

# Implementation and Chaotic PWM control of Cuk DC-DC Converter based MPPT for solar PV system

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**Abstract**— This paper proposes to design PWM with chaotic carrier, is simulated and implemented in terms of their performance in suppressing ripples, increasing converter conversion efficiency and spectral performance in maximum power point tracking (MPPT) circuits (DC-DC converter) of the solar PV system. The nominal duty cycle of the main switch in the Cuk DC-DC converter is adjusted to a value so that the input resistance of the converter is equal to the equivalent output resistance of solar PV module at the MPP. The performance comparison of proposed Chaotic PWM control method has been carried out with conventional PWM based MPP tracking of solar PV system experimentally with a 37-Wp solar PV module

**Key words** — CPWM, Cuk DC-DC converter, MPPT, solar PV module.

## 1. Introduction

Solar Photovoltaic is a key technology option to realize the shift to a decarbonised energy supply and is projected to emerge as an attractive alternate electricity source in the future. Globally, the solar PV grid connected capacity has increased from 9.4 GW in 2007 to 15.7 GW in 2008 and was 67.4 GW at the end of 2011. India is located in the equatorial sun belt of the earth, thereby receiving abundant radiant energy from the sun. In most parts of India, clear sunny weather is experienced 250 to 300 days a year. The annual global radiation varies from 1600 to 2200 kWh/sq.m. The Indian government has launched Jawaharlal Nehru National Solar Mission (JNNSM) with a target of achieving 20000 MW by 2022. Nowadays it is necessary to reduce the costs and increase the efficiency to make solar energy to be more attractive.

The MATLAB model /PSPICE model of the PV module is developed [1-4] to study the effect of temperature and insolation on the performance of the PV module. MATLAB-based modelling and simulation scheme suitable for studying

the I-V and P-V characteristics of a PV array under a nonuniform insolation due to partial shading [4] was proposed. The mathematical model of solar PV module is useful for the computer simulation.

To obtain the maximum power from a PV array, a maximum power point tracking (MPPT) techniques are applied. The several MPPT techniques for solar PV modules have been proposed and compared in the literature

[5] and it can be useful to refer the Table III in [5], at least 19 distinct methods have been reported and concluded that hill climbing/P&O, IncCond, and RCC were best in space satellites and orbital station applications which need minimum time and non-requirement of periodic tuning.

The power electronics interface is connected between a solar panel and a load or battery bus, is a pulse width modulated (PWM) DC-DC converter or their derived circuits is used to extract maximum power from solar PV panel. I-V characteristic curve of photovoltaic (PV) generators based on various DC-DC converters [6-7] was proposed and concluded that Cuk/SePIC converter is the best alternative to track maximum power from PV panel.

The maximum power tracking for PV panel using Cuk converter is developed [8-12] without using micro controller. The nominal duty cycle of the main switch in the Cuk/sePIC converter is adjusted to a value, so that the input resistance of the converter is equal to the equivalent output resistance of the solar PV module at the MPP. This approach ensures maximum power transfer under all atmospheric conditions. In [16], the chaotic carrier is generated to improve the spectral performance and conversion efficiency.

In [13-15], the MPPT for solar PV system is implemented in MATLAB /Simulink environment using various control methods like ZVS-PWM cuk converter, ZCS-Cuk converter to improve the converter conversion efficiency of 91.3% and MPP tracking efficiency of 98.9%.

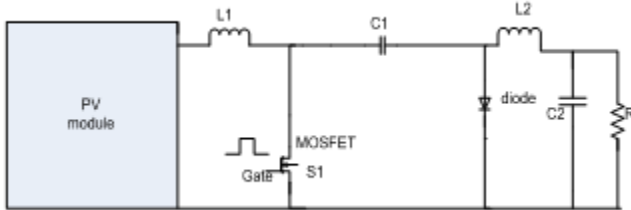
This paper proposed to design chaotic PWM based MPP tracking for solar PV system using Cuk converter in order to

improve the spectral performance, converter conversion efficiency and this method is compared with conventional PWM Cuk converter based MPP tracking. Due to continuous power spectrum feature in chaotic PWM, the power density peak in output voltage and hence the spectral performance is improved to great extent. The proposed MPP tracking is achieved by connecting a chaotic PWM based Cuk converter between a solar panel and a load (Rheostat). The nominal duty cycle of the main switch in the converter is adjusted to a certain value, so that the input resistance of the converter is equal to the equivalent output resistance of the solar module. This process is a continuous one and ensures the maximum power transfer.

