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Research Article

Performance Analysis of Various DC-DC Converters with Optimum Controllers for PV Applications

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Abstract: Alternative vehicles to Internal Combustion Engines (ICE), for instance the electric vehicle is becoming popular. Electric Vehicles (EV) are pollution free and cost effective because the fossil fuel cost increases day by day. These factors make people passion for electric vehicles. Electrical energy demand necessitates charging of electric vehicles using renewable energy. Among the different renewable energy resources, Photovoltaic (PV) cells are suitable for EV. The PV output power capacity is still low, so efforts continue to develop the PV converter and its controller, aiming for higher power-extracting efficiency. The PV system requires a proper DC-DC converter with optimum controller to deliver its maximum power. This study analyses the various DC-DC converters such as buck, boost, cuk and modified cuk converters to find the solution for maximum efficiency. In this study in addition to converters, various Maximum Power Point Tracking (MPPT) methods, such as Perturb and Observe, Incremental Conductance along with a proposed algorithm called Brain Emotional Learning Based Intelligent Controller (BELBIC) has been analyzed. The operation of the BELBIC is based on the emotion processing mechanism in the brain. This intelligent control is stimulated by the limbic system of the mammalian brain. The performance analysis of the converters and MPPT methods are simulated using MATLAB/SIMULINK. Furthermore, experimental results are presented in order to validate the modified cuk converter with proposed BELBIC algorithm.

Keywords: BELBIC, DC-DC converters, modified cuk converter, MPPT, PV system

INTRODUCTION

The world is on the need of a major transition to electric vehicles, which use highly efficient electric motors. Electric vehicles avoid pollution and running cost is very low compared to fuel vehicles. Charging of electric vehicles increases the electrical energy demand. Nowadays in India generation of electricity is not sufficient to meet the load demand. India is facing significant power shortage due to its economic development and demand for power in 2030 is anticipated to be three times higher than the demand in 2005. So increase in EV increases the electrical energy demand more. It leads to alternate energy resource. Among the different energy sources, nowadays the PV system has gained popularity and hence it is suitable for EV. Individual EV can be powered by its own PV system.

The block diagram of PV system comprising of PV panel, DC-DC converter and MPPT controller as shown in Fig. 1. The major technical requirements in developing a practical PV system includes:

- An optimal control that can extract the maximum output power from the PV arrays under all operating and weather conditions.
- A high performance-to-cost ratio to facilitate commercialization of developed PV technologies.

Since the PV array has a highly nonlinear characteristic and its performance changes with operating conditions such as insolation and ambient temperature, it is a technically challenging factor to develop a PV system that can meet these technical requirements.

The selection of DC-DC converter for PV system plays a major role in improving the efficiency of PV system. Various DC-DC converters in PV system are analyzed in many researches earlier. The converters are divided into a number of categories, based on application, types of switching, current modes, etc. The performance of solar power system using buck converter has been analyzed to extract maximum power from the PV panel (Lu *et al*., 2007; Bilsalam *et al*., 2011). In Cakmak *et al*. (2012), an idea about modeling of standalone PV system using boost converter has been discussed. In Vaigundamoorthi and Ramesh (2012) the performance of the solar PV system using cuk converter has experimentally analyzed. From the previous researches, it is obvious that each converter has its own advantages and disadvantages. Therefore it is essential to develop a PV system which has the capability to

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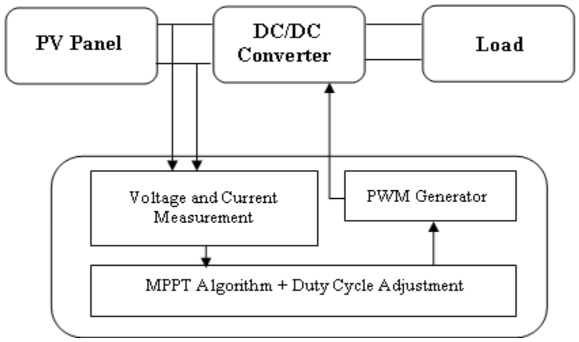

Fig. 1: Block diagram of PV panel with converter and MPPT

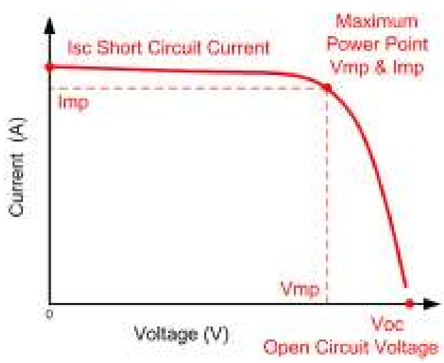

Fig. 2: Current vs. voltage curve of a PV module

produce maximum efficiency, minimum stress and reduced ripple.

Maximum power delivered by PV system not only depends on the irradiation, but also based on operating point of the system. Operating point means the impedance of PV panel. MPPT controllers are used to move the operating point of PV panel from input impedance (R_i) to optimum resistance (R_{MPP}). Different MPPT has been analyzed by various researchers earlier. In Tse *et al*. (2001), a novel maximum power point tracking technique for PV panels has been proposed. In Nashed (2002) a high efficient low cost PV system has been presented. The fuzzy logic controller based MPPT for energy storing PV systems has been discussed in Sahin and Okumus (2012). Early researchers have analyzed the performance of various MPPT algorithms for a variety of PV based applications. It is clear from the previous analyses that maximum efficiency of MPPT is attained with complex algorithm. So it necessitates simple and effective MPPT controller for a PV system. Hence in this study, a novel modified cuk converter with brain emotional learning based intelligent MPPT controller has been proposed for extracting maximum power from the PV system.

METHODOLOGY

Photovoltaic system: The fundamental structural unit of a solar module is the PV cell. A solar cell converts energy in the photons of sunlight into electricity through the photoelectric effect. A single solar cell can generate only a little amount of power. In order to enhance the output power of a system, solar cells are connected in series and parallel to form PV modules and PV modules connected in series and parallel to form PV arrays. PV module characteristics show an exponential and non-linear relation between output current and voltage of PV module shown in Fig. 2. The equation for output current of a PV module is given by Fangrui *et al*. (2008):

$$I_o = n_p - I_{ph} - n_p I_{rs}\left[\exp\left(k_o \frac{V}{n_s}\right) - 1\right] \quad (1)$$

where, I_o represents the PV array output current, PV output voltage is denoted by V, I_{ph} represents the cell photocurrent that is proportional to solar irradiation, I_{rs} denotes the cell reverse saturation current that mainly depends on the temperature, k_o represents a constant, n_s denotes the number of PV cells connected in series and n_p denotes the number of such cells connected in parallel.

