AN205344

PI Theory in Motor Control

This application note describes PI theory and PI in motor inverter control.

1 Introduction

1.1 Purpose

This application note describes PI in motor inverter control.

1.2 Definitions, Acronyms and Abbreviations

P	Proportion
I	Integral

1.3 Document Overview

The rest of document is organized as the following:

Chapter 2 explains the background of PI technical.

Chapter 3 explains the application in motor control.

Chapter 4 explains the application.

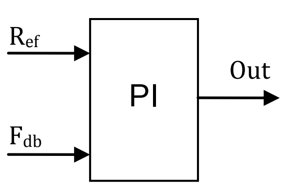
2 Technical Background

PI's theory

2.1 Overview

The PI loops use to faster and control motor.

Figure 1. Sample Module of PI Control



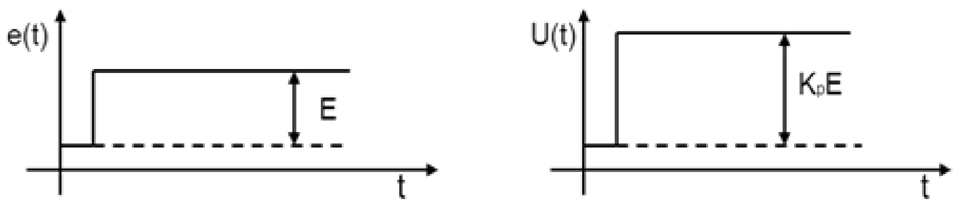
Ref : Reference signal(To set target value)
Fdb : Feedback signal(To adjust target value)
Out: Output signal

2.2 Theory

2.2.1 P- Proportion.

The Proportional term of the regulator is formed by multiplying the error signal by a P gain, using the PI regulator to produce a control response that is a function of the error magnitude. As the error signal becomes larger, the P term of the regulator becomes larger to provide more correction. In short, P is a magnify function.

Figure 2. P Regulator



In figure 2, we can know the P regulator has two characteristic:

1. Timely and faster control.
2. When the adjust process finish, but still have the error signal.

   The P regulator formula is:

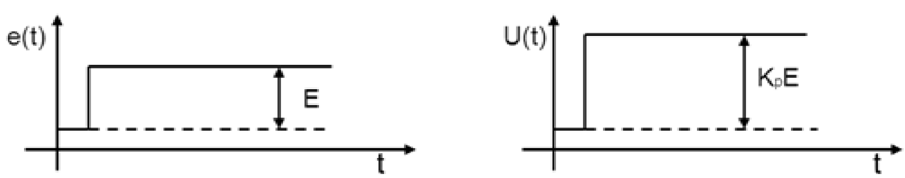
$$\mathbf{u(t) = K_p e(t)} \qquad (1)$$

Where u(t) is output parameter, K_p is the proportion coefficient, e(t) is the input parameter.

2.2.2 I-Integral

The Integral term of the regulator is used to eliminate small steady errors. The I term calculates a continuous running total of the error signal. Therefore, a small steady state error accumulates into a large error value over time. This accumulated error signal is multiplied by an I gain factor and becomes the I output term of the PI regulator.

Figure 3. I Regulator



In Figure 3, we can know the I regulator have five characteristic:

1. Not timely and faster control.
2. If have error signal, the regulator output control will increase, and it's speed always equal to start speed.
3. Control effect from strength to strength when time short and short.
4. I regulator can eliminate error signal.
5. In I regulator easy to bring adjust process surge.

