Design of PSO based Buck Boost Converter for PV based Inverter System

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ABSTRACT

The solar energy conversion system is very interesting alternative on supplement the electric system generation, due to the persistent cost reduction of the overall system and cleaner power generation. To obtain a stable voltage from an input supply (PV cells) that is higher and lower than the output, a high efficiency and minimum ripple DC-DC converter required in the system for residential power production. Buck-boost converters make it possible to efficiently convert a DC voltage to either a lower or higher voltage. Buck-boost converters are especially useful for PV maximum power tracking purposes, where the objective is to draw maximum possible power from solar panel at all times, regardless of the load. This paper analyzes and describes step by step the process of designing, and simulation of high efficiency low ripple voltage buck-boost DC-DC converter for the photovoltaic solar conversion system applicable to a (typical) single family home based on battery-based systems. The input voltage can typically change from (20V) initially, down to (5V), and provide a regulated voltage within the range of the battery (12V). PLECS simulation results provide strong evidences about the high efficiency, minimum ripple voltage, high accuracy, and the usefulness of the system of the proposed converter when applied to either residential or solar home applications.

KEYWORDS: Particle Swarm Optimization (PSO), Photovoltaic (PV), Maximum Power Point Tracking (MPPT)

INTRODUCTION

SOLAR photovoltaic (PV) is envisaged to be a popular source of renewable energy due to several advantages, notably low operational cost, almost maintenance free and environmentally friendly. Despite the high cost of solar modules, PV power generation systems, in particular the grid-connected type, have been commercialized in many countries because of its potential long-term benefits [1]–[6], resulting in rapid growth of the industry. To optimize the utilization of large arrays of PV modules, Particle Swarm Optimization (PSO) is normally employed.

3. Photovoltaic Cells and Array:

Photovoltaic cells are devices that absorb sunlight and convert that solar energy into electrical energy. Solar cells are commonly made of silicon, one of the most abundant elements on Earth. Pure silicon, an actual poor conductor of electricity, has four outer valence electrons that form tetrahedral crystal lattices. The electron clouds of the crystalline sheets are stressed by adding trace amounts of elements that have three or five outer shell electrons that will enable electrons to move. The nuclei of these elements fit well in the crystal lattice, but with only three outer shell electrons, there are too few electrons to balance out, and “positive holes” float in the electron cloud. With five outer shell electrons, there are too many electrons. The process of adding these impurities on purpose is called “doping.” When doped with an element with five electrons, the resulting silicon...
is called N-type ("n" for negative) because of the prevalence of free electrons. Likewise, when doped with an element of three electrons, the silicon is called P-type. The absence of electrons (the "holes") define P-type.

The combination of N-type and P-type silicon cause an electrostatic field to form at the junction. At the junction, electrons from the sides mix and form a barrier, making it hard for electrons on the N side to cross to the P side. Eventually equilibrium is reached, and an electric field separates the sides. When photons (sunlight) hit a solar cell, its energy frees electron-holes pairs. The electric field will send the free electron to the N side and hole to the P side. This causes further disruption of electrical neutrality, and if an external current path is provided, electrons will flow through the path to their original side (the P side) to unite with holes that the electric field sent there, doing work for us along the way. The electron flow provides the current, and the cell's electric field causes a voltage. With both current and voltage, we have power, which is the product of the two. By wiring solar cells in series, the voltage can be increased; or in parallel, the current. Solar cells are wired together to form a solar panel. Solar panels can be joined to create a solar array.

**Power Supply (Battery):**

A battery is a source portable electric power. A storage battery is a reservoir, which may be used repeatedly for storing energy. Energy is charged and drained from the reservoir in the form of electricity, but it is stored as chemical energy. The most common storage battery is the lead-acid battery that is widely used in automobiles. They represent about 60% of all batteries sold worldwide and are usually more economical and have a high tolerance for abuse. Lead-acid batteries are inexpensive, relatively safe and easily recyclable, but have a low energy-to-weight ratio, which is a serious limitation when trying to build lightweight vehicles.

