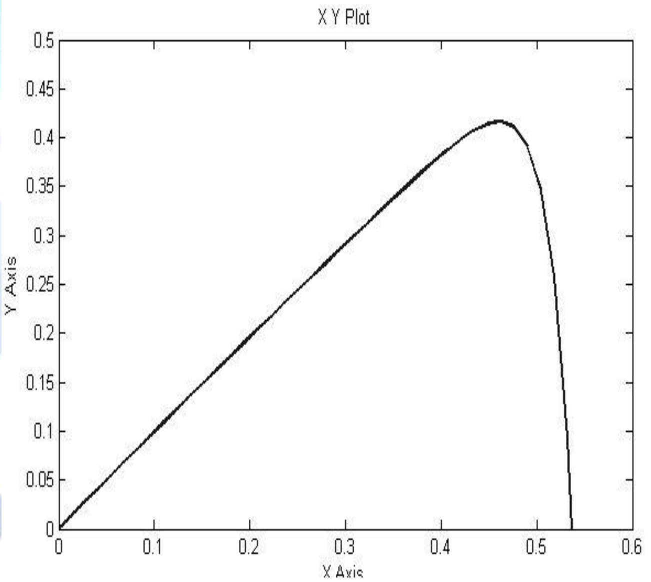

Fig.4. P-V curve of PV cell.

III. AN OVERVIEW OF MAXIMUM POWER POINT TRACKING

A typical solar panel converts only 30 to 40 percent of the incident solar irradiation into electrical energy. Maximum power point tracking technique is used to improve the efficiency of the solar panel. According to Maximum Power Transfer theorem, the power output of a circuit is maximum when the venin impedance of the circuit (source impedance) matches with the load impedance. Hence our problem of tracking the maximum power point reduces to an impedance matching problem. In the source side we are using a boost convertor connected to a solar pan el in order to enhance the output voltage so that it can be used for different applications like motor load. By changing the duty cycle of the boost converter appropriately we can match the source impedance with that of the load impedance.

VI. DIFFERENT MPPT CONTROL USING PSO TECHNIQUES

There are different techniques used to track the maximum power point. Few of the most popular techniques are:

1) Genetic algorithm
2) Incremental Conductance method
3) Fractional short circuit current
4) Fractional open circuit voltage
5) Neural networks
6) Fuzzy logic
7) Perturb and observe (hill climbing method)

4.1 PERTURB & OBSERVE

Perturb & Observe (P&O) is the simplest method. In this we use only one sensor, that is the voltage sensor, to sense the PV array voltage and so the cost of implementation is less and hence easy to implement. The time complexity of this algorithm is very less but on reaching very close to the RPP it doesn't stop at the RPP and keeps on perturbing on both the directions. When this happens the algorithm has reached very close to the RPP and we can set an appropriate error limit or can use a wait function which ends up increasing the time complexity of the algorithm. However the method does not take account of the rapid change of irradiation level (due to which MPPT CONTROL USING PSO changes) and considers it as a change in RPP due to perturbation and ends up calculating the wrong RPP. To avoid this problem we can use incremental conductance method.

4.2 INCREMENTAL CONDUCTANCE

Incremental conductance method uses two voltage and current sensors to sense the output voltage and current of the PV array. At RPP the slope of the PV curve is 0.

$$(dP/dV)_{RPP}=d(VI)/dV$$

$$0=I+VdI/dV_{RPP}$$

$$dI/dV_{RPP} = -I/V$$

The left hand side is the instantaneous conductance of the solar panel. When this instantaneous conductance equals the conductance of the solar then RPP is reached. Here we are sensing both the voltage and current simultaneously. Hence the error due to change in irradiance is eliminated. However the complexity and the cost of implementation increase. As we go down the list of algorithms the complexity and the cost of implementation goes on increasing which may be suitable for a highly complicated system. This is the reason that Perturb and Observe and Incremental Conductance method are the most widely used algorithms. Owing to its simplicity of implementation we have chosen the Perturb & Observe algorithm for our study among the two.

4.3 FRACTIONAL OPEN CIRCUIT VOLTAGE

The near linear relationship between VRPP and VOC of the PV array, under varying irradiance and temperature levels, has given rise to the fractional VOC method.

$$V_{RPP} = k1\, V_{oc}$$

Where, k1 is a constant of proportionality. Since k1 is dependent on the characteristics of the PV array being used, it usually has to be computed beforehand by empirically determining VRPP and VOC for the specific PV array at different irradiance and temperature levels. The factor k1 has been reported to be between 0.71 and 0.78. Once k1 is known, VRPP can be computed with VOC measured periodically by momentarily shutting down the power converter. However, this incurs some disadvantages, including temporary loss of power.

