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Solar fed BLDC motor drive for mixer grinder using a boost converter

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ABSTRACT

The existing mixer grinder comprises of the universal motor operating in alternating current supply due to high starting torque characteristics and simple controlling of the speed. The absence of brushes and the reduction of noise in the Brushless DC (BLDC) extends its lifetime and makes it ideal in a mixer grinder. A novel solar-powered BLDC motor drive for mixer grinder is presented in this paper. A DC-DC boost converter has been utilised to operate a PV (photovoltaic) array at its highest power. The proposed hysteresis current control BLDC system has been developed in the MATLAB. A performance comparison is made using the commercially available mixer grinder along with the simulated proposed system.

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1. INTRODUCTION

Photovoltaic (PV) array are widely used for producing electricity from the light. These PV module converts sunlight to direct current [1-3]. As the PV based electricity generation is ecofriendly and less maintenance, these are employed for the grid connected applications as well as standalone applications i.e. water pump, domestic appliances, street lighting [4]. An electric motor plays a crucial role in developing the economic and energy efficiency of domestic appliances like the mixer grinder. An efficient motor reduces the cost and size of the photovoltaic array [5-9]. The motivation for the work is the commercially available mixer grinder uses the universal motor [10]. Unfortunately, the universal motor is less efficient, and due to its brushes and commutator arrangements, incurs high maintenance cost [11]. To overcome these problems, the permanent magnet BLDC motor is employed due to its higher efficiency [12], simple control [13-15], low electromagnetic interference (EMI) [16-20], and high reliability [21-23]. To help isolated and remote area region, it is designed low voltage appliance so to eliminate the grid power by using renewable energy power from the solar.

In this paper, the solar fed BLDC mixer grinder is designed, which has higher efficiency than the existing AC universal motor mixer grinder. Even the hysteresis current controller is designed for controlling the speed of the BLDC motor.

2. PROPOSED METHOD

Figure 1 shows a proposed BLDC motor drive used in the mixer grinder. A boost converter is employed between PV array and the voltage source inverter (VSI). Additionally, the boost converter is operated by controlling a PV array through the Perturb and Observer MPPT algorithm technique. The BLDC mixer grinder is fed by the VSI. The three current sensors and the hall sensors are fed to a BLDC motor control. The BLDC motor control is the hysteresis current controller it is used because of its excellent dynamic response and capability to control the current ripple peak to peak value in desired hysteresis band limit, and gate signals from a controller are fed to the VSI for controlling speed of the motor.

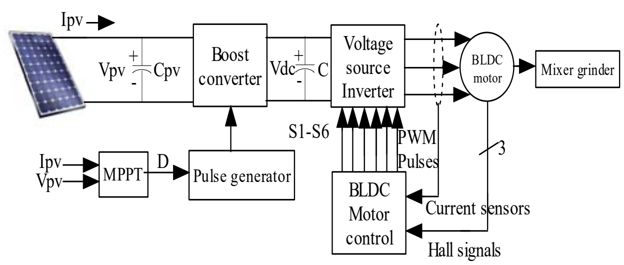


Figure 1. Block diagram of proposed mixer grinder

3. RESEARCH METHOD

For the desired operation of the mixer grinder, suitable specifications and design of the PV array, boost converter, and BLDC mixer grinder play an important role. A 4-pole BLDC motor with 10000 rpm and 200W was selected. The PV array, boost converter, and mixer grinder were selected so that the function of a system is not disturbed under any climatic conditions.

3.1. PV array and maximum power point tracking

A PV array with peak power of 300W is designed for the 200W mixer grinder to compensate the motor and converter losses.