New battery technologies are constantly being explored that can offer better energy-to-weight ratios, lower costs and increased battery life. The nickel-metal-hydride battery has received a great deal of attention as a near future solution. Nickel-metal-hydride batteries offer about twice the energy capacity for the same weight as a current lead-acid battery. Another battery type with an even greater energy density is Lithium ion.

**Voltage Divider:**

In electronics, a voltage divider (also known as a potential divider) is a linear circuit that produces an output voltage (Vout) that is a fraction of its input voltage (Vin). Voltage division refers to the partitioning of a voltage among the components of the divider.

An example of a voltage divider consists of two resistors in series or a potentiometer. It is commonly used to create a reference voltage, or to get a low voltage signal proportional to the voltage to be measured, and may also be used as a signal attenuator at low frequencies. For direct current and relatively low frequencies, a voltage divider may be sufficiently accurate if made only of resistors; where frequency response over a wide range is required, (such as in an oscilloscope probe), the voltage divider may have capacitive elements added to allow compensation for load capacitance. In electric power transmission, a capacitive voltage divider is used for measurement of high voltage. A voltage divider referenced to ground is created by connecting two electrical impedances in series, as shown in Figure 1. The input voltage is applied across the series impedances Z1 and Z2; and the output is the voltage across Z2. Z1 and Z2 may be composed of any combination of elements such as resistors, inductors and capacitors. Applying Ohm's Law, the relationship between the input voltage, V_in, and the output voltage, V_out, can be found:

\[
V_{\text{out}} = \frac{Z_2}{Z_1 + Z_2} \cdot V_{\text{in}}
\]

(1)

The transfer function (also known as the divider's voltage ratio) of this circuit is simply:

\[
H = \frac{V_{\text{out}}}{V_{\text{in}}} = \frac{Z_2}{Z_1 + Z_2}
\]

(2)

In general this transfer function is a complex, rational function of frequency,

\[
V_{\text{out}} = \frac{R_2}{R_1 + R_2} \cdot V_{\text{in}}
\]

(3)

**4. Buck-Boost Converter:**

Controller design for any system needs knowledge about system behavior. Usually this involves a mathematical description of the relation among inputs to the process, state variables, and output. This description in the form of mathematical equations which describe behavior of the system (process) is called model of the system. This paper describes an efficient method to learn, analyze and simulation of power electronic converters, using system level nonlinear, and switched state-space models. The MATLAB/SIMULINK software package can be advantageously used to simulate power converters. This study aims at development of the models for all basic converters and studying its open loop response, so these models
can be used in case of design of any close loop scheme. Also as a complete exercise a closed scheme case has been studied using cascaded control for a boost converter.

5. Mppt:
Maximum power point tracking (MPPT) is a technique that grid-tie 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 cells have a complex relationship between solar irradiation, temperature and total resistance that produces a non-linear output efficiency known as the I-V curve. It is the purpose of the MPPT system to sample the output of the cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions. MPPT devices are typically integrated into an electric power converter system that provides voltage or current conversion, filtering, and regulation for driving various loads, including power grids, batteries, or motors.

**Fig. 1:** VI curve

**Fig. 2:** Solar Cell VI curve

Solar cell I-V curves where a line intersects the knee of the curves where the maximum power point is located. Photovoltaic cells have a complex relationship between their operating environment and the maximum power they can produce. The fill factor, abbreviated FF, is a parameter which characterizes the non-linear electrical behavior of the solar cell. Fill factor is defined as the ratio of the maximum power from the solar cell to the product of Open Circuit Voltage Voc and Short-Circuit Current Isc. In tabulated data it is often used to estimate the maximum power that a cell can provide with an optimal load under given conditions, \( P = FF \times Voc \times Isc \). For most purposes, FF, Voc, and Isc are enough information to give a useful approximate model of the electrical behavior of a photovoltaic cell under typical conditions.

For any given set of operational conditions, cells have a single operating point where the values of the current (I) and Voltage (V) of the cell result in a maximum power output. These values correspond to a particular load resistance, which is equal to \( V / I \) as specified by Ohm's Law. The power \( P \) is given by \( P = V \times I \). A photovoltaic cell, for the majority of its useful curve, acts as a constant current source. However, at a photovoltaic cell’s MPP region, its curve has an approximately inverse exponential relationship between current and voltage. From basic circuit theory, the power delivered from or to a device is optimized where the derivative (graphically, the slope) \( dI/dV \) of the I-V curve is equal and opposite the \( I/V \) ratio (where \( dP/dV = 0 \)). This is known as the maximum power point (MPP) and corresponds to the “knee” of the curve.