The I regulator formula is:

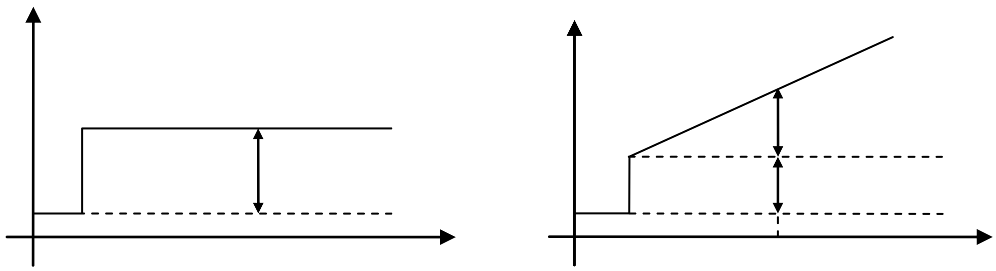
$$\mathbf{u(t) = k_I \int_0^t e(t)dt} \qquad (2)$$

Where u(t) is output parameter, $\mathbf{k_I}$ is the integral coefficient, e(t) is the input parameter, t is the integral time.

2.2.3 PI

The Proportional and Integral are PI. PI regulator is used to produce a control response that is a function of the error until disappear. As the error signal generate, regulator produce a control response of P, the I regulator calculates the error value over time. So, the PI regulator has P and I regulator's virtue, and eliminate themselves defect.

Figure 4. PI Regulator



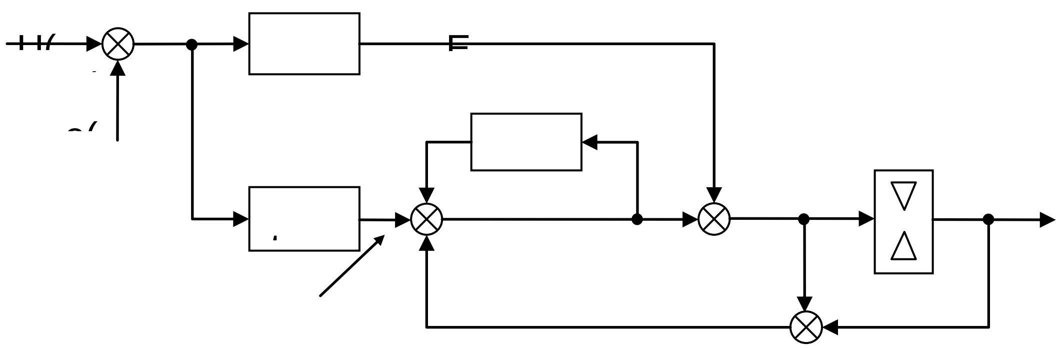
The I regulator formula is:

$$\mathbf{u(t) = u_p + u_i}$$

$$\mathbf{u(t) = K_p \left(e(t) + \frac{1}{T} \int_0^t e(t) dt \right)} \qquad (3)$$

The PI regulator is a adjust module implemented with output saturation and with integral component correction. It can adjust input actual variable to follow the trace of target variable.

