An Advance Solar Power Generation and Control of Brushless DC Motor Using Phase Current Infusion of Sensor Less Vector Control

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Abstract

Solar power is a promising solution in recent environmental aspects so several methods of generation were implemented in past to reach advances in generation capacity and critical conditions of solar. This paper deals with Non-inverting Four Switch buck-boost converter (NFSBBC) which is presented to reach advances in generation with respect to solar condition. The advances of generation include maximum power point tracking using incremental conductance, reliable buck boost operation and voltage stability ratio. Incremental conductance can track rapidly on solar power than perturb and observer method, so proposed power generation draws a continuous power across DC-Link inverter drive for wide speed operation of brushless DC motor. A new phase current infusion is implemented to estimate flux, torque and control of speed in wide range without external infusion and sensing loops in present sensor less vector control. 110W/50V capacity of solar is implemented for present solar power generation; output capacity of converter reaches from 25-100V using buck boost operation. 25V/1500 rpm capacity of brushless DC Motor is controlled using proposed sensor less vector using current infusing logic.

Keywords

Photovoltaic System; DC-DC Converter; Maximum Power Point Tracking (MPPT); Four Switch Buck Boost Converter (NFSBBC); Brushless DC Motor (BLDC); Sensorless Control

Introduction

The photovoltaic improvement in generation is an notable solution in growth of present and future of renewable power plant explained in literature among other resource such as wind, tidal, geo thermal, biomass etc. [1]-[3]. Installation cost of Photovoltaic panel is high meanwhile generation capacity is low and current lagging problems are arrived when compared with other renewable sources. So power converter is used to extract or step up voltage of photovoltaic sources and also used for leading of photovoltaic current in generation [4].The converter performance is important in ensuring about high efficiency by lossless power conversion. A loss conversion depends on active power switching losses and losses on passive devices. Those losses are drawn by high current and voltage losses across elements on power converters [5]-[7].

Even though several power converters are presented in literature, but some special converters are the suitable mediums in generation of photovoltaic plant power generation in present era of environment. The special converters are used in maximum power extraction of photovoltaic systems like Cuk [8], SEPIC [9] and micro inverter [10]. Those special converters are required by an additional active elements and passive elements to fulfill maximum power generation and efficiency. The four switch power converter is showing a particular attention in photovoltaic generation in recent days [11] because it having less number of active devices and passive devices, so lossless power transfer is obtained with high efficiency. This paper presented a simplified buck-boost converter having cascading of simplified and controlled active switching arrangement is perfectly suitable to extract power from varying solar system. Duty cycles control of present converter is derived by MPPT using incremental conductance method. This Incremental conductance method is having a continuous tracking of photovoltaic array...
at different generation levels. The proposed active power generation of photovoltaic is used to provide a continuous and control of power across DC-Link of inverter fed Brushless DC Motor.

The control of brushless DC Motor is presented by infusion of phase current except sensing of other factors such as speed, phase voltage and back emf sensing. This approach is a simplified effective control structure to estimation of speed, flux to obtained desired stator current even at wide load variations. A simple Space vector control is implemented to obtain a desired commutations sequence to voltage source inverter fed BLDC motor. Proposed sensor-less controller does not require any additional loops to gradual control and variation of phase current even at load variation and DC-Link voltage changes. The present enhancement of circuit and controller performance is implemented using MATLAB/Simulink and performance was evaluated using simulation results.

**Advances in Solar Power Generation**

Solar power is a promising aspect in effective extraction of power for further application of power storage and drives control. In this paper, advances in power generation include such as good module of photovoltaic panel, choice of suitable power converter medium with respect to efficiency and derivation of adequate algorithm for maximum power extraction is shown in Fig.1. Those advancement procedures are implemented to reach a desired power generation over classical scheme and advancement of power generation; details are given below.