The cell photocurrent is computed from the Eq. (1):

$$I_{ph} = [I_{scr} + k_i(T - T_r)]\frac{S}{100} \quad (2)$$

where,

I_{scr} : The cell short-circuit current at reference temperature and radiation
k_i : Temperature coefficient of the short circuit current
T : The cell temperature
T_r : The cell reference temperature
S : Solar irradiation in W/m^2

The cell reverse saturation current is computed from the equation:

$$I_{rs} = I_{rr}\left[\frac{T}{T_r}\right]^3 \exp\left(\frac{qE_G}{kA}\left[\frac{1}{T_r} - \frac{1}{T}\right]\right) \quad (3)$$

where,

T_r : The cell reference temperature
I_{rr} : The reverse saturation at T_r
E_G : The band-gap energy of the semiconductor used in the cell
q : Electron charge
A : Curve fitting constant
K : Boltzman's constant

DC-DC converter: In this study, converters based on voltage conversion are analyzed for better suitability in PV system. The converters chosen for analysis are buck, boost, cuk and modified cuk converter.

DC-DC buck converter: The DC-DC buck converter is also called as step-down converter. In general the voltage gain of this converter is always less than one. So this topology can be used for connecting high module voltages to low load or battery voltages. It is a class of Switched Mode Power Supply (SMPS) containing at least two semiconductor switches (a diode and a transistor) and at least two energy storage elements, a capacitor and an inductor.
The Duty cycle (D) of buck converter is:

$$D = \frac{V_o}{V_i} \tag{4}$$

where,
V_o = The output voltage of the converter
V_i = The input voltage of the converter

DC-DC boost converter: In DC-DC boost or step-up converter, the output voltage magnitude is always higher than the input voltage magnitude. So this topology can be used to connect high load/battery voltages and low module voltages. It is a class of SMPS that contains at least two semiconductor switches (a diode and a transistor) and at least one energy storage element, a capacitor, inductor, or the two in combination. Many research works have developed applications for DC-DC boost converter in PV systems (Nejabatkhah *et al*., 2011).
The duty cycle of the boost converter is:

$$D = 1 - \frac{V_i}{V_o} \tag{5}$$

DC-DC cuk converter: Cuk converter is a DC-DC converter that performs like buck-boost converter, capable of stepping up or down, the input voltage with reverse polarity through the common terminal of the input voltage (Rashid, 2001). This topology can be used for connecting nearly-matched battery or load to module voltages. It is a class of SMPS and contains at least one semiconductor switch (a diode and a transistor) and at least four energy storage elements, two capacitors and two inductors. The main difference between cuk converter and buck-boost configuration is the addition of a capacitor and an inductor. Inductor L_i filters the large harmonics in DC input and capacitor C_1 is the energy transfer device.
The duty cycle of the cuk converter is:

$$\frac{D}{1-D} = \frac{V_o}{V_i} \tag{6}$$

An important advantage of this topology is continuous current at the converter input and output. Many researchers have focused on it Zengshi (2012) for maximum power extraction from PV panels through various algorithms. The only hitch in the cuk converter is high electrical stresses on the switch, diode and capacitor C_1. It necessitates reduction of stress on components to improve the efficiency.

Modified cuk converter: Small changes in cuk converter can enhance its performance by reducing the stress in the switch, diode and capacitor. Addition of storage element such as an inductor or capacitor and the diode in the converter reduces the energy in a storage element. It results in reduced stress on the components. Cuk converter is actually the cascade combination of a boost and a buck converter. In this study, a simple switching dual structure to step-up the voltage has been proposed. The step-up structure is formed by two capacitors and two diodes. The step-up structure is inserted in a classical cuk converter to offer a new power supply called Modified Cuk Converter (Boost Mode). The circuit diagram of the modified cuk converter operating in boost mode is shown in Fig. 3. By inserting the capacitor C_2 and diode D_2 in the manner as shown in Fig. 3, the converter operates in a step-up mode (Boris *et al*., 2008).

When the switch S is ON, L_{in} gets charged and capacitors C_1 and C_2 get discharged in series. The current in the capacitor C_1 and C_2 is given by the relation:

$$i_{switch} = i_{in} + i_o \tag{7}$$

$$i_{c1} = i_{c2} = i_0 \tag{8}$$

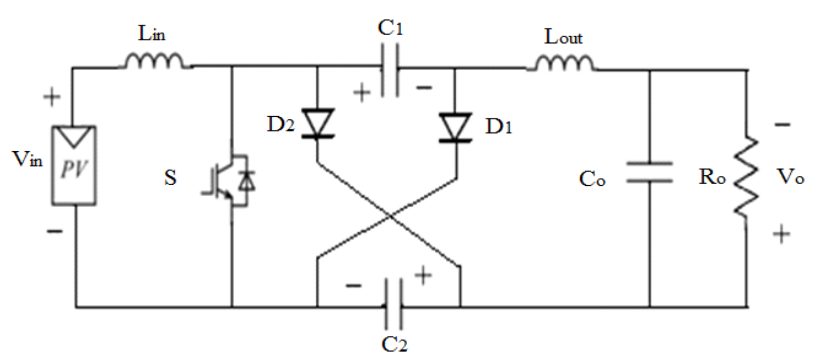

Fig. 3: Schematic of modified cuk converter

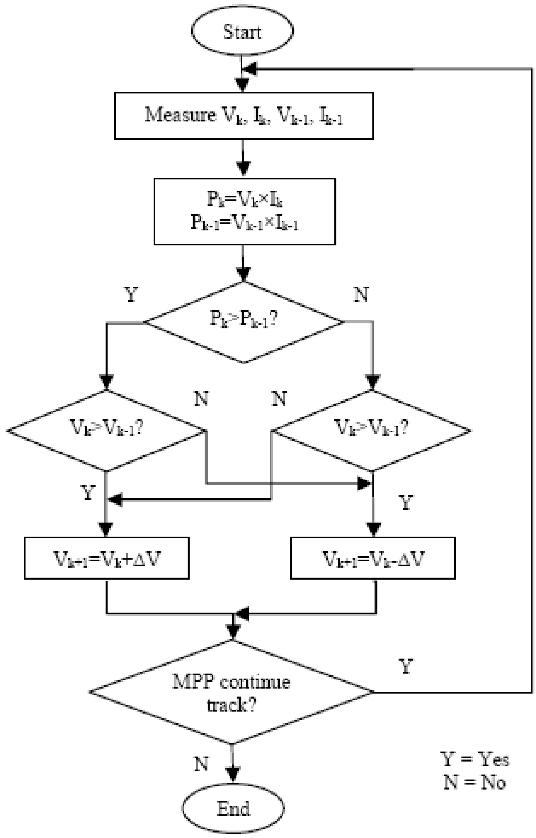

Fig. 4: Flowchart of P&O algorithm

Similarly, when the switch S is OFF, L_{in} gets discharged and capacitors C_1 and C_2 get charged in parallel. The current relations are as follows:

