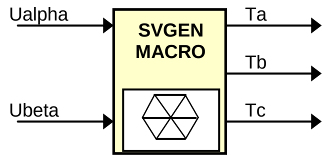
SVGEN_DQ	***Space Vector Generator With Quadrature Control***

Description This module calculates the appropriate duty ratios needed to generate a given stator reference voltage using space vector PWM technique. The stator reference voltage is described by it's (α,β) components, Ualpha and Ubeta.



Availability This IQ module is available in one interface format:

1) The C interface version

Module Properties **Type:** Target Independent, Application Independent

Target Devices: 28x Fixed Point or Piccolo

C Version File Names: svgen_dq.h

IQmath library files for C: IQmathLib.h, IQmath.lib

C Interface

Object Definition

The structure of SVGENDQ object is defined by following structure definition

```
typedef struct    { _iq  Ualpha;    // Input: reference alpha-axis phase voltage
                    _iq  Ubeta;     // Input: reference beta-axis phase voltage
                    _iq  Ta;        // Output: reference phase-a switching function
                    _iq  Tb;        // Output: reference phase-b switching function
                    _iq  Tc;        // Output: reference phase-c switching function
                  } SVGENDQ;

typedef SVGENDQ *SVGENDQ_handle;
```

Item	Name	Description	Format*	Range(Hex)
Inputs	Ualpha	Component of reference stator voltage vector on direct axis stationary reference frame.	GLOBAL_Q	80000000-7FFFFFFF
	Ubeta	Component of reference stator voltage vector on quadrature axis stationary reference frame.	GLOBAL_Q	80000000-7FFFFFFF
Outputs	Ta	Duty ratio of PWM1 (CMPR1 register value as a fraction of associated period register, TxPR, value).	GLOBAL_Q	80000000-7FFFFFFF
	Tb	Duty ratio of PWM3 (CMPR2 register value as a fraction of associated period register, TxPR, value).	GLOBAL_Q	80000000-7FFFFFFF
	Tc	Duty ratio of PWM5 (CMPR3 register value as a fraction of associated period register, TxPR, value).	GLOBAL_Q	80000000-7FFFFFFF

*GLOBAL_Q valued between 1 and 30 is defined in the IQmathLib.h header file.

Special Constants and Data types

SVGENDQ
The module definition is created as a data type. This makes it convenient to instance an interface to space vector generator. To create multiple instances of the module simply declare variables of type SVGENDQ.

SVGENDQ_handle
User defined Data type of pointer to SVGENDQ module

SVGENDQ_DEFAULTS
Structure symbolic constant to initialize SVGENDQ module. This provides the initial values to the terminal variables as well as method pointers.

Methods

SVGEN_MACRO (SVGENDQ_handle);

This definition implements one method viz., the space vector generator computation macro. The input argument to this macro is the module handle.

Module Usage

Instantiation
The following example instances two SVGENDQ objects
SVGENDQ svgen_dq1, svgen_dq2;

Initialization
To Instance pre-initialized objects
SVGENDQ svgen_dq1 = SVGENDQ_DEFAULTS;
SVGENDQ svgen_dq2 = SVGENDQ_DEFAULTS;

Invoking the computation macro
SVGEN_MACRO (svgen_dq1);
SVGEN_MACRO (svgen_dq2);

Example

The following pseudo code provides the information about the module usage.

```
main()
{

}

void interrupt periodic_interrupt_isr()
{
        svgen_dq1.Ualpha = Ualpha1;          // Pass inputs to svgen_dq1
        svgen_dq1.Ubeta = Ubeta1;            // Pass inputs to svgen_dq1

        svgen_dq2.Ualpha = Ualpha2;          // Pass inputs to svgen_dq2
        svgen_dq2.Ubeta = Ubeta2;            // Pass inputs to svgen_dq2

        SVGEN_MACRO (svgen_dq1);             // Call compute macro for svgen_dq1
        SVGEN_MACRO (svgen_dq2);             // Call compute macro for svgen_dq2

        Ta1 = svgen_dq1.Ta;                  // Access the outputs of svgen_dq1
        Tb1 = svgen_dq1.Tb;                  // Access the outputs of svgen_dq1
        Tc1 = svgen_dq1.Tc;                  // Access the outputs of svgen_dq1

        Ta2 = svgen_dq2.Ta;                  // Access the outputs of svgen_dq2
        Tb2 = svgen_dq2.Tb;                  // Access the outputs of svgen_dq2
        Tc2 = svgen_dq2.Tc;                  // Access the outputs of svgen_dq2
}
```