**Photovoltaic System**

A single diode equivalent circuit basis photovoltaic model is sophisticated in this paper because it is having simple structure, reliable in operation and easily adjusting a parameters when this interfacing with power converters over classical multi diodes structures [12], [13]. A single diode of parallel is proposed and series resistance combinations are included in equivalent circuit as shown in Fig.2. The derived form of current-voltage equation is described as [14] by

\[
I_{PV} = N_P \left( I_{ph} - I_0 \left\{ \exp \left( \frac{V_{PV}}{nN_AkT} \right) \right\} \right)
\]

where in above equation (1) current and Voltage of photovoltaic array is denoted by \( I_{PV} \) and \( V_{PV} \) respectively, short circuit current of photovoltaic array and saturation current are denoted by \( I_{ph} \) and \( I_0 \) Respectively. Coulomb constant \( (q) \) \( (1.602 \times 10^{-19}) \) and Boltzmann constant \( (k) \) \( (1.38 \times 10^{-23}J/K) \) are applied for derivation of
photovoltaic current \( (I_{PV})\)

In exchange of solar power to extract maximum power from solar array, a MPPT (Maximum Power Point Tracking) is applied widely in modeling and application solar array as \([15]\). Nominal voltage and current in equation (1) is replaced by \(V_{MPP}\) and \(I_{MPP}\) is given by

\[
I_{MPP} = N_p \left( I_p - I_0 \left( \exp \left( \frac{qV_{MPP}}{nN_pKT} \right) \right) \right)
\]

**Non Inverting Four Switch Buck Boost Converter (NFSBBC)**

The Non-inverting Four Switch Buck Boost Converter (NFSBBC) is a family of buck boost converter topology. But this is separated from classical buck-boost, SEPIC and Cuk converter in the form of reliability, efficiency, high step-up and step-down capability, less number of passive components and low range of components. The design aspects of proposed converter system are obtained by voltage-second balanced theorem. The gain of voltage \(G_V\) is obtained by

\[
G_V = \frac{V_{out}}{V_{PV}} = \frac{D_1}{1-D_2}
\]

\(D_1, D_2\) are derived duty cycles for \(S_A\) and \(S_B\) switch which presented in proposed converter system. \(S_{A1}, S_{A2}\) are rectifier switches for \(S_A, S_B\) switches. Pulse width modulation is designed on the basis of continuous and discontinuous operation. The nature of proposed converter topology is discontinuous power flow in between buck (step-down) and boost (step-up) operation. So this discontinuous power flow is needed to change continuous operation for smooth and steady state operation of voltage. Carrier overlapping scheme is introduced for reference signal comparison to delivered exact pulse duty cycles of \(D_1, D_2\) \([16]\). Reference signal generation and magnitude are important phenomena for proposed Buck-Boost operation and also high step-up ratio. So this is derived by adequate MPPT algorithm using perturb and observer method \([17]\). Due to the condition of photovoltaic system proposed MPPT extract power by using adequate reference signal generation for NFSBBC circuit and duty cycles \(D_1, D_2\) are shown in Fig.3 and Fig.4.

**FIGURE 3 A NEW ENHANCED PHOTOVOLTAIC POWER GENERATION FOR BLDC MOTOR USING SENSOR-LESS HYSTERESIS PWM CONTROL**
### TABLE I

<table>
<thead>
<tr>
<th>Converter specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{\text{in}}(V) )</td>
<td>50</td>
</tr>
<tr>
<td>( P_{\text{in}}(W) )</td>
<td>125</td>
</tr>
<tr>
<td>( V_{\text{out}}(V) )</td>
<td>60</td>
</tr>
<tr>
<td>( L(\mu H) )</td>
<td>800</td>
</tr>
<tr>
<td>( C1(\mu F), C2(\mu F) )</td>
<td>200</td>
</tr>
<tr>
<td>( R(\Omega) )</td>
<td>50</td>
</tr>
<tr>
<td>( L(\text{mH}), C1(\text{nF}) \text{ grid side} )</td>
<td>1</td>
</tr>
</tbody>
</table>