$$i_{c1} = i_{c2} \quad (9)$$

$$i_{D1} = i_{D2} \quad (10)$$

$$i_{D1} = \frac{1}{2}(i_{in} + i_0) \quad (11)$$

$$i_{c1} = \frac{1}{2}(i_{in} - i_0) \quad (12)$$

The voltage balances on L_{in} and L_{out} is given by:

$$V_{in}\,\mathrm{D} + (V_{in} - V_c)\,(1 - \mathrm{D}) = 0 \quad (13)$$

$$(V_o - 2V_c)\mathrm{D} + (V_o - V_c)\,(1 - \mathrm{D}) = 0 \quad (14)$$

Therefore, the output voltage relation is given as:

$$\mathrm{V_o} = \frac{1+\mathrm{D}}{1-\mathrm{D}}\mathrm{V_{in}} \quad (15)$$

A switch in the shunt connection simplifies the drive circuit. Addition of capacitor reduces stress on switch, diode and capacitor. So it is suitable for a PV system to generate maximum power from PV panel with less complexity in order to increase the efficiency.

MPPT algorithms for PV system: Enhancing the efficiency of the PV panel and the inverter is not easy as it depends on the technology available. It may require better components, which can increase drastically the cost of the installation. Hence, improving the tracking of the Maximum Power Point (MPP) with new control algorithms is easier and it is not expensive. The efficient PV system needs simple and effective MPPT controller. In this study, conventional MPPT methods such as Perturb and Observe (P&O) and incremental conductance are compared with the proposed BELBIC algorithm.

Perturb and Observe (P&O) MPPT: In Perturb and Observe (P&O) method, as the name indicates, the working is based on the inspection of the array output power and on the perturbation (adding or subtracting) of the power with respect to the change in array voltage or current. This method continuously adds or subtracts the reference current or voltage with respect to the previous power sample (Elgendy *et al*., 2012). The operation of the P&O MPPT is shown in Fig. 4. The computation of actual state k and previous state k-1 of parameters V and I are considered. The actual and previous state of the parameters power P and voltage V

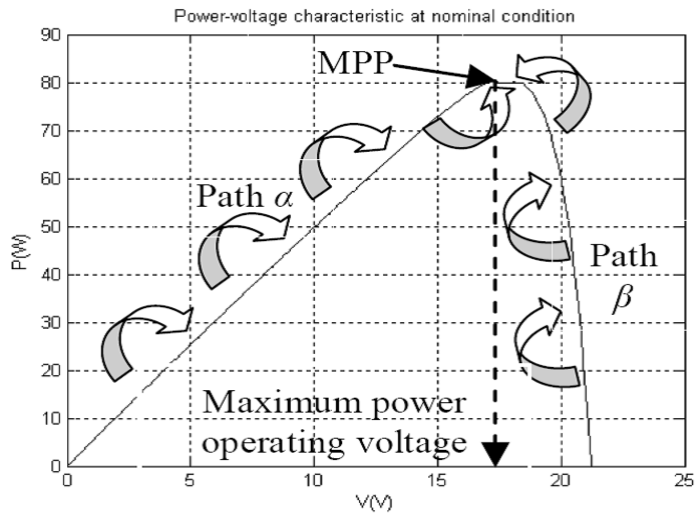

Fig. 5: Principle for MPP tracking

are compared. According to the conditions as represented in Fig. 5, increment or decrement of perturbed voltage ΔV, will be applied to the PV module operating voltage. Figure 5 demonstrates the power-voltage characteristic feature of PV model which discusses the principle of MPP tracking. There are four probable scenarios which will affect the direction of the tracking in P&O MPPT.

Case 1: For $P_k>P_{k-1}$ and $V_k>V_{k-1}$, the situation can be described as path α in Fig. 5. When the operating voltage is increased, then the PV power is also increased. Therefore, a small change of voltage ΔV needs to be added to the present PV operating voltage, followed by monitoring the PV power. This process is continued until the MPP is identified.

Case 2: The $P_k>P_{k-1}$ and $V_k<V_{k-1}$ is referred to the path β in Fig. 5. It can be observed that when the operating voltage is reduced, the PV power is increased. To recognize the MPP operating point, reduction of ΔV should be made on the present PV operating voltage and the parameters P_k and P_{k-1} are compared. If the condition $P_k>P_{k-1}$ is satisfied, the decrement of ΔV will be continued until the MPP is effectively spotted.

Case 3: The $P_k<P_{k-1}$ and $V_k>V_{k-1}$ can be illustrated as path β in Fig. 5. In this scenario, the PV power is diminishing as the increase in PV operating voltage. Hence, it should have a decrement in ΔV on the present PV operating voltage.

Case 4: The $P_k<P_{k-1}$ and $V_k<V_{k-1}$ is illustrated as path α in Fig. 5. The PV power is reducing as the decreasing of PV operating voltage. Thus the PV operating voltage should have an increment in ΔV to track the PV maximum power point.

The main drawback of P&O MPPT approach is that the PV module operating voltage is disturbed in every cycle. This algorithm will always carry out an increment or decrement of ΔV to the PV operating voltage. The process of maximum power tracking will be carried on even the MPP has been effectively tracked. This is because of the output power of PV module for the next perturbed cycle is unpredictable.

