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Engineering

# PERFORMANCE ANALYSIS OF MPPT DRIVEN BLDC MOTOR THROUGH BUCK BOOST AND CUK CONVERTER

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**ABSTRACT** Solar energy is one of the most promising energies in the world and the fast declining cost of PV modules had made the PV power generation cheaper and feasible. This paper presents a solar photovoltaic (SPV) array fed permanent magnet brushless DC (BLDC) motor drive which can be used in applications such as water pumping, fan etc. A comparative analysis is done by driving BLDC through both Buck Boost and Cuk converter. The converter tracks the maximum power by using maximum power point technique. The control pulse to the Buck Boost converter is given through P&O MPPT while the Cuk converter works based on incremental conductance method (INC).The current sensors normally used for speed controlling of BLDC motor are completely eliminated. The VSI operates at fundamental switching frequency, avoiding the high frequency switching losses, in order to enhance the efficiency of the system. An experimental validation is also made to validate the design and simulated results under real circumstances on a developed prototype.

**KEYWORDS :** BLDC motor, SPV, Cuk converter, Buck boost converter, INC-MPPT, P&O

## INTRODUCTION

The global energy crisis in near future makes the renewable energy generations such as solar photovoltaic (SPV) array and wind energies worldwide popular. Drastic reduction in the cost of solar photovoltaic (SPV) modules along with its everlasting and environment friendly nature have motivated the researchers, industrialists and consumers towards the use of SPV technology.

Even though induction motors are widely used due to its robustness, low maintenance cost and ease of availability there are certain limitations for the induction motor which are not favorable for SPV array based applications. The requirement of a complex control and overheating problem are the main disadvantage here. The brushless DC (BLDC) motors have replaced induction motors for small scale pumping applications such as pumping and fan applications, [6] due to its higher efficiency, long life, high reliability, low radio frequency interference, low noise and no maintenance. The BLDC motor used in SPV array based applications so far requires additional control circuitry and sensors to facilitate the speed control, resulting in increased complexity, cost, weight and size of the system [6-8]. Moreover, the voltage source inverter (VSI), feeding the BLDC motor is operated with the high frequency PWM pulses, resulting in increased switching losses. In the proposed work speed of the BLDC motor is controlled through the variable DC link voltage, resulting in sensor free system for speed control. Furthermore, the VSI is operated, by electronic commutation, with the pulses at fundamental frequency, which minimizes the switching losses. The power optimization or so called maximum power point tracking (MPPT) is mandatory for efficient utilization of SPV array. The numerous literatures are available on MPPT techniques [9-11]. A DC-DC converter, as an intermediate power conditioning unit, is commonly used between the SPV array and the VSI to perform MPPT.

DC-DC converters are broadly utilized in SPV system to generate DC power from one voltage level to another and to facilitate the area for maximum power point tracking (MPPT).The single inductor DC-DC converter Buck-Boost and well-known two-inductor topologies, Cuk, SEPIC, have been studied and discussed in the literature from different aspects like voltage gain, operating principle, voltage and current stress and efficiency for many years [11].The Buck and Boost converters can track the maximum power only in a restricted operational region and moreover suffers the problem of having limited voltage conversion ratio. This limits their application for a wide range of speed control by varying DC link voltage. Here a performance analysis is done between the Buck Boost and Cuk converters [1][2]. These converters track maximum power from solar energy and thus drive the BLDC motor through an inverter.

## SYSTEM CONFIGURATION

Renewable energy has been booming day by day. Importance of renewable energy resources increases due to the limited resources and environmental problems of conventional energy resources. Due to the availability and pollution free nature solar energy becomes a major competitor in renewable energy resources. There are many factors such as shadow, dirt etc that affects the efficiency of the solar cell. In order to get maximum efficiency maximum power has to be tracked. The maximum power point can be tracked using many methods such as fractional open circuit, fractional short circuit, perturb and observe(P&O) algorithm, incremental conductance(INC) algorithm etc.

