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High Step up Converter Connected BLDC Motor with MPPT Controller for PV Application

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ABSTRACT—This paper presents a brushless dc motor drive, which is utilized as the load of a photovoltaic system with a maximum power point tracking (MPPT) controller. To achieve a fast and stable response for the real power control, the intelligent controller consists of a Incremental Conductance (Inc - Condi) for maximum power point tracking (MPPT) where the output signal is used to control the interleaved boost converters to achieve the MPP. A brushless DC (BLDC) motor drive system that incorporates a motor controller with proportional integral (PI) speed control loop using MATLAB/Simulink is used to build the dynamic model and simulate the system.

INDEX TERMS —Maximum power point tracking (MPPT); Interleaved converter, BLDC motor, Incremental Conductance (Inc - Condi), photovoltaic (PV) system, PI controller

I.INTRODUCTION

Global warming and energy policies have become a hot topic on the international agenda in the last years. Developed countries are trying to reduce their greenhouse gas emissions. Photovoltaic (PV) power generation has an important role to play due to the fact that it is a green source. The only emissions associated with PV power generation are those from the production of its components. After their installation they generate electricity from the solar irradiation without emitting greenhouse gases. In their lifetime, which is around 25 years, PV panels produce more energy than that for their manufacturing [1]. Also they can be installed in places with no other use, such as roofs and deserts, or they can produce electricity for remote locations, where there is no electricity network. The latter type of installations is known as off-grid facilities and sometimes they are the most economical alternative to provide electricity in isolated areas. PV power generation is more expensive than other resources. Governments are promoting it with subsidies or feed-in tariffs, expecting the development of the technology so that in the near future it will become competitive [2]-[3]. Increasing the efficiency in PV plants so the power generated increases is a key aspect, as it will increase the incomes, reducing consequently the cost of the power generated so it will approach the cost of the power produced from other sources. Photovoltaic (PV) sources are used today in many applications as they have the advantages of maintenance free and pollution free. Solar electric energy demand has grown consistently by 20% to 25% per annum over the past 20 years, which is mainly due to its decreasing cost and price. A photovoltaic (PV) array under uniform irradiance exhibits a current-voltage characteristic with a unique point, called the maximum power point (MPP), where the array produces maximum output power.

MPPT algorithms are necessary because PV arrays have a non linear voltage-current characteristic with a unique point where the power produced is maximum [4]. This point depends on the temperature of the panels and on the irradiance conditions. Both conditions change during the day and are also different depending on the season of the year. Furthermore, irradiation can change rapidly due to changing atmospheric conditions such as clouds. It is very important to track the MPP accurately under all possible conditions so that the maximum available power is always obtained. In the past years numerous MPPT algorithms have been published [5]. They differ in many aspects such as complexity, sensors required, cost or efficiency. However, it is pointless to use a more expensive or more complicated method if with a simpler and less expensive one similar results can be obtained.

This is the reason why some of the proposed techniques are not used. Measuring the efficiency of MPPT algorithms has not been standardized until the European Standard EN 50530 was published at the end of May, 2010 [6]. It specifies how to test the efficiency of MPPT methods both statically and dynamically. In any case, there are no publications comparing the results of the different MPPT method.

The objective of this paper is firstly to review different MPPT algorithms. Then the most popular, Incremental Conductance (Inc - Cond) is analyzed in depth and tested according to the standard mentioned above. After that, improvements to the Inc - Cond are succeeding in the MPP tracking under conditions of changing irradiance. To test the MPPT algorithms according to the irradiation profiles proposed in the standard.

In this paper, an asymmetrical interleaved high step-up converter that combines the advantages of the aforementioned converters is proposed, which combined the advantages of both. In the voltage multiplier module of the proposed converter, the turn's ratio of coupled inductors can be designed to extend voltage gain, and a voltage-lift capacitor offers an extra voltage conversion ratio.

The merits of the interleaved converter are as follows:

- The converter is characterized by a low input current ripple and low conduction losses,
- It suitable for high power applications;
- The converter achieves the high step-up voltage gain that renewable energy systems require;
- The main switch voltage stress of the converter is lower than that of the output voltage;
- Low cost and high efficiency are achieved by the low voltage rating of the power switching device.

II. Operating Principle Description

The proposed high step-up converter with voltage multiplier module [20] is shown in Fig: 3(a). A conventional boost converter and two coupled inductors are located in the voltage multiplier module, which is stacked on a boost converter to form an asymmetrical interleaved structure. Primary windings of the coupled inductors with Np turns are employed to decrease input current ripple, and secondary windings of the coupled inductors with Ns turns are connected in series to extend voltage gain. The turn's ratios of the coupled inductors are the same. The coupling references of the inductor are denoted by "." and "∗ ". It is shown in fig: 3.

