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Symmetrical Hybrid Switched-Inductor type Converter Topology for a Photovoltaic System

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Abstract— In applications involving grid-connected photovoltaic system, high voltage gain is required. For this purpose, a number of high voltage gain converters have been proposed in many literary works. Initially, the capability of symmetrical hybrid switched-inductor converter (SH-SLCs) to produce high voltage gain for small grid applications is analyzed. The suitability of the converter for photovoltaic (PV) interface to boost the dc output voltages as well its performance as maximum power point tracker (MPPT) is analyzed and results are presented. Moreover, the efficiency of the hybrid switched-inductor converter is viewed along with boost and asymmetrical hybrid SLC (AH-SLC) in terms of voltage gain, voltage stress in switching devices and losses in inductor.

Index Terms- Dc-Dc converter, MPPT Algorithm, Photovoltaic module, Voltage gain, MatLab.

I. INTRODUCTION

Renewable energy utilization has become popular due to the increase in demand with decrease in the availability of conventional energy sources. Grid-connected photovoltaic (PV) systems are popular method to convert solar energy into electricity. They are used to feed excess power to the grid to be consumed by several users. Solar energy converted by photovoltaic solar panels, intended for power grids, should be conditioned by a grid-connected inverter for further use. Existing PV panels have a lower and varying output voltage [1]. In many applications, single stage architecture is often preferred owing to the reduction in the system power loss. However, it generally does not boost the PV module voltage for many practical applications. Hence, a dc converter connecting the PVs and the inverter connected to grid, equipped to provide high gain is installed.

Considering the cost and other general issues, the voltage from PV array is insufficient which is required to be around 200 V_{dc} which is approximately ten times the normal boost conversion in such applications. The conventional boost converter apart from not meeting this requirement, provides low efficiency by inducing high current ripple [1-2].

In relation to which, a hybrid switched-inductor converter topology is studied and used for obtaining high voltage ratio in this project. Fig 1 presents the structural block of a solar PV power plant employing hybrid switched-inductor converter.

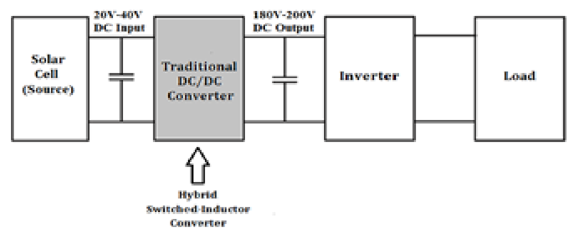

Fig. 1 Structural diagram of hybrid switched-inductor converter fed photovoltaic system

II. HYBRID SWITCHED INDUCTOR CONVERTERS

In the interest of providing high conversion ratio, the duty cycle of the converter must be smaller than 0.1 or higher than 0.9 for conversion. In course of providing a high conversion ratio, the basic topologies of the switched-inductor (SL)/capacitor (SC) converter have been discussed in [2-4]. By placing SL instead of the inductor in a conventional dc converter, switched-inductor operation is achieved. Fig. 2 shows the converter circuit using a switched-inductor.

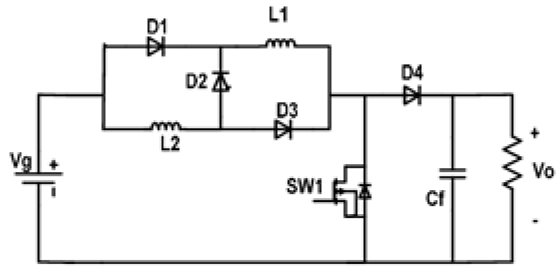

Fig. 2 Switching-inductor boost converter

But the voltage gain for the SL based boost converter is still low and hence its use is limited to the inverter, along with its high voltage stress. In spite of the ability to add more switched cells to increase the voltage gain, the complexity also increases. The basic operation of symmetrical and asymmetrical toplogy of the switched-inductor converter is discussed in the next section.

