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AN204347

FM3 MB9B100A/300A/400A/500A Series Microcontroller Space Vector Pulse Width Modulation

This application note describes SVPWM function Theory, Block, Function, Flow, Sample, Parameter in FM3 family Inverter Platform.

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1 Introduction

This application note describes SVPWM function Theory, Block, Function, Flow, Sample, Parameter in FM3 family Inverter Platform.

2 SVPWM Theory

Technical Background

2.1 Overview

In motor theory, motor speed is defined by the formula:

$$n = \frac{60f}{p} \quad (1)$$

Where f-Power frequency,p-pole pairs

Through the formula ,speed regulate need change the power frequency or the motor pole pairs, and change power frequency easier than change motor pole pairs, so, at present, the great mass of motor speed regulate use frequency convert.

How to change power frequency? Currently, use the type of: AC-DC-AC. It's means, convert 3-phase power AC into DC, then, invert the DC into 3-phase AC and change frequency. First, define the 3-phase power AC interphase voltage is:

$$\begin{cases} u_a = \sqrt{2}U\cos(\omega t) \\ u_b = \sqrt{2}U\cos(\omega t - 2\pi/3) \\ u_c = \sqrt{2}U\cos(\omega t - 4\pi/3) \end{cases} \quad (2)$$

Take this 3-phase AC voltage into stationary system (α-β):

(The formulae deduce please reference the [AN] coordinate transform Clarke Transform formulae (12))

$$\begin{cases} u_\alpha = \left(\frac{2}{3}\right)(\mathrm{u_a} - 0.5\mathrm{u_b} - 0.5\mathrm{u_c}) = \sqrt{2}U\cos(\omega t) \\ u_\beta = \left(-\frac{2}{3}\right)\left(\frac{\sqrt{3}}{2}\mathrm{u_b} - \frac{\sqrt{3}}{2}\mathrm{u_c}\right) = \sqrt{2}U\sin(\omega t) \end{cases} \quad (3)$$

Take this into voltage space vector:

$$\mathrm{u_s} = u_\alpha + ju_\beta \quad (4)$$

In sine power:

$$\mathrm{u_s} = \sqrt{2}U\,(\cos\omega t + j\sin\omega t) = \sqrt{2}Ue^{j\omega t} \quad (5)$$

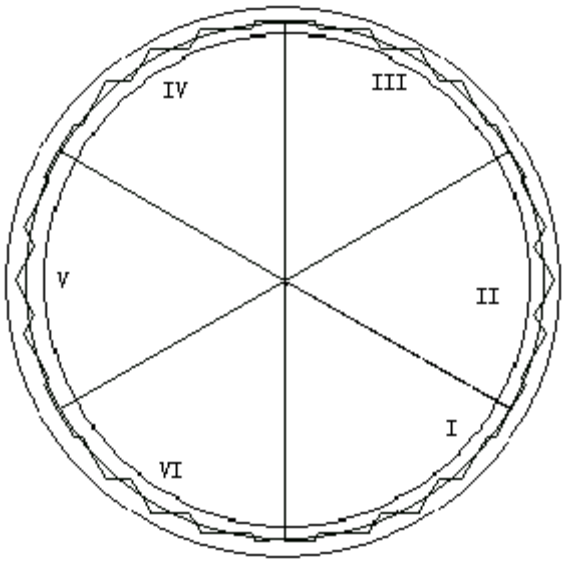
This equation is a circularity in plural plane. So, in motor theory, invariableness' voltage(U) and frequency, stator voltage space vector in plural plane move along with a circularity , and space vector move a cycle in a power frequency cycle.

Figure 1, the line voltage space vector will move other circularity , it's radius more than phase voltage circularity $\sqrt{3}$,and they have 30° phase angle.

In stator 3-phase voltage space vector will move along with a circularity (start) into another circularity (stabile).

The SVPWM use to regulate power frequency and draw a nice circularity through DC–AC part.

Figure 1



Theory

SVPWM: Space Vector Pulse Width Modulation.

