A Hybrid Power Control Concept For PV Inverters Using Resonant Converter

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ABSTRACT
A PV inverter, or Solar converter, converts the variable direct current (DC) output of a photovoltaic (PV) solar panel into an utility frequency alternating current (AC) that can be fed into a commercial electrical grid or used by a local, off-grid electrical network. The output power of the PV panel can be controlled using a hybrid power control concept. Here, two methods of control strategies namely Maximum Power Point Tracking (MPPT) and Constant Power Generation (CPG) are proposed. The MPPT is effective for PV inverters to maximize the energy from PV panel within a power limit. By using the CPG, it will remove the thermal loading occur in the normal circuit. The resonant converter has been used here which has better efficiency compared to boost converter, which also improves the operating range. A detailed simulation study of a hybrid PV system with two control strategies is presented in this paper.

KEYWORDS: solar input, resonant converter, inverter, MPPT and CPG control and load

INTRODUCTION

The term "alternative energy" (renewable energy) encompasses a different variety of power generation sources. Generally, wind or solar energy will produce electrical energy, as opposed to "single-use" resources such as uranium or coal. The most commonly used forms of alternative energy available for homeowner are solar power, wind power and "micro-hydro" power. From an environmental standpoint, solar, wind and water power are all non-emission power sources. Unlike coal combustion power plants, no harmful exhaust is produced when using alternative energy generators. There is also no worry about toxic or radioactive waste products, as there is with nuclear power. In addition to the lack of emissions and waste products, no valuable resources are used up with renewable resource power generation. If every home on earth were powered with an alternative energy system, never cause a shortage of wind, water or sunlight.

In this paper proposing two methods of control strategies for PV panel are Maximum Power Point Tracking (MPPT) [1] and Constant Power generation (CPG) [2]

Block Diagram:
A. Existing System:
The Fig 2.1 shows the block diagram of existing system. In this system boost converter is using.
II. System Description:

A. Solar Panel:

Solar panel refers to a panel designed to absorb the sun's rays as a source of energy for generating electricity. A photovoltaic (in short PV) [8] module is a packaged, connected by different cells. Solar Photovoltaic panels constitute the solar array of a photovoltaic system that generates and supplies solar electricity in domestic and commercial applications. Each module is rated by its DC output power under standard test conditions, and typically ranges from 100 to 365 watts. The efficiency of a module determines the area of a module given the same rated output – an 8% efficient 230W module will have twice the area of a 16% efficient 230W module. There are a few solar panels having more than 19% efficiency. A limited amount of power will produce by the single solar cell; most installations contain multiple modules. A photovoltaic system includes a panel or an array of solar modules, an inverter, and sometimes a battery and/or solar tracker and interconnection wiring.

B. Maximum Power Point Tracking (MPPT):

Maximum Power Point Tracking, referred as MPPT, is an electronic system that operates the Photovoltaic (PV) modules in a manner that allows the modules to produce all the power. It is not a mechanical tracking system but it allows the modules to move at a point in the direction of sun to track the maximum power. Additional power harvested from the modules is then made as increased battery charge current. MPPT can be used in conjunction with a mechanical tracking system but the two systems are completely different. To understand how MPPT [3] [4] works let’s consider the operation of a conventional (non- MPPT) charge controller.
When a conventional controller is charging a discharged battery it simply connects the modules directly to the battery. This forces the modules to operate at battery voltage, typically not the ideal operating voltage at which the modules are able to produce their maximum available power.

The main features of MPPT solar charge controller are:

- In any applications which PV module is energy source, MPPT solar charge controller is used to correct for detecting the variations in the current-voltage characteristics of solar cell.
- MPPT solar charge controller is used for any solar power systems need to extract maximum power from PV module; it forces PV module to operate at voltage close to maximum power point to draw maximum available power.
- MPPT solar charge controller allows users to use PV module with a higher voltage output than operating voltage of battery system. It will reduces the wire size needed while retaining full output of PV module.

MPPT solar charge controller can be applied to other renewable energy sources such as small water turbines, wind power turbines etc.

1) Method of MPPT algorithms:

There are 3 types of algorithms [5] are seen

a. Constant voltage and current
b. Perturb and observe
c. Incremental conductance

Here explaining about perturb and observe algorithm.

a) Perturb and observe algorithm:

As the name of perturb and observe (P&O) [6] states, this process works by perturbing the system by increasing the array operating voltage and observing its effect on the array output power. The operating voltage is perturbed with every MPPT cycle. As soon as MPP is reached, V will oscillate around the ideal operating voltage $V_{mp}$.

