IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 11, Issue 6 Ver. I (Nov. – Dec. 2016), PP 79-86
www.iosrjournals.org

Automatic Monitoring and Interleaved Flyback Inverter for PV Applications

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Abstract: *The utilization of solar energy in proper ways offers huge potential for natural resources, economy and for the expansion of renewable energies on the road to a future oriented energy supply. The growing importance of power consumption in today's appliances leads to new research works on the converter area .The dc-dc converters primarily strive for efficiency , with new technologies playing a role to achieve that goal .The project paper demonstrates analysis and design of converter systems to develop a high efficient dc-dc converter. Efficiency is an important factor while considering dc-dc converter characteristics. It affects the physical package sizes of both power supply and the entire system and has direct effect on the system's operating temperature and reliability .A desired converter should be small and light weight with low system cost. The paper introduces an efficient flyback converter for PV applications. The flyback topology has a benefit to work under high power with reduced cost and size of working elements .The use of three interleaving cells in flyback topology enhance its use under high frequency applications with reduced size of filtering elements . It is demonstrated that the proposed flyback system is extremely good in performance*
Keywords - *PV, Flyback topology, MPPT, Power harvesting, Power quality.*

I. Introduction

The solar energy is considered as one of the most renewable and freely available energy sources. In our new developing world it plays a greater role. Now a day it is not widely used because of the greater implementation cost. The implementation of usual inverter is very costly. But here we use flyback converter. In this converter both inductor and transformer are combined and thereby reducing the size and cost. So this paper mainly concentrates on the effective use of solar energy in minimum cost. Here advanced method is employed in single stage flyback converter in order to operate at high power. Furthermore interleaving is provided. The added benefit of interleaving is that the frequency of the ripple components (undesired harmonics) at the waveforms are increased and so ripples can be easily removed and reducing number of passive filter used.

II. PV Panel

Solar Photovoltaic panels constitute the solar array of a photovoltaic system that generates and supplies solar electricity. A single solar module can produce only a limited amount of power; most installations contain multiple modules.Solar cells produce direct current electricity from sun light which can be used to power equipment or to recharge a battery. The hardware involves a dedicated structure of PV panel.

2.1 Design of PV Stage

An ideal solar cell can be modelled by a current source in parallel with a diode, in practice no solar cell is ideal and so a shunt resistance and a series resistance component are added to the model. The characteristic equation has a common application such as nonlinear regression to extract the values of respective parameters in equivalent circuit. It is on the basis of their combined effects on solar cell behaviour. The light generated current and reverse saturation current get multiplied by the N_P.

Equation governing the voltage current characteristic of a solar cell is given as:

$$I = N_p I_{ph} - N_p I_s \{\exp q \frac{(v+IR_{sm})}{N_s K T_c A} - 1\} \qquad (1)$$

Where,
q: Electron charge = 1.6 × 10-19C
A: Ideality Factor = 1.6
k:Boltzmann Constant = 1.3805 × 10-23J/K
Is: Dark current/cell saturation current
Iph: Photoncurrent/light generated current
Rsm: Solar cell series resistance (Ω)

III. Maximum Power Point Tracking

Maximum power point tracking (MPPT) is a technique in photovoltaic (PV) solar syatems to maximize output. It is the purpose of the MPPT system to sample the output of the PV cells and apply thr proper resistance (loads) to obtan maximum power for any given environmental conditions . MPPT devices are typically integrated into an electric power converter system that provides voltage or current conversions ,filtering and regulation for driving various loads such as batteries. MPP (Maximum power point) is the product of the MPP voltage (V_{mpp}) and MPP current (I_{mpp}).

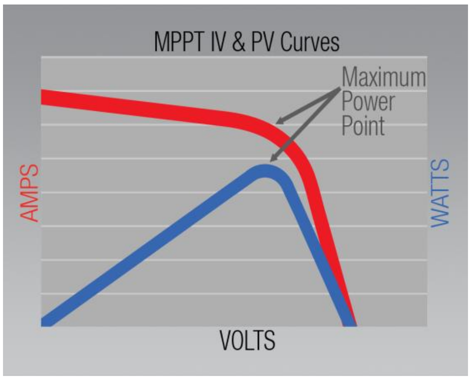

Fig.1 I-V and P-V characteristics

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.