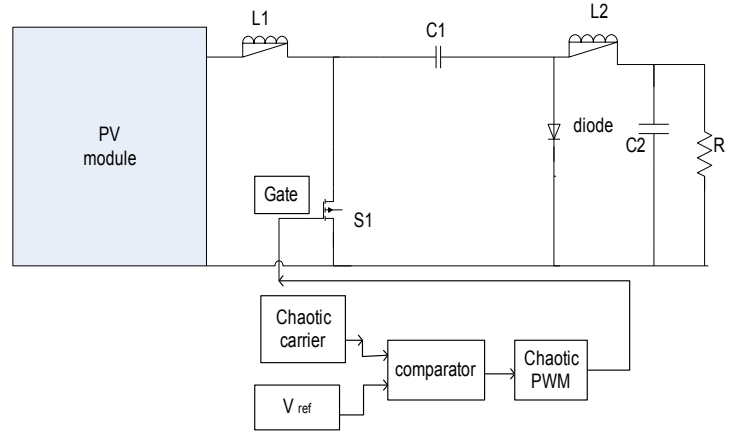
## 2. Circuit configuration

### 2.1 System Description

The Fig.1.shows MPPT system consists of solar PV module, Cuk converter (DC-DC) and load. Cuk converter is capable of sweeping the V-I curve of solar PV module in CCM from open circuit voltage to short circuit current condition and hence Cuk converter is a suitable converter to be employed in designing the MPPT circuits [6]. Soft switching implemented in Cuk converter (Zero voltage and zero current) can increase the conversion efficiency DC-DC Cuk converter, by making the switch to turn on or off at zero current or zero voltage so as to alleviate the high change rates of voltage and current, thus reducing both switching loss and to improve the spectral performance[13-15]; while proposed chaos PWM control increases converter conversion efficiency of the solar PV system by spreading the spectra of signals or time series over the whole frequency band. Compared with conventional Cuk converter and soft switching Cuk converter based MPP tracking, the proposed scheme not only improves the spectral performance and conversion efficiency, but also avoids the occurrence of low-order noises.



a. Conventional Cuk converter based MPP tracking



b. Proposed Chaotic PWM –Cuk converter based MPP tracking

Fig.1. MPPT for solar PV system

### 2.2 Design of Power circuit

Referring to Fig 1.a, the voltage and current transfer ratio of the Cuk converter in CCM is [12]

$$\frac{V_o}{V_{in}} = - \frac{D}{(1-D)} \quad (1)$$

$$\frac{I_{in}}{I_o} = - \frac{D}{(1-D)} \quad (2)$$

Where D is the duty ratio of the switch. The value of the inductor is designed so that the Cuk converter is operated in continuous conduction mode and it has to satisfy the following relation [16]

$$\Delta i_{L1,pp} = 2I_{p,min} = \frac{2P_{pv,min}}{v_p} = \frac{v_p}{L1} D_{max} T_s$$

Where  $I_{p,min}$  is the PV module current corresponding to  $P_{pv,min}$ .  $\Delta i_{L1,pp}$  is the peak to peak ripple value of the input inductor current value.  $v_p$  is the input voltage of the Cuk converter. The inductor  $L_2$  also selected equal to  $L_1$ . The designed values for Cuk converter tracking are  $L_1=L_2=500e-6H$ ,  $C_1=C_2=220e-6F$ . The switching frequency is 25kHz. The duty cycle is around 40%.

### 2.3 Dynamic Input Characteristics of a Cuk Converter at MPP

The input voltage and the equivalent input resistance of the converter are  $V_s$  and  $R_i$  respectively. As the input power  $p_i$  to the converter is equal to the output power  $p_o$  of the solar PV module

$$p_i = p_o = \frac{V_s^2}{R_i} \quad (3)$$

The rate of change  $p_i$  with respect to  $V_s$  and  $R_i$  can be shown below

$$\partial p_i = \frac{2V_s}{R_i} \partial V_s - \frac{V_s^2}{R_i^2} \partial R_i \quad (4)$$

At the MPP, the rate of change of  $p_i$  equals zero and

$$R_i = r_g$$

$$\partial p_i = 0, \text{ hence } \frac{\partial V_s}{\partial R_i} = \frac{V_s}{2R_i} \quad (5)$$

The equation gives the required dynamic resistance characteristics of the tracker at MPP.