4.4 FRACTIONAL SHORT CIRCUIT CURRENT

Fractional ISC results from the fact that, under varying atmospheric conditions, IRPP is approximately linearly related to the ISC of the PV array.

$$I_{RPP} = K2\, I_{sc}$$

Where, k2 is a proportionality constant. Just like in the fractional VOC technique, k2 has to be determined according to the PV array in use. The constant k2 is generally found to be between 0.78 and 0.92. Measuring ISC during operation is problematic. An additional switch usually has to be added to the power converter to periodically short the PV array so that ISC can be measured using a current sensor.

4.5 FUZZY LOGIC CONTROL

Microcontrollers have made using fuzzy logic control popular for DMPPT CONTROL USING PSO over last decade. Fuzzy logic controllers have the advantages of working with imprecise inputs, not needing an accurate mathematical model, and handling nonlinearity.

4.6 NEURAL NETWORK

Another technique of implementing MPPT CONTROL USING PSO which are also well adapted for microcontrollers is neural networks. Neural networks commonly have three layers: input, hidden, and output layers. The number nodes in each layer vary and are user-dependent. The input variables can be PV array parameters like VOC and ISC, atmospheric data like irradiance and temperature, or any combination of these. The output is usually one or several reference signals like a duty cycle signal used to drive the power converter to operate at or close to the RPP.

TABLE 1

Characteristics of different MPPT control using PSO technique

MPPT technique	Convergence speed	Implementation complexity	Periodic tuning	Sensed parameters
Perturb & observe	Varies	Low	No	Voltage
Incremental conductance	Varies	Medium	No	Voltage, current
Fractional V_{oc}	Medium	Low	Yes	Voltage
Fractional I_{sc}	Medium	Medium	Yes	Current
Fuzzy logic control	Fast	High	Yes	Varies
Neural network	Fast	High	Yes	Varies

V. MPPT CONTROL USING PSO

It is a technique that grid connected inverters, solar battery chargers and similar devices use to get the maximum possible power from one or more photovoltaic devices, typically solar panels, though optical power transmission systems can benefit from similar technology.

- Solar inverters convert the DC power to AC power and may incorporate MPPT CONTROL USING PSO: such inverters sample the output power (I-V curve) from the solar cell and apply the proper resistance (load) so as to obtain maximum power.

- RPP (Maximum power point) is the product of the RPP voltage (V RPP) and RPP current (I RPP): some solar panels have a higher maximum power than others.

Three different relay configurations can be obtained: 1) when the top relay is closed; 2) when the bottom relay is closed; and 3) when both relays are closed. The requested active and reactive power generation by the inverter to be transferred to the grid will be determined by the network supervisory block. This will be achieved based on the available PV generation, the grid data, and the current battery variables. The MPPT control using PSO block determines the requested dc voltage across the PV to achieve the MPPT control using PSO condition. This voltage can be determined by using another control loop, with slower dynamics, using the measurement of the available PV power. By using a proportional and integral (PID) controller and decoupling control structure, the inverter requested voltage vector can be calculated. In the proposed system, to transfer a specified amount of power to the grid, the battery will be charged using surplus energy from the PV or will be discharged to support the PV when the available energy cannot support the requested power. The selection of the short vectors will determine which capacitor is to be charged or discharged. To determine which short vector must be selected, the relative errors of capacitor voltages and their effectiveness on the control system behavior are important. A decision function "F," as given in can be defined based on this idea

F = G1eV c1 − G2eV c2

where G1 and G2 are the gains associated with each of the relative errors of the capacitor voltages. G1 and G2 are used to determine which relative error of the capacitor voltages is more important and consequently allows better control of the chosen capacitor voltage.

For example, for an application that requires the balancing of the capacitor voltages as in traditional three-level inverters, G1 and G2 must have the same value with equal reference voltage values, but in the proposed application where the capacitor voltages can be unbalanced, G1 and G2 are different and their values are completely dependent on their definitions of desired capacitor voltages.

The PV can be controlled to the MPPT control using PSO, and C1 voltage can be controlled to allow charging and discharging of the battery. In each time step, the sign of F is used to determine which short vectors are to be chosen. Similarly, when F is negative, the short vectors need to be selected that can charge C2 or discharge C1 in that particular time step. The same control system is applicable for configuration 2) by changing the generated reference voltages for the capacitors. Configuration 3) represents two storage systems connected to grid without any PV contribution, such as at night when the PV is not producing any output power.

