Sensorless Passivity Based Control of a DC Motor

Seethamathavi M.
Vignesh T.
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1 M.Seethamathavi, 2 T.Vignesh
Jay Shriram group of institutions, Tamilnadu, India
1Seethajothi56@gmail.com, 2Vigneshblue8@gmail.com

Abstract -- In last couple of decades, the control of motors has increased drastically. With this increase, current control techniques are developed. In sensor-less passivity control of a DC Motor the term passivity means the property of stability in an input and output. To maintain the stability at the input side the solar pv panel is connected with MPPT which extract maximum and stable voltage. For output we simultaneously regulate, both, the output voltage of the SEPIC-converter to a value larger than the solar panel output voltage, and the speed of motor, in any of the turning senses, so that it tracks a pre-specified constant reference. For a sensor less current control of a PMDC motor, its small-signal model that contains a number of parasitic parameters the observed current may diverge due to the parasitic resistors and the forward conduction voltage of the diode. Moreover, the divergence of the observed current will cause steady state errors in the output voltage a self-correction differential current observer (SDCO) is proposed to eliminate this steady-state error and gain high transient response speed. By carrying out a series of MATLAB simulation verifications, further investigation proves that the proposed algorithm has good robustness.

Keywords: Sensor less, SEPIC converter, Differential current observer, Self-correction, PMDC motor, PCC, MPPT.

I. INTRODUCTION

In recent years, digital control for a permanent magnet dc motor has become one of the research hot topics. Compared with the voltage control mode, the current control mode has higher response speed and larger loop gain bandwidth. However, in current control mode, when the pulse width modulation (PWM) duty ratio is higher than 50%, a slope compensation circuit becomes necessary to maintain system stability. Due to its high robustness and high response speed, predictive current control (PCC) has been brought into sepic converter current control loop design and has been widely investigated. The current sensors have different advantages and drawbacks, and thus could meet different requirements. However, existing techniques might not suit applications which require isolation with minimal price, power loss and size. Therefore, a current observer (CO) turns out to be a suitable substitute for conventional current sensors in digitally controlled converters. The cost, size and power consumption can be reduced since it does not need any auxiliary hardware, even though the accuracy might be affected by the voltage ripple or the mismatches between the observer and the converter. In PCC mode, the inductor current of the next switching cycle should be predicted, and the duty ratio for the next switching cycle can be calculated according to the reference current and predicted current.

In this application, the power converters transfer the Solar panel power to the load represented by a DC motor. As an advanced current control strategy, the predictive current control (PCC) has the characteristics of high robustness and high response speed. It can be combined with the current observer to realize sensor less PCC (SPCC). Both the PCC and current observer technologies have been widely investigated. For the PCC, an algorithm was investigated to eliminate the inductor current disturbance in one switching cycle in peak, average, and valley current control modes. However, in order to maintain the current control loop stability, the specific combination of current control mode with pulse width modulation (PWM) modulation scheme should be obeyed, and it restrains the flexibility of system design.

II PROPOSED SYSTEM FOR PASSIVITY CONTROL OF PMDC MOTOR

A. Basic Current Observer

The construction of SEpic DC-DC converter with the CO based PCC controller, is shown in Figure 1. The controller is a dual-loop system. The voltage loop is a PI compensator, which outputs the reference current $I_{\text{REF}}$. The current loop is the PCC controller, which calculates the duty ratio for the next switching cycle. In every switching cycle, the voltage sampling, the PI regulation, the current sensing and the PCC regulation are processed in sequence. In this way, the current error could be eliminated in two switching cycles.

Figure 1.SEPIC converter with the CO based PCC controller
Ignoring the parasitic parameters, a current differential equation can be derived based on the average voltage on the inductor, shown as equation 1,
\[ \text{LdIL}(t) = \text{VIN}(t) - \text{VO}(t) \]  
(1)

where \( I_L \), \( V_O \), \( D \) and \( V_{\text{IN}} \) denote the inductor current, the output voltage, the duty ratio, the equivalent load resistor and the input voltage, respectively. The equation is the theoretical base for current observer.