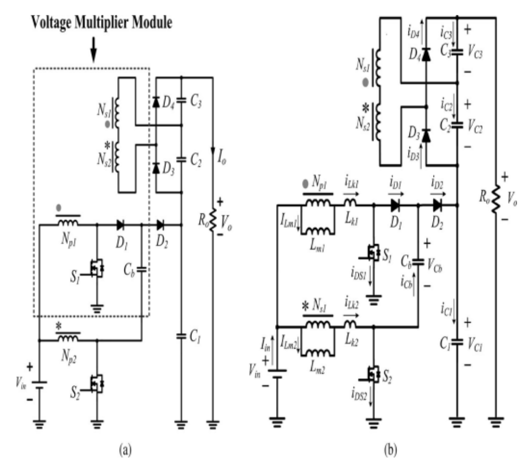

Fig. 3. (a) Proposed high step-up converter with a voltage multiplier module. (b) Equivalent circuit of the proposed converter.

The equivalent circuit of the proposed converter is shown in Fig. 3(b), where Lm1 and Lm2 are the magnetizing inductors, Lk1 and Lk2 represent the leakage inductors, S1 and S2 denote the power switches, Cb is the voltage-lift capacitor, and n is defined as a turn's ratio Ns /Np. The proposed converter operates in continuous conduction mode (CCM), and the duty cycles of the power switches during steady operation are interleaved with a 180◦ phase shift; the duty cycles are greater than 0.5. The key steady waveforms in one switching period of the proposed converter contain six modes, which are depicted in Fig. 4, and Fig. 5 shows the topological stages of the circuit. The interleaved converter design based on the paper [20]

Mode 1 [t0, t1]: At t=t0, the power switches S1 and S2 are both turned ON. All of the diodes are reversed-biased. Magnetizing inductors Lm1 and Lm2 as well as leakage inductors Lk1 and Lk2 are linearly charged by the input voltage source Vin.

Mode 2 [t1, t2]: At t=t1, the power switch S2 is switched OFF, thereby turning ON diodes D2 and D4. The energy that magnetizing inductor Lm2 has stored is transferred to the secondary side charging the output filter capacitor C3 The input voltage source, magnetizing inductor Lm2, leakage inductor Lk2 , and voltage-lift capacitor Cb release energy to the output filter capacitor C1 via diode D2 , thereby extending the voltage on C1 .

Mode 3 [t2, t3]: At t=t2, diode D2 automatically switches OFF because the total energy of leakage inductor Lk2 has been completely released to the output filter capacitor C1. Magnetizing inductorLm2 transfers energy to the secondary side charging the output filter capacitor C3 via diode D4 until t3.

Mode 4 [t3, t4]: At t=t3, the power switch S2 is switched ON and all the diodes are turned OFF. The operating states of modes 1 and 4 are similar.

Mode 5 [t4, t5]: At t=t4, the power switch S1 is switched OFF, which turns ON diodes D1 and D3. The energy stored in magnetizing inductor Lm1 is transferred to the secondary side charging the output filter capacitor C2. The input voltage source and magnetizing inductor Lm1 release energy voltage-lift capacitor Cb via diode D1, which stores extra energy in Cb.

Mode 6 [t5, t0]: At t=t5, diode D1 is automatically turned OFF because the total energy of leakage inductor Lk1 has been completely released to voltage-lift capacitor Cb. Magnetizing inductor Lm1 transfers energy to the secondary side charging the output filter capacitor C2 via diode D3 until t0.

III. **PROPOSED BLOCK DIAGRAM**

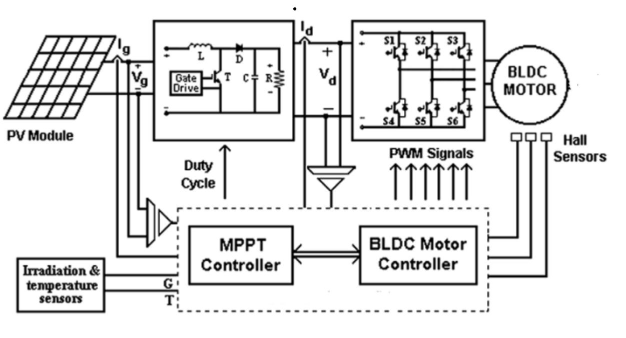

Fig.3 – Block diagram showing the proposed work

It seems that not enough attention has been given to PV systems feeding brushless DC (BLDC) motor loads, despite these motors' favorable features such as high reliability, high efficiency, less maintenance requirements and reduced environmental effects. In various contributions, brushed DC motor or induction motor loads are considered. The performance of DC motors supplied from PV sources has been analyzed by Appelbaum [14]. Two low cost PV utilization schemes for ventilation and air conditioning loads have been presented in Ref. [15]. In that study permanent magnet DC (PMDC) type and AC induction type motors have been employed.