Incremental conductance MPPT: In incremental conductance method, the array terminal voltage (Snyman and Enslin, 1993) is always adjusted according to the MPP voltage. It is based on the incremental and the instantaneous conductance of the PV module. The slope of the PV array power curve is zero at the MPP, increasing on the left side of the MPP and decreasing on the right hand side of MPP.
The basic equations of this method are as follows:

$$\frac{dI}{dV} = -\frac{I}{V} \text{ At MPP} \quad (16)$$

$$\frac{dI}{dV} > -\frac{I}{V} \text{ Left of MPP} \quad (17)$$

$$\frac{dI}{dV} < -\frac{I}{V} \text{ Right of MPP} \quad (18)$$

In the above equations, I and V are PV array output current and voltage, respectively. The left hand side of equations represents incremental conductance of PV module and the right hand side represents the instantaneous conductance. When the ratio of change in output conductance is equal to the negative output conductance, the solar array will operate at the MPP. In other words, by comparing the conductance at each sampling time, the MPPT will track the maximum power of the PV module. Figure 6 shows the operational flow chart of incremental conductance

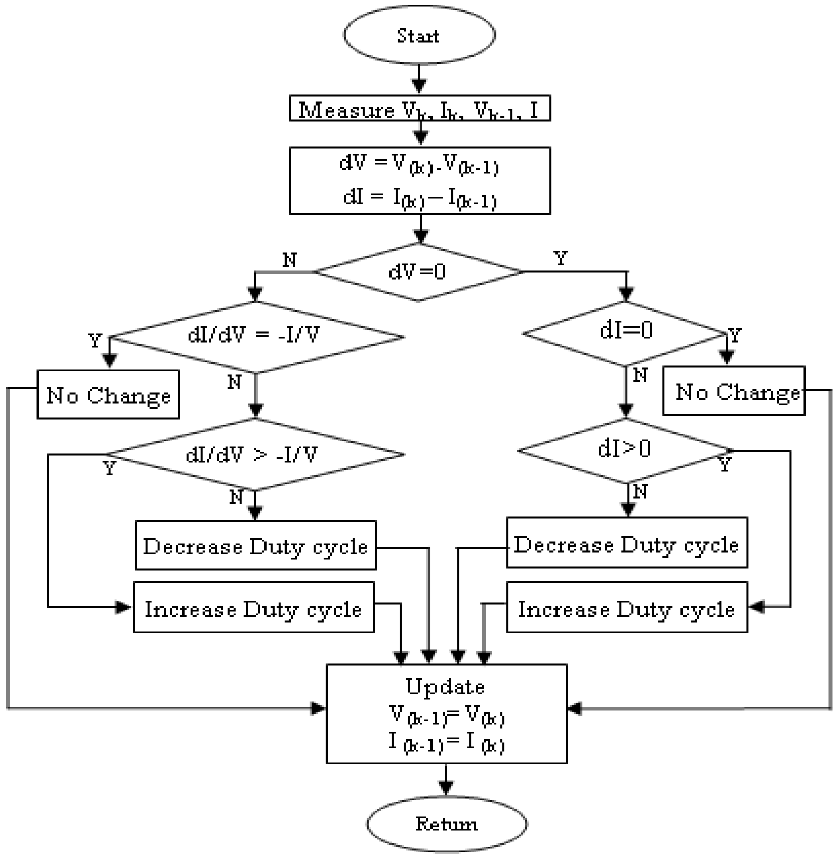

Fig. 6: Flowchart of incremental conductance

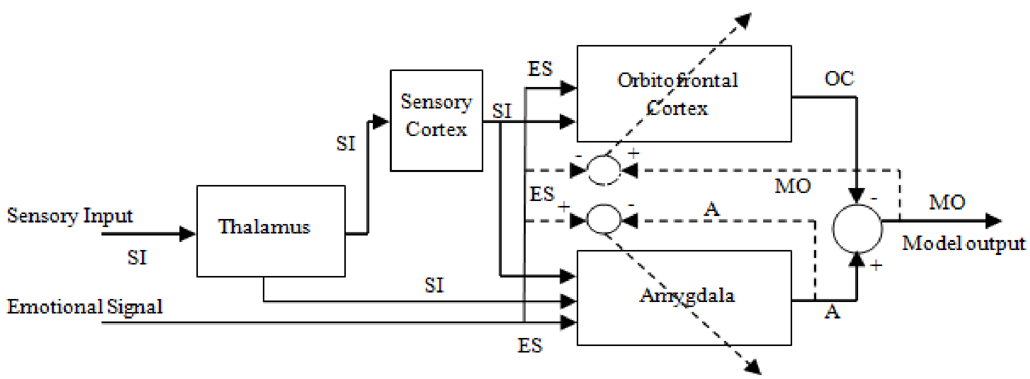

Fig. 7: Simple structure of BELBIC

algorithm. Initially, it starts with measuring the present values of voltage and current of the PV module. Then, it calculates the incremental changes (dI and dV) using the present values and previous values of voltage and current. The main check is carried out using the relationships in the Eq. (16) to (18). If the condition does not satisfies the Eq. (17), it is assumed that the operating point is at the left side of the MPP and hence must be moved to the right by increasing the module voltage.

Similarly, if the condition satisfies the inequality Eq. (18), it is assumed that the operating point is at the right side of the MPP and hence must be moved to the left side by decreasing the module voltage. When the operating point reaches the MPP, the condition satisfies the Eq. (16) and the algorithm bypasses the voltage adjustment. Finally at the end of the cycle, it updates the history by storing the voltage and current data that will be used as previous values in the next cycle. The drawback is that it leads to reliability issues due to noise in the components.

BELBIC controller: To achieve maximum output power, fine tuning of MPPT is needed. It can be achieved by using the proposed BELBIC based MPPT because it has dual feedback controller whereas the P&O and Incremental Conductance MPPT are single feedback controllers. The BELBIC receives the rate of change in power as one feedback and controller output as another feedback. It results in accurate tuning of controller based on the present state. BELBIC is a learning controller based on the computational model of Moren's limbic structure (Lucas *et al*., 2004). This structure is a simple model of the main parts in limbic system i.e., amygdale, orbit frontal cortex, thalamus and sensory cortex input which is shown in Fig. 7.

In this study, rate of change of power in PV panel is considered as an input signal to Sensory input (S). Based on the irradiation, the value of S to the BELBIC also varies. As seen from the Fig. 7, the sensory input is first processed in thalamus. Thalamus is a simple model of real Thalamus in brain in which some simple pre-processing on SI input signals is done. After pre-processing in Thalamus, the signal is sent to Amygdala and Sensory Cortex (SC). The SC has the duty of discriminating the coarse output from thalamus. Then, this filtered signal is sent to Amygdala and Orbitofrontal Cortex (OC). Amygdala is a small structure in the medial temporal lobe of brain which is responsible for the emotional evaluation of stimuli (Javan-Roshtkhari *et al*., 2009). Another main component in limbic system is orbitofrontal cortex that has the duty of inhibiting inappropriate responses from Amygdala. Then Amygdala and Sensory Cortex will receive their processed form and their outputs will be computed by Amygdala and Orbitofrontal based on the Emotional Signal (ES) received from the environment in the form of panel power in present state.