Based on equation 5, the inductor current can be observed using \( D \), \( V_O \), \( V_{\text{IN}} \), \( L \) and \( T \). In detail, for the \( k \)th switch cycle, the voltage absolute value on the inductor is \( V_{\text{IN}}(k)-V_O(k) \) when the MOS switch is on, while being \( V_O(k) \) when it is off. So, \( M_1(k) \) and \( M_2(k) \) can be written as equation 2.

\[ M_1(k) = \text{VIN}(k) - \text{VO}(k) \]
\[ M_2(k) = \text{VO}(k) \]

\[ M_1(k) = M_1(k+1) = M_1M_2(k) = M_2(k+1) = M_2 \]  
(2)

where \( M_1(k) \) and \( M_2(k) \) denote the positive slope and the negative slope of the inductor current, respectively. Meanwhile, the rising duration time of inductor current is \( D(k)T \), and the falling duration time is \( [1-D(k)]T \). Thus, the variation of the inductor current in the \( k \)th switching cycle can be written as equation 3:

\[ \hat{I}\text{OB}(k) = I\text{OB}(k+1) = I\text{OB}(k) = -M_2(k)D'(k)T + M_1(k)D(k)T \]  
(3)

where \( I_{\text{OB}}(k) \) denotes the observed current, and \( D(k) \) is an abbreviation for \( 1-D(k) \). Equation 3 is the basic current observer equation, from which the PCC algorithm is also derived.

**B. Predictive Current Control**

Employing valley current control and trailing edge (TE) modulation, the inductor current waveform is shown in Figure 2.

![Current waveform under valley current control](image)

Figure 2. Current waveform under valley current control \( I_{\text{REF}} \) is the reference current output from the PI regulator. There exists a deviation between \( I_L(k) \) and \( I_{\text{REF}} \). The PCC controller detects the current error, and adjusts the duty ratio \( D(k+1) \), so that \( I_L(k+2) \) reaches \( I_{\text{REF}} \). In this way, the current error can be eliminated in two switching cycles.

As the switching cycle \( T \) is much shorter than the regulation time, the inductor current slope can be regarded as constant in two adjacent switching cycles, that is:

\[ M_1(k) = M_1(k+1) = M_1M_2(k) = M_2(k+1) = M_2 \]  
(4)

Substituting the control objective \( I_{\text{OB}}(k+2) = I_{\text{REF}} \), we have:

\[ D(k+1) = I_{\text{REF}} - I_{\text{OB}}(k+1) + M_2T(M_1+M_2)T \]  
(5)

As shown above, the PCC controller can eliminate the current error in less than two switching cycles, which is relatively fast, so the converter can be designed with fast transient response. However, the CO-based PCC controller has problems such as the divergence of the observed current and the steady state error of the output voltage.

**C. SDCO**

1. **Self correction module**

   For the basic current observer, an integral self-correction module can be added to the system for voltage loop steady-state error elimination. As shown in Figure 2, in the integral self-correction module, \( I_L \) multiplies \( K/s \), and the result is subtracted by \( I_{\text{REF}} \); the relationship between \( I_L \) and \( I_{\text{REF}} \) is \( I_L = I_{\text{REF}}(S/S+K) \).

   In the following, the open-loop transfer function with the self correction module is derived. First, the equation of the basic current observer without self-correction can be described as

\[ I_L(k+1) = I_L(k) + \frac{1}{L}[V_{\text{IN}}(k) - V_O(k)(1-D(k))] \]  
(6)

   Transferring the above equation to continuous domain, then

\[ I_L = \frac{1}{sL}[V_{\text{IN}} - V_O(1-D)] \]  
(7)

   Impose small-signal disturbances \( \Delta \text{REF}, \Delta D \) and \( \Delta V_O \) onto \( \text{REF}, D \) and \( V_O \), respectively, and then substitute them into:

\[ \frac{\Delta I_L}{\Delta D} = \frac{1}{sL}[V_O - \frac{\Delta V_O}{\Delta D}(1-D)] \]  
(8)

![Block diagram of the current controller with self-correction](image)

Figure 3. Block diagram of the current controller with self-correction

\( G_{ID}(S) \) is the transfer function from \( D \) to \( I_L \). Combining the self-correction module with the current observer, \( G_{ID}(S) \) is

\[ G_{ID}(S) = \frac{I_L}{\Delta I} = \frac{1}{sL}[V_O - \frac{\Delta V_O}{\Delta D}(1-D)] \]  
(9)