Our work demonstrates that compared with other studies in the field, the use of a BLDC motor, which exhibits the highest efficiency among all conventional motors, provides an effective demand side energy management technique. Because the energy conversion efficiency of PV generators is generally low.

Proper matching between the PV generators and the electric load should be considered. Therefore, the coupling between the motor load and the PV module is implemented via a maximum power point tracking (MPPT) controller to operate the PV system at its maximum output power for any temperature and solar radiation level. Various MPPT methods have the hill climbing methods [20–22], the perturb and observe (P&O) method tracks the maximum power point (MPP) by repeatedly increasing or decreasing the output voltage at the MPP of the PV module. The implementation of the method is relatively simple and low cost.

The inverter is implemented as the function of the dc voltage and the firing angle from the control block. The firing signals include a chopping option i.e. the current in the two energized phases can be turn on and off anytime during the 60^{0} interval. In each 60^{0} interval when the switches are fired according to the sequence in the table. Which phase current is decaying and which one is raising depends on the rotor position.

The inverter can also take care of the freewheeling diode current and make sure that it can flow only one direction. When diode current reaches zero the voltage will have different value which depends on the back emf. In practice these two voltages are not important but since the motor state space model require two voltages (V_{ab} and V_{bc},) these two voltages must be known at all time

BLDC Motor Details		
Number of poles	P	2
Assigned power rating	W	1.2
Nominal voltage	V	6.0
No load speed	RPM	47130
Stall torque	mNm	0.50
No load current	mA	60
Terminal resistance phase to phase	Ohm	12.50
Terminal inductance phase to phase	mH	0.091
Torque constant	mNm/A	1.05
Rotor inertia	gcm^2	0.005
Friction constant (assumed value)	Nm. s	$1.38.\ 10^{-8}$

Table 2: Details of the BLDC motor

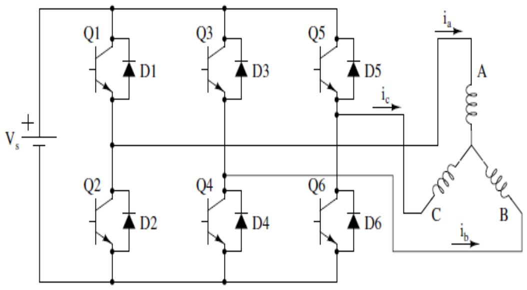

Fig 4: Simplified BLDC Drive Scheme

Switching Interval	Seq. N0.	Position Sensor			Switch Closed		Phase Current		
		H 1	H 2	H 3			A	B	C
0^0 -60^0	0	1	0	0	Q1	Q4	+	-	off
60^0 -120^0	1	1	1	0	Q1	Q6	+	off	-
120^0 -180^0	2	0	1	0	Q3	Q6	off	+	-
180^0 -240^0	3	0	1	1	Q3	Q2	-	+	off
240^0 -300^0	4	0	0	1	Q5	Q2	-	off	+
300^0 -360^0	5	1	0	1	Q5	Q4	off	-	+

Table 3: Switching Sequence of Inverter

IV. SIMULATION MODEL

A.Photovoltaic Cell

The solar cell was modeled in the single diode format. This consists of a 0.1 ohm series resistance and an 8 ohm parallel resistance. This was modeled using the Sim Power System blocks in the MATLAB library. The Simulink model is as shown.