### 2.4 L1235-37Wp Solar PV module

A solar cell is a kind of p-n junction semiconductor device and converts light energy into electrical energy. The output characteristics of the solar PV module depend on the irradiance and the operating temperature of the cell. Solar PV module of L1235-37Wp has non linear V-I characteristics which is shown in Fig.2. The table I shows the parameters of L1235-37W solar PV module which is used for experimental validation. The Fig.3 shows the solar PV module under experimental test.

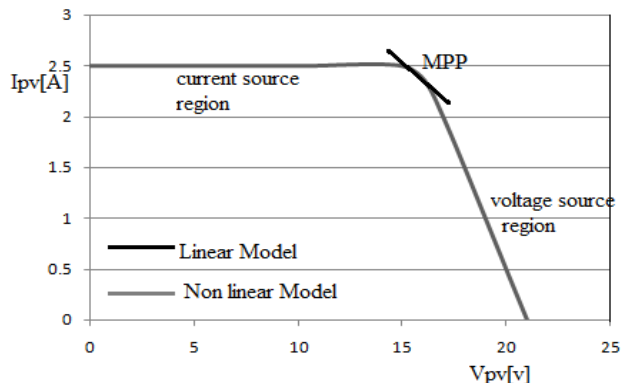


Fig.2. Non linear V-I characteristics of L1235-37Wp solar module



Fig.3 L1235-37Wp solar panel under test

Table 1. Specification of L1235-37Wp solar PV module

Parameters	Values
Open circuit voltage (Voc)	21V
Short circuit current( Isc)	2.5A
Voltage at MPP ( Vmax)	16.4V
Current at MPP ( I max)	2.25A
Power Rating (Pmax)	37W
Maximum system voltage	600V
Module efficiency (%)	10.82
Size(mm)	645*530*16

### 2.5 Generation of chaotic carrier and chaotic PWM in MATLAB /SIMULINK

The MATLAB /Simulink model to generate chaotic carrier and chaotic PWM is shown in Fig. 4.

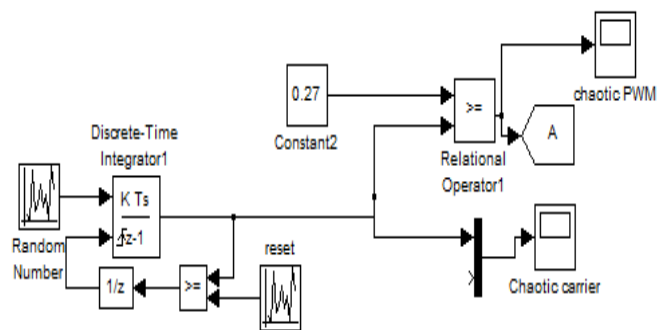


Fig.4. Generation of Chaotic PWM in MATLAB

The simulated chaotic carrier and chaotic PWM is shown in Fig.5 &6

The CPWM adopts sawtooth to modulate, but its carrier period  $T_{\Delta}'$  changes according to the equation (6).

$$T_{\Delta}' = \frac{X_i}{\text{Mean}(x)} * T_{\Delta} \quad (6)$$

where  $T_{\Delta}$  is invariant period,  $x_i, i= 1,2,\dots,N$ , a chaotic sequence,  $X=(X_1,X_2,\dots,X_N)$ , and  $\text{Mean}(X)$  average of the sequence, defined as

$$\text{Mean}(X) = \lim_{N \rightarrow \infty} \frac{\sum_{i=1}^N |X_i|}{N} \quad (7)$$

Similarly, the CPWM also adopts sawtooth to modulate, but its carrier amplitude  $A_{\Delta}'$  changes according to  $A_{\Delta}' = \{1 + k \frac{X_i}{\text{Mean}(x)}\} A_{\Delta}$  (8)

where  $A_{\Delta}$  is the invariant amplitude,  $X_i, i= 1,2,\dots,N$ , a chaotic sequence  $X=(X_1,X_2,\dots,X_N)$ , and  $\text{Mean}(X)$ , average of the sequence, and  $K$  is the modulation factor of the amplitude. The value of  $K$  is selected as low so that the ripple in the output voltage of the Cuk converter is low. Also the ripple in the output voltage controlled by chaotic PWM is low when compared with soft-switching Cuk converter-based MPPT system.