Purpose: SVPWM can directly transform the stator voltage vectors from the two-phase α,β-coordinate system into pulse-width modulation (PWM) signals (duty cycle values). proverbial motor formulae is :

$$U_1 = \frac{d\psi_1}{dt} + R_1 i_1 \quad (6)$$

U_1 is stator voltage vector, Ψ_1 is stator flux vector, i_1 is stator current vector.

When U_1 is a standard sine wave, that is the same size and direction continuous change, the trajectory is an ideal circle. So,

$$\psi_1 = \oint (U_1 - R_1 i_1)\, dt \quad (7)$$

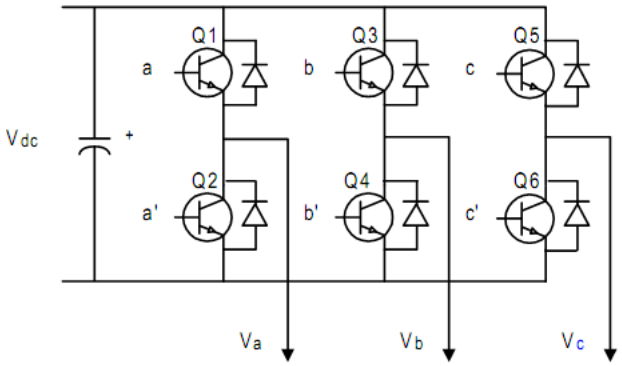
When $R_1 * i_1 << U_1$:

$$\psi_1 = \oint U_1\, dt \quad (8)$$

Flux trajectory depends on voltage vector.

So we can design the circuit of DC to 3-phase AC

Figure 2



As shown in figure 2, in the circuit diagram, have 6 power switch a, b, c, a', b', c' plot out they into 2 groups, S[a,b,c] , S'[a', b', c'], they control the switch ON/OFF, and they mutex,

$$S_x = \begin{cases} S = 1 \\ S' = 0 \end{cases}$$

It's means each voltage vector is coded by the three-digit number and have eight possible switching states (vectors) are feasible.

For example: S_x = [1, 0, 0].

The point [a], [b'], [c'] switch ON, and [a'], [b], [c] switch OFF.

$$U_{aN} = U_{dc}, \quad U_{bN} = U_{cN} = 0$$

In motor theory,

$$\begin{cases} U_a - U_b = U_{aN} - U_{bN} = U_{dc} \\ U_a - U_c = U_{dc} \\ U_a + U_b + U_c = 0 \end{cases}$$

Take $U_{aN} = U_{dc}, \; U_{bN} = U_{cN} = 0$ into the formula,

$$U_a = \frac{2U_{dc}}{3},\quad U_b = -\frac{U_{dc}}{3},\quad U_c = -\frac{U_{dc}}{3}$$

Similarly, can calculate other switching states, below in Table 2-1.

Table 1

Sa	Sa	Sa	Vector	UaN	UbN	UcN	Ua	Ub	Uc
0	0	0	U0	0	0	0	0	0	0
1	0	0	U4	Udc	0	0	2Udc/3	- Udc/3	- Udc/3
1	1	0	U6	Udc	Udc	0	Udc/3	Udc/3	- 2Udc/3
0	1	0	U2	0	Udc	0	- Udc/3	2Udc/3	- Udc/3
0	1	1	U3	0	Udc	Udc	- 2Udc/3	Udc/3	Udc/3
0	0	1	U1	0	0	Udc	- Udc/3	- Udc/3	2Udc/3
1	0	1	U5	Udc	0	Udc	Udc/3	- 2Udc/3	Udc/3
1	1	1	U7	0	0	0	0	0	0

Form formula (3) and (4), the voltage space vector formula:

$$u_s = \left(\frac{2}{3}\right)(u_a + au_b + a^2u_c) \tag{9}$$

Where

$$a = \exp\left(j\frac{2\pi}{3}\right) \qquad a^2 = \exp\left(j\frac{4\pi}{3}\right)$$