Table 1 shows the design of the PV array, and the MPPT technique used is the Perturb and Observer algorithm shown in Figure 2. This algorithm uses less measured parameters and simple feedback scheme. In this method, voltage of a module is periodically gives perturbation, and consistent power output is compared with a prior perturbing cycle. After a peak power is reached, power is zero at MPP and in next instant decreases, then perturbation reverses. When stable condition is reached, algorithm oscillates around a peak power point. To maintain small power variations, the perturbation size kept very small. The method is advanced it sets the reference voltage corresponding to a peak voltage of a module. The PI controller then acts to transfer an operating point of a module to that specific voltage level. The MPPT algorithm operates based on a derivative of a power output (P) relating to a panel voltage (V) is equivalent to zero at the MPP.

Table 1. Design of PV array

PV module (HB-12100)	
N_s	36
V_o	21V
I_o	7.1A
V_m	17V
I_m	6A
V_{oc}	63V
I_{sc}	7.1A
Modules in series	1
Modules in parallel	3
Peak Power	300W

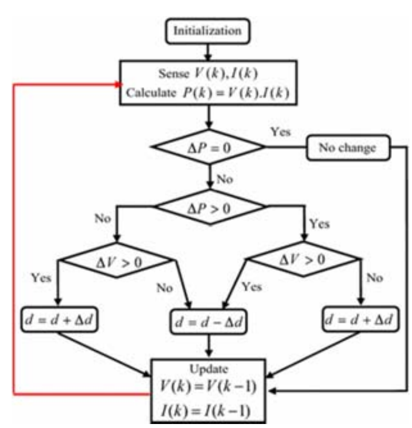


Figure 2. Flowchart of a Perturb and Observer algorithm [24]

3.2. Boost converter

The boost converter is a DC-DC converter, which step-up the output voltage from its low input voltage. Figure 3 represents a circuit of the boost converter. Table 2 shows specification of a boost converter.

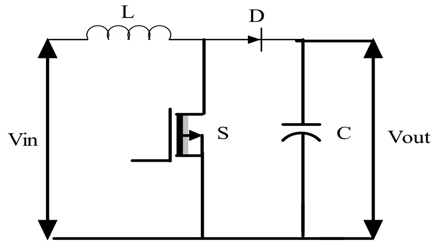


Figure 3. Circuit of a boost converter

Table 2. Specification of a boost converter

Input voltage (V_{in})	17V
Output voltage(V_o)	24V
Switching frequency (f_{sw})	500kHz
Inductor current ripple (I_{ripple})	30%
Output voltage ripple (V_{ripple})	10mV

To calculate the value of the load resistance

$$\text{Load resistance}=\frac{V_o}{I_o} \tag{1}$$

Assume I_o=0.4A
Load resistance=60Ω
To calculate the value of the inductor

$$L=\frac{V_{in}D}{f_s\Delta I_o}=300\ \mu\text{H} \tag{2}$$

To calculate the value of the capacitor

$$C=\frac{I_oD}{f_s\Delta V_o}=2.034mF \tag{3}$$

Table 3 shows the switching states of the VSI. The three hall sensors are used to produce gate signal to the VSI by electronic commutations. The electronic commutations are the commutation of currents flowing through the winding of the BLDC motor in predefined sequences by the decoder such that the direct current is symmetrically drawn from a DC bus of the VSI for 120° and employed in a phase with back emf. The VSI is operates through a fundamental frequency switching pulses for reducing switching loss. Table 4 represents the specifications of the BLDC motor.

Table 3. Switching states of VSI

	Hall signal			Switching state					
Rotor position θ	H_3	H_2	H_1	S_1	S_2	S_3	S_4	S_5	S_6
NA	0	0	0	0	0	0	0	0	0
0-60	1	0	1	1	0	0	1	0	0
60-120	0	0	1	1	0	0	0	0	1
120-180	0	1	1	0	0	1	0	0	1
180-240	0	1	0	0	1	1	0	0	0
240-300	1	1	0	0	1	0	0	1	0
300-360	1	0	0	0	0	0	1	1	0
NA	1	1	1	0	0	0	0	0	0

