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A Solar PV Based Multistage Grid Tie Inverter

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Abstract

The inherent advantage of fuel less and maintenance free energy production from solar photovoltaic makes it a very important source of energy. For harnessing power from the solar photovoltaic (PV) cell/array and to supply it to the utility grid, dc to ac inverters is needed. The conventional line commutated dc-to-ac inverter has square shaped line current which contains higher order harmonics whereas PWM based inverters employing IGBT/ MOSFET are less reliable and has low power handling capability. Moreover, a dc-to-dc converter is generally employed along with the inverter circuit to operate the solar PV array at maximum power point. It adds to the cost, which increases with the size of the system. This paper describes a multistage series converter topology for solar PV based grid tie inverter with low harmonic in line current and inbuilt maximum power point tracking (MPPT) features. The developed prototype has been experimentally tested and verified.

Keywords: Multistage converter, Grid tie inverter, Maximum power point tracker (MPPT), Total harmonic distortion, photovoltaic system.

1. Introduction

The continuously increasing energy demand and consumption has overloaded the distribution grids as well as the power stations, thereby having a negative impact on power availability, quality and security. One of the solutions for overcoming the problem is the distributed generation (DG) system [1]-[3]. DG systems using renewable energy sources like solar, wind or small hydro have the advantage of producing power in close proximity to where it is consumed. There by eliminating the losses due to transmission. Many renewable energy technologies today are well developed, reliable, and cost competitive with the conventional fuel generators. The cost of renewable energy technologies is on a falling trend as demand and production are being increased [4], [5]. The harvest of solar energy using solar photovoltaic (PV) cells has several advantages for instance clean, unlimited supply and its potential to provide sustainable electricity in area not served by the conventional power grid. Nevertheless, a PV system is still much more expensive than traditional energy sources, due to the high manufacturing costs of PV panels. However, the energy input, the light from the sun, is freely available almost everywhere [3]-[6]. Additional advantage of PV system is, it has no moving parts which makes it robust. It has a long lifetime and low maintenance requirements, and most importantly, it offers environmentally friendly power generation. The solar energy produces the dc power, and hence power electronics is required to convert dc power into ac power. There are two types of the solar PV energy systems: stand-alone system and grid-tie system [1]. Both systems have several similarities, but are different in terms of control functions. The stand-alone system is used in off-grid application with battery storage. Its control algorithm must have an ability of bidirectional operation, which is battery charging and converting dc into ac [7]. The grid-tie inverter converts dc power into ac power and simply transfers electrical energy directly to power grid. It utilizes a dedicated inverter for this purpose [8], [9].

Multi-stage inverters have drawn increasing attention in recent years, especially in the distributed energy resources area. Several renewable energy sources (fuel cells, solar PV cells, wind turbines or micro turbines) can be easily connected through a multi-stage inverter to feed a load (off-grid) or interconnect to the ac grid (grid-tie) without voltage balancing problems [10]-[12]. Moreover, multi-stage inverters have a lower switching frequency (mains frequency) than the standard PWM inverters (several tens of KHz) and thus have reduced switching losses. The line current waveform of multi-stage inverter is stepped shaped resulting in reduced harmonics compared to a square-wave inverter.

The electrical power supplied by a solar PV cell depends on many extrinsic factors, such as temperature and insolation level. The peak value of panel power increases with insolation and decreases with ambient temperature. The complex volt-ampere characteristic of the PV panel requires the use of harvesting techniques which is called maximum power point tracking (MPPT). With the help of duty ratio control of a dc-to-dc converter, the solar PV panel voltage is kept at the maximum power point (MPPT) of the solar PV panel, irrespective of the variation of temperature and insolation. Thus the solar PV panel delivers the maximum power. However, the values of both panel voltage and current vary corresponding to the variation of insolation and temperature. These values also correspond to a particular load resistance, which is equal to V/I as specified by ohm's law. The power (P) is given by $P=V*I$. A PV cell has an exponential relationship between current and voltage, and MPP occurs at the knee of the curve where $dP/dV=0$. At this point the characteristic resistance of the PV cell becomes equal to the load resistance (Fig. 1).

MPPT utilize some type of control circuit or logic to search for this point and thus to allow the converter circuit to extract the maximum power available from a cell [13]-[22]. Several harvesting schemes using microcontrollers or digital signal processors (DSP) for tracking MPP based on various control strategies have been proposed for solar grid-tie inverters [20]-[22]. All the above methods regulate the input PV voltage or current in operating the system at MPP. Therefore, an additional stage of conversion is needed and an additional dc-to-dc converter becomes necessary. Thus the overall efficiency of the system reduces.

Interfacing the ac grid involves two major tasks. One is to ensure that the PV array is operated at the MPP. The other is to inject a sinusoidal current into the grid with lowest total harmonic distortion (THD).

This paper presents a multistage inverter topology to eliminate the shortcomings of a conventional inverter by improving the wave shape of the line current. A control algorithm is proposed to do away with the dc-to-dc converter from the MPPT circuit. The prototype for the topology has been developed and MPPT scheme experimentally verified. In the proposed method, the switching angle of inverter itself controls the power flow which lies around MPP. Due to the absence of dc-to-dc converter the overall efficiency of the system increases and the cost of the system decreases.

