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To cite this article: R Brindha et al 2018 J. Phys.: Conf. Ser. 1000 012042

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Application of interleaved flyback micro inverter in a grid connected system

R Brindha1, A Ananthichristy1, P U Poornima1, M Madhana1, S Ashok Rathish1, and Selvam Ragavi1

1EEE department, SRM University, Associate professor, EEE department, Saveetha University, UG students, EEE department, SRM University

Abstract: The two control strategies CCM and DCM have various effects on the loss distribution and efficiency and thus were studied for the interleaved flyback micro inverter concentrating on the loss analysis under different load conditions. The dominant losses with heavy load include the conduction loss and the transformer loss in case of the interleaved flyback micro inverter; whereas driving of gate loss, the turn-off loss in the transformer core loss and in the powermosfets are included in the dominant losses with light load. A new hybrid control strategy which has the one-phase DCM and two-phase DCM control reduces the dominant losses in order to improving the efficiency based on the load in wide load range is proposed here.

1. Introduction

Energy crisis has made a big interest in exploiting renewable resources for the past years. Photovoltaic sources are predicted to have a 30% increase in the upcoming years and contributes the biggest part on the electricity generation [1]. A micro inverter also known as a PV ac module, is becoming popular and also normally has a power range of about 200 W. The micro inverter includes higher efficiency in (MPPT) maximum power point tracking as well as lower manufacturing cost by mass production and safe along with simple installation [2].

Many topologies and control methods have been developed for the micro inverters. [3] and [4] provides information about the topologies of the single phase grid connected PV inverters. Provided by the PV panel a boost stage is usually used in order to boost the low voltage source. Here, [5] gives information about an AC module based DC bus. A rectified sinusoidal waveform is generated by the modulated boost stage and the rectified waveform is unfolded into the grid by using a (CSI) current source inverter which is explained in [6]-[9]. The efficiency is high under heavy load, but low under light load since no more than 90% efficiency is reported from the study.

Alternatively, the flyback inverter is commonly used for its following advantages as simple lower cost, simple structure and higher efficiency [10]. A simple two-stage approach is offered in [11]for the flyback dc/dc converter with H-Bridge (PWM) pulse width modulation inverter along with high frequency isolation. A high DC bus voltage permits capacitance for low de-coupling. Both the stages have high losses, due to operation at high frequencies, thus a single-stage flyback inverter with the centre-tapped secondary winding was presented in [12]-[15]. The transfers of energy to the ac side during a half-line period with two additional MOSFETs is done by the secondary windings. Here [16] and [17] presents the modulated flyback dc/dc converter followed by a CSI. The reduction in cost and conduction loss is provided by the SCRs. Further the efficiency is improved by soft-switching an
interleaved flyback micro inverter under continuous conduction mode (CCM) was presented in [18] and [19]-[21] adopts the technology of active clamp and synchronous rectifier. But, additional auxiliary circuit components are required and they provide higher complexity to the circuit. Thus an interleaved flyback micro inverter with the hybrid control scheme proposed by Emphases Technology [22] which includes the interleaved mode and quasi resonant mode is used. Either way a simple flyback mode or an interleaved flyback mode is applied depending on the output power of the PV panel during a half-line period.

Section II presents the analysis of the interleaved flyback converter and the difference between CCM and DCM. The control model and its principle of operation is provided in Section III. The hardware and software design is presented in section IV. The simulation results are also provided in Section V. Section VI acquaints about the experimental results and discussion. Section VII provides a brief conclusion.

2. Analysis of interleaved flyback converter

2.1 Interleaved Flyback converter

Interleaving involves connecting multiple flyback converters in order to meet the desired power density. Interleaving of high power flyback stages increases the ripple component of the waveform which would be proportional to the number of interleaved cells. This would result easy filtering. Through the usage of small size filtering elements Current in each cell has less peak but same amount of discontinuity. The interleaving in boost topology includes higher efficiency and reduction of input and output ripple. Most of the controllers when configured for the use of interleaved boost applications are used in buck applications. Here the interleaved boost design transforms into a powerful tool to manage current. With respect to energy saving, interleaved construction provides the only way to achieve design objectives. Fig.2 shows the block diagram of interleaved flyback Inverter.

Figure 1. Circuit

2.2 Modes of operation

There are basically two modes of operation for a converter they are (CCM) continuous conduction mode and (DCM) discontinues conduction mode. When both the modes are compared and investigated discontinues conduction mode has low amount of losses when compared to continuous conduction mode. So, we proceed on discontinuous mode of operation.