**FIGURE 4 CONTROL PULSES FOR NON-INVERTING FOUR SWITCH BUCK BOOST CONVERTER (NFSBBC)**

**Maximum Power Point Tracking Using Incremental Conductance Method**

The proposed MPPT is able to extract high power at certain conditions to meet out demand of load and this is capable of tracking continuous power from photovoltaic array, this is having unique merits [18] and this includes charge controller, storage or load demand and ambient temperature. The proposed incremental conductance method is applied to 50V/200W capacity of photovoltaic array to reach 25-100V capacity with respect to demand of inverter DC-Link which is taken in account. Characteristic of incremental conductance graph for present topology is shown in Fig.5

**FIGURE 5 INCREMENTAL CONDUCTANCE CURVE ON PHOTOVOLTAIC SYSTEM**

The following equation is described by left side maximum power increment and right side maximum power decrement as given by

\[
\frac{dP}{dV} = 0 \text{ at MPP} \tag{4}
\]

\[
\frac{dP}{dV} > 0 \text{ at right side of MPP} \tag{5}
\]
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\[
\frac{dP}{dV} < 0 \text{ at left side of MPP} \tag{6}
\]

\[
\frac{dP}{dV} = \frac{d(VI)}{d(V)} = I + VI \cdot \frac{dI}{dV} \tag{7}
\]

where \(\frac{dP}{dV}\) = identifier factors, the following conditions are considered to track or extract maximum power using proposed MPPT Topology

\[
\frac{dI}{dV} = \frac{I}{V} \text{ at MPP and } dV_n = 0 \tag{8}
\]

\[
\frac{dI}{dV} > -\frac{I}{V} \text{ left of MPP } dV_n = +\delta \tag{9}
\]

\[
\frac{dI}{dV} < -\frac{I}{V} \text{ left of MPP } dV_n = -\delta \tag{10}
\]

Considering that the iteration (n+) and iteration increment (n+1) are implemented using above equation (8)-(10). The present MPPT is extracting and generating power up to conditions satisfied as \(\frac{dI}{dV} + \frac{I}{V} = 0\) and process of incremental conductance is given as flow chart shown in Fig.6.

**Sensor-Less Vector Control Using Phase Current Infusion**

A new enhanced vector controller is capable of controlling torque and speed of proposed brushless DC Motor
using simple phase current sensing which is shown in Fig.7. Alternative form of phase power is applied to brushless DC Motor drive operation. Phase current \((i_a, i_b, i_c)\) is exchanged to direct-axis \((d)\) and quadrature-axis \((q)\) using simple park transformation [19] as following form

\[
\begin{align*}
I_d &= \frac{2}{3} \left[ i_a \sin(\omega t) + i_b \sin \left(\omega t - \frac{2\pi}{3}\right) + i_c \sin \left(\omega t + \frac{2\pi}{3}\right) \right] \\
I_q &= \frac{2}{3} \left[ i_a \cos(\omega t) + i_b \cos \left(\omega t - \frac{2\pi}{3}\right) + i_c \cos \left(\omega t + \frac{2\pi}{3}\right) \right]
\end{align*}
\]

(11) (12)

FIGURE 7 FLOW CHART FOR INCREMENTAL CONDUCTANCE

Flux angle \((\varphi)\) or \((\text{phir})\) is estimated from direct and quadrature axis form is by following equation

\[
\begin{align*}
\varphi_\text{ds} &= L_s i_d + \varphi'_r \sum_{n=1}^{\infty} (K_{6n-1} + K_{6n+1}) \sin(6n \theta_r) \\
\varphi_\text{qs} &= L_s i_q + \varphi'_r \sum_{n=1}^{\infty} (K_{6n-1} - K_{6n+1}) \cos(6n \theta_r) + \varphi'_r
\end{align*}
\]

(13) (14)

where \(\varphi'_r\) is a fundamental angle of peak value, \(K_{6n-1}, K_{6n+1}\) are the odd number of back emf which is generated on Rotor side Brushless DC Motor.