A. Symmetrical hybrid switched-inductor converter (SH-SLC)

This section illustrates the operating principle of the symmetrical H-SLC (SH-SLC) in continuous-conduction mode (CCM) along with discontinuous-conduction mode (DCM) [2]. The working circuit diagram for a symmetrical topology of SL converter is shown in Fig. 3.

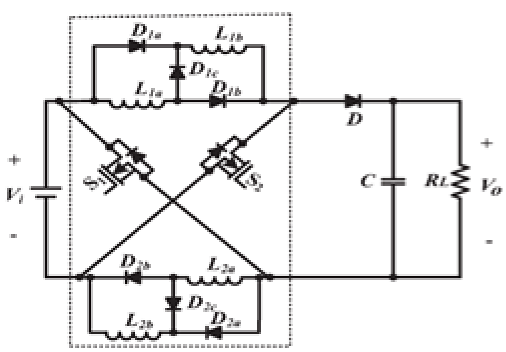

Fig. 3 H-SLC Symmetrical structure

The continuous mode of operation can be distinguished into two modes depending on switches S1 and S2. The corresponding circuit during each mode is given in Figure 4(a) and 4(b). The changes in each mode are described as follows:

For Mode 1, both the switches are in ON condition and the power source charges the inductors L_{1a}, L_{1b}, L_2 to the input voltage in parallel.

In Mode 2, both the switches are in OFF condition and the three inductors get discharged to output in series.

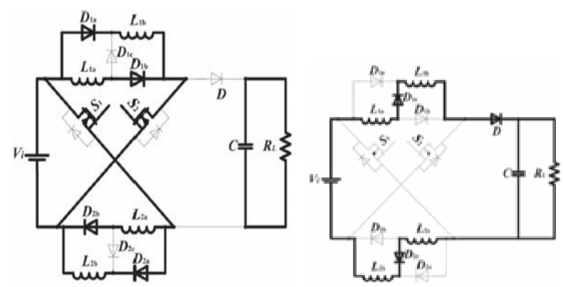

Fig. 4 Mode 1 and Mode 2 in both CCM and DCM operation of the symmetrical H-SLC

Similar to AH-SLC, the discontinuous mode of operation also has three modes differing only in mode 3. Mode 1 and Mode 2 of the DCM is similar to that of the CCM operation similar to previous topology. In Mode 3 of DCM, the switches remain OFF and the capacitor supplies the load. The corresponding circuit of the mode is given in Figure. 5.

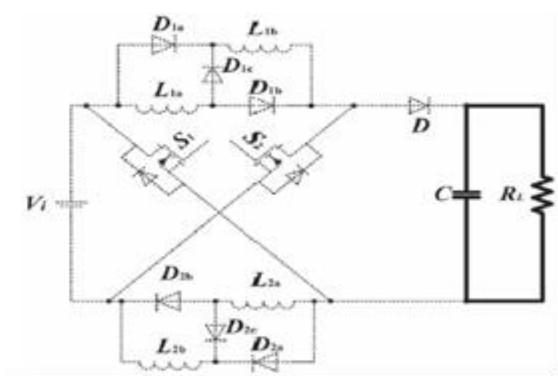

Fig. 5. Mode 3 in the DCM operation of SH-SLC

The voltage, current and the diode equations with key waveforms for all the modes of the symmetrical hybrid-inductor converter used in this study are explained in [2].

B. Asymmetrical hybrid switched-inductor converter (AH-SLC)

The basic operating principle of the asymmetrical H-SLC (AH-SLC) is similar to that of symmetrical H-SLC (SH-SLC) in both conduction modes (CCM and DCM) [2]. The working circuit diagram for an asymmetrical topology is shown in Fig. 6.

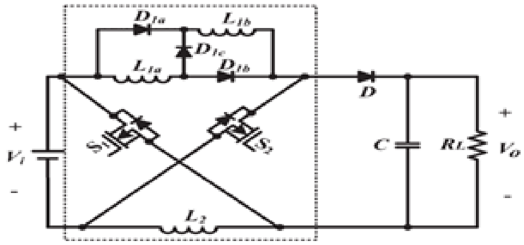

Fig. 6 H-SLC Asymmetrical structure

The voltage, current and the diode equations with key waveforms we use are explained in [2].

