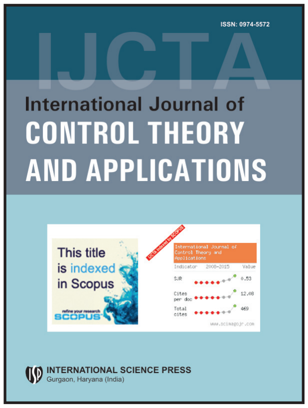

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An Interleaved High-Power Flyback Inverter in DCM for the Renewable Energy Sources

T.R. Premila[a]

[a]*Assistant Professor Department of Electrical and Electronics Engineering, Vels University, Pallavaram, Chennai. Email: premila.se@velsuniv.ac.in*

Abstract: A natural energy has grown in response to increased need of the environment. The use of solar energy in small electric power system applications will be increase largely when the cost of photovoltaic panels and the energy conversion equipment becomes economical for every user. Therefore, the objective of this paper is to develop a low-cost inverter system. For this purpose, an inverter system rated at 2KW is developed by interleaving of three flyback cells with added benefit of the reduced size of the passive filtering element. This paper deals a design of isolated grid-current inverter for photovoltaic applications based on interleaved flyback topology operated in discontinuous current mode (DCM) for residential application. A simulation model is developed in MATLAB/simulink.

Index Terms: Flyback Converter, Harmonics, Interleaved Converters, Photovoltaic Inverters.

1. INTRODUCTION

The solar energy is considered as one of the renewable source of energy and has a great potential to play an wide role of energy market of the world soon. Therefore, the research and the development in the solar technology field is in rise. However, the high cost of the technology limits its usage globally. Especially the low cost is greatly important for commercialization in small electric power systems that include the residential application. This paper proposes a low-cost inverter alternative to the existing high cost designs. The cost reduction in achieved using flyback topology operating in discontinuous mode(DCM).

The flyback topology is known to be the lowest cost converter among the isolated topologies since it uses the least number of components. This fact comes from the ability of the flyback topology to combine the energy storage inductor (the inductor in the buck-boost converter) with the transformer. In other type of isolated topologies, the inductor and the transformer are separate. While the inductor is responsible for energy storage, the transformer on the other hand is responsible for energy transfer while providing galvanic isolation. The combination of these two components in a flyback topology eliminates the bulky and the costly the energy inductor and therefore reduces the overall cost. Now the transformer is required to storage energy, which is not a typical characteristic of a power transformer. To distinguish this transformer from the conventional power transformers, it is called "flyback transformer."

As mentioned before, the choice of operation mode for the converter is DCM. The fundamental motivations for selecting DCM operation are summarized below.

1. It provides very fast dynamic response and a guaranteed stability for all operating conditions under consideration.
2. No reverse recovery problem. The diodes exhibit reverse recovery problems in CCM operation which cause noise, EMI problems, and additional losses. So, DCM operation eliminates all these complications.
3. Easy control. No need for a feedback loop for the control of the grid current.
4. No turn on losses.
5. Small size of the transformer.
6. Easy control. No need for a feedback loop for the control of the grid current.

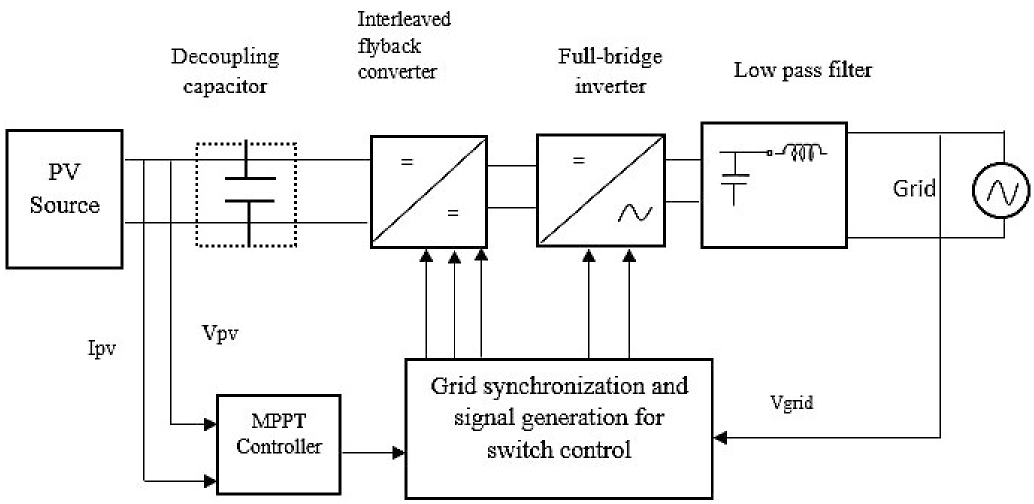

Figure 1: Block diagram of the proposed grid-connected PV inverter system based on interleaved DCM flyback converter topology