Technical Background

The Space Vector Pulse Width Modulation (SVPWM) refers to a special switching sequence of the upper three power devices of a three-phase voltage source inverters (VSI) used in application such as AC induction and permanent magnet synchronous motor drives. This special switching scheme for the power devices results in 3 pseudo-sinusoidal currents in the stator phases.

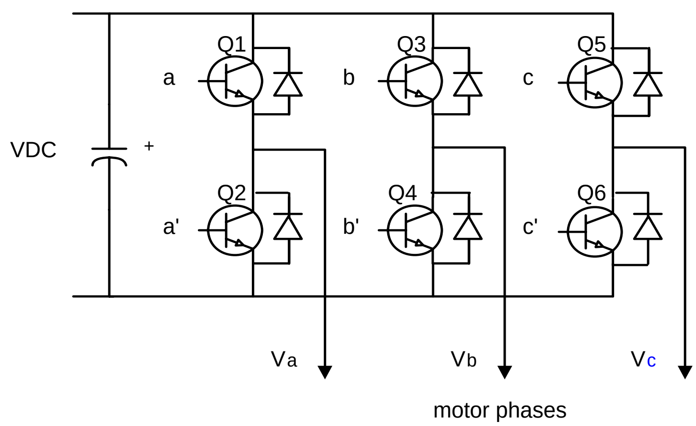


Figure 1 Power circuit topology for a three-phase VSI

It has been shown that SVPWM generates less harmonic distortion in the output voltages or currents in the windings of the motor load and provides more efficient use of DC supply voltage, in comparison to direct sinusoidal modulation technique.

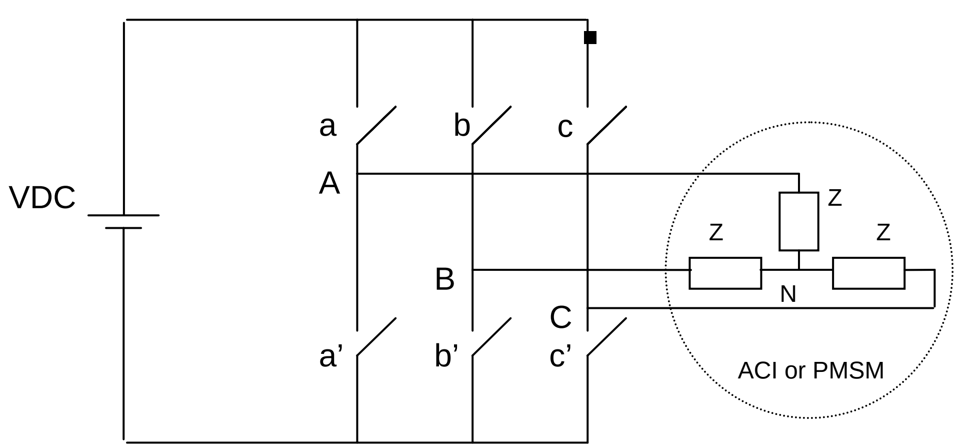


Figure 2: Power bridge for a three-phase VSI

For the three phase power inverter configurations shown in Figure 1 and Figure 2, there are eight possible combinations of on and off states of the upper power transistors. These combinations and the resulting instantaneous output line-to-line and phase voltages, for a dc bus voltage of $V_{DC,}$ are shown in Table 1.