It can be concluded that the symmetrical structure of the SL converter has more gain conversion ratio than the asymmetrical structure of the same. Hence further analysis will be based on the symmetrical switched-inductor converter.

III. ANALYSIS OF SYMMETRICAL H-SLC

This section presents the compared analysis of the symmetrical H-SL converter with both asymmetrical hybrid SL converter and conventional boost converter. Figure 7 gives the circuit diagram of the conventional converter considered for the analysis.

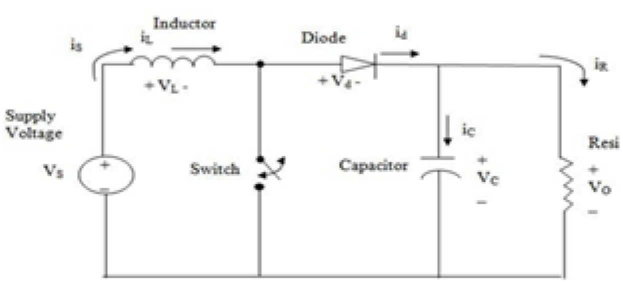

Fig. 7 Conventional boost converter

The detailed analysis with formulas and result has been discussed in [1]. The overall analysis results are shown as follows:

C. *Performance based on voltage gain*

The voltage gains of the converters are calculated in terms of the duty cycle based on the formula given [1]. The values are listed in Table I and the graphical comparison is given below in Fig. 8.

Table I
Comparison of Voltage Gain

Duty cycle *(D)*	SH-SLC	AH-SLC	Boost
0.5	4.7	3.8	1.9
0.6	6.4	5.2	2.4
0.7	9.2	7.4	3.2
0.8	13.6	11.2	4.0
0.9	18.65	17.4	8.9

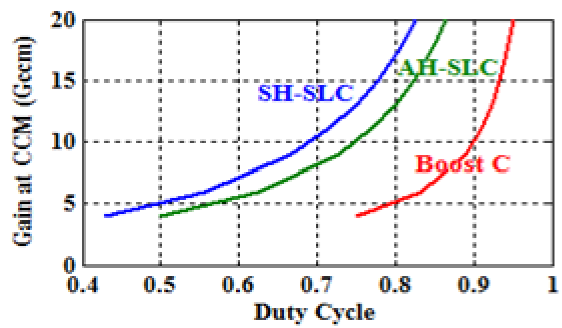

Fig. 8 Comparison of voltage gain

It is inferred that, for all the three non-coupled inductor-type converters, high gain can be realized in the symmetrical SL converter with high voltage gain.

D. *Performance based on voltage stress*

The performances of the converters are analyzed based on the stress across the switches in the circuit. Table II tabulates the values and its graphical comparison is presented in Fig. 9.

Table II
Comparison of voltage Stress

G_{ccm}	SH-SLC	AH-SLC V_{s1}	AH-SLC V_{s2}	Boost
4	2.4	2.87	1.98	3.94
6	3.31	4.11	2.59	5.78
9	4.59	5.76	3.51	8.25
11	5.37	6.83	4.01	9.65
13	6.09	7.27	4.85	10.86
15	6.73	8.69	5	11.87
18	7.57	9.78	5.41	13
20	8.05	10.37	5.71	13.55

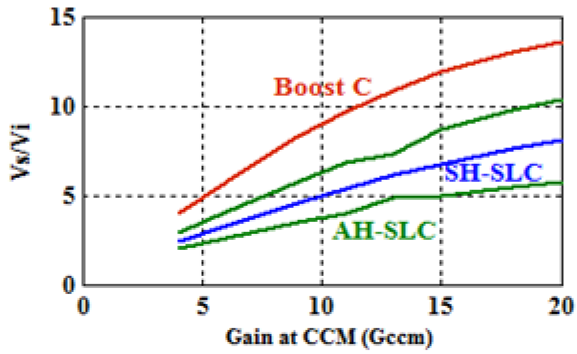

Fig. 9 Comparison of voltage stress

It is observed that, for realizing the same conversion ratio, the SH-SLC presents the low voltage stress across the switch; whereas the switch voltage stress is higher in boost.