A load with resistance \( R = V/I \) equal to the reciprocal of this value draws the maximum power from the device. This is sometimes called the characteristic resistance of the cell. This is a dynamic quantity which changes depending on the level of illumination, as well as other factors such as temperature and the age of the cell. If the resistance is lower or higher than this value, the power drawn will be less than the maximum available, and thus the cell will not be used as efficiently as it could be. Maximum power point trackers utilize different types of control circuit or logic to search for this point and thus to allow the converter circuit to extract the maximum power available from a cell.
Controllers usually follow one of three types of strategies to optimize the power output of an array. Maximum power point trackers may implement different algorithms and switch between them based on the operating conditions of the array.

**Perturb and observe:**
In one method, the controller adjusts the voltage by a small amount from the array and measures power; if the power increases, further adjustments in that direction are tried until power no longer increases. This is called the perturb and observe method and is most common, although this method can result in oscillations of power output. It is referred to as a hill climbing method, because it depends on the rise of the curve of power against voltage below the maximum power point, and the fall above that point. Perturb and observe is the most commonly used MPPT method due to its ease of implementation. Perturb and observe method may result in top-level efficiency, provided that a proper predictive and adaptive hill climbing strategy is adopted.

**Incremental conductance:**
In the incremental conductance method, the controller measures incremental changes in array current and voltage to predict the effect of a voltage change. This method requires more computation in the controller, but can track changing conditions more rapidly than the perturb and observe method (P&O). Like the P&O algorithm, it can produce oscillations in power output. This method utilizes the incremental conductance (dI/dV) of the photovoltaic array to compute the sign of the change in power with respect to voltage (dP/dV).

The incremental conductance method computes the maximum power point by comparison of the incremental conductance (ΔI/ΔV) to the array conductance (I/V). When the incremental conductance is zero, the output voltage is the MPP voltage. The controller maintains this voltage until the irradiation changes and the process is repeated.

**Current Sweep Method:**
The current sweep method uses a sweep waveform for the PV array current such that the I-V characteristic of the PV array is obtained and updated at fixed time intervals. The maximum power point voltage can then be computed from the characteristic curve at the same intervals.

**Constant voltage:**
The term "constant voltage" in MPP tracking is used to describe different techniques by different authors, one in which the output voltage is regulated to a constant value under all conditions and one in which the output voltage is regulated based on a constant ratio to the measured open circuit voltage (VOC). The latter technique is referred to in contrast as the "open voltage" method by some authors. If the output voltage is held constant, there is no attempt to track the maximum power point, so it is not a maximum power point tracking technique in a strict sense, though it does have some advantages in cases when the MPP tracking tends to fail, and thus it is sometimes used to supplement an MPPT method in those cases.

In the "constant voltage" MPPT method (also known as the "open voltage method"), the power delivered to the load is momentarily interrupted and the open-circuit voltage with zero current is measured. The controller then resumes operation with the voltage controlled at a fixed ratio, such as 0.76, of the open-circuit voltage VOC. This is usually a value which has been determined to be the maximum power point, either empirically or based on modeling, for expected operating conditions. The operating point of the PV array is thus kept near the MPP by regulating the array voltage and matching it to the fixed reference voltage Vref=kVOC. The value of Vref may be also chosen to give optimal performance relative to other factors as well as the MPP, but the central idea in this technique is that Vref is determined as a ratio to VOC.

One of the inherent approximations to the "constant voltage" ratio method is that the ratio of the MPP voltage to VOC is only approximately constant, so it leaves room for further possible optimization.

**Comparison of methods:**
Both perturb and observe, and incremental conductance, are examples of "hill climbing" methods that can find the local maximum of the power curve for the operating condition of the array, and so provide a true maximum power point. The perturb and observe method can produce oscillations of power output around the maximum power point even under steady state illumination.