2. Proposed topology

The proposed topology is shown in Fig. 2. It has two-stage converter in which two converters are connected in series at the secondary terminal of the multi-winding centre-tapped transformer. It operates in inversion mode when switching angle for both converters is kept above 90^o. The high value of inductor ensures unidirectional and constant load current. The switching sequence and the conduction diagram for the inversion operation is shown in table I and Fig. 3 respectively. The current waveforms at the secondary and primary side terminal of the topology are shown in Fig. 4.During the positive half-cycle of grid voltage, thyristor T_1 and T_3 are forward biased and in the negative half-cycle of the grid voltage, T_2 and T_4 are forward biased. T_1, T_2, T_3 and T_4 are triggered at α_1, α_2, α_3 and α_4 and the switching angles are kept above 90^o (for operation in inversion mode).

4. Simulation

The Sim Power System tool in MATLAB/ Simulink package offers wind turbine models but there is no PV model to integrate with power electronics simulation tools. Thus, it is difficult to simulate and analyse a PV system connected to power electronics converters and systems. Therefore, a generalized model for PV cell which is extended to include array is developed and used in integration with power converter block sets. To get useful output from PV cell, it has to be connected in series (to increase voltage level) and/or parallel (to increase current output). The equations relating the PV array voltage to the PV array current are given by (1)-(3). These are the basic governing equation for a solar cell. But, the parameters appeared in equation are not independent rather they depend on external factors such as temperature and insolation [26].

$$I_{pv} = N_p * I_{ph} - N_p * I_d - \left(\frac{\frac{N_p * V_{pv}}{N_s} + I_{pv} * R_s}{R_p}\right) \quad (1)$$

$$V_{pv} = N_s * V_d - \frac{N_s * I_{pv} * R_s}{N_p} \quad (2)$$

$$I_d = I_o * \left(e^{\frac{q\left(\frac{V_{pv}}{N_s} + \frac{I_{pv} * R_s}{N_p}\right)}{n * k * T}} - 1\right) \quad (3)$$

Where

Np No. of solar cells in parallel.

Ns No. of solar cells in series.

Ipv solar cell current, in A.

Iph photo current at reference temperature, in A.

Id diode current, in A

Vd diode voltage, in Volts.

Vpv solar cell voltage, in Volts.

q electronic charge, in Coulumbs.

k boltzmann constant.

Io reverese saturation current in A.

n ideality factor.

Rs series Resistance, in V/A.

Rp parallel Resistance, in V/A,

The photocurrent (I_{ph}) mainly depends on the solar insolation and cell's working temperature [23]-[26], which is given by

$$Iph = Iph(T1) + Ki*(T - T1). \qquad (4)$$

$$Iph(T1) = Isc(T1) * \frac{G}{Gnom}. \qquad (5)$$

where, $I_{sc}(T1)$ is the cell's short-circuit current at a 25°C and 1kW/m^2, Ki is the cell's short-circuit current temperature coefficient, T is the cell's temperature, and G is the solar insolation in kW/m^2. The cell's saturation current varies with the cell temperature, which is given by

$$Io = Io(T1) * (T/T1)^n * e^{\frac{qEg*(\frac{1}{T}-\frac{1}{T1})}{n*k}}. \qquad (6)$$

$$Io(T1) = \frac{Isc(T1)}{e^{\frac{q*Voc(T1)}{n*k*T1}} - 1} \qquad (7)$$

where, $I_{sc}(T1)$ is the cell's reverse saturation current at a reference temperature and a solar radiation, Eg is the bang-gap energy of the semiconductor used in the cell. The ideal factor, n, is dependent on type of cell. Since Eg does not change much in the temperature range 273 K to 373 K. Thus, we select a value of 1.12 for Eg in this temperature range which is a good approximation for Silicon semiconductor [23]. The resistance also depends on temperature which is given by [24],

$$Rs = k_1 + k_2 * T \qquad (8)$$

$$Rp = k_3 * e^{-k_4 T} \qquad (9)$$

where k_1, k_2, k_3 and k_4 are constants depending on cell used. Actual equations used by [24] shows dependence of R_s

on insolation but to avoid complexity, a linear model for Rs is taken. Using the above nine equations, a PV cell model is proposed which is extended to a PV array.

The parameters set for the purpose of simulation are shown in table II. The simulation model for the proposed topology is shown in Fig. 5. The model is run for various switching angle combinations at different insolations. The PV model of a cell and the P-V characteristic of an array is shown in Fig. 6 (a) and Fig 6 (b) respectively. From Fig. 7 and Fig. 8, it can be observed that maximum power is available for switching angle combination (105^o, 130^o) for high as well and low insolation. Moreover, this point of operation lies in the region of low THD. Thus, in order to operate the solar PV based series multi-stage grid tie inverter at MPP of PV array, the switching angle combination should be kept as (105^o, 130^o) for the upper leg thyristors of upper and lower converters respectively. Figure 9 shows the MPPT operation of the proposed inverter circuit. Stepped waveform shows the maximum available power at different insolation level. The other waveform is the power transferred to the grid. It closely follows the maximum available power from the PV array.