If several sensory inputs are required for controller design, Thalamus output will be the maximum of these sensory inputs, as shown in Eq. (19). Otherwise single sensory input will directly be sent to Amygdala:

$$S_{th} = \max(S_i) \tag{19}$$

In the Amygdala, each A node has a plastic connection weight V. The sensory input is multiplied by the weight and forms output of the node. And in orbitofrontal cortex, each O is similar to A node. The output of amygdala and orbitofrontal cortex is computed by considering the i-th sensory input S_i is as follows:

$$A_i = S_i V_i \tag{20}$$

$$A_{th} = S_{th} V_{th} \tag{21}$$

$$O_i = S_i W_i \tag{22}$$

Based on output of Amygdala and Orbitofrontal cortex, the model output is computed by using Eq. (23):

$$MO = \sum A_i - \sum O_i + A_{th} \tag{23}$$

Learning in Amygdala and Orbitofrontal cortex is defined through formula (24)-(26):

$$\Delta V_{th} = \propto . \max\left(0, S_{th}\left(\text{stress} - \left(\sum A_i + S_{th} V_{th}\right)\right)\right) \tag{24}$$

$$\Delta V_i = \propto . \max\left(0, S_i\left(\text{stress} - \left(\sum A_i + S_{th} V_{th}\right)\right)\right) \tag{25}$$

$$\Delta W_i = \beta . S_i (E - \text{stress}) \tag{26}$$

In above formulas, V_i is gain for amygdala, the W_i is gain for orbitofrontal cortex, α and β are learning rates of amygdala and orbitofrontal cortex respectively that determine the rate at which they affect emotional cues into model output. As we can see in formula (24) and (25), amygdala has the function of directing output in order for the association to be made between sensory input and emotional cue signal. Also, as seen in formula (26), learning in orbitofrontal cortex will cause output inhibition if expected signal mismatches that of reinforcement. Based on the above equations, the mathematical model of BELBIC is formed. MO is the

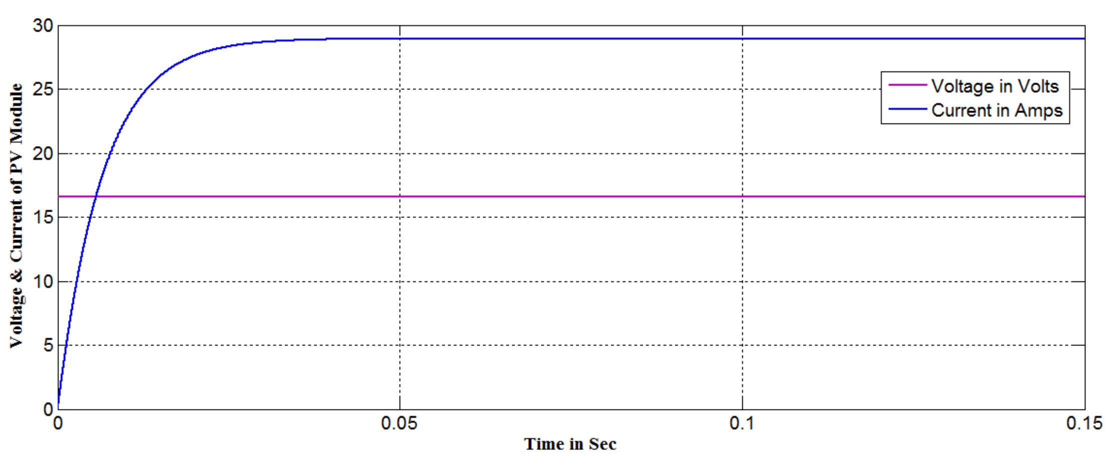

Fig. 8: Output voltages and current of the PV module

modulation index for PWM to trigger the switch in the converter. The BLEBIC based MPPT is easy to implement and consumes less processing time. Due to the presence of dual feedback controller, it enhances the performance of MPPT.

SIMULATION RESULTS AND DISCUSSION

The PV system is simulated using MATLAB/SIMULINK software. It is analyzed with various converters like buck, boost, cuk and modified