Moreover, the voltage gain of SH-SLC is higher than AH-SLC with the later presenting asymmetrical stress across the devices. Considering the above results symmetrical topology is preferred along with simple system design.

IV. MODELLING OF PHOTOVOLTAIC ARRAY

PV module is built with series and parallel connected solar cells for desired output levels. When the solar cell absorbs incident energy, it excites free electrons, converting into electrical energy. For simplicity, a single-diode model shown in Fig. 11 is considered for analysis.

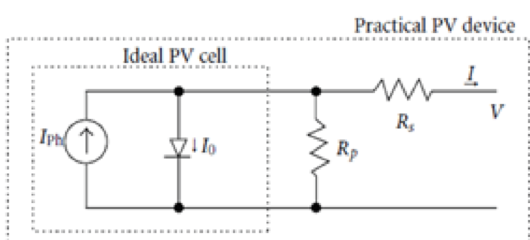

Fig. 11 Diode modeled PV cell

PV cells are linked to PV modules, which are further interlinked into PV arrays. The basic equations from [5],[6] mathematically describe the single-diode structure of the photovoltaic cell.

The photocurrent that flows in PV is represented by

$$I_{ph} = \left[I_{SCr} + K_i \left(T_k - T_{ref} \right) \right] \times \frac{\lambda}{1000} \qquad (1)$$

Where the values are generated at the nominal condition (25·C and 1000W/m^2), k_i (current/temperature coefficient) is 0.0017 A/K, T_k and T_{ref} are the reference and actual temperature (Kelvin), λ is irradiation (W/m^2), q (electron charge) is 1.6×10^{-19} C, V_{oc} (open-circuit voltage as per Solkar module) is 21.24 V, K (Boltzmann constant) is 1.3805 × 10-23 J/K, A (ideality factor) is 1.6, E_{g0} (Band-gap energy of polycrystalline Si at 25°C)) ≈ 1.1 eV.

The output current using the no. of parallel connections ($N_{p=1}$) and no. of series connection (Ns=36) is obtained from the above equations. The PV output current is given as,

$$I_{pv} = N_P I_{ph} - N_P I_o \left[exp\left(\frac{q\left(V_{pv} + I_{pv} R_s\right)}{N_s AKT} \right) - 1 \right]$$

(4)

The simple simulation module is inferred and presented in Fig. 12. And the overall circuit of the diode model of the PV cell using Simulink is presented in Fig. 13.

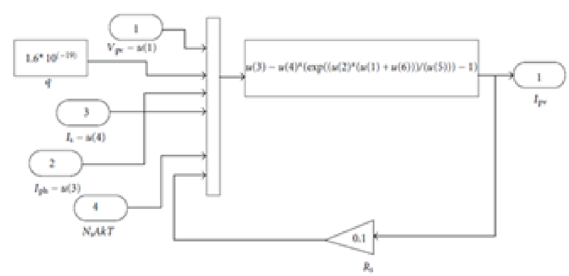

Fig. 12 Simulation circuit of PV current

The reference model of the PV considered is based on the Solkar 36W_P PV module for which the data sheet is also given in [5]. Basic characteristic of a PV Array is presented by Fig. 14.