Here two different strategies are implemented for driving BLDC. Fig 1 shows the driving circuit of BLDC motor with Buck Boost converter using Perturb and Observe algorithm and Fig 3 shows the driving circuit of BLDC with Cuk converter using incremental conductance algorithm. Both control strategies include solar power as the input source and BLDC motor as the load.

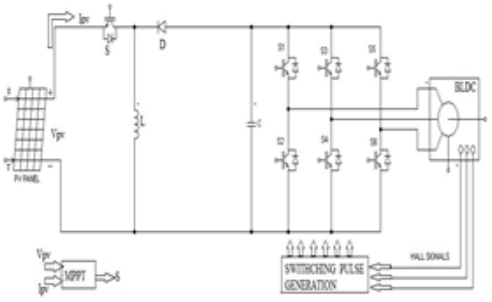


**Figure 1: Solar powered BLDC motor using Buck Boost converter**

System 1 (BLDC motor with Buck Boost converter) uses the Perturb and Observe algorithm based maximum power point tracking to extract maximum power under all conditions. Here the panel voltage will be given a perturbation and the corresponding output power is compared with that of previous perturbation cycle. If power increases then perturbation is continued in the same direction. Maximum power point controls the switching of Buck Boost converter. The extracted solar power is fed to voltage source inverter through Buck Boost converter, which change the ranges of input voltage to the desired value. The entire V-I characteristics of PV panel represents the range of operation of Buck Boost dc to dc converter.

Fig: 2 represents the flowchart of P and O algorithm. In P and O algorithm, when change in power and change in voltage is positive or negative, then voltage is incremented by a small amount. Voltage is decremented when change in power is positive and change in voltage is negative and vice versa. Changes in current is not recorded in this algorithms which leads to oscillations in maximum power point.

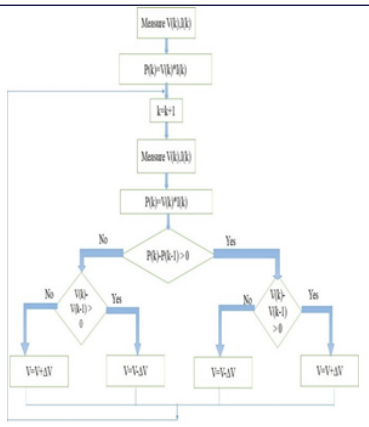

**Figure 2: Flowchart of P & O algorithm**

The Incremental Conductance algorithm is used for maximum power point tracking in System 2 (BLDC motor with Cuk converter). Proper operation of BLDC motor is done by properly switching the semiconductor switches in the voltage source inverter. The supply of voltage source inverter is fed from PV panel through an intermediate Cuk dc to dc converter. Cuk converter is a modified version of Buck Boost converter. It provides regulated output with negative polarity and input inductor reduces the harmonic content. Another important advantage of Cuk converter is that it provides continuous input and output current and has low switching losses thereby increasing efficiency.

Incremental conductance algorithm is used for tracking the maximum power point. The figure below shows the implemented control strategy for tracking maximum power. Due to higher steady state accuracy and environmental adaptability Incremental Conductance algorithm becomes one of the important techniques in MPPT.

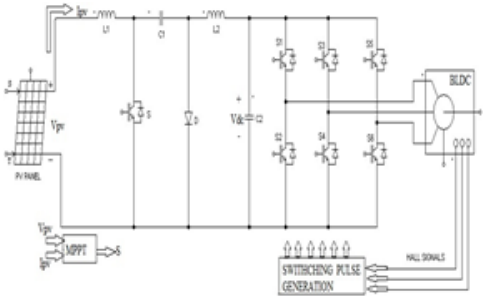


**Figure 3: Solar powered BLDC motor using Cuk converter**

In Incremental conductance algorithm, adjusting of array voltage takes place in accordance with the voltage at maximum power point based on the incremental and instantaneous conductance of the PV panel. Solar array operates at its maximum power point when change in output conductance is equal to the negative output conductance. This algorithm provides good tracking efficiency and fast response. Here change in irradiance is considered by measuring the value of current at each point.