3.1 Method Selection and Control System Design

- The Perturb and Observe (P&O) method is selected as the MPPT algorithm because of its implementation simplicity. Based on the measured I_{PV} and V_{PV} values, the MPPT block generates the peak value of the duty ratio information.
- (D_{peak}) in order to regulate the magnitude of the grid current. The signal generated by the MPPT block in this application regulates the magnitude of the grid current.

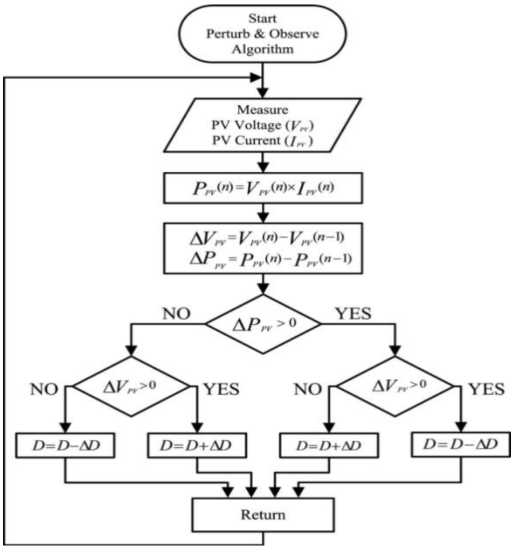

Fig.2 P&O Algorithm implemented in the Controller

- In the design of ATMEGA microcontroller firmware, the PWM interrupt is utilized and the controller waits for the interrupt. When the interrupt is generated, the PV voltage and current (V_{PV} & I_{PV}), Grid voltage (V_{grid}) are registered. Further followed by MPPT algorithm (sets D_{peak}).

The figure 2. Showsflowchart P&O algorithm .Besides the magnitude regulation for maximum power transfer; the controller should achieve synchronization of the current with grid voltage and a wave shape that is sinusoidal.

IV. Interleaved Flyback Converter

The flyback converter is the lowest cost converter among the isolated topologies since it uses the least number of components. This advantage arises from the ability of the flyback topology combining the energy storage inductor with the transformer. This eliminates the bulky and costly energy storage inductor and thus achieves a reduction in cost and size of the converter. The implementation of high power flyback converter requires large air gap. As a result in the reduction of magnetizing inductance with low leakage inductance and also causes large leakage flux and poor coupling with poor energy transfer efficiency. The interleaving of flyback converter stages facilitates its use in high power applications with an added benefit of easy filtering of the ripple components or using smaller sized filtering elements. The switching frequency of each flyback cell is 40 kHz. The choice of operation mode for the converter is discontinuous current mode (DCM).

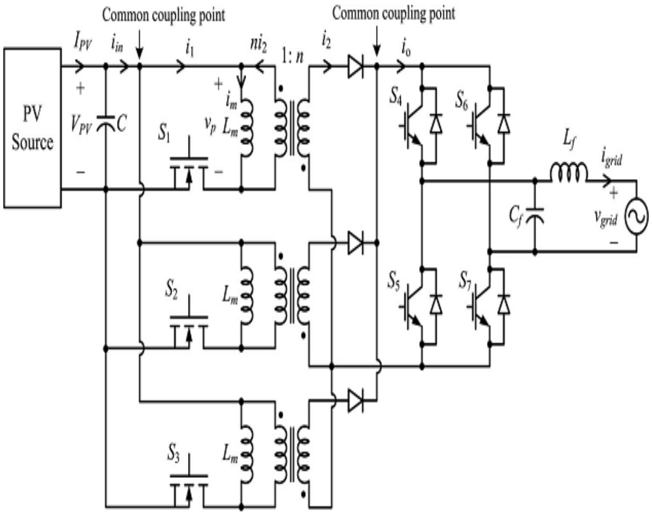

Fig.3 Proposed PV Inverter Three Cell Interleaved

4.1 Flyback Transformer

A flyback transformer is multiwinding coupled inductor where energy is stored. Inductor design depends greatly on the inductor current operating mode.

- Discontinuous inductor current mode: when the instantaneous ampere-turns (totaled in all windings) dwell at zero for a portion of each switching period.
- Continuous inductor current mode: In this mode total ampere-turns do not dwell at zero (although the current may pass through zero).