In conclusion, this study has developed and presented the technology in full detail to produce a grid-tied, isolated, and central type inverter based on the flyback converter topology at 2 KW.

For the flyback transformer to store energy, the magnetizing inductance must be reduced and typically, a large air gap must be inserted. Having to have a relatively large air gap results in large amount of leakage flux and so reduced coupling, and poor energy transfer efficiency.

Because of this reasons, he flyback converters are generally not designed for high power. The recommended use of flyback topology is limited below 200W. Nevertheless, if advanced design techniques are employed, the power limit to higher levels is to employ interleaving technique.

As mentioned before, the discontinuous mode of operation is preferred and used to simplify the control system, and to obtain always a stable system with fast dynamic response. The discontinuous currents in the DCM operation yield higher rms values compared to the currents in continuous current mode (CCM) case, and therefore more power losses are generated.

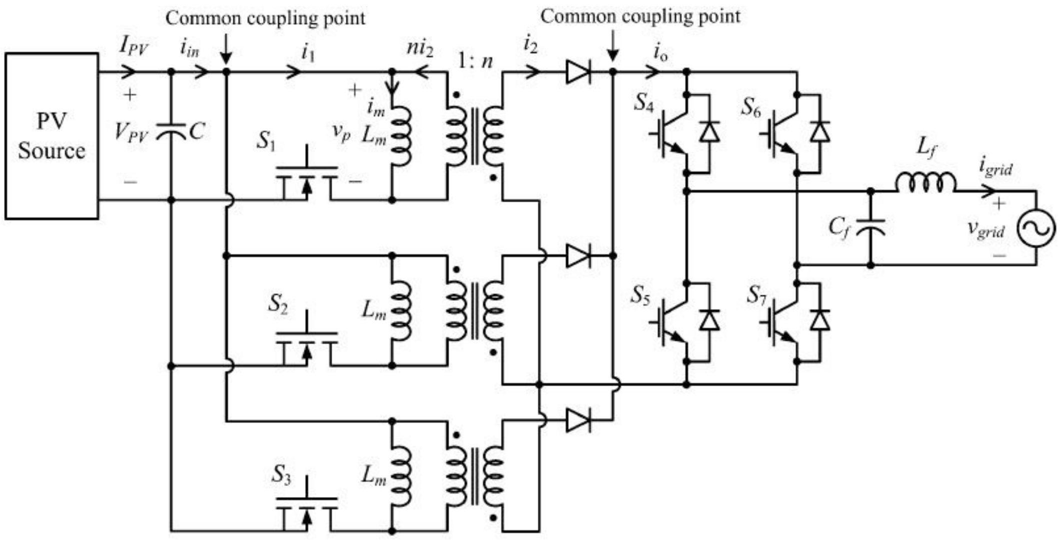

Figure 2: Circuit schematic of the proposed PV inverter system based on three-cell interleaved flyback converter topology

The interleaving technique can also be a solution to this problem. The results of earlier work based on the same topology where the primary objective was to prove the concept with a design at 1KW.

The remainder of the paper is organized as follows. Section II describes the converter topology. Section III performs the analysis of the converter and derives the design equations. Section IV presents the design of the converter in steps. Section V presents the controller design and VI give the simulation results, respectively. Finally, Section VII provides the conclusions.

2. CONVERTER DESCRIPTION

As shown in Figure 2, the PV source is applied to a three-cell interleaved flyback converter through a decoupling capacitor. Each flyback converter uses a metal–oxide–semiconductor field-effect transistor (MOSFET) for switching at the primary side, a flyback transformer, and a diode at the secondary side. The topology also should employ a full-bridge inverter and a low-pass filter for proper interface to the grid. When the flyback switches (s_1, s_2, s_3) are turned on, a current flow from the common point (the PV source) into the magnetizing inductance of the flyback transformers, and energy is stored in the form of magnetic field. During the on time of the switches, no current flows to the output due to the position of the secondary side diodes; therefore, energy to the grid is supplied by the capacitor C_f and the inductor L_f. When the flyback switches are turned off, the energy stored in the magnetizing inductances is transferred into the grid in the form of current. So, the flyback inverter acts like a voltage-controlled current source.