5. Experimental Results

Figure 10 shows the proposed topology incorporating MPPT scheme for two stage grid-tie inverter where a PIC 16F877A microcontroller generates the trigger signals and controls the overall performance of the solar PV based multi-stage series grid-tie inverter. Figure 11 shows the driver circuit, which is used to isolate the low power microcontroller circuit from the grid connected power circuit. Figure 12 shows photograph of the complete experimental setup of the solar PV based multi-stage grid-tie inverter. At 400 W/m^2, line current and corresponding THD including harmonics at MPP are shown in Fig. 13 (a) and Fig. 13 (b) respectively. The THD has reduced to 19.7%. This is a significant improvement compared to 48% in case of a thyristor based square wave conventional inverter.

6. Conclusions

A multi-stage grid-tie inverter topology has been proposed with better THD (in line current) and power output for a solar PV based system. Two stage inverter scheme has been simulated in simulink software and hardware realised. The THD has reduced significantly (19.7%) in case of two stage inverter as compared to 48% in case of a conventional square wave inverter. The result has been experimentally verified. A novel MPPT scheme for the system has been suggested. The proposed MPPT scheme has been simulated on SIMULINK/ MATLAB and experimentally verified. The absence of a dc-to-dc converter on the PV side of inverter in the MPPT scheme reduces the cost and the efficiency of the overall system increases. PIC microcontroller used for implementing the scheme is cheap and readily available compared to other microcontrollers available in market. The proposed MPP scheme tracks the maximum power point to a high degree of accuracy.

References

[1] B. H. Khan, (2006). Non conventional energy sources, Tata McGraw Hill education.

[2] R. Messenger and J. Ventre, (1999). Photovoltaic system engineering, CRC Press.

[3] T. kerekes, (2009). Analysis and modeling of transformerless photovoltaic inverter systems, Phd thesis, Aalborg University, Institute of Energy Technology, Denmark.

[4] N. Jenkins, (1995). Photovoltaic systems for small-scale remote power supplies, Power Engineering Journal, 9(2), (pp. 89-96).

[5] IEA-International Energy Agency (2008). Trends in Photovoltaic Applications: Survey report of selected IEA countries between 1992 and 2007, Report IEA-PVPS T1-17.

[6] J. T. Bialasiewicz (2008). Renewable energy systems with photovoltaic power generators: operation and modeling, *IEEE Transaction on Industrial Electronics,* 55(7), 2752-2758.

[7] J. Vieira and A.M Mota, (2008). Maximum power point tracker applied in batteries charging with PV panels, *IEEE International Symposium on Industrial Electronics, ISIE 2008,*(pp.202-207).

[8] S. Saha and V.P. Sundarsingh, (1996). Novel grid-connected photovoltaic inverter, *IEE Proceedings-Generation, Transmission and Distribution*, 143(2), 219-224.

[9] E. Villanueva, P. Correa, J. Rodriguez and M. Pacas, (2009). Control of a Single-Phase Cascaded H-Bridge Multilevel Inverter for Grid-Connected Photovoltaic Systems, *IEEE Transaction on Industrial Electronics,* 56(11), 4399-4406.

[10] L. M. Tolbert, F. Z. Peng, T. G. Habetler, (1999). Multilevel converters for large electric drives, *IEEE Transaction on Industrial Application*, 35(1), 36-44.

[11] J. S. Lai and F. Z. Peng, (1996). Multilevel converters – A new breed of power converters, *IEEE Transaction on Industrial Application*, 32(3), 509-517.

[12] M.S.Jamil Asghar (2004) Power Electronics, PHI learning, India.

[13] T. Esram, P.L. Chapman, (2007). Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques, *IEEE Transaction on Energy Conversion,* 22(2), 439-449.

[14] G.Walker, (2001). Evaluating MPPT converter topologies using a matlab pv model, J. Electrical and Electronics Engineering, **21**(1), 49-56.

[15] M. Veerachary, T. Senjyu, and K. Uezato, (2002). Voltage-based maximum power point tracking control of PV system, *IEEE Transaction Aerospace Electronics System,* 38(1), 262–270.

[16] V. Salas, E. Olias, A. Barrado, and et al, (2006). Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems, *Sol. Energy Materials & Sol. Cells*, 90(1), 1555-1578.

[17] A. K. Abdelsalam, A. M. Massoud, S. Ahmed and P. N. Enjeti, (2011). High-performance adaptive perturb and observe MPPT technique for photovoltaic-based microgrids, *IEEE Transaction On Power Electronics* 26(4), 1010-1021.

[18] Fangrui Liu, Shanxu Duan, Fei Liu, Bangyin Liu and Yong Kang, (2008). A Variable Step Size INC MPPT Method for PV Systems, *IEEE Transactions on Industrial Electronics*, 55(7), 2622-2628.