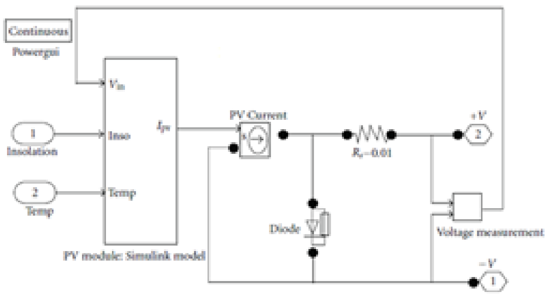

Fig. 13 Simulink model of PV cell

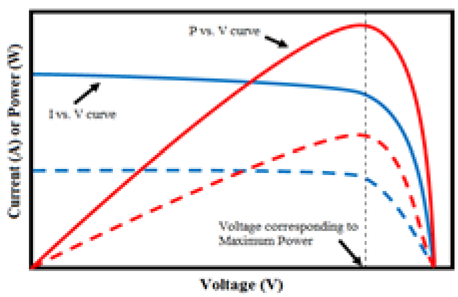

Fig. 14 Basic characteristics of the PV

Accordingly, 2 PV panels connected in series is considered, each with maximum power point voltage of 16.54V, maximum power point current of 2.25V and maximum power of 37.08W. Hence, PV array size of 2 × 1 with maximum voltage of 33.08V and maximum power of 74.16W is used to carry out the simulation at the standard test conditions.

V. MPPT USING INCREMENTAL CONDUCTANCE ALGORITHM

Solar cells produce non-linear output due to the complexity between temperature and total resistance of the circuit. The maximum power point tracking (MPPT) techniques samples this output and applies proper resistance to obtain maximum power from the circuit for the given environmental conditions.

The MPPT has various types which differ mainly based on their iteration techniques. In this paper we are going to use Incremental conductance (InC) method to reach the maximum power value from the array. In the incremental conductance method, we use the incremental difference in the array current and voltage to enumerate the difference in power with respect to the voltage (dP/dV). A detailed analysis on this method is given in [9-12]. The flowchart of the InC, shown in Fig. 15 gives the working concept of the maximum power point tracking.

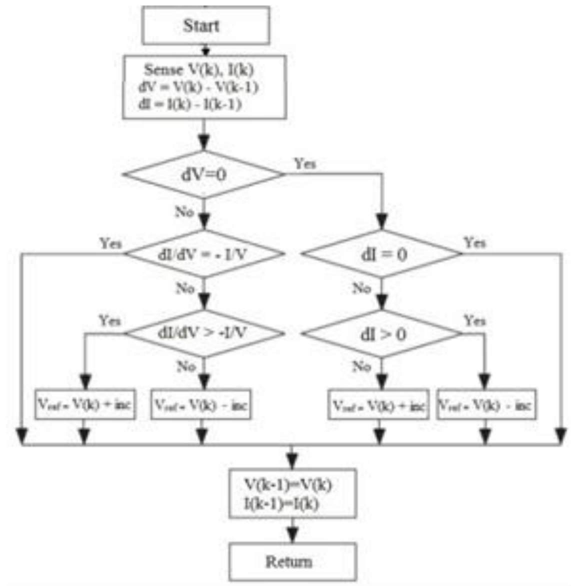

Fig.15 Flowchart for InC algorithm

With the help of the above flowchart, MatLab coding for incremental conductance technique is used to execute MPPT using MatLab function block. The MatLab coding was written with the help of [10] and [11]. The simulation results of the MPPT showed that the MatLab coding can track maximum voltage with respect to the reference values.

VI. SIMULATION RESULTS

The simulation circuit of symmetrical hybrid switched-inductor converter supplied from a dc source is presented in Fig. 16. The component parameters for the simulation circuits are given in Table IV.

TABLE IV CIRCUIT COMPONENTS

Components	SH-SLC / AH-SLC values
Input voltage (V_{in})	20-50V
Switching frequency (f_s)	15kHz
Inductors (L_{1a}, L_{1b}, L_{2a}, L_{2b})	7.5µH
Power MOSFET(s_1, s_2)	FQPF 8n60c
Diodes	10A10, 10A
Input Capacitor	200µH
Output Capacitor	320µH

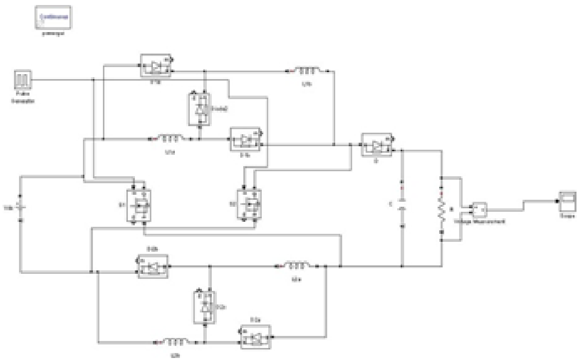

Fig. 16. Simulation circuit of SH-SLC

From the simulation of symmetrical hybrid switched-inductor converter using the above parameters, and the output waveforms of the symmetrical hybrid converter obtained is given in Fig. 17.