The converter is operated in DCM for easy and stable generation of AC currents at the grid interface. Such currents are shown in Figures 3 and 4 for a conceptual case. Specifically, Figure 3 shows the conceptual flyback converter input currents and Figure 4 shows the output currents.

The full-bridge inverter is only responsible for unfolding the sinusoidally modulated DC current packs into AC at the right moment of the grid voltage. Since the switches of the inverter are operated at the grid frequency, the switching losses are insignificant. Only conduction losses are concerned. For this reason, the bridge can use thyristor or even transistor switches for lower cost. However, for easy control also the availability in the laboratory for fast prototyping, we prefer using IGBT switches for this design.

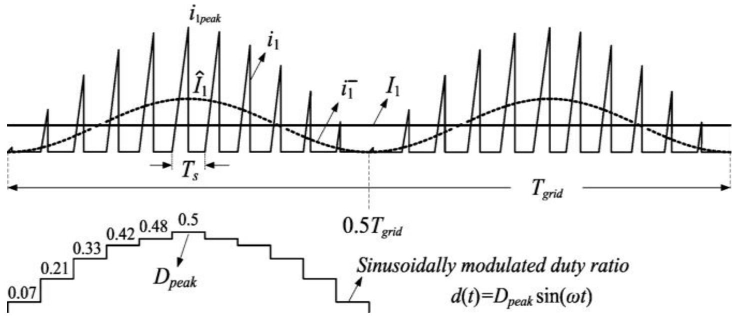

Figure 3: Instantaneous flyback converter input current (i_1), its instantaneous average (i_1) over one switching period, and the extended average (I_1) over one grid period, also the sinusoidally modulated duty ratio over one-half cycle of a grid period

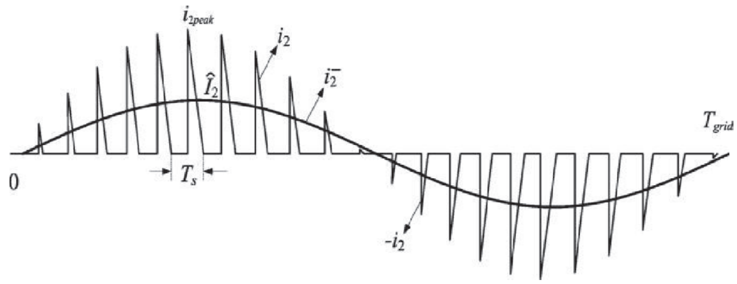

Figure 4: Instantaneous flyback converter output current (i_2) after unfolded by the full-bridge inverter and its instantaneous average (i_2) over one switching period.

3. CONVERTER ANALYSIS

The analysis of the converter is performed based on the circuit schematic given in Figure 2 and only considers the first flyback cell. And it is done over one switching period when both the grid voltage and the duty ratio are at their peak values. Consequently, Figure 5 shows the control signal for the flyback switch, flyback transformer primary voltage (v_p), and magnetization current (i_m) with its components and over the selected switching period where the duty ratio is at its peak (D_{peak}). Note that the waveforms represent discontinuous current mode of operation.

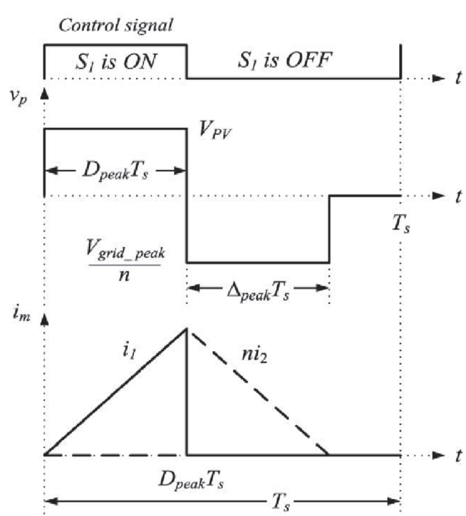

Figure 5: Flyback switch control signal, flyback transformer primary voltage (V_p), and magnetization current (i_m) with its components i_1 and ni_2 over the switching period when the grid voltage is at its peak.