The choice of operation mode for the converter is discontinuous current mode (DCM).

4.2 FlybackTransformer Design

The flyback transformers have to store large amount of energy and then transfer it to the output through magnetic coupling at every switching cycle.When inductors are designed for the discontinuous mode, with significant core loss, the total loss is at a broad minimum when core and winding losses are approximately equal. In order to store and return energy to the circuit efficiently and with minimal physical size, a small non-magnetic gap is required in series with a high permeability magnetic core material.

Table I

Design parameters	Specifications
Maximum power output(W)	60
PV voltage(V)	6
Duty ratio (D_{peak})	0.5
No. of interleaving cells(n)	3
Turns ratio(N)	1:10
Magnetic inductance(L_m,μH)	9.2

4.3 Inductance Calculation

Several methods are in common use for calculating inductance:

Discrete gap length l_g:

$$L=\frac{\mu_0 N^2 A_g}{L_g} * 10^{-2} \quad (2)$$

(3)

$$l_g = \frac{\mu_0 N^2 A_g}{2} * 10^4 \quad (3)$$

Inductance factor A_L:

$$L = N^2 A_L nH \quad (4)$$ (4)

From the duty cycle D, transformer turns ratio, n, is calculated according to the relationship:

$$n = \frac{V_{in}}{Vo} * \frac{D}{1-D} \quad (5)$$ (5)

$$D = \frac{nV_0}{V_{in} + nV_0} \quad (6)$$ (6)

Where
L: inductance in Henry
l_g: discrete gap length
A_g: corrected gap area
D: duty ratio
N: transformer turns ratio

The next major objective in the design of the flyback transformer is to obtain the lowest leakage inductance.Using 6VforV$_{PV}$, 40kHzfor f$_S$, 3for n$_{cell}$ and0.5forD$_{peak}$ andthepanelpower(P$_{PV}$) as18W andthemagneticinductancebecomes9.2µH. It can be made possible by reducing the number of winding layers so that less space between the layers. The low-voltagewinding use 20 turns and the high-voltage winding uses 210 turns to get the turns ratio of 1:10.The switching frequency (f_s) is selected as 40KHzin order to achieve high efficiency along with smaller sized magnetics.

V. Driver Circuit –Tlp250

TLP250 is suitable for gate driving circuit of IGBT or power MOSFET. It has an input stage, an output stage and a power supply connection. It is used for optical isolation and amplification.

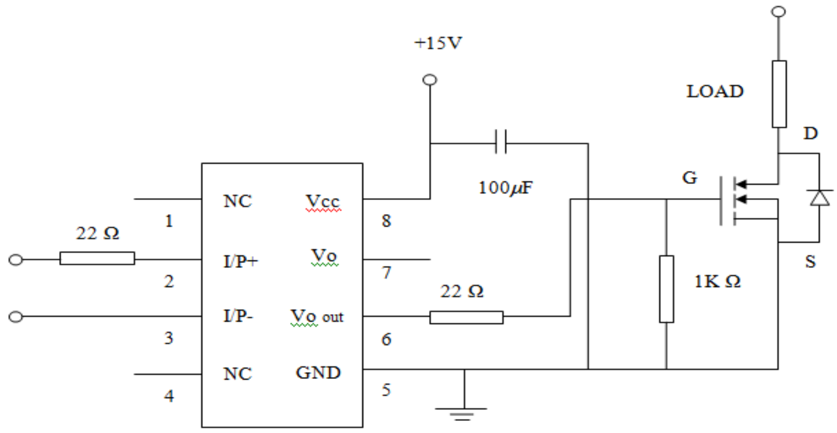

Fig.4 Circuit Diagram of TLP250

A capacitor of 100µfarad is used at the output of TLP250; this capacitor is called strip capacitor, which is used for dv/dt protection. 22Ω resistor is used for current limiting. The protection of gate source is made possible by using a 1kΩ resistor.