Figure 3.1 shows the control action of the P&O method. The voltage of the reference voltage, $V_{ref}$, will be changed according to the current operating point. For example, when the controller senses that the power from solar array increases ($dP > 0$) and voltage decreases ($dV < 0$), it will decrease (-) $V_{ref}$, by step size $C1$, so $V_{ref}$ is closer to the MPP. The MPP represents the point where $V_{ref}$ and scaled down $V_{sa}$ become equal.

<table>
<thead>
<tr>
<th>Case</th>
<th>$dP$</th>
<th>$dV$</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;0</td>
<td>&lt;0</td>
<td>+</td>
</tr>
<tr>
<td>2</td>
<td>&lt;0</td>
<td>&gt;0</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>&gt;0</td>
<td>&lt;0</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>&lt;0</td>
<td>&gt;0</td>
<td>+</td>
</tr>
</tbody>
</table>

Fig. 3.1: Perturb and Observe (P&O) control action

Several improvements of the P&O algorithm have been proposed. One of the simplest entails the adding of a ‘waiting’ function that will cause a momentary cessation of perturbations if the algebraic sign of the perturbation is reversed several times in a row is indicating that the MPP has been reached. This reduces the MPP oscillations in the steady state and improves the algorithm’s efficiency under constant irradiance conditions. It also makes the MPPT slower to respond to changing atmospheric conditions. Another modification is there where involves at array voltage $V1$ measure the array power $P1$, perturbing the voltage and measuring the array’s power $P2$ again, at the new array voltage $V2$, and then changing the voltage back to its previous value and again measure the array’s power, $P1$ at $V1$. The algorithm can determine whether the irradiance is changing, from the two measurements at $V1$. Again, as with the previous modifications, increasing the number of samples of the array’s power slows the algorithm down. By using the two measurements at $V1$ to make a measurement of how much the irradiance has changed between sampling periods, and to use this in
deciding how to perturb the operating point. This slows the operation of the MPPT and increases the complexity of the algorithm. The flow chart for P&O [7] algorithm shown in Fig 3.2

C. Constant Power Generation (Cpg):
It is an advanced power control strategy by limiting the maximum feed-in power of PV systems, which can ensure a fast and smooth transition between maximum power point tracking and Constant Power Generation (CPG) [8]. Regardless of the solar irradiance levels, stable operation and good-performance are always achieved by the proposed control strategy. It can regulate the PV output power according to any set-point values, and also force the PV systems to operate at the left side of the maximum power point without causing any stability problems.

The operational principle of the conventional P&O-CPG algorithm is illustrated in fig 3.4. It can be divided into two modes:

a) MPPT mode ($P_{pv} \leq P_{limit}$), where the P&O algorithm should track the maximum power.

b) CPG mode ($P_{pv} > P_{limit}$), where the PV output power is limited at $P_{limit}$.

During the MPPT operation, the behavior of the algorithm is similar to the conventional P&O MPPT algorithm – the operating point will track and oscillate around the MPP. In the case of the CPG operation, the PV voltage $V_{pv}$ is continuously perturbed toward a point referred to as Constant Power Point (CPP),
i.e., $P_{pv} = P_{limit}$ \hfill (3.1)

After a number of iterations, the operating point will reach and oscillate around the CPP. Although the PV system with the P&O-CPG control can operate at both CPPs, only the operation at the left side of the MPP (CPP-L) is focused for the stability concern.

Where $v_{pv}$ can be expressed as

$$v_{pv}^* = \begin{cases} v_{MPPT, \text{when } P_{pv} \leq P_{limit}} \\ v_{pv,n} - v_{\text{step}}, \text{ when } P_{pv} > P_{limit} \end{cases} \hfill (3.2)$$

Where,

- $v_{MPPT}$ is the reference voltage from the MPPT algorithm
- $v_{pv,n}$ is the measured PV voltage, and
- $v_{\text{step}}$ is the perturbation step size.

D. Resonant Converters:

In both the SMPS and PWM inverters, the switching devices are made to turn-on and turn-off the entire load current at high $di/dt$. The devices handling high $di/dt$ also experience high-voltage stresses across them; due to these two effects, there are increased power losses in the switching devices. In case size and weight of the converter components is to be reduced, switching frequencies are increased. At these high frequencies, switching losses and high-voltage stresses are further aggravated. Another major drawback of high $di/dt$ and high $dv/dt$ caused by rapid on and off of the switching devices is the electromagnetic interference.