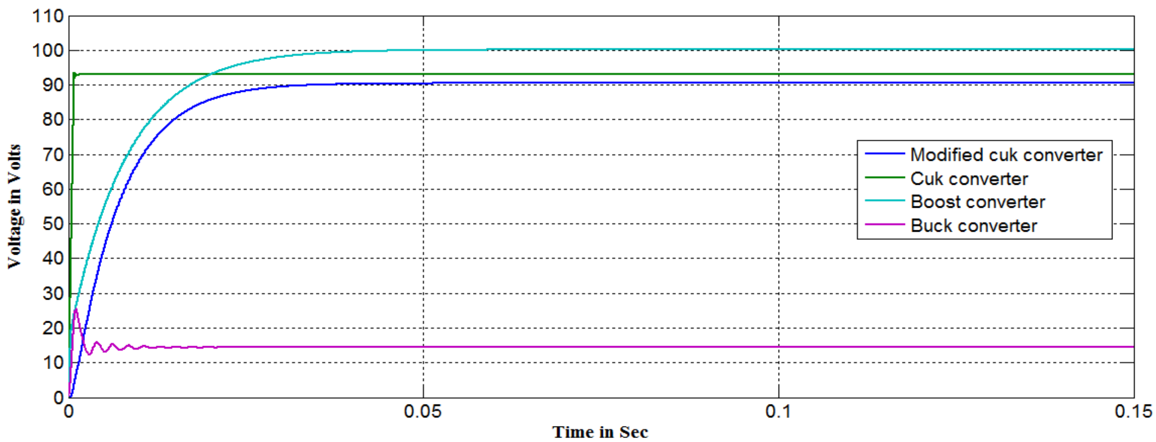

Fig. 9: Output voltage of various converters using P&O algorithm

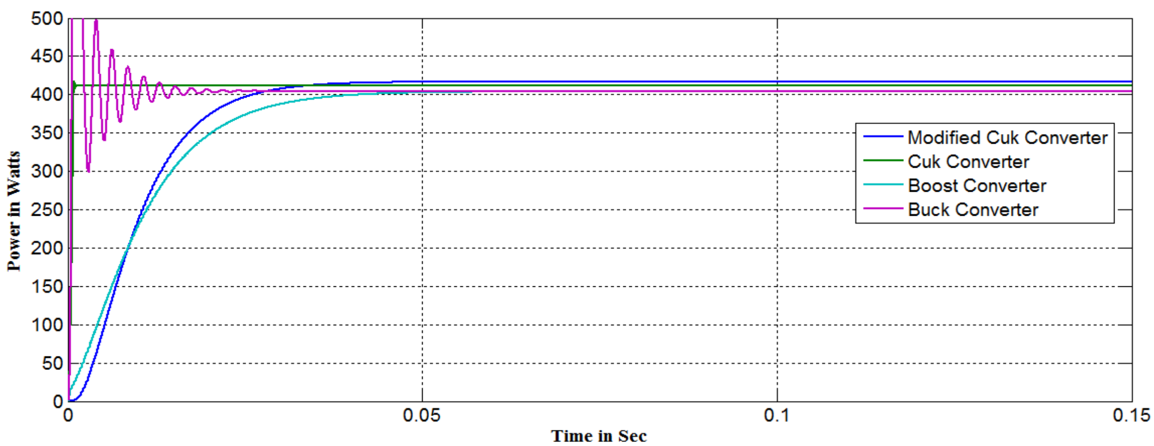

Fig. 10: Output power of various converters using P&O algorithm

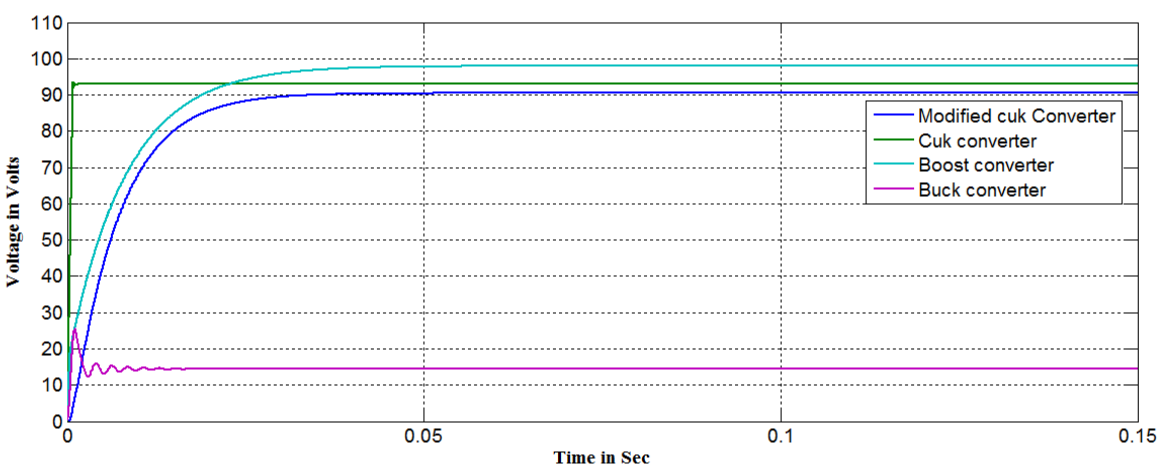

Fig. 11: Output voltage of various converters using incremental algorithm

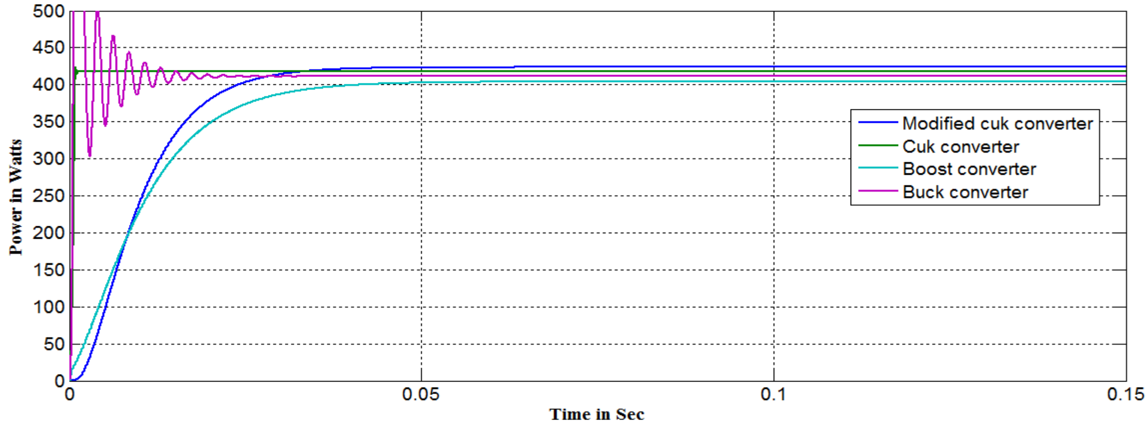

Fig. 12: Output power of various converters using incremental algorithm

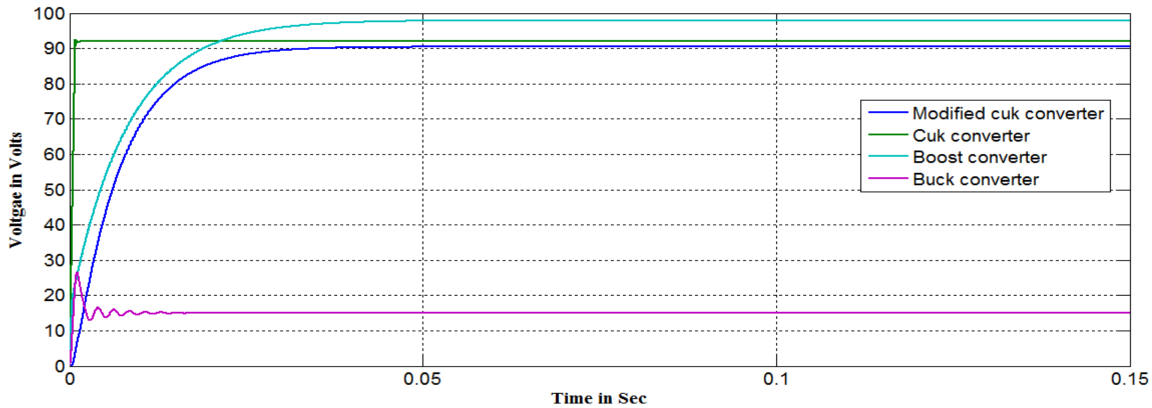

Fig. 13: Output voltage of various converters using BELBIC

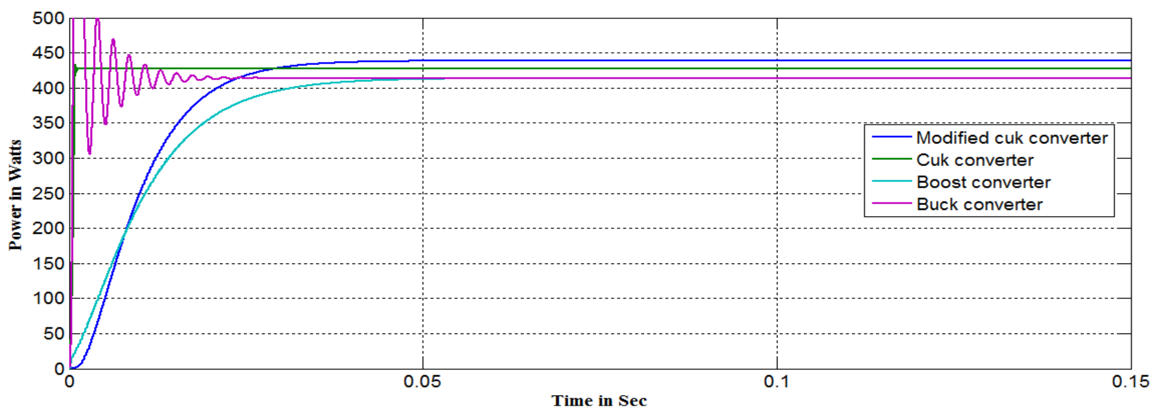

Fig. 14: Output power of various converters using BELBIC

Table 1: Numerical comparison of converters and controllers

	MPPT								
	P&O			INC CON			BELBIC		
Converter	Input power	Output power	Efficiency in %	Input power	Output power	Efficiency in %	Input power	Output power	Efficiency in %
Buck	481.4	404.5	84.03	481.4	411.1	85.41	481.4	413.8	85.97
Boost	478.8	404.1	84.41	478.8	404.0	84.39	478.8	413.9	86.45
Cuk	479.3	412.2	85.99	479.3	417.8	87.16	479.3	427.3	89.15
Modified cuk	480.8	417.0	86.72	480.8	423.8	88.13	480.8	438.9	91.28

cuk converter. The various converters are analyzed with various MPPT algorithms such as P&O, Incremental Conductance and BELBIC. The output voltage and current of the PV module is shown in Fig. 8. Figure 9 shows the output voltage of various converters using P&O MPPT algorithm. The output power of various converters with P&O algorithm is shown in Fig. 10. Figure 11 is the output voltage of various converters using an incremental conductance algorithm. Similarly, Fig. 12 shows the output power waveforms of various converters with incremental conductance algorithm. Figure 13 is the output voltage of the various converters using BELBIC algorithm. The output power waveforms of various converters with BELBIC algorithm is clearly illustrated in Fig. 14. As seen from the power waveforms, the output power of modified cuk converter with BELBIC algorithm is comparatively higher when compared with other converters.

From the graphs it is apparent that buck converter produces less voltage which is not suitable for the load. Boost converter increases the voltage but voltage is increased more than required. That is a higher steady state error in voltage is produced. Cuk converter produces less steady state error in voltage and maximum efficiency. The modified cuk converter delivers very less steady state error in voltage and maximum efficiency when compared with cuk converter. Table 1 shows the numerical performance comparison of above converters with P&O, Incremental Conductance and BELBIC MPPT algorithms. From the Table 1, it is noticeable that the modified cuk converter with BELBIC produces high efficiency.