VI. Single Phase Inverter

The output DC from the flyback converter is transferred to the primary part of the inverter section. The inverter is a single phase inverter consisting of four MOSFETS as switching device. The demand of the load by the PV source to deliver fluctuating power causes voltage ripple in the single phase PV inverters. In addition, the voltage drop across the secondary side diodes and MOSFETs are part of nominal switch voltage. Only conduction losses are concerned, and associated high turn –off losses. So, the choice of switching device is important and MOSFET is selected which has low voltage ratings with much lower on-state resistance. The filter capacitor, C_f placed after the Full bridge inverter a shown in fig.3 .But it is contrary to place the capacitor before the inverter section. Thus it is possible to reduce the parasitic inductance since the area is minimized. Both ways have benefits , one could decide the right place for the capacitance based on the layout preference.

VII. Simulation and Hardware Results

7.1 Simulation Result

The hardware requirements of certain section can be determined through the comprehensive simulations. It is also used to verify the design. The current ratings of capacitor, inductor and so on can be easily determined from the simulation results. It is hard to determine RMS rating by means of only analysis since the current through these elements include several components with different frequencies. MATLAB Simulink platform is used for the design and analysis of the system.

The final simulation is the integration of different sections such as PV system, MPPT, flyback converter and inverter. The systems are further divided to sub systems.

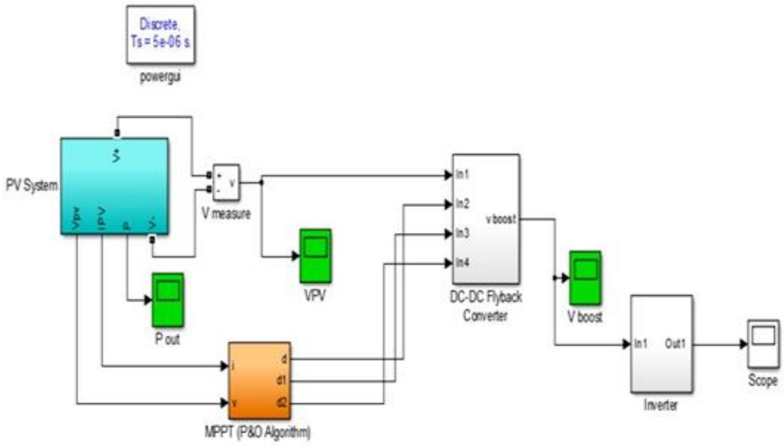

Fig 5. MPPT simulated flyback –inverter system

Based on the irradiance level, output parameters changes. P-V and I-V characteristics are simulated and shown in Fig.6. and Fig.7. In order to ensure optimum operation the maximum power point (MPP) tracker is inserted between the solar module and the load. The flyback converter which contains high frequency switch providing a matching between the load and the solar module. The maximum power output of the panel is shown in Fig 7.

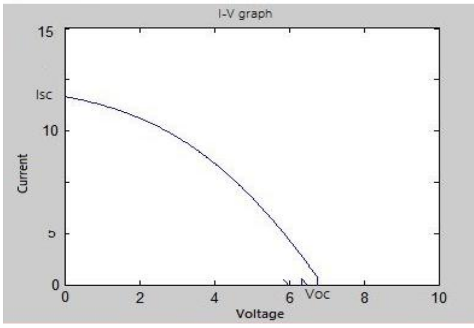

Fig 6. I-V characteristic

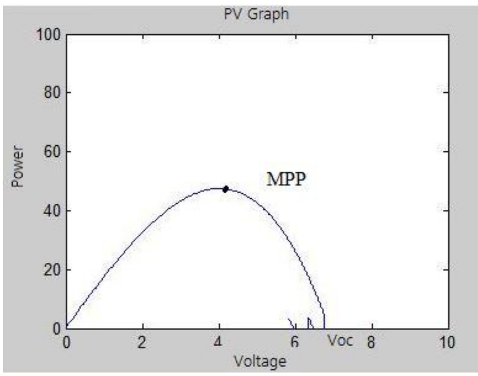

Fig. 7. P-V characteristic

The flyback converter boost the voltage and the output obtained is 54 V in the simulation. The converter waveform is shown in fig 8. This output is fed to the H-bridge inverter for unfolding and to obtain AC.