[19] Qiang Mei, Mingwei Shan, Liying Liu, J. M. Guerrero, (2011). A Novel Improved Variable Step-Size Incremental-Resistance MPPT Method for PV Systems, *IEEE Transaction on Industrial Electronics*, 58(6), 2427-2434.

[20] H. Koizumi, T. Mizuno, T. Kaito, Y. Noda, N. Goshima, M. Kawasaki, K. Nagasaka, and K. Kurokawa, (2006). A novel microcontroller for gridconnected photovoltaic systems, *IEEE Transaction on Industrial Electronics*, 53(6), 1889–1897.

[21] C. Hua, J. Lin and C. Shen, (1998). Implementation of a DSP-controlled photovoltaic system with peak power tracking, *IEEE Transaction on Industrial Electronics*, 45(1), 99–107.

[22] E. Koutroulis, K. Kalaitzakis and N. C. Voulgaris, (2001). Development of a microcontroller-based, photovoltaic maximum power point tracking control system, *IEEE Transaction on Power Electronics,* 16(1), 46–54.

[23] M. G. Villalva, J. R. Gazoli, and E. R. Filho, (2009). Comprehensive approach to modeling and simulation of photovoltaic arrays, *IEEE Transactions on Power Electronics*, 24(5), 1198-1208.

[24] J. Szlufcik, S. Sivoththaman, J.F. Nlis, R.P. Mertens, R. Van Overstraeten, (1997). Low-cost industrial technologies of crystalline silicon solar cells , *Proceedings of the IEEE* , 85(5), (pp.711-730).

[25] A. Breeze, (2008). Next generation thin-film solar cells, *IEEE international reliability physics symposium*, IRPS 2008.

[26] H. Rauschenbach, (1980). Solar cell array design handbook, Van Nostrand Reinhold, Ltd.

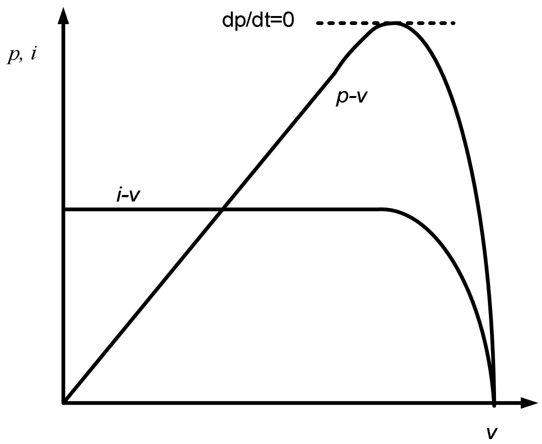


Fig. 1. Static i-v characteristics of solar PV cell.