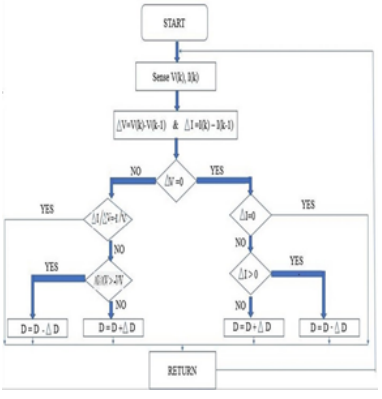


**Fig 4: Flowchart of INC algorithm**

Rotor position of BLDC motor can be recorded using hall effect sensors. Using these hall effect signals, electronic commutation of BLDC motor takes place and thereby switching pulses or PWM signals for inverter switches are generated.

## DESIGN OF PROPOSED SYSTEM

### Design of PV Module

A PV module was designed with 36 cells connected in series. It has an open circuit voltage of 21.4 V and short circuit current of 3.2 A. The voltage at maximum power is 17 V and maximum power is 47 V.

### Design of Converters

The rated DC voltage of the BLDC motor is, $V_{dc}$ = 24 V and the PV voltage at maximum power point is 17 V. The switching frequency is selected as 20 kHz to achieve a ripple free inductor current. The relationship between the duty ratio, D of the MOSFET switch, output voltage, $V_{dc}$ and input voltage, $V_{pv}$ of both converters is given as

$$\frac{Vdc}{Vpv} = \frac{D}{1-D} \qquad (1)$$

For the Buck Boost converter the average inductor current is taken as the sum of input current $I_{pv}$ and output current $I_{dc}$. Assuming 40% ripple for inductor current and 3% ripple for capacitor voltage the values of L and C are taken.

$$L = \frac{D*Vpv}{fsw*\Delta IL} \qquad (2)$$

$$C = \frac{D*Idc}{fsw*\Delta Vdc} \qquad (3)$$

The Cuk converter is a two inductor topology in which current through the first inductor $L_1$ is input current and current through $L_2$ represents the output current. Allowing 10% ripple in $I_{L1}$ and $I_{L2}$, $\Delta I_{L1}$ and $\Delta I_{L2}$ are calculated as follows

$$L1 = \frac{D*Vpv}{fsw*\Delta IL1} \qquad (4)$$

$$L2 = \frac{D*Vpv}{fsw*\Delta IL2} \qquad (5)$$

The voltage $V_{C1}$ across energy storage capacitor $C_1$ is calculated as

$$Vc1 = \frac{Vpv}{1-D} \qquad (6)$$

Allowing a 3% ripple in in $V_{C1}$, $C_1$ is estimated as

$$C1 = \frac{Ipv*(1-D)}{fsw*\Delta VC1} \qquad (7)$$

### Design of DC Link Capacitor of VSI

VSI output voltage frequency, ω (in rad/sec.) is calculated corresponding to the rated speed of the BLDC motor as

$$\omega = \frac{2*3.14*N\ rated*P}{120} \qquad (8)$$

Where f is the frequency of VSI output voltage in Hz; Nrated is rated speed of the BLDC motor; P is the numbers of poles in the BLDC motor.

The capacitor C is estimated by allowing 3% ripple in output voltage

$$C = \frac{Idc}{6*\omega*\Delta Vdc} \qquad (9)$$

The speed of the BLDC motor is controlled through varying DC link voltage.

## SIMULATION MODELS AND RESULTS

The proposed systems are simulated in MATLAB Simulink. The responses of the BLDC motor with Buck Boost converter and Cuk converter are analyzed and recorded. Buck Boost converter with P & O algorithm and Cuk converter with Incremental Conductance algorithm at different irradiance level are demonstrated in Figs: 5-6.