- The effect of a step change in the requested active and reactive power to be transferred to the grid when the solar irradiance is assumed to be constant.
- The effect of a step change of the solar irradiation when the requested active and reactive power to be transmitted to the grid is assumed to be constant.

V. PARTICLE SWARM OPTIMIZATION

In this section the problem involved in solving the MPPT control using PSO technique is discussed. The PSO method is a simple and effective meta-heuristic approach that can be applied to a multivariable function optimization having many local optimal points. The PSO uses several cooperative agents and each agent shares the information attained by each individual during the search process. Here PSO initializes the variables randomly in a given space. The number of decision variables determines the dimension of space. Each optimization problem is to search the solution space of a particle, each particle runs at a certain speed in the search space, the speed of particles is in accordance with its own flight experience and flight experience of other examples with dynamic adjustments. In the optimization space, each particle has decided to adapt the objective function value, and recorded their own best position Pi found so far, and the entire group of all particles found in the best position Pg.

5.1 STEPS INVOLVED IN OPTIMIZATION

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 Gbest (Global Best).
Step 5- Update the position and velocity of each particle with respect to the Gbest.
Step 6- Repeat Step 3 & 4 till the optimum solution is reached.
Step 7- Gbest at the end of the last iteration gives the optimized value.
Step 8- Compute the Duty-cycle using the given formula.

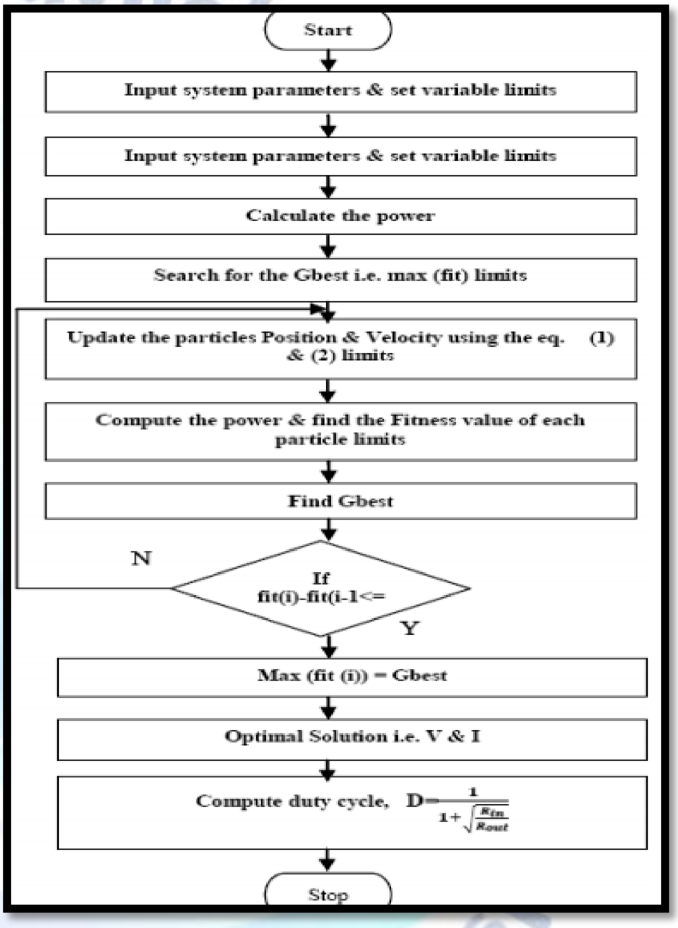

Fig.5. Flowchart for PSO implementation.

5.2 ALGORITHM

As stated before, PSO simulates the behaviors of bird flocking. Suppose the following scenario: a group of birds are randomly searching food in an area. There is only one piece of food in the area being searched. All the birds do not know where the food is. So what's the best strategy to find the food? The effective one is to follow the bird which is nearest to the food.

PSO learned from the scenario and used it to solve the optimization problems. In PSO, each single solution is a "bird" in the search space. We call it "particle". All of particles have fitness values which are evaluated by the fitness function to be optimized, and have velocities which direct the flying of the particles. The particles fly through the problem space by following the current optimum particles.

