AC synthesis from switched PV arrays

Abstract

The use of switches within a photovoltaic arrays architecture is gaining recognition as an optimal solution to the partial shading problem because it allows the array to behave in a flexible manner which is ideal for rapid response to unpredictable shading environments. An interesting alternative reason for implementing a dynamic array is that it is able to exhibit complex behaviors. One such behavior is the ability to directly synthesize an alternating current by the switching of DC cells in a controlled sequence. Voltage inversion is a very well researched field and commercial inverters can achieve very high efficiencies (typically over 95%). However, high powered models are expensive and are often the cause of system failure. This paper discusses the concept of AC synthesis through the switching of PV sources and looks at the similarities with the conventional *modified sine wave* and *multilevel* inversion techniques. Many interesting new features are evident and implementing a PV array like this can ultimately remove the need for and inverter altogether.

AC-DPVA basics

A 'sub string' is a collection of PV cells which are hardwired in series to produce a sufficiently high voltage to justify switching (typically 12V) and it is the lowest level of granularity that the switching mechanism operates with. The aim is to connect these sub-strings into larger strings of varying length (and therefore voltage) according to the instruction from the control. A microcontroller will be using a timer and knowledge of the array to switch the sub-string such that the output voltage follows the contours of a sinusoidal waveform.

This method is similar to the multi level inverter topologies but instead of sequentially switching divisions of fixed DC voltage, the DC voltage itself is varying in magnitude. There is of course quantization errors caused by the abrupt nature of the switching and this will affect the total harmonic distortion (THD) of the waveforms. In order to become a true sine wave source the THD must be below 3% and the requirements for achieving this will be investigated in detail.

In order to extract 100% of the power from the PV devices, they all must be continuously supplying current to a load. As expected from an oscillating power source, there are times when not all of the sub-strings contribute to the flow of current. The solution here is to have two channels operating simultaneously and drive them such that every single sub-string is providing current during each step of the switch sequence. It means an AC-DPVA will have two outputs producing complementary waveforms.

Two switching circuits have been identified and although they can produce identical outputs, they have slightly different topologies and produce different *default* output wave forms. Both strategies produce a particular set of phases between the two outputs and each method is able to include a 'current reversal' technique using an H-bridge circuit. By including an H-Bridge between the array and the load the effective amplitude of the alternating current can be doubled, thus reducing the number of sub-strings required to achieve the desired maximum amplitude. However by using an H bridge to reverse current through the load, the phase difference between the outputs gets shifted. As each strategy can produce the same waveforms, an analysis of other attributes will aim to highlight the benefits of one particular method over the other.

Transverse wave Vs Longitudinal Wave techniques

The 'transverse wave' method relies on the switching of the grounding node within the array such that the switch sequence looks like an oscillating transverse wave. It's the simpler of the two to implement and its main attribute is that it inherently produces a negative voltage at one of the output nodes. This means the ground rail is both simultaneously a high side and low side return path for produced current.

The 'longitudinal wave' method maintains a static ground potential and switches the output nodes of the PV devices in such a way that the sequence looks like a longitudinal wave. Here the ground node always remains a low side return path and its main attribute is that separate bus bars carry the current to the load.

Tandem Waveforms

As mentioned, if H bridges are included in the design then both strategies can produce the exact same waveforms. So to simplify the discussion, the transverse wave method is used for all examples here. The only difference between the two methods is the correlation between H bridges being active and the output phase of the wave forms.

The first output waveform (wave A) is produced when the AC-DPVA is driven in 'transverse mode' without utilizing the H bridges. The two sinusoidal outputs are in phase and the peak to peak amplitude is equal to the maximum voltage produced by the array. The switching frequency is proportional to the number sub-strings and the desired frequency of the output waveform.

The second waveform (wave B) is produced when the AC-DPVA is driven and one H bridge is permanently active. This reverses the current through one of the loads and the two sinusoidal outputs are now 180° out of phase. Once again, the peak to peak amplitude is equal to the maximum voltage produced by the array and the switching frequency is proportional to the number sub-strings and the desired frequency of the output waveform.