Experimental results: In order to make an experimental study on solar system, an experimental setup has been developed for modified cuk converter with BELBIC controller. In case of conventional direct coupled system, the maximum power is not transferred to the load because the source and the load impedance are not matched. Hence, a modified cuk converter serves the purpose of transferring maximum power from the PV panel to the load. The schematic diagram of the proposed converter with BELBIC controller is illustrated in Fig. 15. As seen from the figure, a modified cuk converter acts as an interface between the PV module and the load. Firstly, the voltage and current parameters of the solar panel are acquired by a dsPIC using current/voltage measurement units. Secondly, the power is calculated using the obtained values and then dsPIC starts to generate PWM signals required for the converter operation.

Inorder to move the operating point of the PV panel to the maximum power point, the sensed voltage and current parameters are processed to the dsPIC to generate the error signal. The error signal in digital form is given to the DAC which convert it to the corresponding analog signal. This analog signal is further compared with a high frequency triangular wave to generate the PWM pulse. The generated pulse is given to the gate of the power semiconductor device (MOSFET), in order to match the source and load impedance to transfer maximum power to the load. The overall experimental setup of the proposed system is shown in Fig. 15. The solar panel (Model No. Websol W100) is used for the experimental setup and the specifications of the panel are shown in Table 2.

Table 2: Solar panel specifications (insolation-1000 W/m^2, temperature -25°C)

Parameters	Typical value
Maximum power (P_{max})	100.00 W
Open circuit voltage (V_{oc})	20.70 V
Short circuit current (I_{sc})	7.20 A
Maximum power voltage (V_{mp})	16.75 V
Maximum power current (I_{pm})	6.00 A
Dimensions	1500×550×34 mm

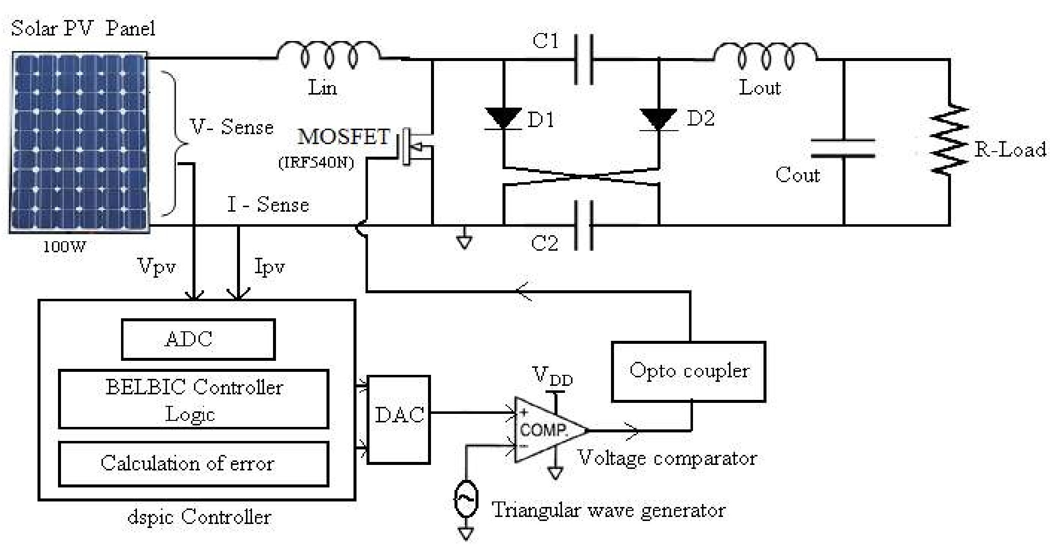

Fig. 15: Schematic diagram of the proposed converter with MPPT system

The Digital Storage Oscilloscope (DSO) and Precision Power Analyzer (PPA) are used to trace the practical characteristics. The hardware results of input voltage, input current, output voltage and output current waveforms are shown in Fig. 16. The input and output values of voltage, current and power are clearly illustrated in Fig. 17. As seen from this figure, the input voltage of 14.940 V is boosted to 34.506 V. Figure 18 illustrates the waveforms of voltage across the input inductor (L_{in}), voltage across the diode (D_1), voltage across the capacitor (C_1) and current through the capacitor (C_1). Figure 19 shows the duty cycle ratio