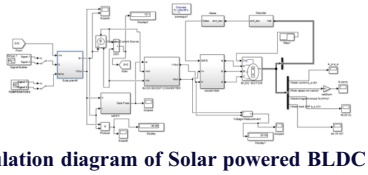

**Fig 5: Simulation diagram of Solar powered BLDC motor using Buck Boost converter**

Here rotor positions are recorded by using hall effect sensors. Using these hall signals, back emf of the three phases of BLDC motor are generated.

Gate pulses for the semiconductor switches in voltage source inverter are generated using these back emf signals.

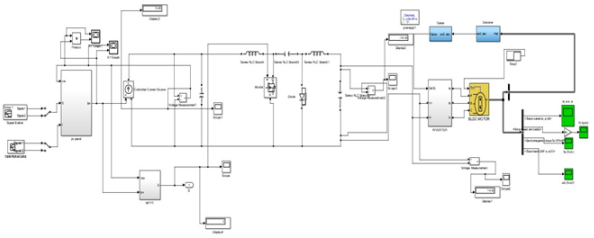

**Fig 6: Simulation diagram of Solar powered BLDC motor using Cuk converter**

Fig: 7 and Fig: 8 represents the current-voltage characteristics and power-voltage characteristics of PV panel at different irradiations.

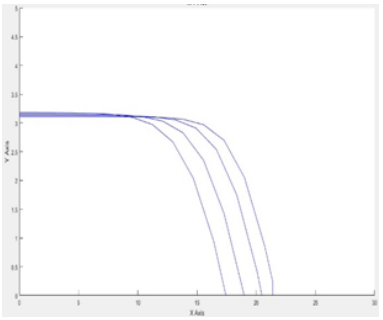

**Fig 7: I-V chara of PV panel**

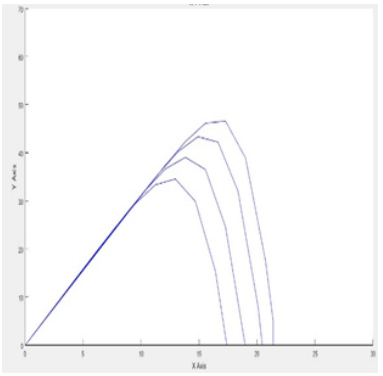

**Fig 8: P-V chara of PV panel**

Responses of both systems are compared in Simulink and the corresponding waveforms are shown below Fig: 9-12.

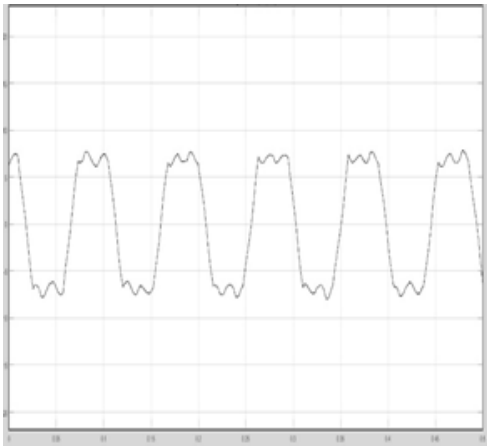

**Fig 9: Simulated response of back emf of BLDC motor with Buck Boost converter**

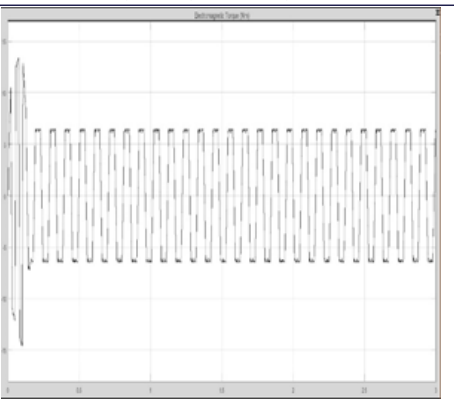

**Fig 10: Simulated response of back emf of BLDC motor with Cuk Converter**

Fig 9 and Fig 10 demonstrates the back emf of BLDC motor with Buck Boost and Cuk converters respectively. Back emf representation in BLDC motor is trapezoidal in nature. Simulated responses revealed that system 2 provides a better back emf waveform than system 1. It indicates ripple free nature of Cuk converter.