In above equation (13) and (14), they show the location and approximation of flux linkage on dq-reference frame. Flux linkage of stator is varied in six time of fundamental frequency, so we can control stator flux by varying d-axis frame of current as shown in (15).

\[
|\varphi_s| = \sqrt{\varphi_\text{ds}^2 + \varphi_\text{qs}^2}
\]

(15)

In above (15) equation, \(\varphi_\text{ds}^2, \varphi_\text{qs}^2\) are varied with respect to time, so stator flux is not been constant as it is given rotor dq-reference frame as (11). The following equation are obtained as \(\delta, \rho\) and \(\gamma\).

\[
\begin{align*}
\gamma &= \frac{1}{\sin} \left( L_{qs} i_{qs} / \varphi_\text{qs} \right) + \frac{1}{\cos} \left( L_{qs} i_{qs} / \varphi_\text{s} \right) - \frac{\pi}{2} \\
\rho &= - (\varphi_s + \gamma - \frac{\pi}{2}) \\
\delta &= \frac{\pi}{2} - \frac{1}{\cos} \left( L_{qs} i_{qs} / \varphi_\text{s} \right)
\end{align*}
\]

(16) (17) (18)

Moreover, X-plan is explained as

\[
\chi = \varphi_\text{qs} \cos \left( \frac{1}{\sin} \left( L_{qs} i_{qs} / \varphi_\text{s} \right) \right)
\]

(19)
Estimating of torque using speed curve and reference of estimation by using park transformation as mentioned [19] is estimated by

$$T_{em} = \frac{3P}{4w_{re}} e_q(\theta_{re})i_q^r + e_d(\theta_{re})i_q^r$$

$$= \frac{3P}{4} k_q(\theta_{re})i_q^r + k_d(\theta_{re})i_q^r$$

Reference voltage is derived from $\alpha$ and $\beta$ reference frame from controlled direct and quadratur axis current, a simple space vector scheme is applied to drive switching sequence which is shown in Table II, III and Fig.8. A voltage of references is driving for proposed BLDC drive as

$$\bar{V}_{ref} = V_\alpha + jV_\beta = \frac{2}{3}(V_a + aV_b + a^2V_c)$$

Similarly, $|\bar{V}_{ref}| = \sqrt{V_a^2 + V_b^2}$, $\alpha = \tan^{-1}\left(\frac{V_b}{V_a}\right)$

$$V_\alpha + jV_\beta = \frac{2}{3}(V_a + e^{2\pi j/3}V_b + e^{-2\pi j/3}V_c)$$

**TABLE II SWITCHING STATE OF PROPOSED INVERTER**

<table>
<thead>
<tr>
<th>state</th>
<th>Leg A</th>
<th>Leg B</th>
<th>Leg C</th>
</tr>
</thead>
<tbody>
<tr>
<td>S_1</td>
<td>S_4</td>
<td>V_{an}</td>
<td>S_3</td>
</tr>
<tr>
<td>1</td>
<td>on</td>
<td>off</td>
<td>V_a</td>
</tr>
<tr>
<td>0</td>
<td>off</td>
<td>on</td>
<td>0</td>
</tr>
</tbody>
</table>

**TABLE III SWITCHING STATE OF SPACE VECTOR**

<table>
<thead>
<tr>
<th>Space vector</th>
<th>Switching state (three phases)</th>
<th>ON-state switch</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero vector</td>
<td>$V_1$</td>
<td>$S_1, S_4, S_5$</td>
<td>$0$</td>
</tr>
<tr>
<td></td>
<td>$[1 1 1]$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$[0 0 0]$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$V_1$</td>
<td>$S_1, S_4, S_5$</td>
<td>$0$</td>
</tr>
<tr>
<td>Active vector</td>
<td>$V_2$</td>
<td>$S_1, S_4, S_6$</td>
<td>$\bar{V}_1 = \frac{2}{3}V_a e^{j\beta}$</td>
</tr>
<tr>
<td></td>
<td>$[1 0 0]$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$V_3$</td>
<td>$S_1, S_4, S_5$</td>
<td>$\bar{V}_1 = \frac{2}{3}V_a e^{-j\beta}$</td>
</tr>
<tr>
<td></td>
<td>$[1 1 0]$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$V_4$</td>
<td>$S_4, S_3, S_2$</td>
<td>$\bar{V}_1 = \frac{2}{3}V_a e^{j\beta}$</td>
</tr>
<tr>
<td></td>
<td>$[0 1 0]$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$V_5$</td>
<td>$S_4, S_3, S_5$</td>
<td>$\bar{V}_1 = \frac{2}{3}V_a e^{-j\beta}$</td>
</tr>
<tr>
<td></td>
<td>$[0 0 1]$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$V_6$</td>
<td>$S_4, S_3, S_5$</td>
<td>$\bar{V}_1 = \frac{2}{3}V_a e^{j\beta}$</td>
</tr>
<tr>
<td></td>
<td>$[0 1 1]$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$V_7$</td>
<td>$S_1, S_4, S_5$</td>
<td>$\bar{V}_1 = \frac{2}{3}V_a e^{-j\beta}$</td>
</tr>
<tr>
<td></td>
<td>$[1 0 1]$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$$V_\alpha + jV_\beta = \frac{2}{3}(V_a + \cos \frac{2\pi}{3}V_b + V_a + \cos \frac{2\pi}{3}V_c) + \frac{j}{2}(\sin \frac{2\pi}{3}V_b - \sin \frac{2\pi}{3}V_c)$$