Fig. 16: Voltage and current waveforms of modified cuk converter for 85.3% duty cycle

Fig. 17: Input and output values of modified cuk converter (85.3% duty cycle)

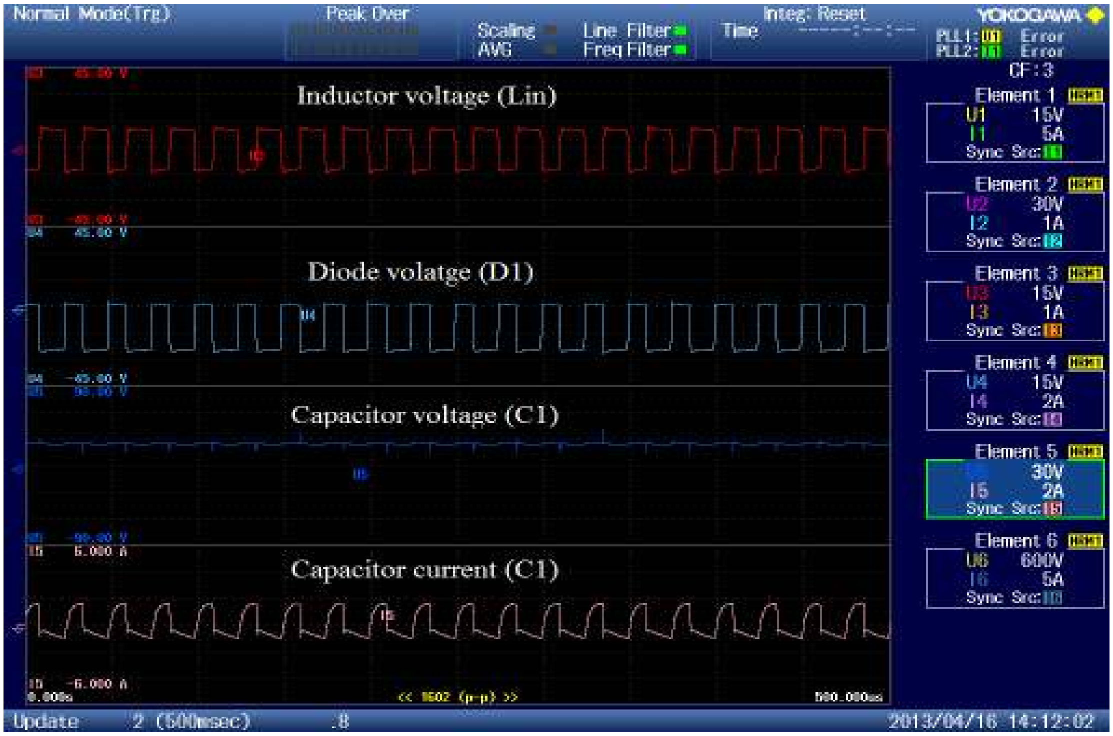

Fig. 18: Voltage and current waveforms of inductor and capacitor (85.3% duty cycle)

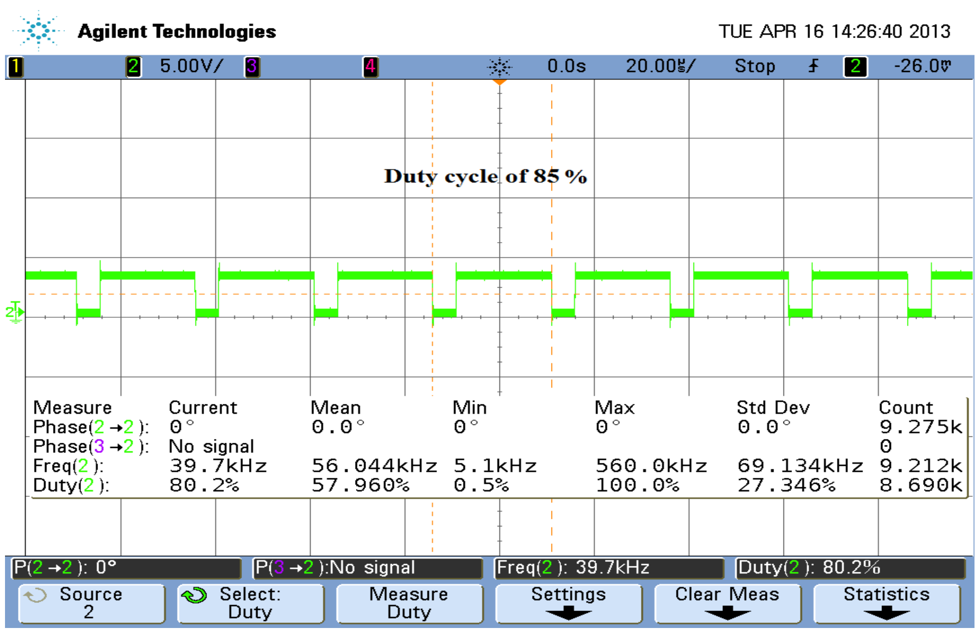

Fig. 19: Duty cycle waveform

(85%) of the PWM pulse produced by the dsPIC. The calculated efficiency of the proposed converter with BELBIC controller is 85.3%.

CONCLUSION

This study analyses PV system with various converters such as buck, boost, cuk and modified cuk converter. Each converter is analyzed with P&O, incremental conductance and proposed BELBIC MPPT algorithms. The whole system is analyzed using MATLAB/SIMULINK environment. From the obtained simulation results, it is clear that the modified cuk converter with BELBIC algorithm has considerable increase in efficiency with minimum ripples. The main advantage of modified cuk converter is that the increased number of storage elements reduces the stress on all components and it reduces the size and weight of inductors. In order to validate the simulation results of the proposed converter with BELBIC controller, an experimental setup has been made. Hence, the modified cuk converter with BELBIC algorithm is suitable for PV system in electric vehicles.

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