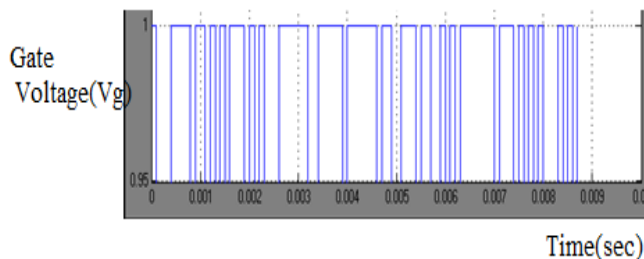


Fig.5. Generation of Chaotic PWM using MATLAB

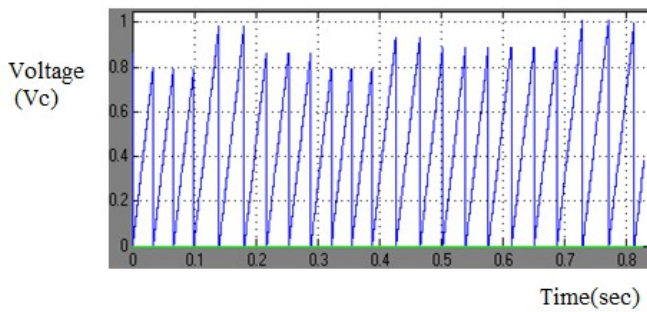


Fig.6.Generation of Chaotic carrier using MATLAB

### 3. Simulation results

The closed loop diagram was simulated in MATLAB /Simulink which is given in Fig.7.that includes PV module electric circuit subsystem (Matlab model), Cuk dc-dc converter and a resistive load. The chaotic PWM control method is proposed in this work in order to improve the performance in suppressing ripples, increasing converter conversion efficiency and spectral performance.