c	b	a	V_{AN}	V_{BN}	V_{CN}	V_{AB}	V_{BC}	V_{CA}
0	0	0	0	0	0	0	0	0
0	0	1	$2V_{DC}/3$	$-V_{DC}/3$	$-V_{DC}/3$	V_{DC}	0	$-V_{DC}$
0	1	0	$-V_{DC}/3$	$2V_{DC}/3$	$-V_{DC}/3$	$-V_{DC}$	V_{DC}	0
0	1	1	$V_{DC}/3$	$V_{DC}/3$	$-2V_{DC}/3$	0	V_{DC}	$-V_{DC}$
1	0	0	$-V_{DC}/3$	$-V_{DC}/3$	$2V_{DC}/3$	0	$-V_{DC}$	V_{DC}
1	0	1	$V_{DC}/3$	$-2V_{DC}/3$	$V_{DC}/3$	V_{DC}	$-V_{DC}$	0
1	1	0	$-2V_{DC}/3$	$V_{DC}/3$	$V_{DC}/3$	$-V_{DC}$	0	V_{DC}
1	1	1	0	0	0	0	0	0

Table 1. Device on/off patterns and resulting instantaneous voltages of a 3-phase power inverter

The quadrature quantities (in the (α,β) frame) corresponding to these 3 phase voltages are given by the general Clarke transform equation:

$$V_{s\alpha} = V_{AN}$$

$$V_{s\beta} = \left(2V_{BN} + V_{AN}\right)/\sqrt{3}$$

In matrix from the above equation is also expressed as,

$$\begin{bmatrix} V_{s\alpha} \\ V_{s\beta} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{AN} \\ V_{BN} \\ V_{CN} \end{bmatrix}$$

Due to the fact that only 8 combinations are possible for the power switches, $V_{s\alpha}$ and $V_{s\beta}$ can also take only a finite number of values in the (α,β) frame according to the status of the transistor command signals (c,b,a). These values of $V_{s\alpha}$ and $V_{s\beta}$ for the corresponding instantaneous values of the phase voltages (V_{AN}, $V_{BN,}$ V_{CN}) are listed in Table 2.

c	b	a	$V_{s\alpha}$	$V_{s\beta}$	Vector
0	0	0	0	0	O_0
0	0	1	$\frac{2}{3}V_{DC}$	0	U_0
0	1	0	$-\frac{V_{DC}}{3}$	$\frac{V_{DC}}{\sqrt{3}}$	U_{120}
0	1	1	$\frac{V_{DC}}{3}$	$\frac{V_{DC}}{\sqrt{3}}$	U_{60}
1	0	0	$-\frac{V_{DC}}{3}$	$-\frac{V_{DC}}{\sqrt{3}}$	U_{240}
1	0	1	$\frac{V_{DC}}{3}$	$-\frac{V_{DC}}{\sqrt{3}}$	U_{300}
1	1	0	$-\frac{2}{3}V_{DC}$	0	U_{180}
1	1	1	0	0	O_{111}

Table 2: Switching patterns, corresponding space vectors and their (α,β) components

These values of $V_{s\alpha}$ and $V_{s\beta}$, listed in Table 2, are called the (α,β) components of the basic space vectors corresponding to the appropriate transistor command signal (c,b,a). The space vectors corresponding to the signal (c,b,a) are listed in the last column in Table 2. For example, (c,b,a)=001 indicates that the space vector is U_0.The eight basic space vectors defined by the combination of the switches are also shown in Figure 3.

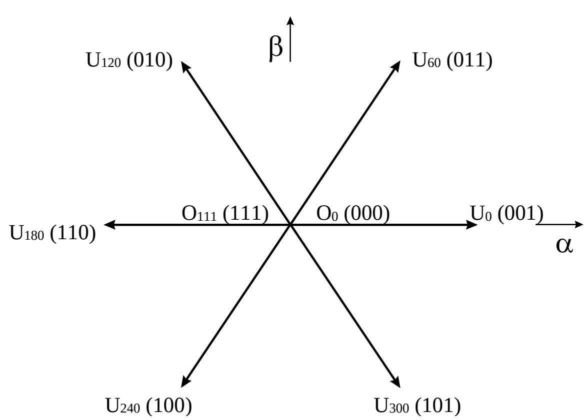


Figure 3: Basic space vectors

Projection of the stator reference voltage vector U_{out}

The objective of Space Vector PWM technique is to approximate a given stator reference voltage vector U_{out} by combination of the switching pattern corresponding to the basic space vectors. The reference vector U_{out} is represented by its (α,β) components, Ualpha and Ubeta. Figure 4 shows the reference voltage vector, it's (α,β) components and two of the basic space vectors, U_0 and U_{60}. The figure also indicates the resultant α and β components for the space vectors U_0 and U_{60}. $\Sigma V_{s\beta}$ represents the sum of the β components of U_0 and U_{60}, while $\Sigma V_{s\alpha}$ represents the sum of the α components of U_0 and U_{60}. Therefore,