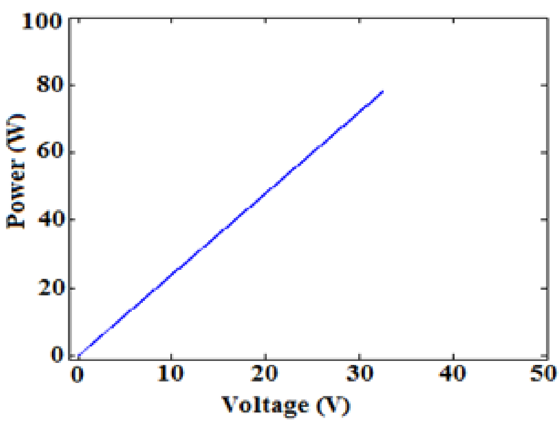

Fig. 19. PV characteristics showing tracking of maximum power

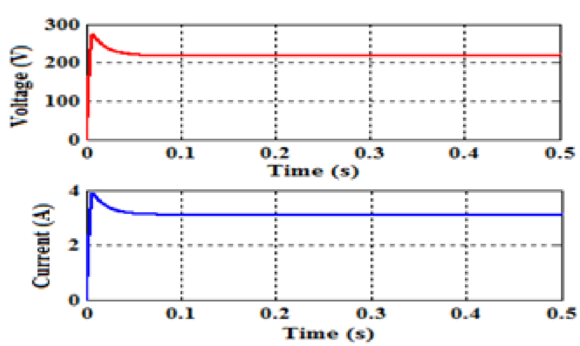

Fig. 17. Voltage and current waveform of SH-SLC

A 2 × 1 photovoltaic array designed from the single diode model studied above is implemented in simulation. Then the incremental conductance algorithm is used to code a program for tracking the maximum power point for the designed Photovoltaic cell. The overall circuit model of symmetrical hybrid switched converter interfacing with photovoltaic array using incremental conductance is conveyed in Fig. 18. The tracking of maximum power is traced and depicted in Fig. 19.

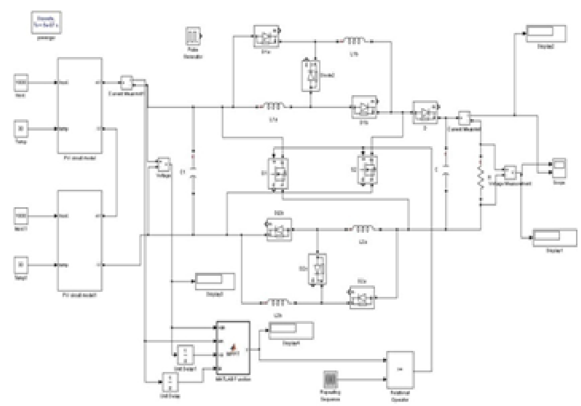

Fig. 18. MatLab schematic of the converter interfacing PV array

As discussed before, the symmetrical hybrid switched-inductor converter operates at higher gain. Using the incremental conductance algorithm the interfacing of PV array with the symmetrical converter was carried out. The maximum power point tracking with symmetrical hybrid inductor converter is validated by varying insolation levels and presented in Fig. 20.