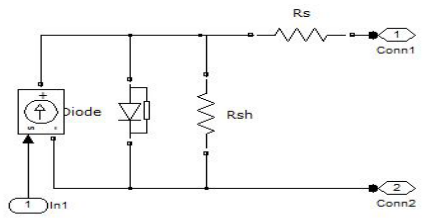

Fig 5: Solar cell modeled in single diode format

A controlled current source is utilized to drive the solar cell. The control signal is provided by the Ilg generator unit. The Ilg generator takes into account the number of series connected, number of parallel connected solar cells and the temperature to determine the input signal from the solar cell [17], [15], and [19]. The MPPT unit for this method utilizes the power and the voltage values instead of the current

B. Model for Incremental Conductance (Inc - Cond) Algorithm

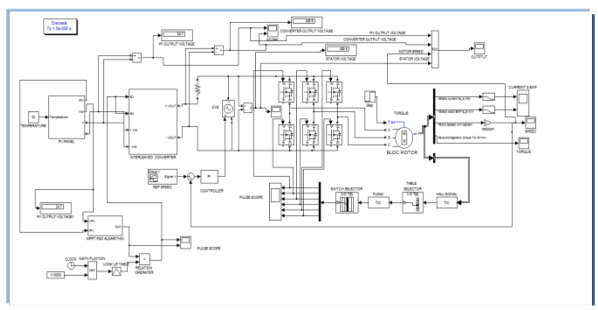

Fig 6: Model of solar cell with interleaved boost converter and MPPT system

The voltage values as in incremental conductance method. Rest every unit is similar to the previous model units. The repeating sequence being utilized in the model has an operating frequency of 10 KHz. This is also the frequency of the gating signal.

D. Model For Interleaved boost converter

In this research, an interleaved control is proposed to reduce the input current ripples, the output voltage ripples, and the size of passive components with high efficiency compared with the other topologies. In addition, low EMI and low stress in the switches are expected. The proposed dc/dc converter is compared to other converter topologies such as conventional boost converter (BC). The dc/dc interleaved converter topologies and their controller are designed and investigated by using MATLAB/Simulink.

COMPANENTS	SYMBELS	PARAMETERS
Magnetizing inductance	Lm 1, Lm2	133 micro Henry
Leakage inductance	L k1, Lk2	1.6 micro Henry
Turns ratio	n(Ns/Np)	1
Power switches	S1,S2	IRFP4227
Diode	D1,D3,D4 D2	FCF06A-40 BYQ28E -200
Capacitors	Cb,C2,C3 C1	220,470micro frd

Table 4: Components and ratings of interleaved converter

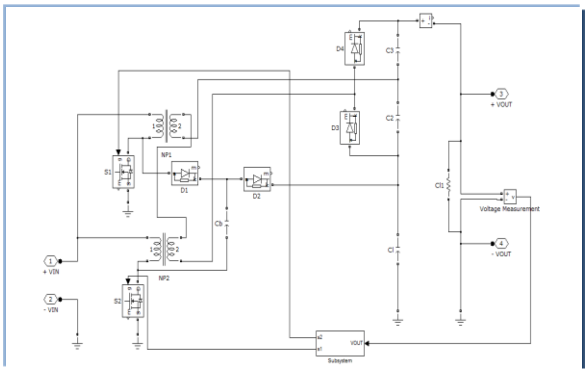

Fig 7: Model of interleaved boost converter

Finally, the circuit with a 40-V input voltage, 500-V output, and 1200- W output power is operated to verify its performance. The highest efficiency is 96.8%.

V. SIMULATION RESULT

A. Signal Builder Speed

In this paper from the signal builder three reference speeds are given to the PI controller it is shown in fig: 8. based on the error speed the required voltage is developed by the converter. The voltage is fed in to the power electronics switches.

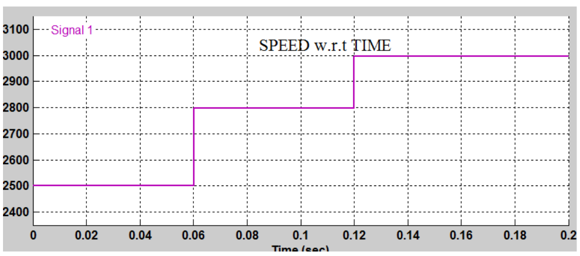

Fig 8: Signal builder speed

The motor speed same as that of the signal builder speed it is shown in fig: 9

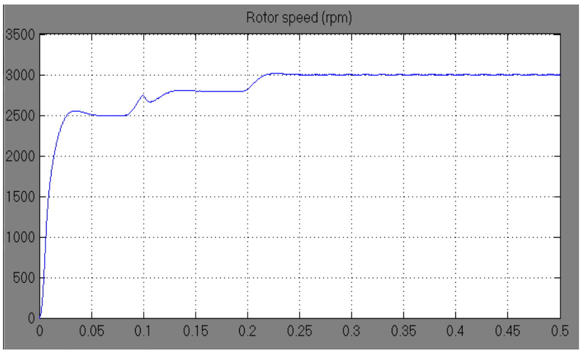

Fig 9: Motor speed

B. PV and converter output voltage

The fig: 10 show the PV and converter output voltage. The converter output voltage will vary based on the speed of the rotor. The rotor speed is sensed by the sensor. The rotor speed and reference speed is given to PI controller

C. Comparing stator speed, converter and PV voltage I - V, P- V characteristics

The fig: 11 shows the PV output voltage, I –V and P-V Characteristics and fig 12 shows the Comparing the stator speed, converter voltage and stator output voltages. It seems that the converter and stator output voltages are same.