Take table 2-1 vector:

$$U_4 = \frac{2}{3}U_{dc} \qquad U_6 = \frac{2}{3}U_{dc}\ \exp\left(j\frac{\pi}{3}\right)$$
$$U_2 = \frac{2}{3}U_{dc}\ \exp\left(j\frac{2\pi}{3}\right) \qquad U_3 = \frac{2}{3}U_{dc}\ \exp(j\pi) \tag{10}$$
$$U_1 = \frac{2}{3}U_{dc}\ \exp\left(j\frac{4\pi}{3}\right) \qquad U_5 = \frac{2}{3}U_{dc}\ \exp\left(j\frac{5\pi}{3}\right)$$

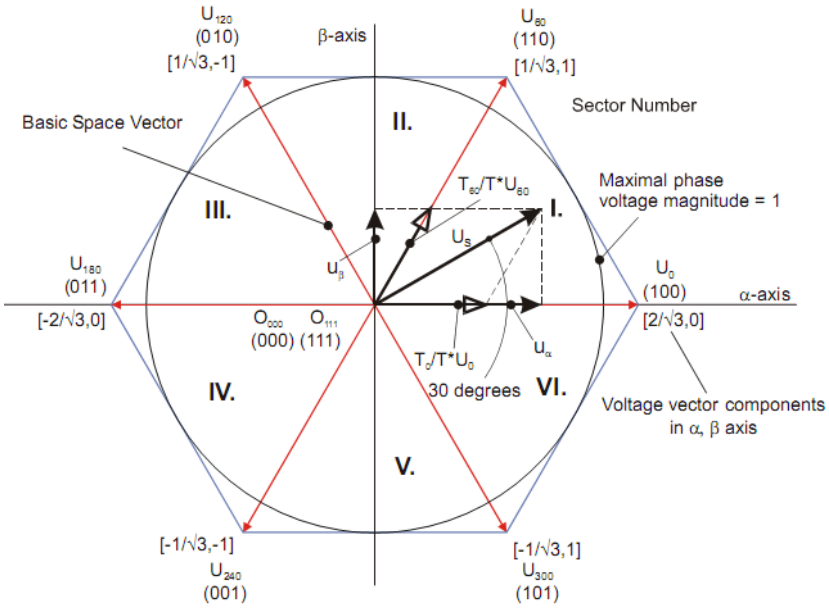
All of non-zero vectors have the same amplitude $\frac{2}{3}U_{dc}$, and between border two vectors angle is $\frac{\pi}{3} = 60°$, for example, f=50Hz, the vector change time:

$$t = \frac{60}{360} * \frac{1}{50} = 3.33ms$$

.

Graphical representation of all combinations is the hexagon shown in Figure 3. There are six non-zero vectors, U0, U60, U120, U180, U240, U300, and two zero vectors, O000 and O111, defined in α, β coordinates.

Figure 3



In figure 4, the red line plot out the hexagon into six sectors, every between border two vectors angle is 60°, the border two vectors and zero vector could compose random voltage vector.

$$\int_0^T U_{ref}\,dt = \int_0^{T_x} U_x\,dt + \int_{T_x}^{T_x+T_y} U_y\,dt + \int_{T_x+T_y}^{T} U_0\,dt \qquad (11)$$

Or

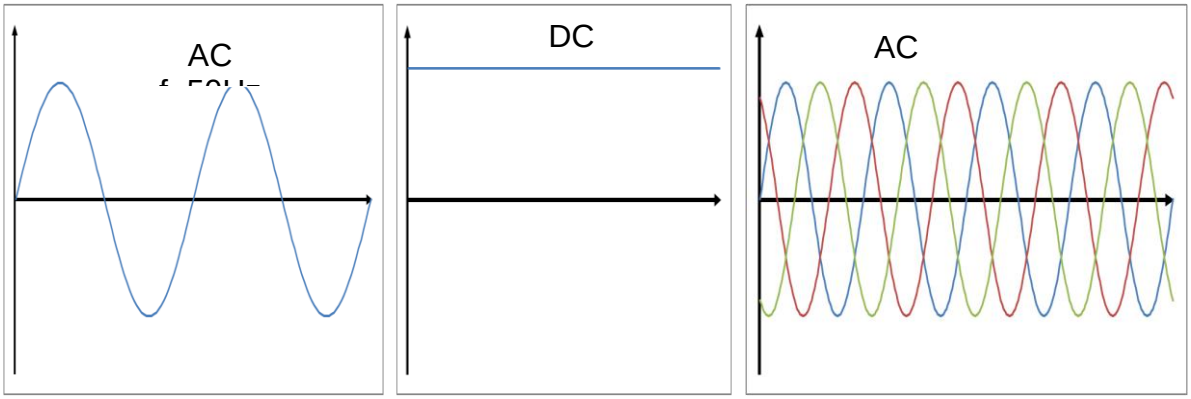
$$U_{ref}\,T = U_x\,T_x + U_y\,T_y + U_0\,T_0 \qquad (12)$$