PSO is initialized with a group of random particles (solutions) and then searches for optima by updating generations. In every iteration, each particle is updated by following two "best" values. The first one is the best solution (fitness) it has achieved so far. (The fitness value is also stored.) This value is called **pbest.**

Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the population. This best value is a global best and called **gbest**. When a particle takes part of the population as its topological neighbours, the best value is a local best and is called **lbest**.

After finding the two best values, the particle updates its velocity and positions with following equation (a) and (b).

v[] = v[] + c1 * rand() * (pbest[] - present[]) + c2 * rand() * (gbest[] - present[]) (a)

present[] = present[] + v[] (b)

v [] is the particle velocity, present[] is the current particle (solution). pbest[] and gbest[] are defined as stated before. Rand () is a random number between (0,1). c1, c2 are learning factors. Usually c1 = c2 = 2. The pseudo code of the procedure is as follows, For each particle

```
Initialize particle END Do For each particle
      Calculate fitness value
      If the fitness value is better than the best
fitness value (pBest) in history
         set current value as the new pBest
   End
   Choose the particle with the best fitness value of
all the particles as the gBest
   For each particle
      Calculate particle velocity according equation
(a)
      Update particle position according equation
(b)
   End
```

While maximum iterations or minimum error criteria is not attained Particles' velocities on each dimension are clamped to a maximum velocity Vmax. If the sum of accelerations would cause the velocity on that dimension to exceed Vmax, which is a parameter specified by the user. Then the velocity on that dimension is limited to Vmax.

5.3 COMPARISONS BETWEEN GENETIC ALGORITHM AND PSO

Most of evolutionary techniques have the following procedure

1) Random generation of an initial population.
2) Reckoning of a fitness value for each subject. It will directly depend on the distance to the optimum.
3) Reproduction of the population based on fitness values.
4) If requirements are met, then stop. Otherwise go back to 2.

From the procedure, we can learn that PSO shares many common points with GA. Both algorithms start with a group of a randomly generated population, both have fitness values to evaluate the population. Both update the population and search for the optimum with random techniques. Both systems do not guarantee success.

However, PSO does not have genetic operators like crossover and mutation. Particles update themselves with the internal velocity. They also have memory, which is important to the algorithm.

Compared with genetic algorithms (GAs), the information sharing mechanism in PSO is significantly different. In GAs, chromosomes share information with each other. So the whole population moves like a one group towards an optimal area. In PSO, only gBest (or lBest) gives out the information to others. It is a one -way information sharing mechanism. The evolution only looks for the best solution. Compared with GA, all the particles tend to converge to the best solution quickly even in the local version in most cases.

VI. SIMULATION

The MATLAB system consists of five main parts:

*1) The MATLAB language***.** This is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It allows both “programming in the small” to rapidly create quick and dirty throw-away programs, and “programming in the large” to create complete large and complex application programs.

2) The MATLAB working environment. This is the set of tools and facilities that you work with as the MATLAB user or programmer. It includes facilities for managing the variables in your workspace and importing and exporting data. It also includes tools for developing, managing, debugging, and profiling M-files, MATLAB's applications.

3) Handle Graphics. This is the MATLAB graphics system. It includes high-level commands for two-dimensional and three-dimensional data visualization, image processing, animation, and presentation graphics. It also includes low-level commands that allow you to fully customize the appearance of graphics as well as to build complete Graphical User Interfaces on your MATLAB applications.

4) The MATLAB mathematical function library: This is a vast collection of computational algorithms ranging from elementary functions like sum, sine, cosine, and complex arithmetic, to more sophisticated functions like matrix inverse, matrix eigen values, Bessel functions, and fast Fourier transforms.

5) The MATLAB Application Program Interface: This is a library that allows you to write C and FORTRAN programs that interact with MATLAB. It includes facilities for calling routines from MATLAB, calling MATLAB as a computational engine, and for reading and writing MAT-files.

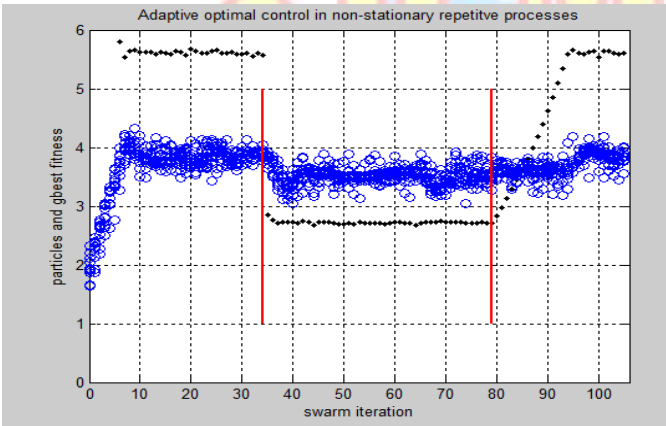

Fig.6. Adaptive optimal control in non-stationary repetitive process.