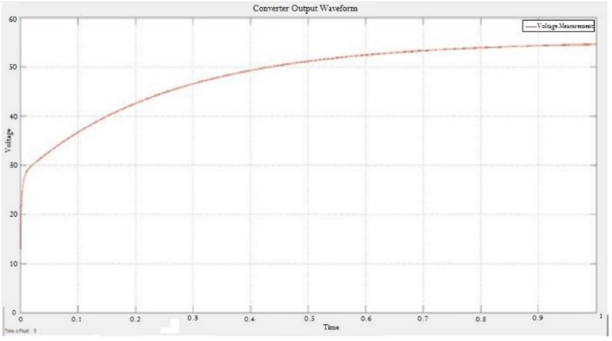

Fig 8. Converter output waveform

The output voltage waveform of ideal inverters should be sinusoidal ,but in reality the waveforms of inverters are non-sinusoidal and contain certain harmonics .Harmonic is a sinusoidal voltage and current at frequencies that are integer multiple of main generated or fundamental frequency .Harmonic distortion levels can be characterized by the complete harmonic spectrum with magnitudes and phase angles of each individual harmonic component .In pulse width modulated(PWM) inverters .The input DC voltage is essentially constant in magnitude and AC output voltage has controlled magnitude and frequency.Therefore the inverter must control the control the magnitude and frequency of output voltage .This is achieved by PWM of inverter switches .Fig. 9 shows the inverter pulses.

Prototype circuit of the proposed interleaved high power flyback converter rated at 60W was built to evaluate the real time performance.

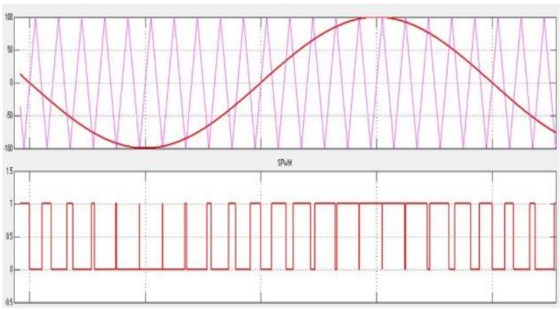
Fig.9. SPWM gate pulse

The output voltage waveform of ideal inverters should be sinusoidal, but in reality the waveforms of inverters are non-sinusoidal and contain certain harmonics .Harmonic is a sinusoidal voltage and current at frequencies that are integer multiple of main generated or fundamental frequency .Harmonic distortion levels can be characterized by the complete harmonic spectrum with magnitudes and phase angles of each individual harmonic component. In pulse width modulated (PWM) inverters. Fig.10 Simulated inverter output waveform. The inverter can be operated by controlled turn ON and turn OFF semiconductor devices such as BJT, MOSFET, IGBT and others. In the proposed system MOSFET is used as the main power control devices .The output waveform of simulated output is shown in the fig10. The MOSFET is preferred for lower voltage, power ratings and application that require high efficiency and high switching frequency.

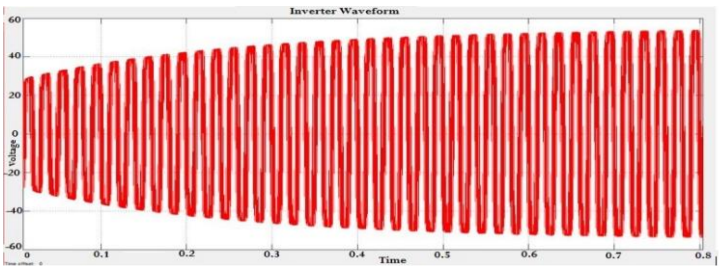

Fig.10. output waveform of inverter

7.2 Hardware Result

A prototype circuit at rate power was built to evaluate the real time performance of the proposed inverter system as shown in Fig 11. The major components used in the prototype circuit are Flyback MOSFET, Flyback diode, Flyback transformer, H-Bridge inverter components, TLP 250 driver circuit and ATMEGA 16 microprocessor.