4. CONTROLLER DESIGN

A. Power Processing Requirements

For the power processing part, the input side requirements are determined by the choice of the PV panel used. The developments in PV technologies focus on improving the conversion efficiency of the PV cell and on reducing the system cost. Various PV cell technologies, based on different materials and fabrication methods are currently under active research. These include silicon based technologies (in the mono-crystalline, poly-crystalline, amorphous and micro-crystalline forms), and technologies based on III-V compounds, organics, nanotechnology and multi-junctions.

Despite all the exciting progress in the research laboratories around the world, most of the commercial PV products at present are still based on mono-crystalline and poly-crystalline silicon. It is believed that they would continue to dominate the PV market for at least another decade. This belief is further strengthened by the recent plummeting of the cost of silicon PV modules.

B. Power Control Requirements

Overall, the power control part oversees controlling the power processing part to ensure the requirement for operating at the MPP imposed by the PV module and requirements for the grid connection specified by international standards.

C. MPPT Requirement

The Power point tracker is a high frequency DC to DC converter. They take the DC input from the solar panels, change it to high frequency AC, and convert it back down to a different DC voltage and current to exactly match the panels to the batteries. MPPT's operate at very high audio frequencies, usually in the 20-80 kHz range.

In most DC to DC converters, this is strictly an electronic process - no real smarts are involved except for some regulation of the output voltage. Charge controllers for solar panels need a lot more smarts as light and temperature conditions vary continuously all day long, and battery voltage changes.

MPPT's are most effective under these conditions:

- Cold weather - solar panels work better at cold temperatures, but without a MPPT you are losing most of that. Cold weather is most likely in winter
- The time when sun hours are low and you need the power to recharge batteries the most. Low battery charge - the lower the state of charge in your battery, the more current a MPPT puts into them - another time when the extra power is needed the most. You can have both conditions at the same time.

D. Long Wire Runs

If you are charging a 12-volt battery, and your panels are 100 feet away, the voltage drop and power loss can be considerable unless you use very large wire. That can be very expensive. *Selection of MPPT Controller*

The two methods of MPPT include perturb & observe (P&O) and incremental conductance (ICC). Either algorithm can be applied to the microcontroller, based on different conditions.

Perturb and observe is a method where the controller adjusts the voltage by a small amount from the array and measures power. If the power increases, more adjustments in that direction are tried until power no longer increases. This is notably the most common method in MPPT. This method can result in oscillations of power output. It is often referred to as the hill climbing method, since it depends on the rise of the curve of power against voltage below the maximum power point, and the fall above that point.

Incremental conductance (ICC) is a method where the controller measures incremental changes in array voltage and current to predict the effect of a voltage change. ICC requires more computation in the controller, but it can track changing conditions more rapidly than the P&O method. It can produce oscillations in power output, like the P&O method. ICC utilizes the incremental conductance (dI/dV) of the PV array to compute the sign of the change in power with respect to voltage (dP/dV).

E. Perturb & Observe

The P&O algorithms are widely used in control of MPPT thanks to their simple structure and reduced number of necessary measured parameters. The flowchart implementation of P&O method is given in Figure 7. As the name implies, the concept behind of this method is based on observation of PV array output power and its perturbation by changing the current or the voltage of PV array operation.

The algorithm increments or decrements continuously the reference voltage or current based on the previous value of power until reaches the MPP. When dP/dV > 0 and the operating voltage of PV array is perturbed in a specific direction, it known that perturbation moves the operating point of PV array to the MPP.