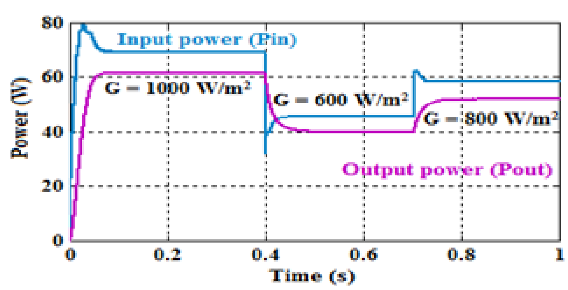

Fig. 20 Input and output power curves of the converter with MPPT

It is observed that the maximum power is tracked. The output power and the converter losses about 5 W equal to the input power generated by PV array for all insolation changes.

CONCLUSION

In this paper, a detailed performance comparison has been made among symmetrical hybrid inductor converter, asymmetrical hybrid inductor converter and conventional boost converter in terms of voltage gain and voltage stress. From this comparison, symmetrical topology is found to be superior and provides high gain about 6.5 and has less stress. This topology has been simulated for interfacing PV array with MPPT algorithm. The working of MPPT has been proven with support of varying insolation levels. The hardware for this converter structure will be carried out in the near future.

REFERENCES

[1] Yu Tang, Dongjin Fu, Ting Wang, and Zhiwei Xu, "Hybrid Switched-Inductor Converters for High Step-Up Conversion," *IEEE Trans. Ind. Electron*, vol. 62, no.3, pp. 1480-1490, March 2015.

[2] Y. Axelrod Berkovich and A. Ioinovici, "Switched-capacitor/ switched-inductor structures for getting transformer-less hybrid DCDC PWM converters," *IEEE Trans. Circuits Syst. I, Reg. Papers*, vol. 55, no. 2, pp. 687–696, Mar. 2008

[3] L. S. Yang, T. J. Liang, and J. F. Chen, "Transformer-less DC-DC converters with high step-up voltage gain," *IEEE Trans. Ind. Electron*, vol. 56, no. 8, pp. 3144–3152, Aug. 2009.

[4] R. G. Ganesan and M. Prabhakar, "Non-isolated high gain boost converter for photovoltaic applications," in *Proc. IEEE ICPEC*, pp.277–280,2013.

[5] Natarajan Pandiarajan, Ramabadran Ramaprabha, and RanganathMuthu, "Application of Circuit Model for Photovoltaic Energy Conversion System" *International Journal of Photoenergy* Volume 2012, Article ID 410401, 14 pages.

[6] N. Pandiarajan and R. Muthu, "Viability analysis on photovoltaic configurations," in *Proceedings of the IEEE Region 10 Conference (TENCON '08)*, Hyderabad, India, November 2008.

[7] J. A. Gow and C. D.Manning, "Development of a photovoltaic array model for use in power-electronics simulation studies," *IEE Proceedings on Electric Power Applications*, vol. 146, no. 2, pp. 193–200, 1999.

[8] N. Pandiarajan and Ranganath Muthu, "Mathematical Modeling of Photovoltaic Module with Simulink" 2011 1st International Conference on Electrical Energy Systems.

[9] Moacyr, G.A., Luigi, G., Sampaio, L.P., Guilherme, M.A., Carlos, C.A.: "Evaluation of the main MPPT techniques for photovoltaic applications", *IEEE Trans. Ind. Electron*., 2013, 60, pp. 1156–1167.

[10] Kish, G.J., Lee, J.J., Lehn, P.W. "Modelling and control of photovoltaic panels utilising the incremental conductance method for maximum power point tracking", *IET Proc. Renew. Power Gener*., 2012, 6, pp. 259–266

[11] Zhou Xuesong,Song Daichun,Ma Youjie, Cheng Deshu, "The simulation and design for MPPT of PV system based on Incremental Conductance Method" *WASE International Conference on Information Engineering*, pp. 314-317, 2010

[12] Rasoul Faraji, Amin Rouholamini, Hamid Reza Naji, Roohollah Fadaeinedjad, Mohammad Reza Chavoshian, "FPGA-based real time incremental conductance maximum power point tracking controller for photovoltaic systems" *IET Power Electron*., 2014, Vol. 7, Iss. 5, pp. 1294–1304.

[13] www.mathworks.com.