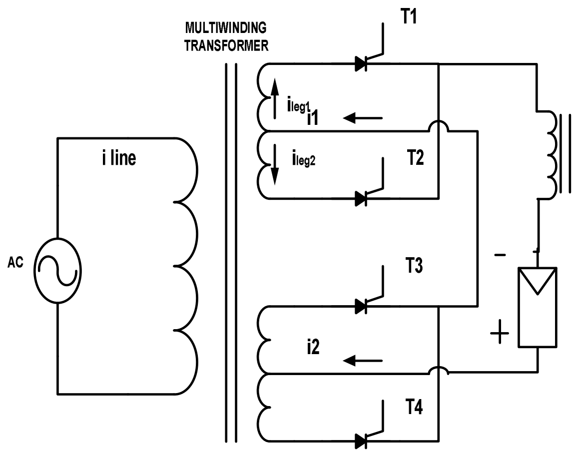


Fig. 2. Proposed topology

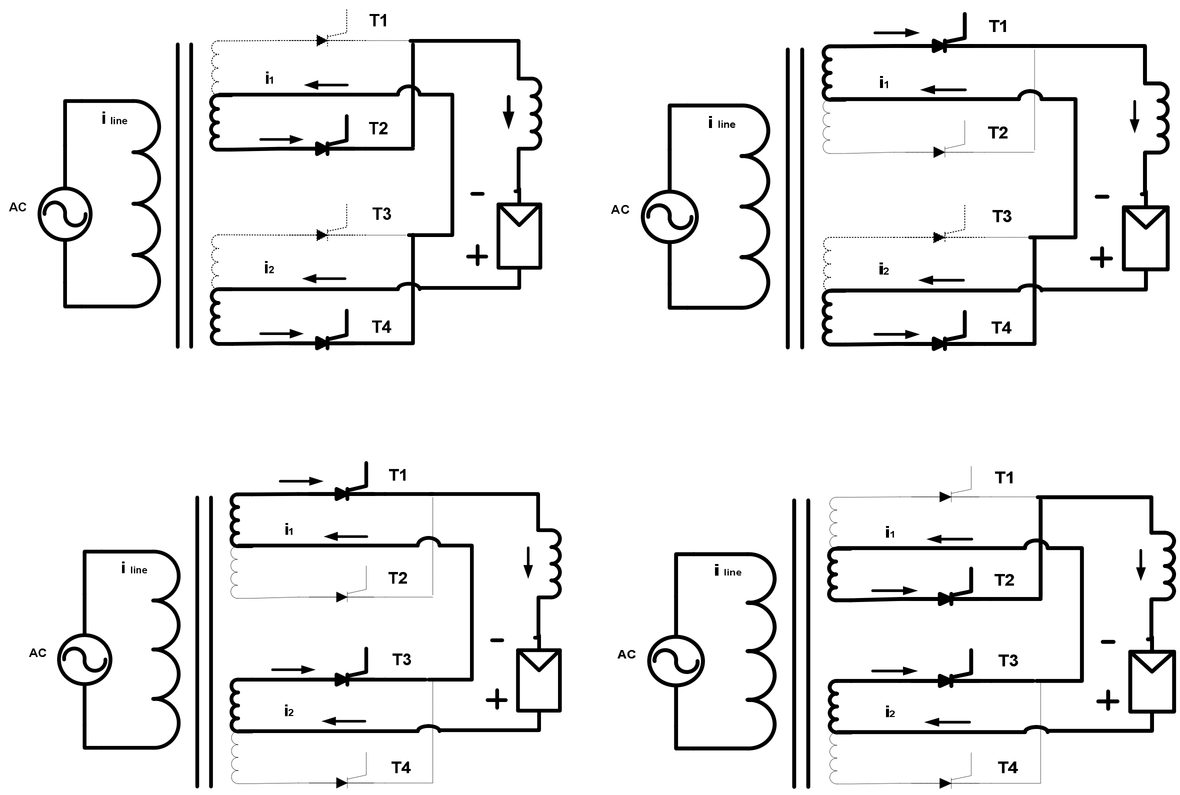


Fig. 3. Conduction diagram

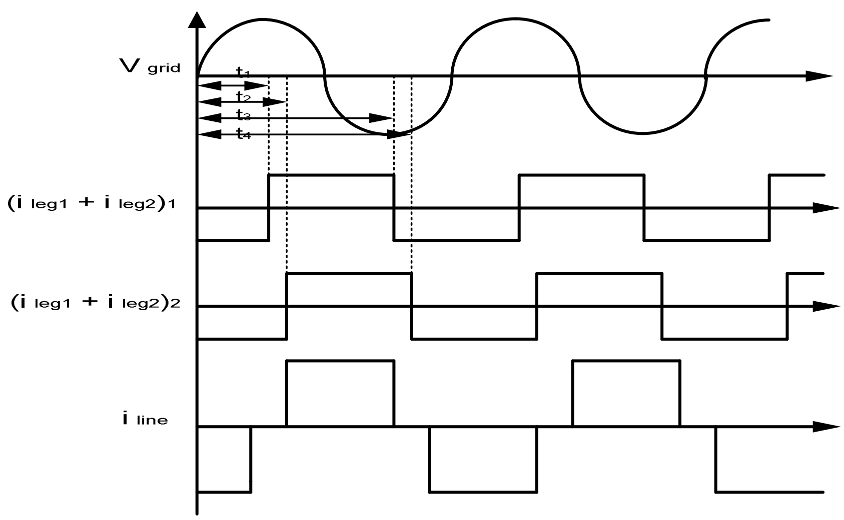


Fig. 4. Current waveforms

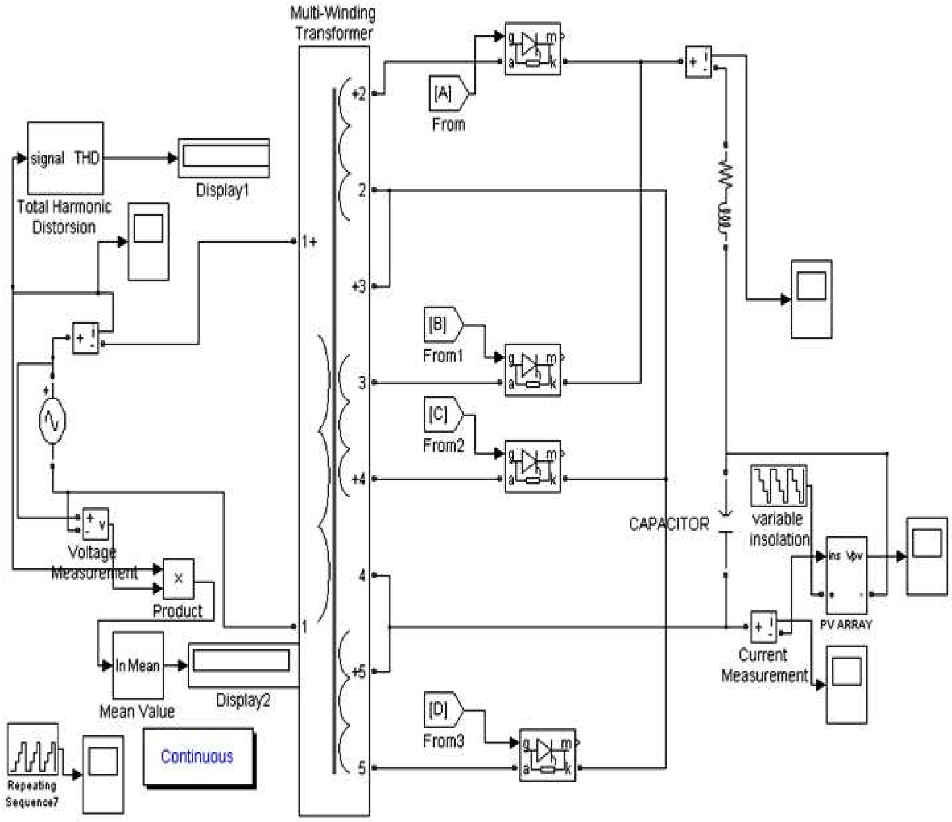
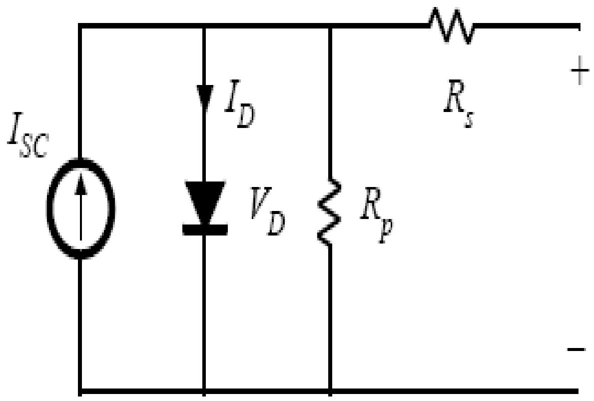
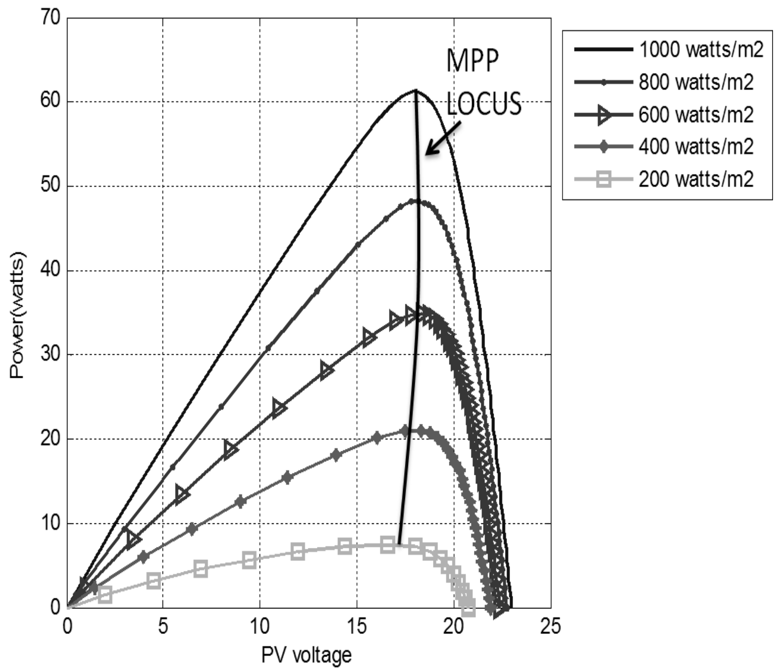