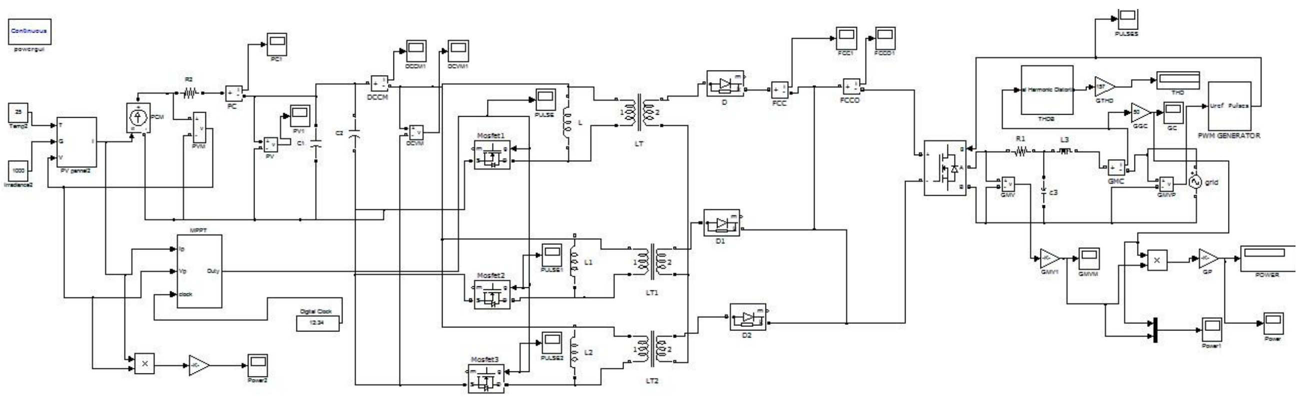

Figure 6: MATLAB model of the proposed PV inverter system including the power stage and the controller

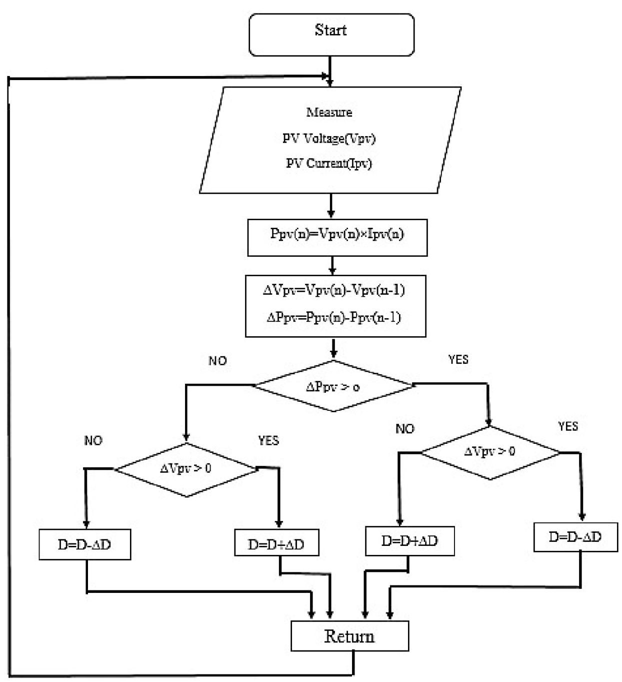

Figure 7

P&O method will then continue to perturb the PV voltage in the same direction. When dP/dV < 0, the perturbation moves the operating point of PV array away from the MPP and the P&O method reverses the direction of the perturbation.

Although this method can result in oscillation of power output. It is referred to as a hill climbing method. Because, it depends on the rise of power against voltage below MPP and above MPP. Figure 7. Perturb & observe algorithm implemented in the controller.

F. Grid Requirement

When the utility grid is down due to a fault or a scheduled maintenance, 'Grid Monitor' should be able to detect the situation and cut down the power from microinverter to provide anti-islanding function. When the grid condition is normal again, the grid monitor assists in restarting the inverter and reconnecting to the grid. Besides, the grid monitor also helps in synchronizing the inverter voltage waveform with the grid voltage waveform under normal operating conditions. It is expected to be working all the time even when the inverter is stopped. This allows it to wake the inverter up when the grid returns to normal. Power quality requirement is fulfilled by the main controller. It is required that the total harmonic distortion (THD) in injected current, shall be less than 5% at the same PCC. In addition, each individual harmonic shall be less than a specified level. Due to IEC 61727, the micro-inverter is not required to adjust the power factor. But it shall operate at a power factor above 0.9 when the output is greater than 50% of rated inverter output power.

5. SIMULATION RESULTS

Before the implementation step, comprehensive simulations are done to verify the design, also to determine some of the hardware requirements. For example, current ratings of the capacitors, inductors, cables, and so on can be easily determined from the simulation results. It is hard to determine RMS ratings by means of only analysis since the current through these elements include several components with different frequencies. Figure 6 shows the model used during the simulation studies.