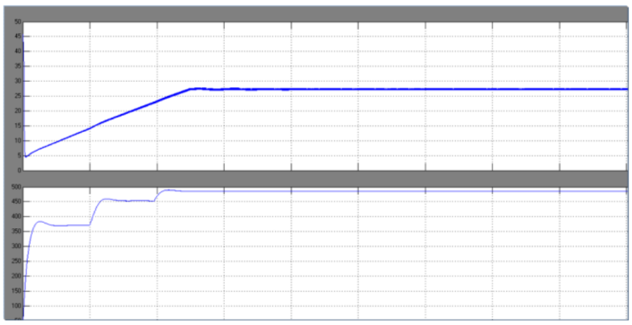

Fig: 10 PV output voltage and converter output voltage

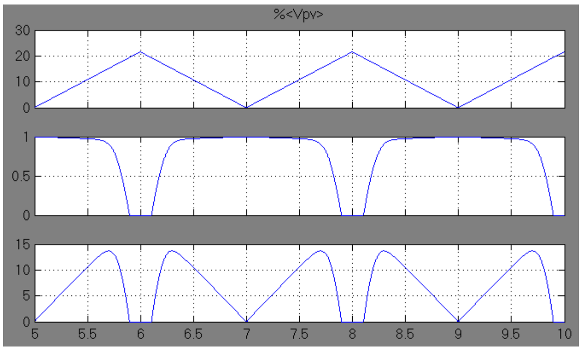

Fig 11: PV output voltage, I –V and P-V Characteristics

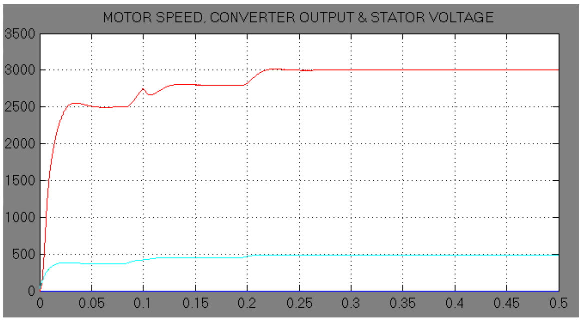

Fig 12: stator speed, converter and stator voltage

Commutation delay is necessary in practice, but the simulation show that it should be kept as possible because it cause increased torque ripples.

VI. CONCLUSION

In this paper, most of the MPPT algorithms which can find the real MPP were reviewed. For simplicity and effectiveness reasons, Incremental Conductance (Inc - Cond) selected. The performance and dynamic MPPT efficiencies were studied according to the European Standard EN 50530. A simplified model of the PV system was developed. It is found that the Incremental Conductance (Inc - Cond) technique is the most extensively used in commercial MPPT systems because it is straight forward, accurate, and easy to implement. Its accuracy and tracking time depend on perturbation size.

The main part of the work was involved in the development of the six step inverter and its interaction with BLDC motor. The aim was to make a model that would be simple, accurate, and easy to modify and fast running. The settling time of the motor is also reduced by 0.225 seconds. It is believed that the goals have been reached parameters of a real BLDC motor were used and it was verified that the model performed according to the information given in the motor's datasheet.

The interleaved converter performed importantly among the system because the system required a sufficiently high step-up conversion. The interleaved boost converter magnetically coupled to a voltage double circuit, which provides a voltage gain far higher than that of the conventional boost topology. This converter has low-voltage stress across the switches, natural-voltage balancing between output capacitors, low-input current ripple, and magnetic components operating with the double of switching frequency. These features make this converter suitable to renewable energy applications where a large voltage step-up is demanded such as grid-connected systems etc the above conclusions are based on simulations and the reported results in the literature.

VII. FUTURE ASPECTS

Improvement to this project can be made by tracking the maximum power point in changing environmental conditions. Environmental change can be change in solar irradiation or change in ambient temperature or even both. In the Simulink models the solar irradiation and the temperature can be given as variable inputs instead of constant values as done here.

Instead of using Inc - Cond MPPT Technique can use other technique like IncCond/Hybrid MPPT techniques. The comparative analysis can also be study

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