3. Proposed control model and operation

3.1 Proposed System

The main drawbacks of the grid connected pv systems are voltage regulations and dropping of power quality due to voltage flickering, hence, in our project we will use a closed loop through which the pulses are given to semiconductor devices with the help of the feedback given by the grid voltage. As a result error is rectified and power quality is enhanced.
3.2 Operation

Input to this circuit is fed through a solar panel (i.e., DC Supply). This supply is fed to the circuit through an input capacitor which helps in providing a constant dc supply to the converter circuit. Converter circuit consists of two switches S1 and S2 to which the pulses are given. When flyback switches are switched on, current flows to magnetizing inductance of a flyback transformer from PV in which energy is stored. During “on” time no current flows as output. Therefore energy is passed through the capacitor and inductor. When switches are off, in the form of current energy stored is transferred to the grid. To reduce the variations at the terminal voltage at the output of the flyback converter decoupling capacitor is placed. The sinusoidal modulated dc current at the right moment of the grid voltage back to ac is unfolded by a full bridge inverter. The two operations which are discussed here are boosting operation and inverting operation which will be discussed in detailed in hardware description.

4. Design procedure and implementation

The above fig.4 shows the control circuit of a closed loop circuit. The main components in the circuit are

4.1 PV module
4.2 Converter circuit
4.3 Inverter circuit
4.4 PWM module
4.5 MPPT

A. PV(Photovoltaic) system

The “photovoltaic” is a term consisting of photo; which defines light and voltaic, which defines the measurement value for the expression of electric field, or the potential difference. Photovoltaic has cells to convert sunlight into electricity. Sunlight is been converted into electricity through photovoltaic cells. According to quantum physics light is a particle and also a wave. The particles of light is referred to as photons. Photons do not have any mass which travel at speed of light. The photon energy depends on its wavelength (1/f) and the frequency (f), and we can be calculated by the Einstein's law as follows:

\[ E = h \nu \]

Where:
- \( E \) – represents photon energy
- \( h \) – represents Planck's constant \((h = 6.626 \times 10^{-34} \text{Js})\)
- \( \nu \) – represents Photon frequency

Generally in metals, electrons can either exist as free or as valence. Valence electrons are similar to the atom, while the free electrons are free to move. The energy which is \( > \) to the energy of binding is required for the valence electron to be free. Energy of binding is the energy required for an electron to cover an atom in any of the atomic bonds. The electron by collision acquires the necessary energy with the photon, in the case of the photoelectric effect. Free electrons gained by the photoelectric effect is also referred to as photoelectrons. A valence electron of an atom requires an energy to release itself which is called a “Work out” \( W_i \), and depends on the material type where the photoelectric effect has occurred. The equation describing this process is as follows:

\[ h \nu = W_i + E_{\text{kin}} \]

Where:
- \( h \nu \) - photon energy
- \( W_i \) - work out
- \( E_{\text{kin}} \) - kinetic energy of emitted electron

The previous equation(2) implies that only if the energy of photon is greater than the work output, the electron will be liberated from the bond. The photoelectric conversion in the diode is defined as the two differently doped semiconductor layers which lies within a boundary; one is a P-type layer (which consists of maximum number of electrons and holes), and the second one is an N-type (more number of electrons and less number of electrons). At the boundary between the N and the P area, there lies an electric field, which affects the holes and electrons generated and estimates the direction of the current.

![Figure 4 Energy generation in PV system](image-url)
The photoelectrons move in a specified direction due to the influence of electric field. Precisely in the impoverished area of PV junction (diode), the electric field is present in semiconductors. The process of conversion of valence electrons into free electrons is called as generation and this tends to result in the formation of cavity while the process where the free electrons fills up the empty space it is called as recombination. If the electron cavity pairs are far from the present state then, it is possible to combine them without the help of electric field. Photoelectrons and cavities in semiconductors are positioned at opposite ends to create an (emf) electromotive force. Thus the flow of current occurs and hence electricity is be obtained, when a consuming device is connected to such a system.

**B. Converter circuit**

In this circuit we use a dc to dc converter which helps in boosting the input voltage supplied which is done with the help of step-up transformer and semiconductor devices which will help in improving the efficiency. Here we use MOSFET as a semiconductor device. Converter circuit has an inductor which acts as a transformer.

**C. Inverter Circuit**

Converter circuit is connected to inverter circuit with the help of a dc link capacitor which will help in terms of providing a constant dc supply to an inverter circuit with the help of rectifying the ripple and provide a constant supply. After boosting the voltage by the converter circuit the boosted voltage is fed as input to the inverter circuit. Then inverter converts dc to ac for connecting to the grid. Even after inversion there present some amount of dc component at the inverter output so, we connect a filter at the output of inverter which removes the unwanted dc content from the inverter circuit and gives a sine wave as the output.