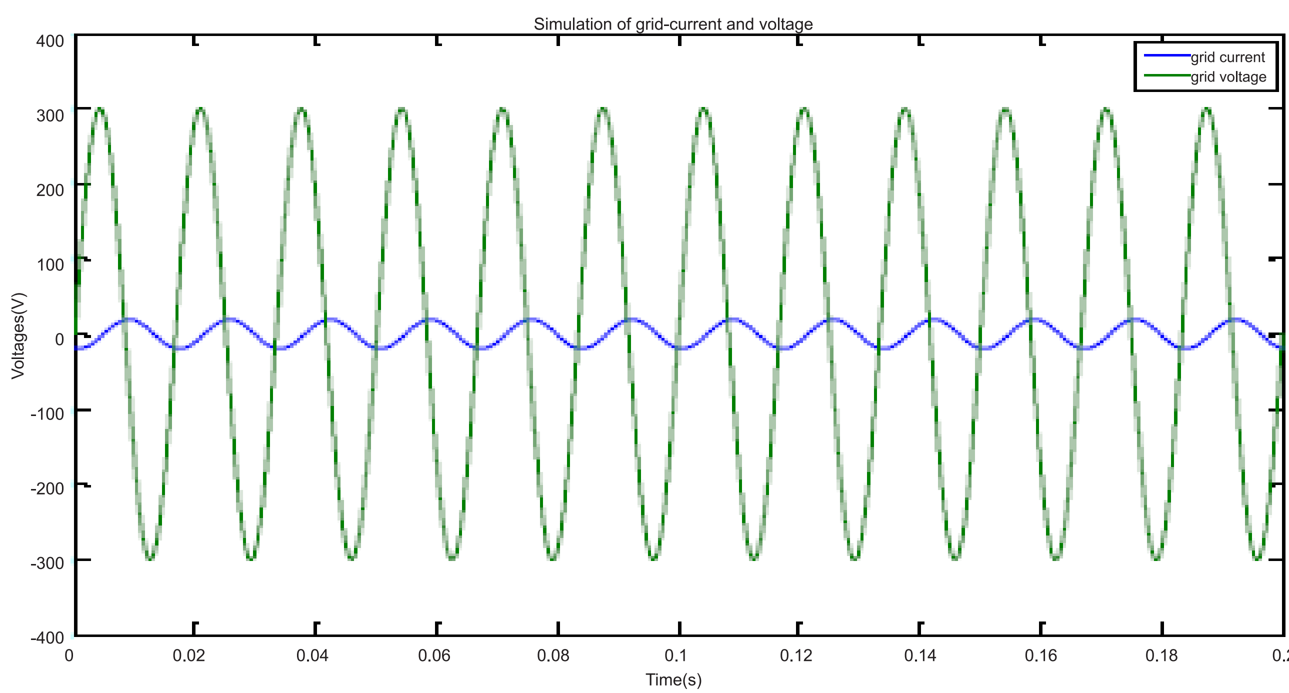

Figure 8: Simulated waveforms of the grid voltage and current

The top trace the peak value of the duty ratio (also the current modulation ratio) generated by the P&O MPPT algorithm for the simulated PV module output power and the power delivered to the grid. Based on these results, it can be concluded that the simulated MPPT algorithm works successfully and achieves a tracking performance of 99.33% at the maximum Sun. Moreover, the tracking time is less than 0.1 s. In addition, Figure 9 shows the simulated waveforms of the grid voltage and current. The waveforms demonstrate the success of the controller and the DCM mode flyback topology in achieving the high-quality energy transfer into the grid. The grid current has 3.9% THD under this ripple condition. Moreover, it is verified via simulations that if the value of the decoupling capacitor is increased, the THD reduces almost proportionally. Therefore, if the THD value somehow exceeds the 5% requirement during the experiment, the decoupling capacitor is going to be resized accordingly; otherwise, it is going to be maintained at the selected value.

6. CONCLUSION

A central type photovoltaic inverter for small electric power system applications rated at 2 kW is implemented based on the interleaved flyback converter topology. The 2kW power level is achieved by interleaving of three flyback cells. The flyback topology is selected because of its simple structure and easy power flow control with high power quality outputs at the grid interface. Also, the THD of the grid current is measured as 4.42% and the power factor is 0.998, which are confirming the high-power quality interface to the grid. Consequently, it is demonstrated that interleaved flyback topology is practical at high power as a central type PV inverter, which is the main contribution of this study. Furthermore, the performance of the proposed system is comparable to the commercial isolated grid-connected PV inverters in the market, but it may have some cost advantage due to its topological benefit.

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