This formula means, in sector the voltage vector rotating course could plot out many small part , it's have the same effect.

So, in the interest of bring 3-phase sine AC voltage, use the voltage vector compose, begin from U4(100),every time increase a little increment, every increment could compose from between border two vectors and zero vector. Then the enactment voltage vector equivalent with the rotating voltage vector, and that all is SVPWM.

The figure2-4 show the SVPWM transform course, a f = 50Hz single phase voltage transform into DC voltage, then transform into a f=100Hz 3-phase voltage.

Figure 4

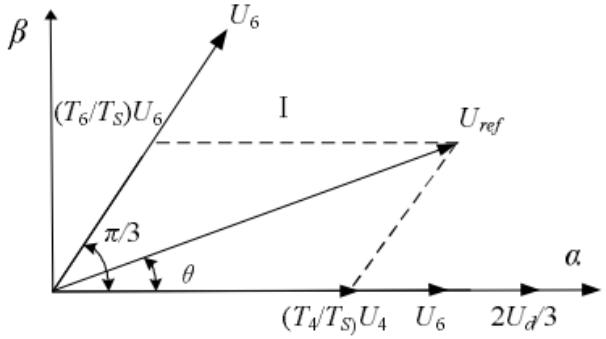


SVPWM Actualize

3-phase AC voltage rotating speed : $\omega = 2\pi f$, rotating a cycle need time T=1/f, if carrier wave frequency is f_s , the frequency ratio R =f_s/f, it's means voltage rotating plane plot out R unit increment , so the voltage vector increment angle is $r = \frac{2\pi}{R} = \frac{2\pi f}{f_s} = 2\pi T_s/T$

For example, need compose a voltage vector U_{ref} , it's station at I at sector first increment, then will use two non-zero vector(U4,U6) and two zero vector(U0,U7), shown the Figure 5.

Figure 5



In stationary system 2-phase (α-β), the U_{ref} with U4 angle is θ, then

$$\frac{|U_{ref}|}{\sin 2\pi/3} = \frac{|T_6U_6/T_z|}{\sin\theta} = \frac{|T_4U_4/T_z|}{\sin(\frac{\pi}{3}-\theta)} \quad (13)$$

Because: $U_4 = U_6 = \frac{2}{3}U_{dc}$, the vector hold time is

$$\begin{cases} T_4 = mT_s\sin(\frac{\pi}{3}-\theta) \\ T_6 = mT_s\sin\theta \end{cases} \quad (14)$$

$$m = \frac{\sqrt{3}|U_{ref}|}{U_{dc}}$$

Where m is SVPWM regulate ratio:

Then zero vector hold time: $T_7 = T_0 = (T_s - T_4 - T_6)/2$

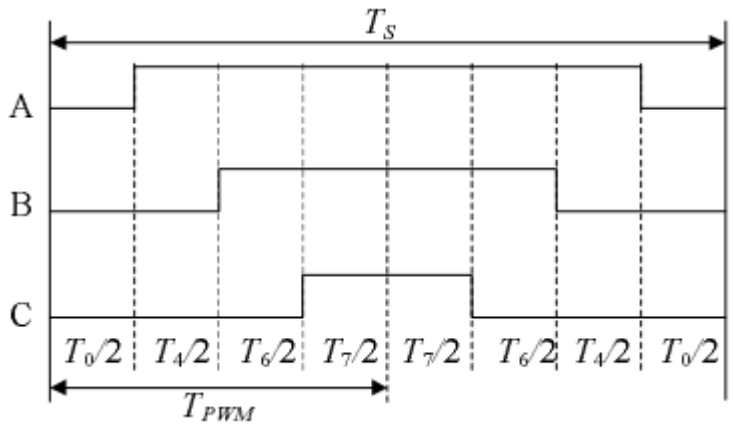
For reduce the switch waste, every time only changes one phase switch state, and the best sequence is below the Table 2-2.

Table 2

Uref	switch sequence
I sector (0°≤θ≤60°)	0-4-6-7-7-6-4-0
II sector (60°≤θ≤120°)	0-2-6-7-7-6-2-0
III sector (120°≤θ≤180°)	0-2-3-7-7-3-2-0
IV sector (180°≤θ≤240°)	0-1-3-7-7-3-1-0
V sector (240°≤θ≤300°)	0-1-5-7-7-5-1-0
VI sector (300°≤θ≤360°)	0-4-5-7-7-5-4-0

Then use the table 2-2 ,after voltage rotating a cycle, will have R unit compose vector, and in I sector have 3-phase voltage wave shown in figure 6

Figure 6



2.2 SVPWM Arithmetic in FM3 family

In FM3 family Inverter platform SVPWM compose sine wave need have 4 steps:

1. Make sure the U_{ref} belong to which sector.
2. To calculate X,Y,Z which are used to determine open time of 2 adjacent basic vector.
3. To determine each conduction time for 2 adjacent basic vector.
4. To determine To write OCCP register value to CH1,CH3,CH5 which used to create SVPWM waveform

2.2.1 Make sure the U_{ref} belong to which sector

Function Application

Function: To calculate sector no. of SVPWM voltage vector.

Function Name: CalcSectorNo

C file name: SVPWM.C, SVPWM.H

Function interface:

INT8U CalcSectorNo(_stDataInFixAxis *pstDataInFixAxis //fixed 2-axis system)

typedef struct

{

Q15_VAL32 alpha_Q15;//

Q15_VAL32 beta_Q15;//

}_stDataInFixAxis;

Table 3

Item	Name	Description	Format
Inputs	alpha	phase- alpha of fixed 2- phase	Q15_VAL32
	beta	phase- beta of fixed 2- phase	Q15_VAL32
Outputs	SectorNo	Sector no. of SVPWM voltage vector	Q15_VAL32

The following code is example for this module.

```
void example_ CalcSectorNo ()
{
    CurrentInFixAxis. alpha_Q15= INa;//Input alpha
    CurrentInFixAxis. beta_Q15= INb;//Input beta
    CalcSectorNo (&pstDataInFixAxis);
    OUTa= SectorNo;
}
```

Determine open time of 2 adjacent basic vector

Function Application

Function: To calculate X,Y,Z which is used to determine open time of 2 adjacent basic vectors.

Function Name: CalcDutyTime

C file name: SVPWM.C, SVPWM.H

```
void CalcDutyTime(_stDataInFixAxis *pstDataInFixAxis, _stXYZ *pstXYZ,
  INT8U WhichMFT, INT8U WhichFRTCh)
typedef struct
{
   Q15_VAL32 alpha_Q15;
   Q15_VAL32 beta_Q15;
}_stDataInFixAxis;
typedef struct
{
   INT32S X;
   INT32S Y;
   INT32S Z;
}_stXYZ;
```

Table 4

Item	Name	Description	Format
Inputs	alpha	phase- alpha of fixed 2- phase	Q15_VAL32
	beta	phase- beta of fixed 2- phase	Q15_VAL32
	WhichMFT	Which MFT, valid value is MFT0, MFT1	INT8U
	WhichFRTCh	Which FRT channel to configure	INT8U
Outputs	X	X is conduction time	INT32S
	Y	Y is conduction time	INT32S
	Z	Z is conduction time	INT32S