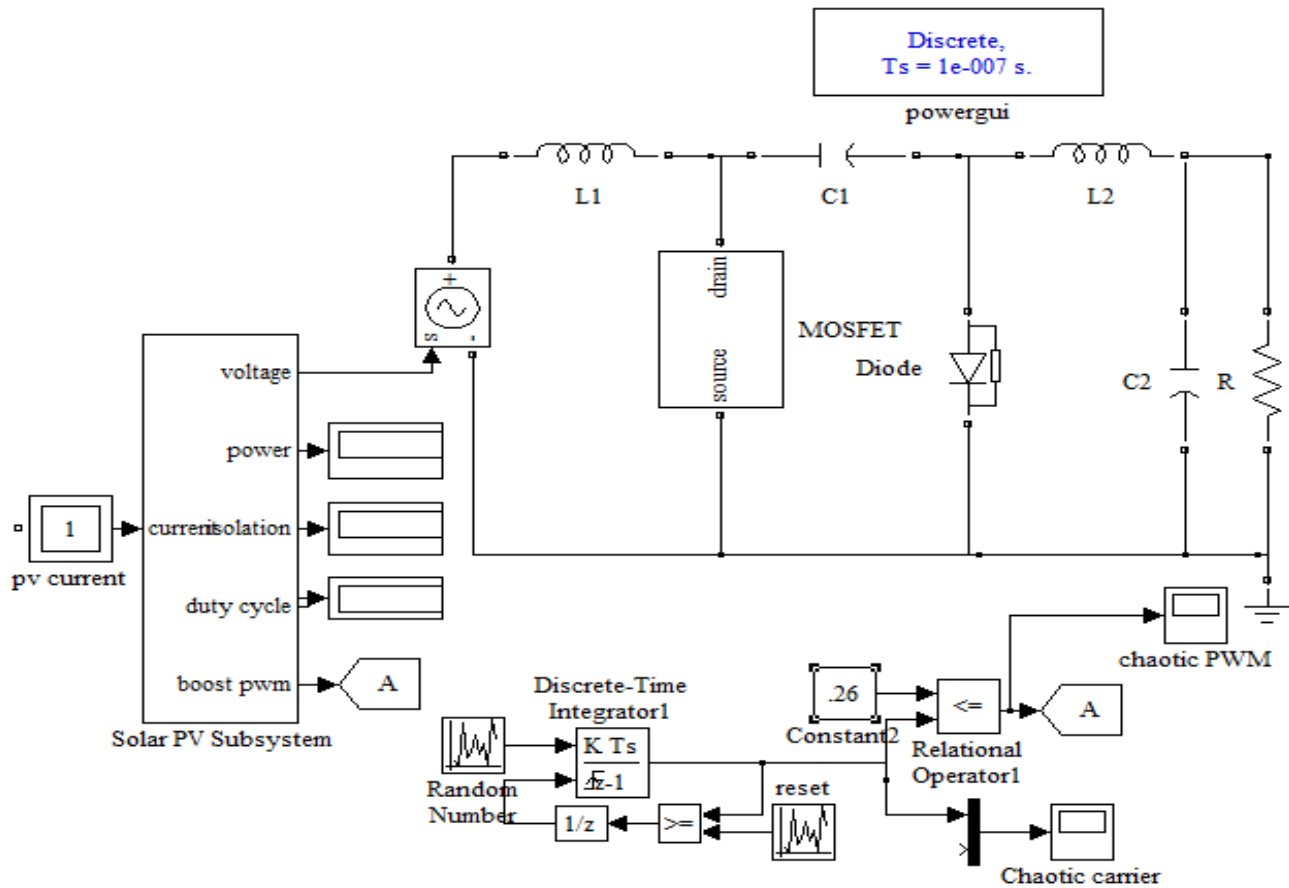


Fig.7 Chaotic PWM Cuk DC-DC converter based MPP tracking

Also the changing irradiation is modeled to study the system operation. The temperature is constant at 25°C and the illumination level is varying between two levels. Initial irradiation is set as 1000W/m<sup>2</sup>. After 0.01sec, the irradiation (G) is suddenly changed to 500W/m<sup>2</sup>.

The relationship between the duty cycle and solar PV power are shown in Figs.8 and 9. It shows that the output power at G=1000 W/m<sup>2</sup> and 500W/m<sup>2</sup> are 36.74W and 17W

respectively for the computer simulation

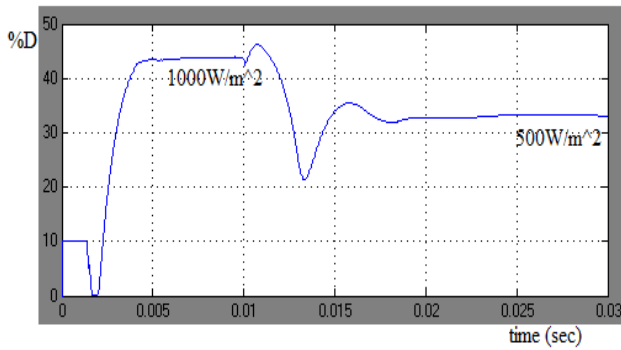


Fig.8. Change in duty cycle for various irradiation level power

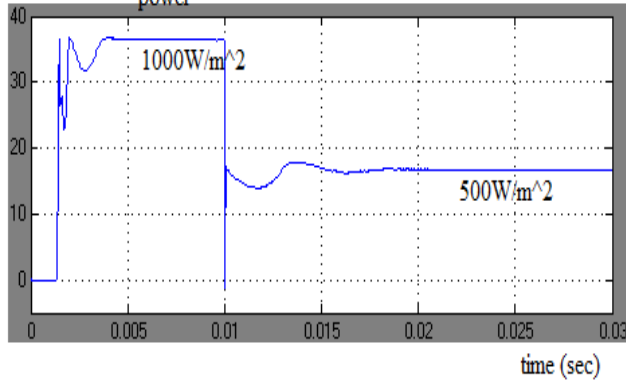


Fig.9. Change in power for various irradiation level

#### 4. Steady state performance

The steady state performance of the proposed control scheme is tested under constant temperature condition. Fig.10. show the duty cycle of the main switch of Cuk converter against different load resistance at the constant irradiation (G) of 1000 W/m<sup>2</sup>. Fig.11. shows that, for the load range of  $1\Omega \leq R_L \leq 7\Omega$ , the obtained tracked power for the computer simulation.

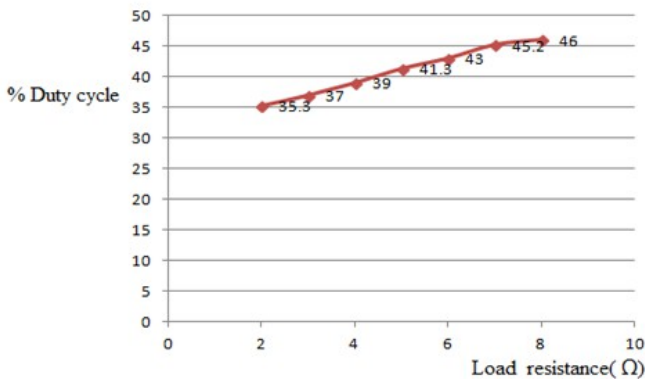


Fig.10 Variation in Duty cycle for the changes in load resistance

The table 2 shows the steady state performance of two different control methods for Cuk converter based MPPT

tracking .The converter conversion efficiency is increased from 86.26% to 93.1%. during stand test condition with two different control methods