Table 4. Specification of BLDC motor

Rated Power	200W
Input Voltage	24V
Rated Speed	10000 rpm
Stator Resistance(R_s)	0.5ohms
Stator Inductance (L_s)	0.6mH
Number of Poles (P)	4
Friction Coefficient (B)	0.0682e-3
Inertial Coefficient (J)	15.5e-3 J/kgm^2

3.3. Modelling of the proposed BLDC drive system

To run a motor at different speeds, the BLDC motor drive requires a speed controller for smooth controlling of the drive. The closed loop speed controller of the BLDC motor drive is depicted in Figure 4. In a closed loop operation, at the desired time the reference speed can be changed for a drive to work at the desired speeds. In the closed loop speed controller drive, actual speed of the motor is fed back to a input. By using the control systems, the speed can be varied as per requirement. The actual speed is fed back to input and is measured with a reference value of speed, which generates the error signals. This is fed to the PI controller, which controls the speed.

The past and the present error gets nullifies by a PI controller [25]. The speed fed to the PI controller generates a torque reference value. This reference torque is compared with an actual motor torque fed from hall sensors. The reference current is generated by the error signals produced by the reference torque and measured by the actual torque. This reference current and the measured current generate error signals are fed to a hysteresis current controller. The gate pulses to a VSI switch to turn ON or OFF is produced by a hysteresis current controller. The DC link capacitor acts as the source to a VSI. All the feedbacks to generate error signals are sensed by the hall sensor. The speed controller by the current control method yields better results.

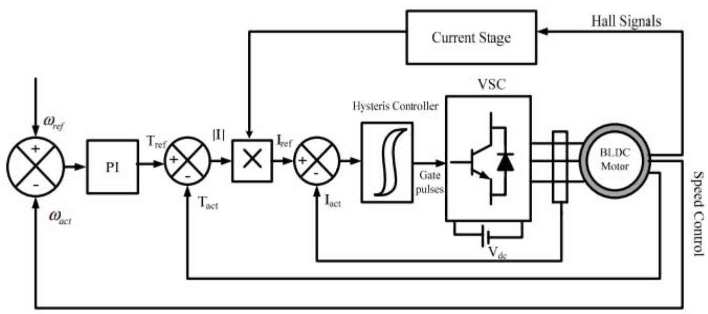


Figure 4. Diagram of speed control of BLDC motor

3.4. Mathematical Modelling of the BLDC Motor

Consider the cylindrical rotor and stator as having 3 phase windings, namely, a, b, and c. The rotor is of permanent magnets with a uniform air gap, while the stator has three phases, which are star-connected. The motor is not saturated as it is operated within the rated current. The dynamic equations of phase a, phase b, and phase c are:

$$V_{an} = R_S + L\frac{di_a}{dt} + M\frac{di_b}{dt} + M\frac{di_c}{dt} + e_a \tag{4}$$

$$V_{bn} = R_S + L\frac{di_b}{dt} + M\frac{di_c}{dt} + M\frac{di_a}{dt} + e_b \tag{5}$$

$$V_{cn} = R_S + L\frac{di_c}{dt} + M\frac{di_a}{dt} + M\frac{di_b}{dt} + e_c \tag{6}$$

Where, R is a resistance of the armature, L is a self-inductance of the armature, M is a mutual inductance of the armature, V_{an}, V_{bn}, and V_{cn} is the voltage of the terminals, and i_a, i_b, and i_c is the input current of the motor. In the BLDC motor, function of the rotor position is related to a back emf. Each phase of a back emf has 120^0 phase angle differences. Therefore, the equations for each phase are as follows:

$$e_a = K_a f_a(\theta)\omega_r \tag{7}$$

$$e_b = K_b f_b(\theta - \frac{2\pi}{3})\omega_r \tag{8}$$

$$e_c = K_c f_c(\theta + \frac{2\pi}{3})\omega_r \tag{9}$$

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + L_s \begin{bmatrix} \frac{di_a}{dt} \\ \frac{di_b}{dt} \\ \frac{di_c}{dt} \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (10)$$