Figure 5. Implementation Process of PI Regulator as a Adjust Module



INPUT $\mathbf{Y_{ref}, Y_{bf}}$

$$\mathbf{Y_e = Y_{ref} - Y_{fb}}$$

$$\mathbf{U = X + K_p \cdot Y_e}$$

$$\mathbf{if(U_{min} \leq U_k \leq U_{max})}$$

$$\mathbf{U_k = U}$$

$$\mathbf{else\ if(U_k > U_{max})}$$

$$\mathbf{U_k = U_{max}}$$

$$\mathbf{else}$$

$$\mathbf{U_k = U_{min}}$$

OUTPUT U_k

$$\mathbf{U_e = U - U_k}$$

$$\mathbf{X = X \cdot Z^{-1} + K_i \cdot Y_e + U_e}$$

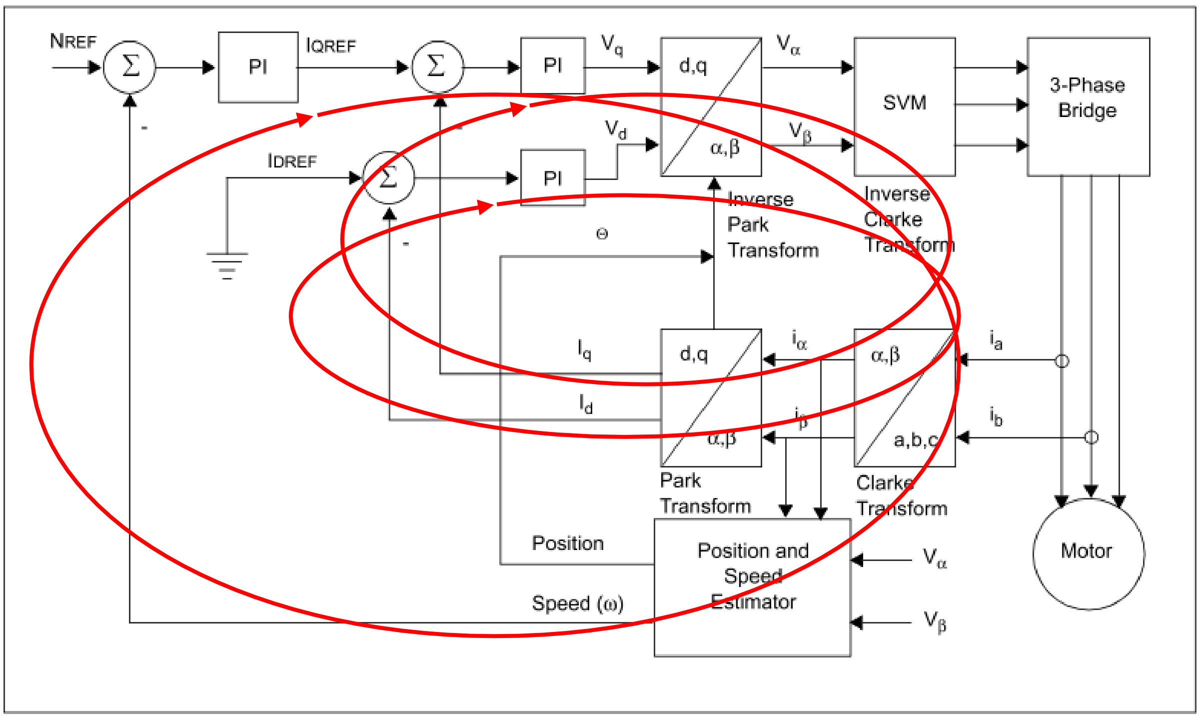
3 Application in motor control

PI regulator application in motor control

3.1 PI loop in FM3 inverter platform

Three PI loops are used to control three interactive variables independently, Speed PI loop, d-axis current PI loop, q-axis current PI loop.

Figure 6. Three PI Loops Covered over Whole System



In the figure 6, we can know the outer loop controls the motor velocity. The two inner loops control the transformed motor currents, Id and I_q. The Id loop is responsible for controlling flux, and the Iq value is responsible for controlling the motor torque. so we can use PI loop to control motor flux and torque.

3.2 Increment type PI loop in FM3 inverter platform

In FM3 inverter platform the PI loop type is increment type.

What is increment type PI loop? For example, define a array temp[10]={0,1,2,3,4,5,6,7,8,9 }, every time output the temp[k]= 0,1,2,3,4,5,6,7,8,9; Or output the temp[0], then output temp[1]=temp[0]+1,then output temp[2]=temp[1]+1 ……; it's mean: this time output is last time output add the delta, this is the increment type PI loop.

$$\mathrm{u}[\mathrm{k}] = \mathrm{u}[\mathrm{k}-1] + \{\mathrm{u}[\mathrm{k}] - \mathrm{u}[\mathrm{k}-1]\}$$

Define: $$\mathrm{delta} = \{\mathrm{u}[\mathrm{k}] - \mathrm{u}[\mathrm{k}-1]\}$$

Then: $$\mathrm{u}[\mathrm{k}] = \mathrm{u}[\mathrm{k}-1] + \mathrm{delta}$$

Where: $\mathrm{u}[\mathrm{k}\text{-}1]$ is last time PI output , $\mathrm{u}[\mathrm{k}]$ is the PI output, delta is the PI error.