Fig. 5. SIMULINK/ MATLAB model for the proposed topology



(a)



(b)

Fig. 6(a) Equivalent circuit of typical solar PV cell. (b) The characteristic of the solar array.

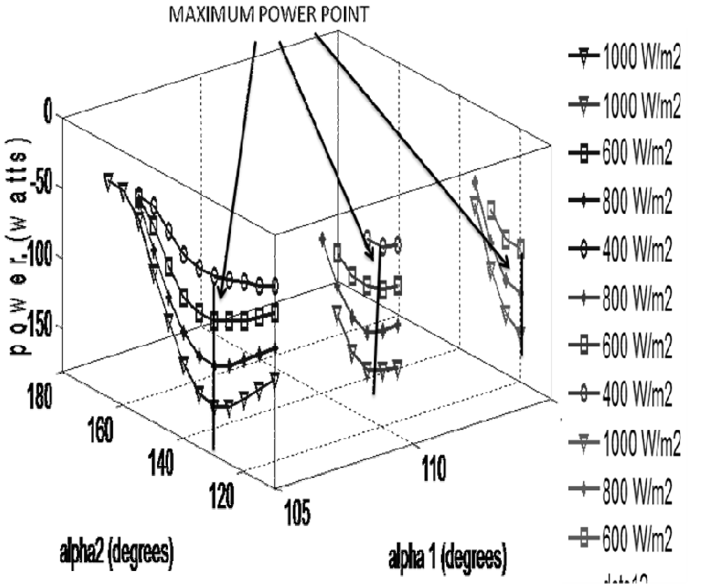


Fig. 7. Variation of power with switching angle at different insolation level.