The total torque was as follows:

$$e_a = K_a \omega_r \quad (11)$$

$$P_m = e_a i_a + e_b i_b + e_c i_c \quad (12)$$

$$T_e = \frac{P_m}{\omega_{rm}} = \frac{(e_a i_a + e_b i_b + e_c i_c)}{\omega_r} \frac{P}{2} \quad (13)$$

Mechanical part

$$T_e - T_L = J \frac{d\omega_{rm}}{dt} + B\omega_{rm} \quad (14)$$

$$\frac{d\omega_{rm}}{dt} = \frac{P}{2J}(T_e - T_L - \frac{2B}{P}\omega_r) \quad (15)$$

Where, B is the flux density, T_L is the load torque, T_e is the electromagnetic torque, and J is the current density.

4. RESULTS AND DISCUSSION

The proposed solar-based current controlled BLDC mixer grinder was simulated in the MATLAB software. The solar irradiance was varied from 500W/m^2-1000W/m^{2,} and the power output of a PV array is depicted in Figure 5.

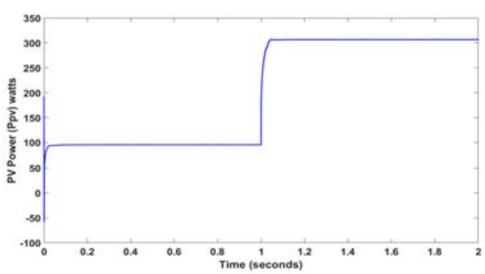
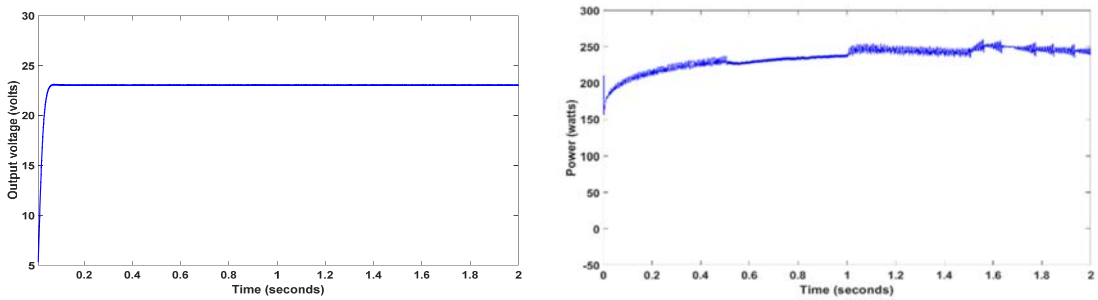


Figure 5. Output power from a PV panel

From Figure 5, it can be observed that the output power is higher when the solar irradiance is 1000W/m^2 and temperature is 25^{0}C.

Figure 6(a) represents output voltage from the boost converter when a solar irradiance is 1000W/m^2.From the 17V of the PV panel the boost converter steps up the voltage to 24V without affecting the efficiency of the converter. Figure 6(b) represents power output from the boost converter when a solar irradiance is 1000W/m^2.

From the PI controller, the speed is regulated as depicted in Figure 7. BLDC reference speed was set at 3000rpm and after 0.4 sec speed is gradually increased to 3500rpm at 0.6sec and then after 1 sec speed is increased to 4000rpm at 1.4 sec. The reference speed and measured speed is summed, and error signals generated is given to the PI controller to nullify the error signals and the speed of the BLDC motor is controlled.