The following code is example for this module.

```
void example_ CalcDutyTime ()
    pstDataInFixAxis. alpha_Q15= INa;//Input alpha
    pstDataInFixAxis. beta_Q15= INb;//Input beta
    WhichMFT=0;
    WhichFRTCh=0;
    CalcDutyTime (&pstDataInFixAxis,& pstXYZ, WhichMFT, WhichFRTCh);
    OUTa= pstXYZ->X;
    OUTb= pstXYZ->Y;
    OUTc= pstXYZ->Z;
```

2.2.2 Calculate conduction time

Function Application

Function: To determine each conduction time for 2 adjacent basic vectors.

Function Name: CalcTon

C file name: SVPWM.C, SVPWM.H

```
void CalcTon(INT8U SectorNo, _stXYZ *pstXYZ, _stOnTimingOfUVW *pstOnTimingOfUVW,
        INT8U WhichMFT, INT8U WhichFRTCh)
typedef struct {
   INT32S X;
   INT32S Y;
   INT32S Z;
}_stXYZ;
typedef struct
{
   INT32S TU;
   INT32S TV;
   INT32S TW;
}_stOnTimingOfUVW;
```

Table 5

Item	Name	Description	Format
Inputs	X	X is conduction time	INT32S
	Y	Y is conduction time	INT32S
	Z	Z is conduction time	INT32S
	SectorNo	Sector no. of SVPWM voltage vector	INT8U
	WhichMFT	Which MFT, valid value is MFT0, MFT1	INT8U
	WhichFRTCh	Which FRT channel to configure	INT8U
Outputs	TU	Conduction time of A phase connecting to DC power supply	INT32S
	TV	Conduction time of B phase connecting to DC power supply	INT32S
	TW	Conduction time of C phase connecting to DC power supply	INT32S

The following code is example for this module.

```
void  example_ CalcTon ()
{
    pstXYZ .X= INa;
    pstXYZ .Y = INb;
    pstXYZ .Z=INc;
    SectorNo=1;
    WhichMFT=0;
```

```
    WhichFRTCh=0;
    CalcTon (SectorNo ,& pstXYZ,& pstOnTimingOfUVW, WhichMFT, WhichFRTCh);
    OUTa= pstOnTimingOfUVW ->TU;
    OUTb= pstOnTimingOfUVW ->TV;
    OUTc= pstOnTimingOfUVW ->TW;
}
```

2.2.3 Create SVPWM waveform

Function Application

Function: To determine To write OCCP register value to CH1,CH3,CH5 which used to create SVPWM waveform

Function Name: WriteCmpValToReg

C file name: SVPWM.C, SVPWM.H

```
void WriteCmpValToReg(INT8U WhichMFT, _stOnTimingOfUVW *pstOnTimingOfUVW)
typedef struct
{
   INT32S TU;
   INT32S TV;
   INT32S TW;
}_stOnTimingOfUVW;
```

Table 6

Item	Name	Description	Format
Inputs	TU	Conduction time of A, phase connecting to DC power supply	INT32S
	TV	Conduction time of B, phase connecting to DC power supply	INT32S
	TW	Conduction time of C phase connecting to DC power supply	INT32S
	WhichMFT	Which MFT, valid value is MFT0, MFT1	INT8U

The following code is example for this module.

```
void  example_ WriteCmpValToReg ()
{
   pstOnTimingOfUVW .TU=INa;
    pstOnTimingOfUVW .TV=INb;
    pstOnTimingOfUVW .TW=INc;
    WhichMFT=0;
    WriteCmpValToReg (WhichMFT,& pstOnTimingOfUVW);
```

3 Document History

Document Title: AN204347 - FM3 MB9B100A/300A/400A/500A Series Microcontroller Space Vector Pulse Width Modulation

Document Number: 002-04347

Revision	ECN	Orig. of Change	Submission Date	Description of Change
**	_	CBZH	07/04/2011	Initial Release
*A	5029359	CBZH	12/04/2015	Migrated Spansion Application Note AN706-00036-1v0-E to Cypress format

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