From above fig.6. adaptive optimal control in non-stationary repetitive process can able to find gbest values by assuming number of swarm is 1, diversity factor is 0.01, evapouration rate is 1.05, velocity clamping is 0.5. Based on this process plotting curve between swarm iteration and particle and fitness function, therefore we see the swarm iteration becomes constant from (34 to 79) iteration of 6 gbest values.

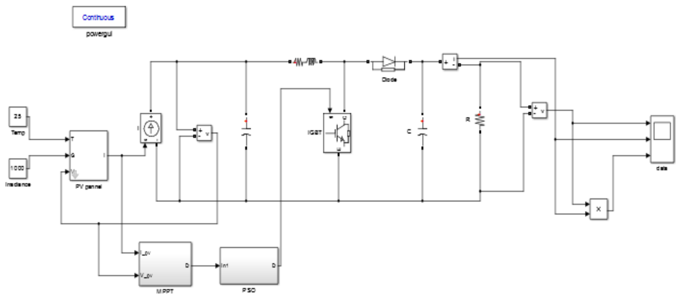

Fig.7. Simulink model of system.

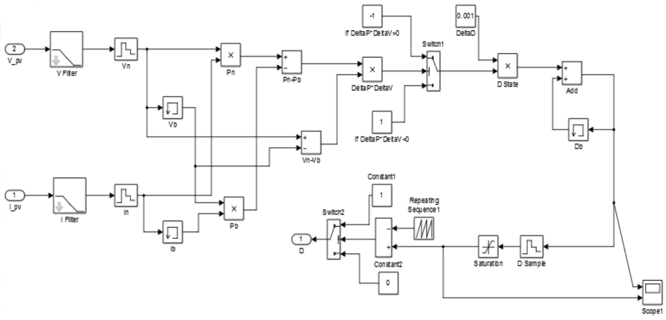

Fig.8. MPPT controller design.

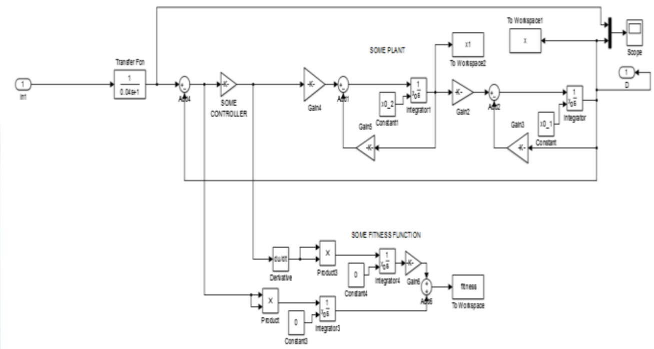

Fig.9. Implementation of PSO algorithm.

Po = (*MPPT on when PPV(t) < Plimit)*

Po = (PSO *on when PPV(t) > Plimit)*

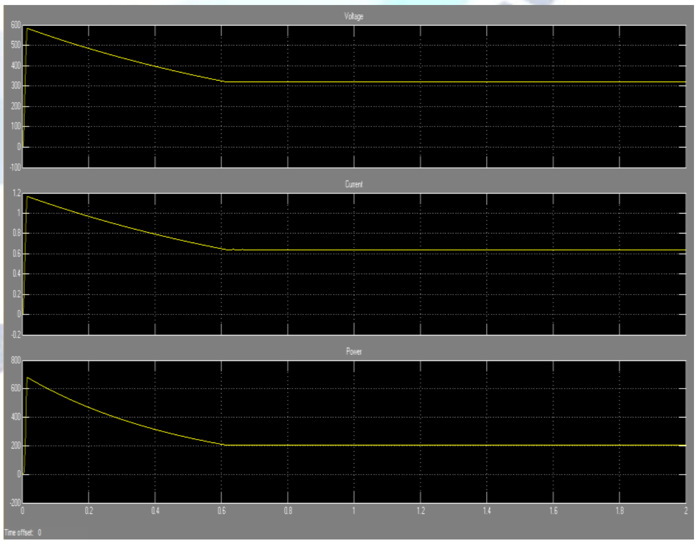

Fig.10 Output power of inverter in boost mode.