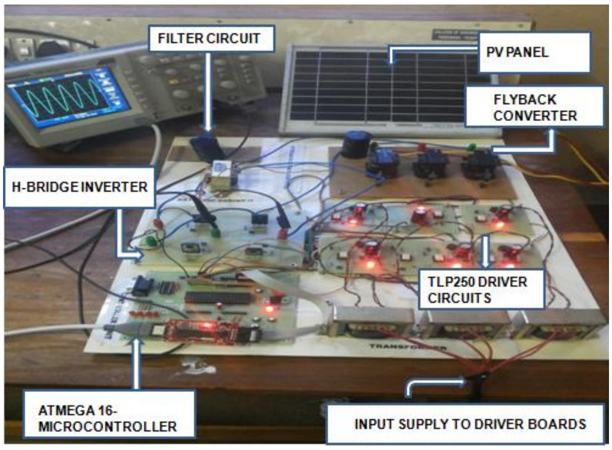

Fig.11. Experimental setup of proposed PV-inverter system

As seen in Fig.11, the power stage is constructed using high quality printed circuit board (PCB) technology in order to reduce losses and parasitic inductances. The traces on the PCB are made 100 micrometer thick and wide for high RMS current carrying capability.

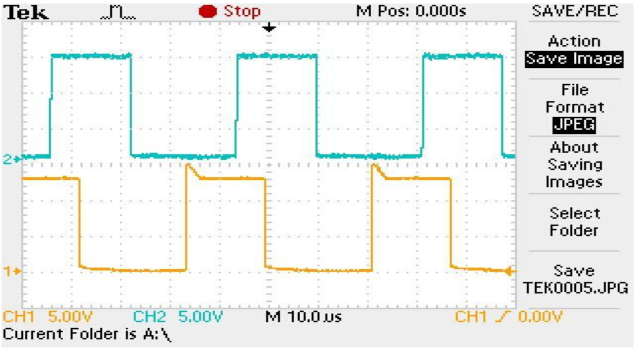

Fig.12. Phase shifted trigger pulse for Flyback converter MOSFETS

The pulse may show sudden peak point at the ON time period and it may be due to the magnetic interference, external temperature condition or noise in the circuit

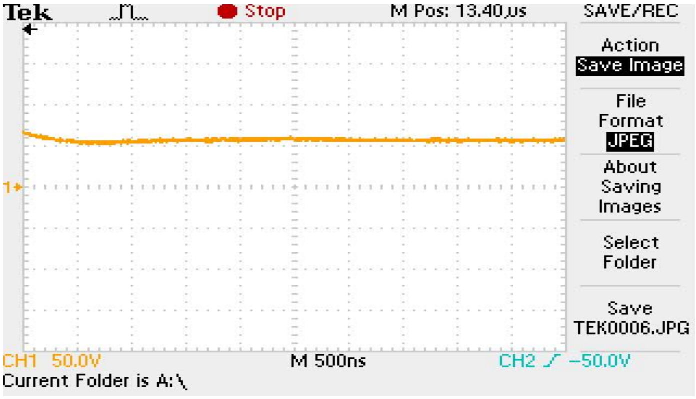

Fig.13. Output waveform of flyback converter

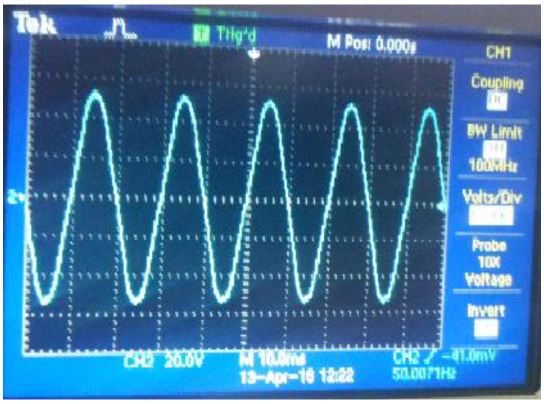

Fig.14. Output waveform of inverter

The measured efficiency of the proposed system (88.3 %) is comparable to the two stage schemes where the MPPT stage is generally a boost converter followed by an isolated inverter. The power losses are determined for each component. The major losses are the MOSFET turn-off losses, conduction losses, and the transformer core losses. The performance of the individual flyback cells as far as the efficiency is concerned is slightly better.

VIII. Conclusion

A central type photovoltaic inverter for small electric power system applications rated at maximum power of 60 W is implemented based on the interleaved flyback converter topology. The 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. The experimental results prove the successful operation of the inverter and compliance to the specifications. The inverter current, with High Power quality (PQ), better efficiency (88.3%) and reduced ripple (7.4%) are obtained. The system covers all economic concerns with good performance characteristics.

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