With regulating rule of PCC the \( G_{PCC}(S) \) is derived. \( G_{PCC}(S) \), i.e., the transfer function from \( \Delta I \) to \( D \), can be obtained by the same method, i.e.,

\[ G_{PCC}(S) = \frac{\Delta L}{\Delta D} = \frac{1}{V_O - \frac{\Delta V_O}{\Delta D}(1-D)} \]  
(10)
2. **Differential Current Observer**

After involving the self-correction module into the current observer, the output voltage steady-state error can be eliminated, and $IL$ tends to be constant. However, the problem still exists in two respects. First, the predicted current $IL$ is still increasing, eventually leading to the calculation result overflowing. More importantly, the influences on the parasitic parameters, e.g., device aging, will diverge $IL$ from the actual inductor current. As shown in Fig.4, in order to deduce $D(k + 1)$, it is only necessary to calculate $\Delta I$ rather than $IL$. After extracting common factor $1/sT$, $\Delta I$ becomes

\[
\Delta I = I_{REF} - I_L = \frac{1}{sT}(\Delta I_{REF} - \Delta I_L) = \frac{1}{sT}\Delta I'
\]

In , $\Delta I_{REF}$ and $\Delta I_L$ are the differential values of $I_{REF}$ and $I_L$, respectively. When the system reaches their steady states, both of them converge to zero, and the calculation overflow can be effectively avoided.

The current observer equation in the continuous domain can be converted , i.e.,

\[
I_L = \frac{1}{sT_L}[V_{IN} - V_O(1 - D)]
\]

Then the differential current observer is

\[
\Delta I_L = \frac{1}{sT_L}[V_{IN} - V_O(1 - D)]
\]

Whereas $\Delta I_{REF}$ can be calculated by

\[
\Delta I_{REF} = K_P(1 + 1/sT1)sT
\]

![Figure 4 Block diagram of the current controller with differential observer](image)

Fig. 5 shows the input voltage of 24V, which is obtained from solar mppt. The MPPT algorithms are necessary in PV applications because the MPP of a solar panel varies with the irradiation and temperature, so the use of MPPT algorithms is required in order to obtain the maximum power from a solar array.

![Figure 6 Armature current of the PMDC motor](image)

Fig. 6 shows the output current obtained from simulation. On this basis, the system small-signal model, including the parasitic parameters, is constructed and analyzed. Then an SCDO is proposed. PMDC motor has high starting current and its getting reduced after the motor start to run at its desired speed.

![Figure 7 Torque of the PMDC motor](image)

![Figure 8 output voltage of the PMDC motor](image)

**III. EXPERIMENTAL RESULTS**

To verify the proposed algorithm, experiments are carried out with a DC motor with sepic converter interface. SIMULINK model is created PMDC motor/SEPIC converter combination powered via a solar panel. This model contains renewable solar energy source, permanent magnet DC motor, and predictive current controller, control circuit which has PI controller, PWM and sepic converter interface. The waveforms based on these calculations are shown as follows.
The basic cause of the output voltage steady-state error in a sensor less current-controlled sepic converter has been eliminated in fig 8 and it is proved through theoretical derivations.

![Graph of Speed vs Time](image)

**Figure 9 Speed of the PMDC motor**

Fig 9 shows the speed of the motor and Fig 7 shows the torque of the motor. The above figures are matched with the practical performance of the PMDC motor. When the speed increases the torque and the armature current decreases. Speed is inversely proportional to the torque.

On this basis, the compensation strategy for output voltage sampling in both current loop and voltage loop has been proposed. In addition, the system modeling error caused by the parasitic parameters and nonlinear factors has been also compensated. The system ultimately achieves high-precision sensor less predictive peak current control without the voltage steady-state error with the comprehensive compensation strategy.

**III CONCLUSION**

The basic cause of output voltage steady-state error in a sensor less current controlled PMDC motor has been established in theory. On this basis, the system small-signal model, including the parasitic parameters, is constructed and analyzed. Then an SCDO is proposed. Simulation shows that the proposed algorithm is very robust. In addition, its computational complexity is low and easy to implement. With the proposed algorithm, the system ultimately achieves no voltage steady-state error with good transient performance despite parasitic parameters variation. Experimental results show that the control of permanent magnet DC motor is proposed in this paper is accurate and effective and has a good theoretical and practical application potential. The result of this property would be the increase of speed and efficiency. This system is suitable for industrial applications.

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**REFERENCE**