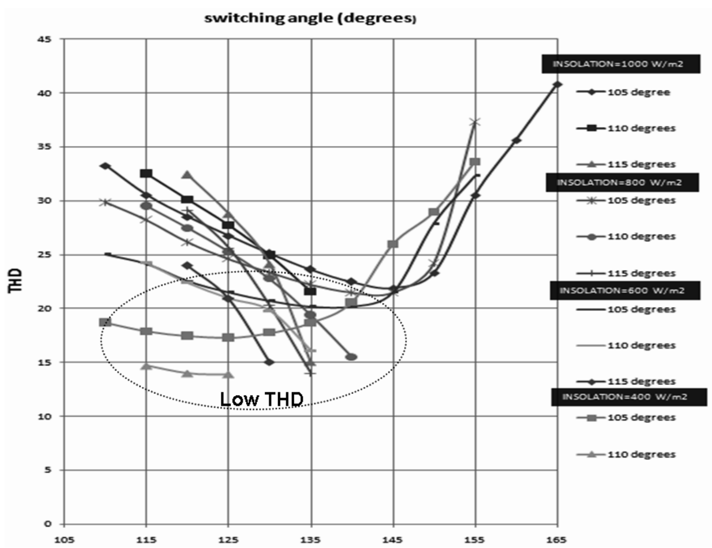


Fig. 8. Variation of THD with switching angle at different insolation level.