The shortcoming enunciated above can be minimised if each switch in a converter is switched on and off when the voltage across it and/or current through it is zero at the instant of switching [9]. The converter circuits which employ zero current and/or zero voltage switching are called resonant converters. In most of these converters, some form of LC resonance is used, that is why these are known as resonant converter. Here using L type resonant converter, this is described in fig 3.5

![Fig. 3.5: Circuit diagram of L type resonant converter](image)

E. Inverter:

Inverter [10] in Power-Electronics refers to a class of power conversion circuits that operate from a dc voltage source or a dc current source and convert it into a symmetric ac voltage or current. It does reverse of what ac-to-dc ‘converter’ does. The input to the inverter is a direct dc source or dc source derived from an ac source. For example, the primary source of input power may be utility ac voltage supply that is converted to dc by an ac - dc rectifier with filter capacitor and then ‘inverted’ back to ac using an inverter. Here, the final ac output may be of a different frequency and magnitude than the input ac of the utility supply.

If the input dc is a voltage source, the inverter [11] is called a Voltage Source Inverter (VSI). One can similarly think of a Current Source Inverter (CSI), where the input to the circuit is a current source. The VSI circuit has direct control over ‘output (ac) voltage’ whereas the CSI directly controls ‘output (ac) current’.

The simplest dc voltage source for a VSI may be a battery bank or a solar photovoltaic cells stack. An ac voltage supply, after rectification into dc can also serve as a dc voltage source. A voltage source is called stiff, if the source voltage magnitude does not depend on load connected to it. All voltage source inverters assume stiff voltage supply at the input.

Output of voltage waveforms of ideal inverters should be sinusoidal. However practical inverter waveforms are non sinusoidal and contain certain harmonics. For low and medium power applications square wave or quasi square wave voltages are acceptable.

Figure 3.7 shows the power circuit diagram for single phase bridge voltage source inverter. In this four switches (in 2 legs) are used to generate the ac waveform at the output. Any semiconductor switch like IGBT,
MOSFET or BJT can be used. Four switches are sufficient for resistive load because load current \( i_o \) is in phase with output voltage \( v_o \). However this is not true in case of RL load where the \( i_o \) is not in phase with \( v_o \) and diodes connected in anti-parallel with switch will allow the conduction of the current when the main switch is turned off. These diodes are called as Feedback Diodes since the energy is fed back to the dc source.

**Fig. 3.6:** Single phase bridge voltage source inverter power circuit diagram

**F. LCL Filter:**

The LCL-filter [12] is a third order filter having attenuation of 60db/decade for frequencies above full resonant frequency, hence lower switching frequency for the converter switches could be utilized. Decoupling between the filter and the grid connected inverter having grid side impedance is better for this situation and lower current ripple over the grid inductor might be attained. The LCL filter will be vulnerable to oscillations too and it will magnify frequencies around its cut-off frequency.

**Fig. 3.7:** Single Phase Grid Connected Inverter along with LCL Filter

Therefore the filter is added with damping to reduce the effect of resonance. Therefore LCL-filter fits to our application. In the interim, the aggregate inductance of the received LCL filter [13] is much more diminutive as contrasted with the L filter. Commonly, the expense is lessened. Besides, enhanced dynamic execution, harmonic attenuation and decreased volume might be accomplished with the utilization of LCL filter. The conduction and switching losses that are caused by the filter are calculated and are optimized considering the level of reduction of harmonics.

a) **Design Of The LCL Filter:**

The greater part of the configuration mathematical statements are communicated in per unit basis of the volt-ampere rating of the power converter. Single phase equivalent circuit of the LCL filter with passive damping is demonstrated in Figure 4.11. The line-to-neutral output voltage \( V_{LN} \) is the base voltage, and the three-phase kilovolt-ampere rating is the base volt-ampere. The fundamental frequency of 50 Hz is the base frequency. The inverter yield voltage and current are spoken to by \( u_i \) and \( i_i \), and the output voltage and current are spoken to by \( u_o \) and \( i_o \). The switching frequency is spoken to by \( f_{sw} \) (in hertz) or \( \omega_{sw} \) (in radians for every second). Considering power grid as a perfect voltage source, i.e., zero impedance, and it is supplying a steady voltage/current just at the fundamental frequency.
Fig. 3.8: Single Phase Equivalent Circuit of an LCL Filter with Passive Damping

The LCL filter transfer function which influences the closed-loop system bandwidth in the grid-connected mode of operation is represented as:

\[
F(s) = \frac{1}{s(L_1 + L_2) + S^2L_1L_2C}
\]