**D. PWM Module**

In order to obtain the output voltage with less error and obtain a pure sinusoidal wave we go for a closed loop operation. PWM stands for pulse width modulation which is defined as a process in which it regulates the on and off time of a semiconductor device. PLL(phase locked loop) is one type of PWM techniques. Here we use PLL technique(Fig.6) for closed loop operation.

\[ \text{Error signal} = \text{input signal} - \text{reference signal} \]
iii. Voltage control oscillator (VCO):
   It is used for generating output phase

- A phase locked loop is a control system which beget output signal in which the phase of an input signal is related with the phase.
- This electronic circuit has the following:
  i. Phase detector (PD):
     This component compares two input signals that is the input signal with the reference signal.
  ii. Low pass filter (LPF):
     The highest power transfer efficiency would change as the amount of sunlight varies resulting the efficiency of the system optimized. The power transfer efficiency would be the highest if the load characteristics changes. This load characteristics is defined as the maximum power point, which is the process to find the point and to keep the load characteristics there.

5. Simulation results and discussions
A. Open loop

Open loop consists of a dc source, converter and inverter circuit, filter and load. Here in the open loop, pulses for mosfet are provided with the help of signal generators.

![Figure 6 Open loop simulation](image)

![Figure 7 Input voltage](image)

iii. Voltage control oscillator (VCO):
   It is used for generating output phase

E. MPPT(Maximum power point tracking)
MPPT is a technique in which the turbines for the wind system and (PV) Photovoltaic solar systems are used for maximizing of power extraction under certain conditions. The solar cell efficiency
depends on the electrical characteristics of Output voltage and the amount of sunlight fall over the solar panels which also depends on the various elemental properties by that the panels are made.

Disadvantages

- **Accuracy**
  The system in inaccurate because they don’t have a feedback mechanism.

- **Noise Reduction**
  The disturbances occurring from external sources are difficult to remove because of the absence of feedback mechanism.

B. Closed loop

The main difference between the open and closed loop is the feedback path that rectifies the error signals. As stated earlier feedback path is given by PWM technique.

Advantages

- **Accuracy**
  As this system has a feedback mechanism and the error signal is sensed and fed as a feedback to the input. Hence it is very accurate.

- **Noise reduction**
  This system is highly protected from external noises.

As stated the main difference between the open and closed loop is the PWM pulses (adjusted on and off time period).
6. Experimental setup and results
   A. Hardware

   The hardware system of the proposed converter is implemented using a PIC micro-controller. The software system like MPLAB is used for the system design for coding the pulses in to the PIC controller. The power supply circuit is designed that will control the PIC and driver circuit to drive the pulses to the MOSFET.

   B. Software used

   - MPLAB
     MPLAB Integrated Development Environment (IDE) is a free, integrated toolset for the development of embedded applications on Microchip's PIC and dsPIC microcontrollers.

   C. Working

   Initially the hardware circuit is supplied with the help of solar panel connected to a battery (12V). The power generated by the solar panel which is mainly done by the conversion of sunlight into electricity is stored in this battery so here battery acts as a supply, moreover the sunlight. A 12V supply is fed to a mosfet with a step up transformer connected to in series. This step up transformer boosts the input voltage according to transformer turns ratio and supplies to the flyback circuit.

   For operation of semiconductor devices in the booster circuit should be given a triggering pulses. These triggering pulses are generated by controller circuit and driver circuit supplies those trigger signals to semiconductor devices. With those triggering pulses flyback converter boosts the supply voltage as per the turns ratio of the transformer and stores in the dc link capacitor.

   As we know that ac is used for household purposes those boosted dc voltage is fed to an inverter circuit where conversion of dc to ac takes place. Even though after inversion there presents some

![PWM pulses](image1)

![Hardware setup](image2)
amount of dc content in the output. So, to obtain pure ac output after the inversion is passed though LC filter. These filter removes dc content from the fed input and gives a pure ac output. Those obtained output will be greater than the input supply voltage. The obtained output voltage depends on various parameters like transformer turns ratio, duty cycle, inductance.

The below block diagram represents the generation of pulses by the control unit (i.e., PIC micro-controller).

![Figure 13 Controller circuit power flow diagram](image)

**D. Results**

**Input Voltage**

![Figure 14 Practical Input voltage](image)

Input voltage which we give is nearly 13V

**Output Voltage without filter circuit**

![Figure 15 Practical Output voltage](image)

Output voltage we obtained was 80V.
Output voltage after filter circuit

![Output voltage waveform](image)

Figure 16 Practical Output waveform

The output voltage rms value decreases after filter circuit because the filter circuit removes the dc component which is present even after inversion.

7. Conclusion

Energy is the most important source in today's world, the more the better. Renewable energy sources is beginning to boom and we need to make best out of it. In our project we worked on solar energy, which is the third most used energy source. Many methods are available to prevent the energy loss age and to increase the efficiency. The design guide lines of PV grid connected system along with a flyback converter and an inverter have been proposed in this thesis. Another feature is cost reduction for material from a new architecture of distributed dc-dc flyback converter feeding an inverter with a dc rejection controller. Then, the analysis and design guide lines have been verified through practical and theoretical tests. We hereby conclude that save energy and use it efficiently because today's wastage is tomorrow's shortage.

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