The incremental conductance method has the advantage over the perturb and observe method that it can determine the maximum power point without oscillating around this value. It can perform maximum power point tracking under rapidly varying irradiation conditions with higher accuracy than the perturb and observe method. However, the incremental conductance method can produce oscillations and can perform erratically under rapidly changing atmospheric conditions. The computational time is increased due to slowing down of the sampling frequency resulting from the higher complexity of the algorithm compared to the P&O method.
In the constant voltage ratio (or "open voltage") method, the current from the photovoltaic array must be set to zero momentarily to measure the open circuit voltage and then afterwards set to a predetermined percentage of the measured voltage, usually around 76%. Energy may be wasted during the time the current is set to zero. The approximation of 76% as the MPP/VOC ratio is not necessarily accurate though. Although simple and low-cost to implement, the interruptions reduce array efficiency and do not ensure finding the actual maximum power point.

**MPPT placement:**

Traditional solar inverters perform MPPT for an entire array as a whole. In such systems the same current, dictated by the inverter, flows through all panels in the string. Because different panels have different IV curves and different MPPs (due to manufacturing tolerance, partial shading, etc.) this architecture means some panels will be performing below their MPP, resulting in the loss of energy.

Some companies (see power optimizer) are now placing peak power point converters into individual panels, allowing each to operate at peak efficiency despite uneven shading, soiling or electrical mismatch.

**Operation with batteries:**

At night, an off-grid PV power system may use batteries to supply loads. Although the fully charged battery pack voltage may be close to the PV array's maximum power point voltage, this is unlikely to be true at sunrise when the battery has been partially discharged. Charging may begin at a voltage considerably below the array maximum power point voltage, and an MPPT can resolve this mismatch. When the batteries in an off-grid system are fully charged and PV production exceeds local loads, an MPPT can no longer operate the array at its maximum power point as the excess power has no load to absorb it. The MPPT must then shift the array operating point away from the peak power point until production exactly matches demand. (An alternative approach commonly used in spacecraft is to divert surplus PV power into a resistive load, allowing the array to operate continuously at its peak power point.) In a grid-tied photovoltaic system, the grid must be forced to absorb all excess power delivered from solar panels. The MPPT in a grid-tied PV system will always attempt to operate the array at its maximum power point.

6. **PSO:**

Particle swarm optimization method is a population based stochastic optimization technique. In this optimization process it provides a population base search by getting the best solution from the problem by taking the particles and moving them into the search space. Dr. Eberhart and Dr. Kennedy in 1995 originated this technique in a simple social system. The system starts with a random populations and the optimization takes place when updating the particles. The particles searches the space by following the optimum particles. And the PSO has the position vector (x) and a velocity vector (v). The population is called as swarm and in the swarm each member is called as a particle.

**Swarm:** A set of particles

**Particle:** A Potential solution or a member of a swarm

i) position

\[ x_i = (x_{i1}, x_{i2}, \ldots, x_{id}) \in \mathbb{R}^d \]  

(4)

ii) velocity

\[ v_i = (v_{i1}, v_{i2}, \ldots, v_{id}) \in \mathbb{R}^d \]  

(5)

Each Particle maintains its previous best position

iii) individual best position

\[ P_{best} = (P_{best1}, P_{best2}, \ldots, P_{bestd}) \in \mathbb{R}^d \]  

(6)

iv) swarm global position

\[ P_{gbest} \in \mathbb{R}^d \]
**Fig. 3: PSO Algorithm**

7. **Simulink Block Diagram:**

   A PSO with the capability of direct duty cycle is used to track the MPPT of a PV system. It is shown that the proposed MPPT controller exhibits an adaptive form of the HC method. To improve the tracking speed, a simple and efficient method is proposed to reinitialize the particles to search for the new MPPT, resulting in superior dynamic response.

   The feasibility of the project is analyzed in this phase and business proposal is put forth with a very general plan for the project and some cost estimates. During system analysis the feasibility study of the proposed system is to be carried out. This is to ensure that the proposed system is not a burden to the company. For feasibility analysis, some understanding of the major requirements for the system is essential.