(3.3)

\[
\omega_r = \frac{1}{L_pC}
\]

(3.4)

\[
L_p = \frac{L_1L_2}{L_1 + L_2}
\]

(3.5)

\[
L_1 = a_1L_2
\]

(3.6)

\[
\omega_r = \frac{1}{L_p\left(\frac{1}{a_1} + s\right)}
\]

(3.7)

Where \(L_1\) - inverter side inductance &
\(L_2\) - Grid side inductance

Taking resonant frequency \(\omega_r\) constant, is derived at the minimum capacitance follows,

\[
\frac{\delta C}{\delta a_1} = 0
\]

(3.8)

Whose simplification gives \(a_1 = 1\). In this way, the most modest capacitance estimation of the LCL filter is gotten when \(L_1 = L_2\). Then

\[
\omega^2 = \frac{4}{L_C}
\]

(3.9)

After solving equations

\[
L = \frac{1}{\omega^2}\left[\frac{1}{\pi^2L} - \frac{\delta^2}{\pi^2L^2}\right]
\]

(3.10)

It gives the base \(L = L_1 + L_2\) per unit that will fulfill the standard suggestions for current ripple at the obliged switching frequency. The passive damping scheme is the real target of damping is to decrease the Q-element at the resonance frequency without influencing the frequency response at different frequencies. The aggregate power dispersal in the damping circuit is additionally an imperative parameter to be considered

\[
L_1 = L_2
\]

\[
C_d = a_1C_1 \quad \text{and}
\]

\[
C = C_1 + C_2
\]

(3.11)

Where \(C_d\) the damping capacitor.
The required transfer function is
\begin{equation}
\frac{u_c(j\omega)}{u_i(j\omega)} = \frac{0.5 + j 0.5\omega C d R_d}{(1 - \frac{\omega^2}{\alpha} + j \omega R_d \left(\frac{1}{\omega^2} + \frac{1}{\alpha C}\right)}
\end{equation}

(3.12)

\begin{equation}
Q_c = \frac{1 + j \omega R_d \left(\frac{1}{\alpha C} + \frac{1}{\alpha C}\right)}{j \omega R_d \left(\frac{1}{\alpha C} + \frac{1}{\alpha C}\right)}
\end{equation}

(3.13)

\begin{equation}
R_d = \frac{1}{\sqrt{C}}
\end{equation}

(3.14)

Where, \( R_d \) is the damping resistor.

IV Simulation Results:

The simulation [13] diagram is shown in Fig 4.1. Solar module output depends on the sunlight incident on it and other environmental factors. Major factors on which solar cell output relays are temperature and irradiation level. The generated power is given to MPPT and CPG control. 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 and the MPPT mode is active when the dc power is below the specific power level. The proposed MPPT-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.

The fig 4.2 shows the output voltage. Fig 4.3 shows the output current and Fig 4.4 shows the output power of solar panel. Fig 4.5 shows that the capacitor voltage and inductor current waveform of resonant converter. Here single phase voltage source inverter is used. Inverter in Power-Electronics refers to a class of power conversion circuits that operate from a dc voltage source or a dc current source and convert it into a symmetric ac voltage or current. It does reverse of what ac-to-dc ‘converter’ does. Fig 4.6 shows that the inverter output voltage. The input to the inverter is a direct dc source or dc source derived from an ac source. Then the DC output from the inverter is given to the LCL filter.

Fig. 4.1: simulation diagram
Fig. 4.2: solar panel output voltage

Fig. 4.3: solar panel output current

Fig. 4.4: solar panel output power

Fig. 4.5: capacitor voltage and inductor current waveform of resonant converter
Conclusion:

In this project the solar panel is connected with the inverter by DC-DC resonant converter. By the usage of the resonant converter, there is no voltage stress and no circulating current and hence the losses are reduced. Here two types of algorithms are used to generate gate pulses to the resonant converter. The two algorithms are Maximum Power Point Tracking (MPPT) and Constant Power Generation (CPG). The generated power from the solar is given to MPPT and CPG controllers. CPG control mode is activated by using a direct power control when the DC power from PV panels reaches to a specific limit and the MPPT mode is active when the dc power is below the specific power level. The proposed MPPT-CPG control concept allows a reduction of required power ratings of PV inverters. For the elimination of harmonics in the output of the inverter LCL filter is connected. The LCL filter is a third order filter having attenuation of 60db/decade for frequencies above full resonant frequency.

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