The third waveform (wave C) is produced when both H bridge are used, and they are active only for half a cycle. The waveform will produce a sine and cosine wave function where the effective amplitude of the current is twice that of the maximum voltage of the array. Due to the increase in amplitude, the switching frequency will need to have doubled in order to maintain the same output frequency exhibited in waves A and B.

The fourth waveform (wave D) is a composite of the two where one output uses its H bridge for half its cycle while the other output does not use an H bridge at all. The result is an output wave that contains a fundamental frequency and an odd 1st harmonic with a DC offset.

The power producing properties of each waveform and potential circuits for extracting power will be discussed. The simplest arrangement is to drive the array so that it produces wave A and then connect each end of a centre tapped transformer to the outputs. The oscillating electric field will produce a single wave form with an amplitude equal to the sum of the inputs.

Producing Sinusoidal waveform

The control algorithm only requires a precision timer and knowledge of the sub-string voltage in order to produce a sinusoidal waveform. As the array can only produce voltages in discreet steps, the time at which the next 'step' is required can be simply be calculated from the desired frequency and the trigonometric equation describing the sine wave. To create a fast and responsive system, these switching times can be calculated off line and stored in a look up table. This means the whole system is essentially a time driven state machine, leaving the implementation extremely trivial.

As the switching sequence is controlled entirely by a programmable timer, it is possible to change the frequency of the output wave simply by altering the switching times accordingly. This means an appropriately sized array can produce waveforms suitable for any region in the world and even emulate marine and aviation AC sources. Another interesting yet unexplored feature is the ability to produce more complex power source waveforms such as composite, saw tooth and even tangential waveforms. Although this seems very unconventional in power electronics, just having the ability to produce such outputs highlights the arrays ability to provide avenues for future research.

Conclusion

This paper discusses the principles of AC synthesis through the direct switching of DC sources within a dynamic photovoltaic array. The switch circuitry is very simple to implement and control sequencing relies only on timing parameters that can be found in look up tables. With a sufficient ratio of sub-string voltage to sub-string granularity the device could potentially produce grid grade sinusoidal power without the use of a conventional inverter. The full paper will describe the operation of the system in detail and provide results to indicate its performance and capabilities.

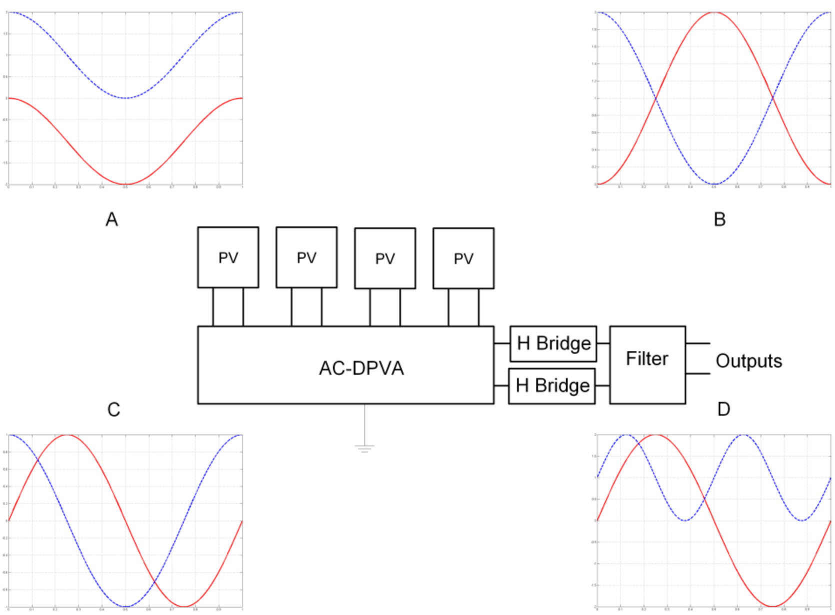

Figure 1: AC-DPVA Block diagram with four possible waveforms