$$\begin{cases} \sum V_{s\beta} = 0 + \dfrac{V_{DC}}{\sqrt{3}} = \dfrac{V_{DC}}{\sqrt{3}} \\ \sum V_{s\alpha} = \dfrac{2V_{DC}}{3} + \dfrac{V_{DC}}{3} = V_{DC} \end{cases}$$

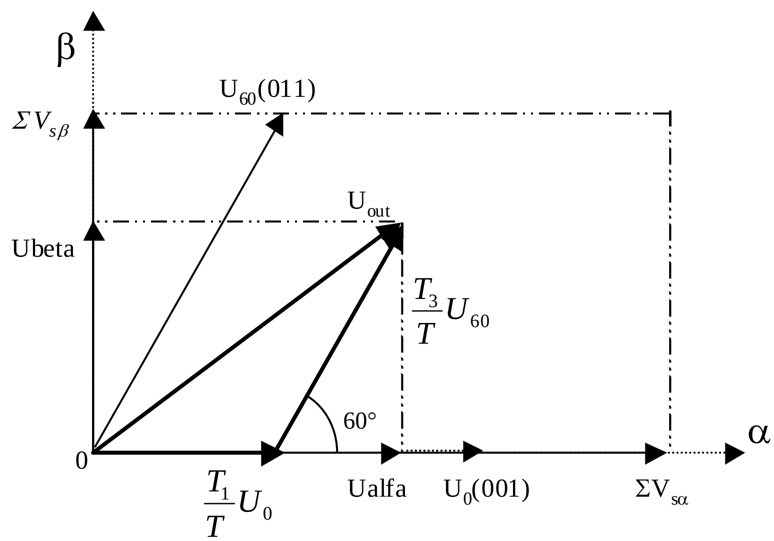


Figure 4: Projection of the reference voltage vector

For the case in Figure 4, the reference vector U_{out} is in the sector contained by U_0 and $U_{60.}$ Therefore U_{out} is represented by U_0 and U_{60}. So we can write,

$$\begin{cases} T = T_1 + T_3 + T_0 \\ U_{out} = \dfrac{T_1}{T}U_o + \dfrac{T_3}{T}U_{60} \end{cases}$$

where, T_1 and T_3 are the respective durations in time for which U_0 and U_{60} are applied within period T. T_0 is the time duration for which the null vector is applied. These time durations can be calculated as follows:

$$\begin{cases} U_{beta} = \dfrac{T_3}{T}\left|U_{60}\right|\sin(60°) \\ U_{alfa} = \dfrac{T_1}{T}\left|U_0\right| + \dfrac{T_3}{T}\left|U_{60}\right|\cos(60°) \end{cases}$$

From Table 2 and Figure 4 it is evident that the magnitude of all the space vectors is $2V_{DC}/3$. When this is normalized by the maximum phase voltage(line to neutral), $V_{DC}/\sqrt{3}$, the magnitude of the space vectors become $2/\sqrt{3}$ i.e., the normalized magnitudes are $|U_0| = |U_{60}| = 2/\sqrt{3}$. Therefore, from the last two equations the time durations are calculated as,

$$T_1 = \frac{T}{2}\left(\sqrt{3}U_{alfa} - U_{beta}\right)$$
$$T_3 = TU_{beta}$$