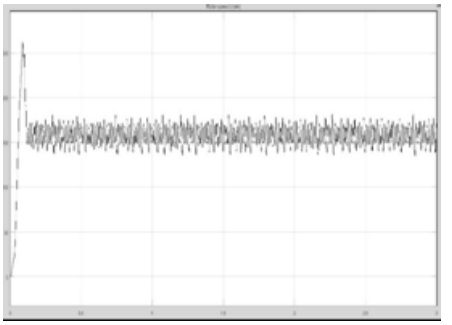

**Fig 11: Simulated response of output speed of BLDC motor with Buck Boost converter**

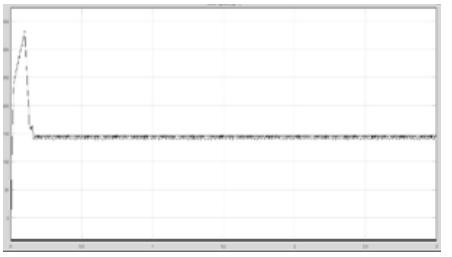

**Fig 12: Simulated response of output speed of BLDC motor with Cuk converter**

Above figures 11 and 12 represents the output speed of BLDC motor with Buck Boost and Cuk converter respectively. The ripple content in the output speed of BLDC motor is reduced when we use Cuk converter. An external filter is needed with Buck Boost converter to drive a BLDC motor.

Finally, experiment research is implemented to the solar system and BLDC load with Buck Boost and Cuk converters. Maximum power point is tracked more efficiently in Incremental conductance due to zero oscillation at maximum power point. Fig 13 and Fig 14 represents the hardware setup of MPPT with Buck Boost converter and with Cuk converter to drive BLDC motor is given below.

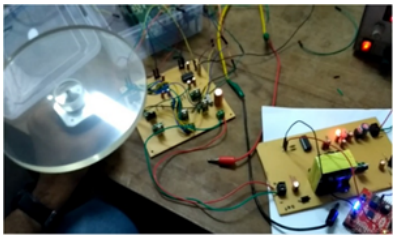

**Fig 13: Hardware setup of BLDC motor with buck boost converter**

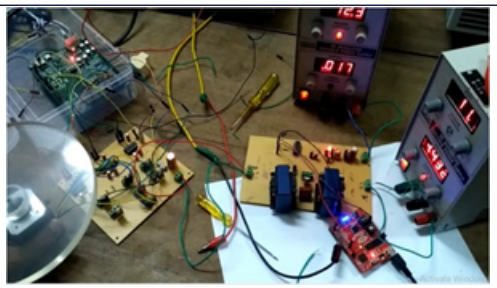

**Fig 14: Hardware setup of BLDC motor with cuk converter**

## CONCLUSIONS

The proposed solar photovoltaic array- converter fed VSI-BLDC system has been designed, modeled and simulated in MATLAB/Simulink environment. The proposed system was validated through experimental setup and BLDC motor has been proved as a suitable drive. Both Cuk and Buck Boost converters can either step up or step down voltage and hence can provide accurate maximum power point tracking .Compared to P&O, INC proves to be more efficient with zero oscillations at MPP. They give almost the same output but energy is stored in inductor in Buck – Boost, whereas in capacitance in case of a Cuk converter. The Cuk converter has less output current ripple compared to Buck Boost and can be connected in parallel to measure PV modules with greater power.

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