**Figure 8** A simple space vector scheme for proposed inverter fed brushless DC motor
By equating the real and imaginary parts derived by,

\[ V_a = \frac{2}{3} \left( V_a + \cos \frac{2\pi}{3} V_b + \cos \frac{2\pi}{3} V_c \right) \]
\[ V_b = \frac{2}{3} \left( 0 V_a + \sin \frac{2\pi}{3} V_b - \sin \frac{2\pi}{3} V_c \right) \]

\[ \begin{bmatrix} V_d \\ V_q \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & \cos \frac{2\pi}{3} & \cos \frac{2\pi}{3} \\ 0 & \sin \frac{2\pi}{3} & \sin \frac{2\pi}{3} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \]

(23)

**TABLE IV**

<table>
<thead>
<tr>
<th>Motor Specification</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage(V)</td>
<td>50</td>
</tr>
<tr>
<td>Rated Current(A)</td>
<td>15A</td>
</tr>
<tr>
<td>Nominal speed (rpm)</td>
<td>600</td>
</tr>
<tr>
<td>Stator Resistance(Ω)</td>
<td>0.19</td>
</tr>
<tr>
<td>Stator Inductance(mH)</td>
<td>0.835</td>
</tr>
<tr>
<td>Rotor moment of inertia (kg.m²)</td>
<td>1.9959μ</td>
</tr>
</tbody>
</table>

**Simulation Result**

The proposed circuit and topology is implemented using MATLAB/Simulink as shown in Fig.9 using parameters shown in Table I and IV. A maximum extraction of single diode photovoltaic system is implemented on 50V/200W capacity shown in Fig.10 and lossless power conversion is obtained using incremental conductance based MPPT topology with high efficiency and present MPPT drives Non-inverting Four switch buck-boost converter (NFSBBC) with high step up ratio and capability of present converter performance are shown in Fig.11 across DC-Link.

Sensor-less current infusion provides a good control of torque and speed in wide load range by phase current...
infusion and control of speed, torque and angle of phase current control. The present Brushless DC Motor performances were achieved by present sensor-less topology in stator current, torque as well as speed which is shown in Fig.12 and 13, respectively.
Conclusion

This present paper is focusing on advancement in solar power generation using Non-inverting Four Switch Buck Boost Converter (NFSBBC) and provides a continuous power to sensor-less inverter fed brushless DC Motor. Advancement of generation covers a design of solar panel and extracting power using incremental conductance. Proposed Non-inverting Four Switch Buck Boost Converter (NFSBBC) is used to obtain a high step up lossless power conversion by continuous tracking capability of incremental conductance and also provides a continuous power to inverter DC-Link. Proposed sensor-less vector control is having simplified approach and torque, speed control is achieved using phase current infusion based sensor-less vector control approach. Performance of drive is maintained in desired limits by phase current of angle control, field control of speed and flux control circuitry. The performance of solar power generation using NFSBB converter fed sensor-less controller for Brushless DC Motor is implemented using MATLAB/Simulink and performance which are verified by simulation results.

REFERENCES

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