In this curve boost converter input voltage of about 590V followed by input current rated as 1.2A, hence output power of 708W boost mode get constant flow from 0.6 to 2.

VII. CONCLUSION

A hybrid MPPT-PSO control concept is proposed for grid connected PV inverters by considering the long-term mission profiles and the system level power management requirements. A fore mentioned advantage are compromised with the energy loss due to the proposed control, allowing the optimal selection of the power control limit depending on specific mission profiles. In the study case of a single-phase PV inverter, the power limit is selected as 80% of the maximum feed-in power of the PV panels, which is corresponding to a 6.23% energy yield reduction under a specific yearly mission profile. The PV inverter utilization is increased by 17% and the lifetime of the power devices is extended to 5.62 times of that in MPPT control mode. The proposed control strategy enables to increase the utilization factor of PV inverters and to reduce the temperature variations on power devices. Moreover, it is beneficial to system level power management by smoothing and limiting the PV inverter output power to some extent. This benefit is especially important to increase the PV installations with the existing grid infrastructure under a high PV penetration degree in the future. The power device is extended to 5.62 times of that in MPPT control mode. The effectiveness of the proposed topology and control algorithm was tested using simulations and results are presented. The results demonstrate that the proposed system is able to control ac-side current, and battery charging and discharging currents at different levels of solar irradiation.

In future a Solar PV module is mathematically modeled and connected at the DC input of the DC –DC LUO Converter. In order to switch the converter two complementary pulses were generated at a switching frequency. And in order to track the maximum power point using PSO algorithm is also implemented in the simulation and which will vary the duty cycle according to the V & I of the solar panel.

REFERENCES

[1] N. Pandiarajan and Ranganath Muth" Mathematical Modeling of Photovoltaic Module with Simulink" in 2011 1st International Conference on Electrical Energy Systems.

[2] Alps P. Parekh, Bravery N. Vaidya and Chirac T. Patel "Modeling and Simulation Based Approach of Photovoltaic System" in Global Research Analysis Volume 2 Issue 4 April 2013 • ISSN No 2277 – 8160.

[3] Pandiarajan N, Ramaprabha R and Ranganath Muthu" Application Of Circuit Model For Photovoltaic Energy Conversion System".

[4] G. Venkateswarlu and Dr.P.Sangameswar Rajas" Simscape Model Of Photovoltaic Cell" in International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering Vol. 2, Issue 5, May 2013.

[5] Vanda Khanna, Bijoy Kishore Das, Dinesh Bisht "MATLAB/SIMELECTRONICS Models Based Study of Solar Cells" in INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH Vandana Khanna et al., Vol.3, No.1, 2013..

[6] Mine Rosu-Hamzescu, Sergiu Opera" Practical Guide to Implementing Solar Panel RPPT Algorithms".

[7] P.Sathya, Dr.R.Natarajan" Design and Implementation of 12V/24V Closed loop Boost Converter for Solar Powered LED Lighting System " in International Journal of Engineering and Technology (IJET) Volume No 1 Feb-Mar 2013.

[8] R. Tonkoski, L. A. C. Lopes, and T. H. M. EL-Fouly, "Coordinated active power curtailment of grid connected PV inverters for overvoltage prevention," IEEE Trans. Sustain. Energy, vol. 2, no. 2, pp. 139–147, Apr. 2011.

[9] Y. Ueda, K. Kurokawa, T. Tanabe, K. Kitamura, and H. Sugihara, "Analysis results of output power loss due to the grid voltage rise in grid-connected photovoltaic power generation systems," IEEE Trans. Ind. Electron., vol. 55, no. 7, pp. 2744–2751, Jul. 2008.

[10] U. Scheuermann, "Pragmatic bond wire model," Presentation at ECPE Workshop Lifetime Modeling Simulation, Jul. 3–4, 2013.

[11] Y. Yang, H. Wang, and F. Blaabjerg, "Reduced junction temperature control during low-voltage ride-through for single-phase photovoltaic inverters," IET Power Electron., pp. 1–10, in press, 2014. DOI: 10.1049/ietpel. 2013.0734.

[12] D. Sera, L. Mathe, T. Kerekes, S. V. Spataru, and R. Teodorescu, "On the perturb-and-observe and incremental conductance RPPT methods for PV systems," IEEE J. Photovoltaic's, vol. 3, no. 3, pp. 1070–1078, Jul. 2013