   This study is carried out to check the technical feasibility, that is, the technical requirements of the system. Any system developed must not have a high demand on the available technical resources. This will lead to high demands on the available technical resources. This will lead to high demands being placed on the client. The developed system must have a modest requirement, as only minimal or null changes are required for implementing this system.
The DC-DC buck, boost, buck-boost, and Cuk converters was previously designed, and simulated on digital computer using Matlab package with the parameters given in Table 1, and Table 2. Inductor current and capacitor voltage for open loop simulation of all converters are as shown.

Each of the power electronic models represents subsystems within the simulation environment. These blocks have been developed so they can be interconnected in a consistent and simple manner for the construction of complex systems. The subsystems are masked, meaning that the user interface displays only the complete subsystem, and user prompts gather parameters for the entire subsystem. Relevant parameters can be set by double-clicking a mouse or pointer on each subsystem block, then entering the appropriate values in the resulting dialogue window.

<table>
<thead>
<tr>
<th>$V_L$</th>
<th>$L$</th>
<th>$C$</th>
<th>$R$</th>
<th>$f$</th>
<th>$V_o$</th>
</tr>
</thead>
<tbody>
<tr>
<td>24, 10, 24 V</td>
<td>$69 mH$</td>
<td>$220 \mu F$</td>
<td>$13 \Omega$</td>
<td>$100 \text{ KHz}$</td>
<td>12, 20, -24 V</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

Results of Closed loop using a cascaded control scheme for a boost converter is shown in Fig 4. Here the output voltage rises up to 21.3V (6.5%) for the step variation of load from 10Ω to 13Ω (30%). The output voltage resumes its reference value (of 20V) within 15ms after the transient variation of load. For a step change at the input voltage from 10V to 18V (80%) (at 0.5 Sec instant), a satisfactory performance is obtained in the output voltage which has a rise up to 22.8V (14%), but it is quickly dropped to its set value (20V) within 16 ms. Simulation results verify that the control scheme in this section gives stable operation of the power supply. The output voltage and inductor current can return to the steady state even when it is affected by line and load variation.

Fig. 4: Buck-Boost Converter
Since all electronic circuits work only with low DC voltage we need a power supply unit to provide the appropriate voltage supply. This unit consists of transformer, rectifier, filter and regulator. AC voltage typically 230V rms is connected to a transformer which steps that AC voltage down to the level to the desired AC voltage. A diode rectifier then provides a full-wave rectified voltage that is initially filtered by a simple capacitor filter to produce a DC voltage. This resulting DC voltage usually has some ripple or AC voltage variations. A regulator circuit can use this DC input to provide DC voltage that not only has much less ripple voltage but also remains the same DC value even the DC voltage varies some what, or the load connected to the output DC voltages changes.

Fig. 5: PV Input Power, Voltage and Current

Fig. 6: Inverter Vabc

Fig. 7: Inverter Va
Fig. 8: MPPT Output Voltage and Modulation Index

Fig. 9: Grid Voltage and Current

Fig. 10: PV Output Power

Conclusion:
In this project, a PSO with the capability of direct duty cycle is used to track the MPP of a PV system. It is shown that the proposed MPPT controller exhibits an adaptive form of the HC method. To improve the tracking speed, a simple and efficient method is proposed to reinitialize the particles to search for the new MPP, resulting in superior dynamic response. The results indicate that the proposed controller outperforms the HC and gives a number of advantages

1) it has a faster tracking speed;
2) it exhibits zero oscillations at the MPP;
3) it could locate the MPP for any environmental variations including partial shading condition and large fluctuations of insolation; and
4) the algorithm can be easily developed using a low-cost microcontrollers.

The main purpose of this Project is to develop a MPPT algorithm for centralized-type PSO operating under Buck Boost Converter. The standard version of PSO is applied to meet the practical consideration of PSO operating under Buck Boost converter. The problem formulation and design procedure are described and explained in detail. Three different shading patterns are utilized to experimentally validate the correctness of the proposed system. According to the experimental results, the proposed method can obtain the GMPP in all the
test cases no matter where the GMPP locates. The tracking efficiencies in three test cases are all higher than 99.7%.

REFERENCES