(a) (b)

Figure 6. (a) Output voltage from a boost converter. (b) Output power from a boost converter

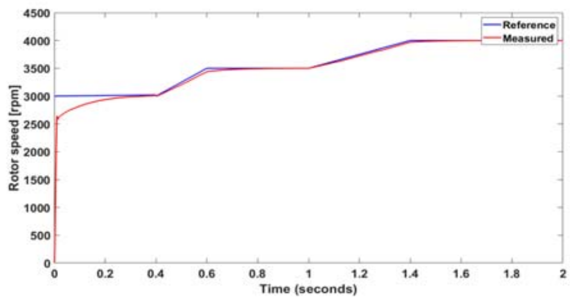
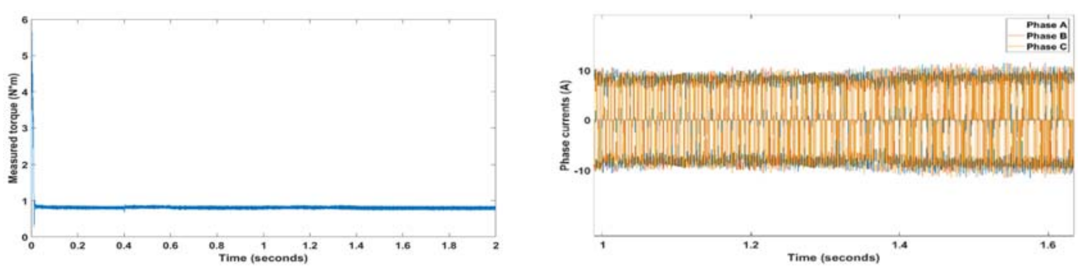


Figure 7. Reference and measured speed from the 200W BLDC motor

Figure 8(a) displays the measured torque of a BLDC motor. The commercially available mixer grinder has load torque range at 0.1 to 1 Nm. At the starting, when the back emf is zero, the torque is high. As the speed increases, the torque decreases as the speed and torque is inversely proportional. Figure 8(b) represents phase currents of the BLDC motor. As the load increases, the motor draws more current and when the speed varies even the current varies. The torque and current is directly proportional to each other.



(a) (b)

Figure 8. (a) Measured torque from the BLDC motor. (b) Phase currents from the BLDC motor

The Philips HL 1643/04 model was used for the experimental demonstration. The specifications of this model are 600W, 230V AC, and speed of 18000 rpm. Flux 435 series II power quality and energy analyser was used for taking the readings as shown in Figure 9.

Table 5 shows the comparison of an existing mixer grinder and the simulated proposed 24V BLDC system under no load and load condition. If the crest factor is 1.41, then there is an absence of distortion, and if the crest factor is above 1.8, then the amount of distortion is very high.

Figure 9. Experimental demonstration of existing mixer grinder

Table 5. Comparison of the experimental existing mixer grinder and simulated proposed 24V BLDC system at no load and load condition

	Experimental existing mixer grinder (600W) No load condition	Simulated proposed mixer grinder (200W) No load condition	Experimental existing mixer grinder (600W) With load	Simulated proposed mixer grinder (200W) With load
Amount of distortion (Crest factor)	Cf=2.39	Cf=1.41	C_f=2.05	C_f=1.39
Total Harmonic distortion	Voltage=5% Current=20.2%	Voltage=3.35% Current=3.25%	Voltage=4.8% Current=15.3%	Voltage=3.15% Current=3.05%
The efficiency of the system	48.25%	79.35%	48.02%	78.68%

5. CONCLUSION

As per the specification data, the proposed solar fed BLDC mixer grinder was simulated in the Matlab/Simulink. The closed loop hysteresis current controller BLDC system was used for controlling the speed of the motor. The torque, variable speed, and stator currents characteristics were also discussed. A comparative analysis of the efficiency and the harmonic distortion of the experimental existing universal motor and the simulated proposed BLDC motor system was determined. Due to the absence of friction of the brushes, the efficiency of the BLDC motor was higher than of the mixer grinder operating in the universal motor. The crest factor and the total harmonic distortion was higher in the existing universal motor compared with the proposed system.

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