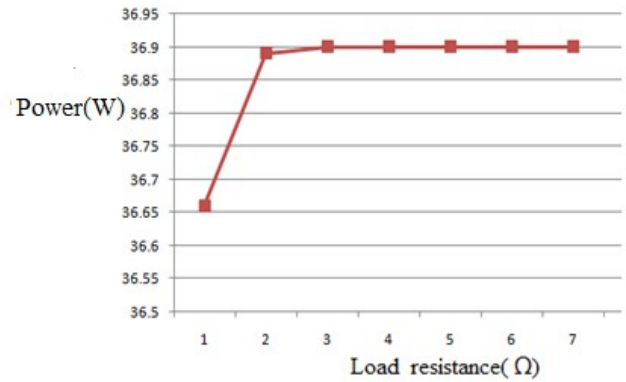


Fig.11 Variation in Tracked power for the changes in load resistance

**Table 2.** Performance comparison of Cuk converter-based PV system with various control methods

MPPT tracking circuits	Converter conversion efficiency	PSD value in output voltage ripples ( Fundamental frequency =25kHz)	Output voltage ripples
Cuk converter with periodic carrier	86.26%	+4 DB	200mv
Chaotic PWM Cuk converter	93.1%	-48db	80 -100mV

#### 5. Hardware Results

The block diagram of MPPT system with closed loop control using Cuk converter illustrate in Fig.12 To verify the functionality and performance of the proposed Chaotic PWM control, a 37W low power test bench as shown in Fig.13 has been setup experimentally. The Direct control is used to extract maximum power from solar PV module is carried out and tested with rheostat (0-50 Ω/5A) for the irradiation of 1000W/m<sup>2</sup>.

The duty cycle of the main switch S in the Cuk converter varied to equalize solar PV module output resistance with load resistance to ensure the maximum power extracted. The experimentation is conducted to validate the effectiveness of the proposed CPWM control.

The average solar flux on the solar PV module was measured as 940 W/m<sup>2</sup> that is in accordance with the average solar flux at 11:45 A.M. on November 5, 2013 at Chennai, India.

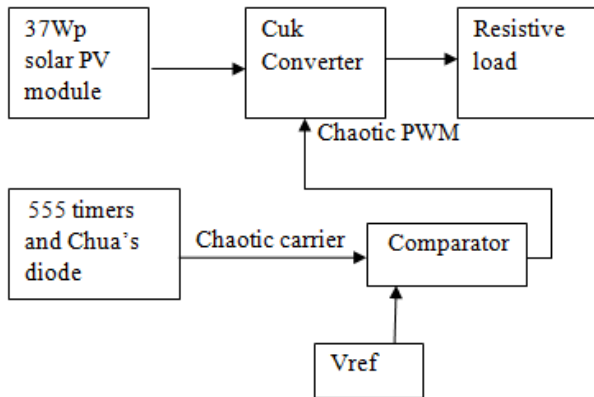


Fig. 12. Block diagram of experimental setup

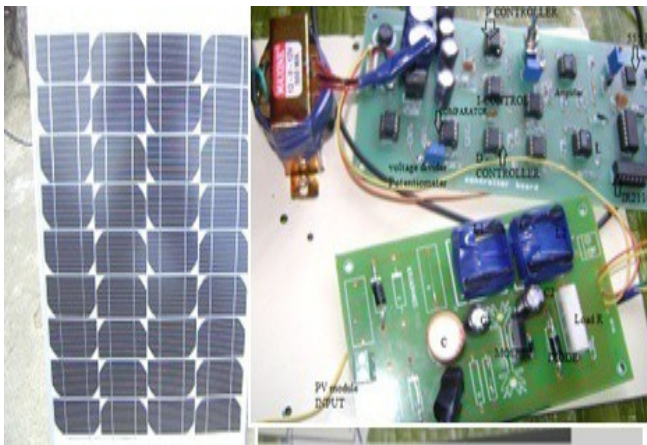


Fig. 13. Photography of experimental setup

The control circuit shown in Fig. 14 used to generate chaotic carrier is designed by coupling a Chua diode with a 555 timer triangular wave generator. This circuit contains only resistor, capacitor and operational amplifier. By selecting the proper values of element, the control circuit experimentally generates chaotic carrier.