Where, Ualpha and Ubeta also represent the normalized (α,β) components of U_{out} with respect to the maximum phase voltage($V_{DC}/\sqrt{3}$). The rest of the period is spent in applying the null vector T_0. The time durations, as a fraction of the total T, are given by,

$$t1 = \frac{T_1}{T} = \frac{1}{2}\left(\sqrt{3}U_{alfa} - U_{beta}\right)$$
$$t2 = \frac{T_3}{T} = U_{beta}$$

In a similar manner, if U_{out} is in sector contained by U_{60} and U_{120}, then by knowing

$|U_{60}| = |U_{120}| = 2/\sqrt{3}$ (normalized with respect to $V_{DC}/\sqrt{3}$), the time durations can be derived as,

$$t1 = \frac{T_2}{T} = \frac{1}{2}\left(-\sqrt{3}U_{alfa} + U_{beta}\right)$$
$$t2 = \frac{T_3}{T} = \frac{1}{2}\left(\sqrt{3}U_{alfa} + U_{beta}\right)$$

where, T_2 is the duration in time for which U_{120} is applied within period T

Now, if we define 3 variables X, Y and Z according to the following equations,

$$X = U_{beta}$$
$$Y = \frac{1}{2}\left(\sqrt{3}U_{alfa} + U_{beta}\right)$$
$$Z = \frac{1}{2}\left(-\sqrt{3}U_{alfa} + U_{beta}\right)$$

Then for the first example, when U_{out} is in sector contained by U_0 and U_{60}, t1= -Z, t2=X.

For the second example, when U_{out} is in sector contained by U_{60} and U_{120}, t1=Z, t2=Y.

In a similar manner t1 and t2 can be calculated for the cases when U_{out} is in sectors contained by other space vectors. For different sectors the expressions for t1 and t2 in terms of X, Y and Z are listed in Table 3.

Sector	U_0, U_{60}	U_{60}, U_{120}	U_{120}, U_{180}	U_{180}, U_{240}	U_{240}, U_{300}	U_{300}, U_0
t1	-Z	Z	X	-X	-Y	Y
t2	X	Y	Y	Z	-Z	-X

Table 3: t1 and t2 definitions for different sectors in terms of X, Y and Z variables

In order to know which of the above variables apply, the knowledge of the sector containing the reference voltage vector is needed. This is achieved by first converting the (α,β) components of the reference vector U_{out} into a balanced three phase quantities. That is, Ualpha and Ubeta are converted to a balanced three phase quantities V_{ref1}, V_{ref1} and V_{ref1} according to the following inverse clarke transformation:

$$\begin{cases} V_{ref1} = U_{beta} \\ V_{ref2} = \dfrac{-U_{beta} + U_{alfa} \times \sqrt{3}}{2} \\ V_{ref3} = \dfrac{-U_{beta} - U_{alfa} \times \sqrt{3}}{2} \end{cases}$$

Note that, this transformation projects the quadrature or β component, Ubeta, into $V_{ref1.}$ This means that the voltages V_{ref1} V_{ref2} and V_{ref3} are all phase advanced by 90^{O} when compared to the corresponding voltages generated by the conventional inverse clarke transformation which projects the α component, Ualpha, into phase voltage V_{AN}. The following equations describe the (α,β) components and the reference voltages:

$$\begin{cases} U_{alfa} = \sin \omega t \\ U_{beta} = \cos \omega t \\ V_{ref1} = \cos \omega t \\ V_{ref2} = \cos(\omega t - 120°) \\ V_{ref3} = \cos(\omega t + 120°) \end{cases}$$

Note that, the above voltages are all normalized by the maximum phase voltage ($V_{DC}/\sqrt{3}$).

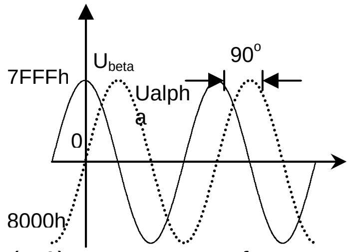


Figure 5: (α,β) components of stator reference voltage

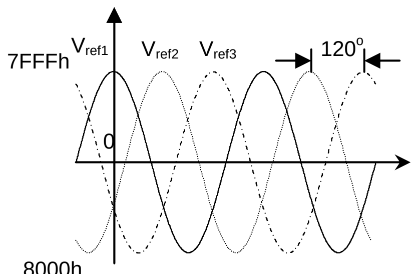


Figure 6: Voltages V_{ref1} V_{ref2} and V_{ref3}

From the last three equations the following decisions can be made on the sector information:

If $V_{ref1} > 0$ then a=1, else a=0

If $V_{ref2} > 0$ then b=1, else b=0

If $V_{ref3} > 0$ then c=1, else c=0

The variable *sector* in the code is defined as, sector = 4∗c+2∗b+a

For example, in Figure 3 a=1 for the vectors U_{300}, U_0 and U_{60}. For these vectors the phase of V_{ref1} are $\omega t=300°$, $\omega t=0$ and $\omega t=60°$ respectively. Therefore, $V_{ref1} > 0$ when a=1.

The (α,β) components, Ualpha and Ubeta, defined above represent the output phase voltages V_{AN}, V_{BN} and V_{CN}. The following equations describe these phase voltages:

$$\begin{cases} V_{AN} = \sin \omega t \\ V_{BN} = \sin(\omega t + 120°) \\ V_{CN} = \sin(\omega t - 120°) \end{cases}$$

The Space Vector PWM module is divided in several parts:

- Determination of the sector
- Calculation of *X, Y* and *Z*
- Calculation of t_1 and t_2
- Determination of the duty cycle *taon*, *tbon* and *tcon*
- Assignment of the duty cycles to *Ta*, *Tb* and *Tc*

The variables t_{aon}, t_{bon} and t_{con} are calculated using the following equations:

$$\begin{cases} t_{aon} = \dfrac{PWMPRD - t_1 - t_2}{2} \\ t_{bon} = t_{aon} + t_1 \\ t_{con} = t_{bon} + t_2 \end{cases}$$

Then the right duty cycle (txon) is assigned to the right motor phase (in other words, to Ta, Tb and Tc) according to the sector. Table 4 depicts this determination.

sectors	U_0, U_{60}	U_{60}, U_{120}	U_{120}, U_{180}	U_{180}, U_{240}	U_{240}, U_{300}	U_{300}, U_0
Ta	taon	tbon	tcon	tcon	tbon	taon
Tb	tbon	taon	taon	tbon	tcon	tcon
Tc	tcon	tcon	tbon	taon	taon	tbon

Table 4: Table Assigning the Right Duty Cycle to the Right Motor Phase

Example: Sector contained by U_0 and U_{60}.

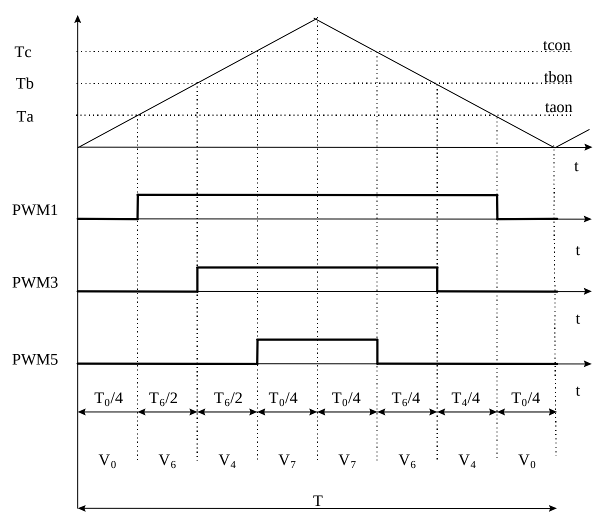


Figure 7: PWM Patterns and Duty Cycles for sector contained by U_0 and U_{60}

Next, Table 5 shows the correspondence of notations between variables used here and variables used in the program (i.e., svgen_dq.c, svgen_dq.h). The software module requires that both input and output variables are in per unit values.

	Equation Variables	Program Variables
Inputs	Ualpha	Ualpha
	Ubeta	Ubeta
Outputs	Ta	Ta
	Tb	Tb
	Tc	Tc
Others	V_{ref1}	Va
	V_{ref2}	Vb
	V_{ref3}	Vc

Table 5: Correspondence of notations