In math formula:

$$\mathrm{u_k} = \mathrm{k_p}\left(\mathrm{e_k} + \frac{\mathrm{T}}{\mathrm{T_i}}\sum_{j=0}^{k}\mathrm{e_j}\right) \tag{4}$$

$$\mathrm{u_{k-1}} = \mathrm{k_p}\left(\mathrm{e_{k-1}} + \frac{\mathrm{T}}{\mathrm{T_i}}\sum_{j=0}^{k-1}\mathrm{e_j}\right) \tag{5}$$

$\Delta\,\mathrm{u} = \mathrm{u_k} - \mathrm{u_{k-1}}$:

$$\Delta\mathrm{u} = \mathrm{u_k} - \mathrm{u_{k-1}} = \mathrm{k_p}\left(\mathrm{e_k} - \mathrm{e_{k-1}} + \frac{\mathrm{T}}{\mathrm{T_k}}\mathrm{e_k}\right) = \mathrm{k_p}(\mathrm{e_k} - \mathrm{e_{k-1}}) + \mathrm{k_I}\mathrm{e_k} \tag{6}$$

Where: $\mathrm{e_k}$ is k time sample error value.

$\mathrm{k_p}$ is the proportion coefficient.

$\mathrm{k_I}$ is Integral coefficient, $\mathrm{k_I} = \mathrm{k_p}\frac{\mathrm{T}}{\mathrm{T_k}}$.

$\mathrm{u_k}$ is the output value.

$\Delta\mathrm{u}$ is the twice between border output error value.

4 Application

PI application achieve in system code

4.1 Function Description

```
/* active statistic task number */
Function Name:      PI_WeakenI

C file Name:        PI.C,  PI.H
Function interface: Q15_VAL32 PI_WeakenI(volatile _stPIDPara *pPI_Q15)
```

```
typedef struct
{
   Q15_VAL32 Kp_Q15; // PI factors
   Q15_VAL32 Ki_Q15;
   Q15_VAL32 e_Q15; // PI input
   Q15_VAL32 e_Last1_Q15;
   Q15_VAL32 u_last1_Q15; // PI output
   Q15_VAL32 uMax_Q15;
   Q15_VAL32 uMin_Q15;
}_stPIDPara;
_stPIDPara *pPI.
```

Table 1. Input and Output of the Function

Item	Name	Description	Format
Inputs	e_Q15	This time error value input	Q15_VAL32
	e_Last1_Q15	Last error value input	Q15_VAL32
	Kp_Q15	P gain value	Q15_VAL32
	Ki_Q15	I gain value	Q15_VAL32
Outputs	u_last1_Q15	Last output	Q15_VAL32
	uMax_Q15	Output Integral limit maximal value	Q15_VAL32
	uMin_Q15	Output Integral limit minimal value	Q15_VAL32

4.2 Module usage

The following code is example for this module.

```
void  example_ PI_WeakenI ()
{
    Q15_VAL32  PI_output;
    pPI.e_Q15= INa;
    pPI.e_Last_Q15= INb;
    pPI.Kp_Q15=INc;
    pPI.Ki_Q15=INd;
   PI_output  = PI_WeakenI (&pPI);
}
```

5 Document History

Document Title: AN205344 - PI Theory in Motor Control

Document Number: 002-05344

Revision	ECN	Orig. of Change	Submission Date	Description of Change
**	-	CCTA	03/24/2011	Initial Release
			04/07/2011	Redraw some picture and add explanation
			06/08/2012	Changed the format
*A	5045172	CCTA	01/05/2016	Migrated Spansion Application Note from MCU-AN-510105-E-12 to Cypress format
*B	5701669	AESATMP9	04/19/2017	Updated logo and copyright.

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