Analogue carriers used for the DC-DC converters, such as triangle waves and sawtooth waves, are generated by charging and discharging of a capacitor. A simple circuit shown in Fig. 14. which contains a (555 timer) triangular wave generator and a three segment piecewise linear resistor is known as a Chua diode. The operational amplifiers and the associated resistances ( $R_{d1}$  .....  $R_{d6}$ ) are used to realise linear resistor called Chua diode. The parameters for Chua's diode are chosen as  $R_{d1} = 2.4$  k $\Omega$ ,  $R_{d2} = 3.3$  k $\Omega$ ,  $R_{d3} = R_{d4} = 220\Omega$ , and  $R_{d5} = R_{d6} = 20$  k $\Omega$ .

The resistor R is a potentiometer and can be used to tune the circuit to observe chaotic behavior. The 555 timer circuit uses two comparators, comparing  $V_T$  against 1/3 and 2/3 of  $V_{cc}$  (15V) to determine whether to flip the output state. The

capacitor voltage is charged up or down by turning on or off a discharge transistor. This transistor pulls charge out of the capacitor, or when off, it allows the capacitor to charge up toward the positive supply. The astable mode of operation is preferred in order to generate sawtooth waveform and it is operated in the passive mode.

The charging and discharging times of the capacitor generally are different depending on whether the transistor in 555 timer is turned on or off.

$$t_1 = 0.693(R_1 + R_2) C \text{ charging, output HIGH}$$

$$t_2 = 0.693R_2 C \text{ discharging, output LOW}$$

The frequency of oscillation is given by the inverse of the period, where the period is  $t_1 + t_2$ , or in terms of R and  $C_T$

$$F = 1.44 / (R_1 + 2R_2) C_T$$

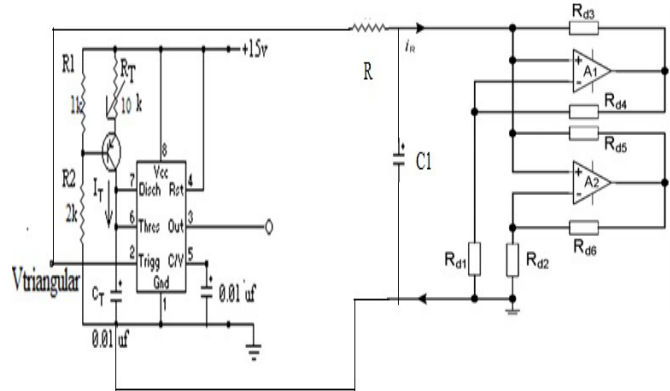


Fig. 14 Control circuit for generation of chaotic carrier

The Figs 15, 16, 17, 18 show the generated periodic carrier, Chaotic carrier, conventional PWM, chaotic PWM and chaotic PWM from the hardware. The solar PV module output voltage (converter input voltage) waveform as shown in the Figs. 19. The Fig 20 shows the output voltage ripples obtained during the conventional PWM -Cuk converter with based MPP tracking. The output voltage ripples is 200mV.

It is seen from Fig. 21 that the high frequency harmonic components are eliminated and hence the spectral performance is improved in case of Chaotic PWM-Cuk converter based MPP tracking when compared with conventional PWM Cuk converter based MPP tracking. The PSD value corresponds to fundamental frequency is -48dB for chaotic PWM - Cuk converter.

It is also seen from Fig 20 that the ripple is only by 80mV as the periodic carrier is replaced by chaotic PWM, while the efficiency of the Cuk converter is improved from 86.26 % to 93.1%. The ripple content in output voltage of converters is observed during the MPP tracking, the presence of transients in the output voltage is low if chaotic PWM control is used.