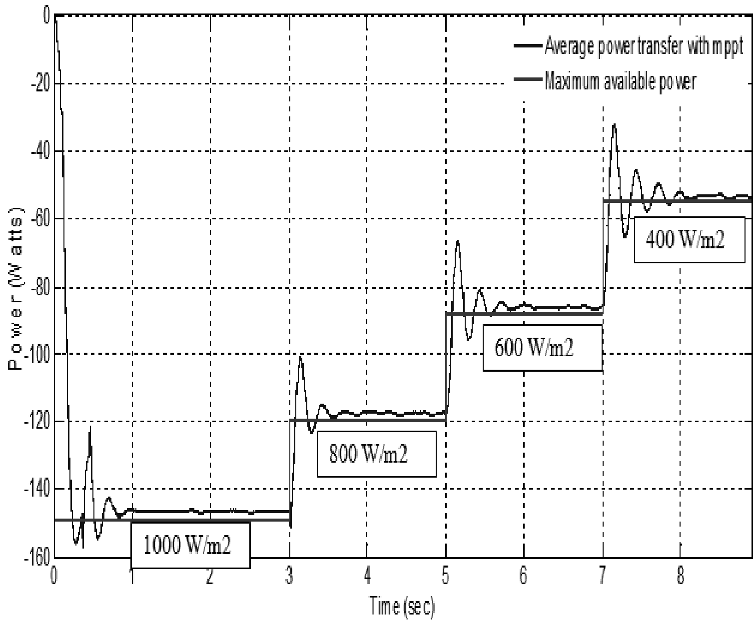


Fig. 9. Maximum power tracking

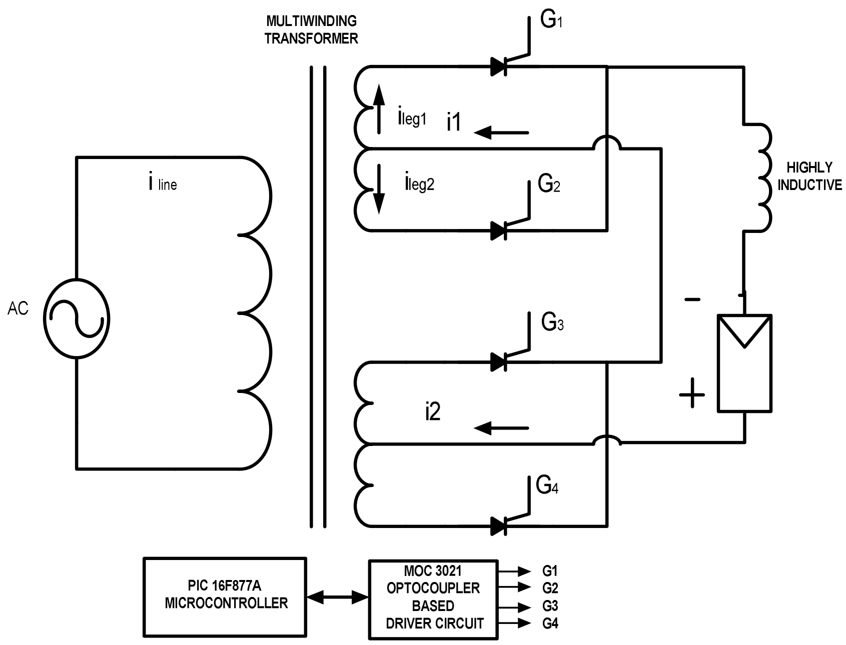


Fig. 10. Circuit for two-stage grid-tie inverter

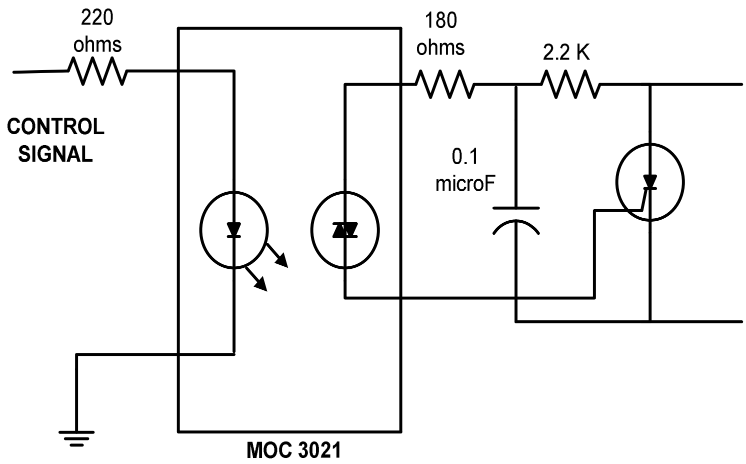


Fig. 11. MOC 3021 optoisolator based driver circuit

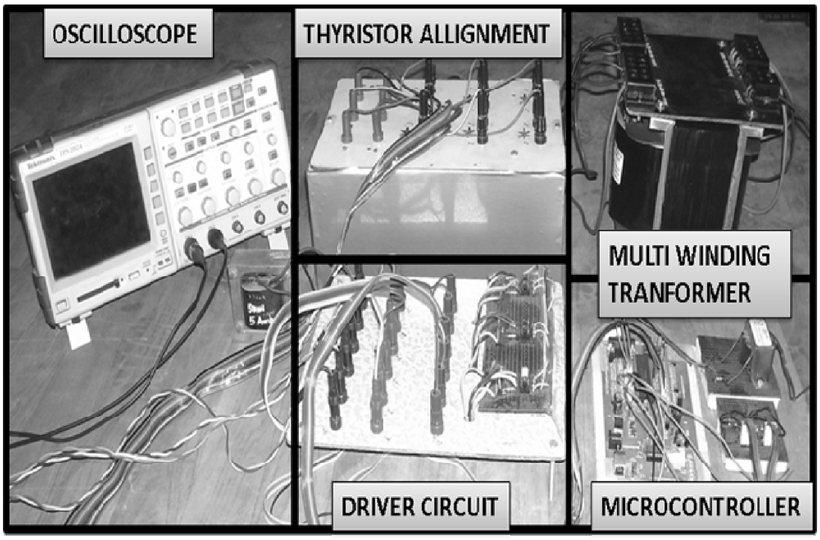
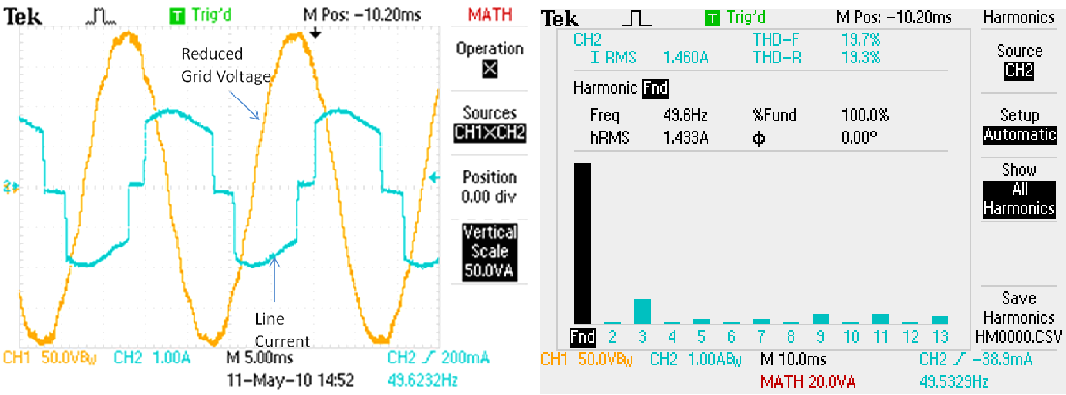


Fig. 12. Experimental Setup of the prototype



(a) (b)

Fig. 13. (a) Line current (blue curve) at a switching combination of α_1=105° and α_2=130° along with grid voltage (red curve).

(b) Harmonics in line current with switching combination of α_1=105° and α_2=130°.

TABLE 1: Switching sequence

Sl. No.	Switching instant	Thyristor conducting	Line current due to converter 1 (A)	Line current due to converter 2 (A)	Net Line Current (A)
1.	α_1	T2, T4	-I	-I	-2I
2.	α_2-α_1	T1, T4	+I	-I	0
3.	α_3-α_2	T1, T3	+I	+I	+2I
4.	α_4-α_3	T2, T3	-I	+I	0

Table II: circuit parameters for simulation

Array rating	
Voc	46 Volts
Isc	5.2 A
Vmpp	0.82*Voc
Transformer rating	
KVA rating	1 KVA
i/p voltage	220 Volts
o/p voltage	50-0-50 Volts
Circuit parameters	
Inductance	0.05 Henry
Resistance	0.02 ohm
Capacitance	100 microfarad
Grid voltage	220 Volts