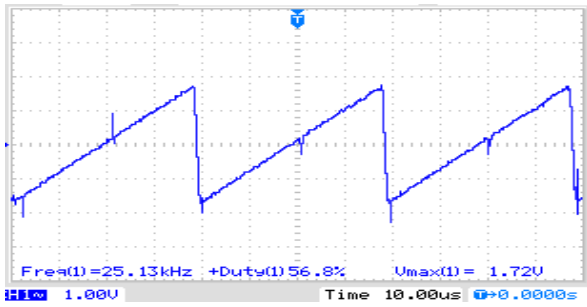


Fig.15 Periodic carrier

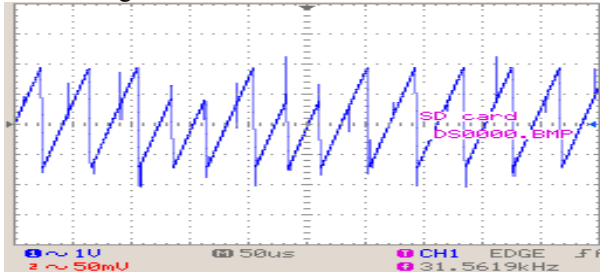


Fig.16 Chaotic carrier

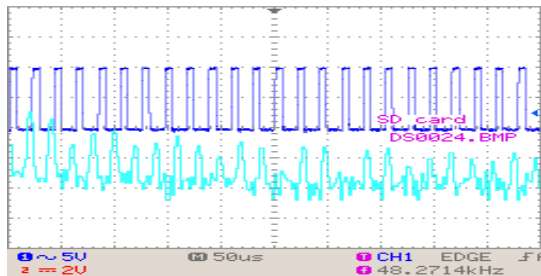


Fig.17 Conventional PWM

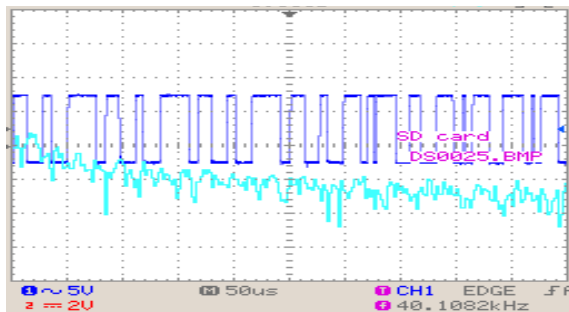


Fig.18. Chaotic PWM

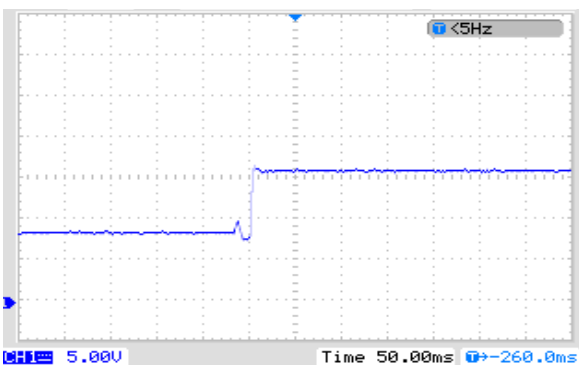


Fig.19 Tracked Input voltage waveform of the converter

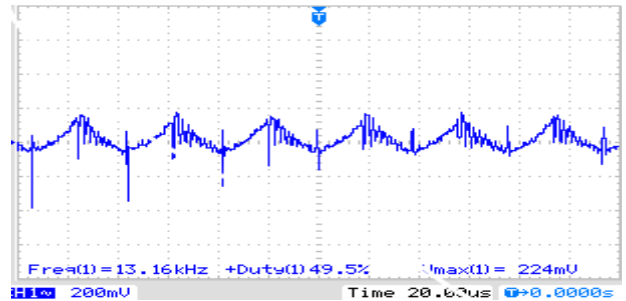


Fig.20. Conventional PWM –Cuk converter- Output voltage ripples

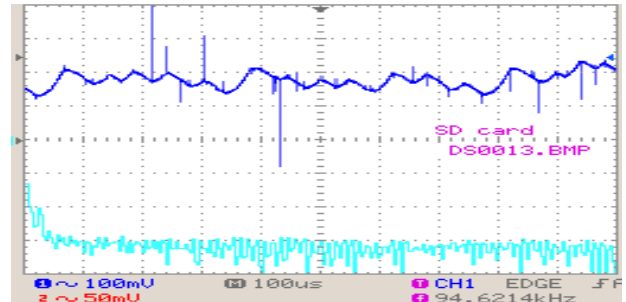


Fig.21 CPWM-Cuk converter –output voltage ripples and its FFT analysis

## 6. Conclusion

Two different control methods for Cuk DC-DC converter were analyzed for Maximum Power Tracking Circuits to improve the converter conversion efficiency of the solar PV system. The converter conversion efficiency is increased when Chaotic PWM control is used. The ripple is only by 80mV as the periodic carrier is replaced by chaotic PWM, while the efficiency of the Cuk converter is improved from 86.26 % to 93.1%. Both simulation and experimental results have confirmed that chaotic-PWM based Cuk converter improves the spectral performance in MPPT solar powered system.

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