# The 3_Phase PWM Voltage Source Reversible Rectifier Based on a Novel Space Vector Control Method

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**Abstract:** In this paper, a novel voltage space vector (NVSV) method used for 3-phase pulse width modulation voltage source reversible rectifier (PWM VSR) is described in detail. Based on the conventional voltage space vector(CVSV) method and its geometry topology, the actual switching time has a very simple form. With the $\alpha\beta$-coordinate transformation, the NVSV can be easily realized. Its effect is exactly the same as the CVSV method. Thus, the NVSV method can be simply implemented by using a common microprocessor. It has the attractive features such as short execution time and little memory size compared with the method. Furthermore, every phase of the converter can have its switching stopped for 120° in one period, so the switching loss of power device can be minimized about 33%. The proposed method is implemented by 80c196KC and its performance has been proved by a 15kW IGBT laboratory prototype.

**keywords:** Power System Pulse Width Modulation(PWM) Voltage Source Reversible Rectifier (VSR) Voltage Space Vector

## I. INTRODUTION

Recently, by the concern of the growing harmonic pollution within the power system, many public works have described pulse width modulation voltage source reversible rectifier (PWM VSR) that features such as constant DC voltage bus control, low harmonic distortion of the utility currents, bi-directional power flow and controllable power factor[1-3]. Based on the voltage space vector (VSR) PWM control method, the voltage source reversible rectifier which has been applied for power system or high power high performance motor drive application, results in the excellent DC bus voltage utilization, and simplifies the filter design of AC bus, as compared with the hysteresis current control and the sine-triangle control. Especially when VSR operates over a wide range of utility voltage without current distortion, the CVSV PWM method is becoming increasingly attractive[4].

However, there is also one disadvantage in the conventional voltage space vector (CVSV) control method, which limits the digital realization of this technique. In the CVSV control method, the actual switching time of six power switch devices is determined by the eight voltage vectors of the PWM VSR. Thus, two nearest active voltage vectors and two zero voltage vectors should be predetermined according to the reference voltage space vector. Then, the actual switching time is produced by the recombination of these voltage vectors. So the CVSV modulation method comes to be very complex and needs longer calculation time or more memory size for lookup table.

In this paper, a novel voltage space vector (NVSV) method is described . Based on the CVSV method and its geometry topology, the actual switching time has a very simple form. With the $\alpha\beta$-coordinate transformation, the NVSV can be easily realized. Its effect is exactly the same as the CVSV method . Thus, the NVSV method can be simply implemented by using a common microprocessor. It has the attractive features such as short execution time and little memory size compared with the method. Furthermore, every phase of the converter can have its switching stopped for 120° in one period, so the switching loss of power device can be minimized about 33%. The proposed method is implemented by 80c196KC and its performance has been proved by a 15kW IGBT laboratory prototype.

## II. PRINCIPLE OF CVSV PWM METHOD

As shown in Fig. 1, the main circuit of 3-phase PWM VSR is described. Form the average voltage concept, in the CVSV modulation method, the reference vector can be generated using two nearest active vector $\vec{V}(k)$ and $\vec{V}(k+1)$ with zero vector $\vec{V}(0)$ and $\vec{V}(7)$. That is: if the terminal fundamental voltage space vector $\vec{V}_R$ is located in the sector-k(k=1~6), the active voltage vector $\vec{V}(k)$ $\vec{V}(k+1)$ is selected. In this case, $\vec{V}(k)$ is applied to the PWM VSR during $T_1$ interval, and consequently $\vec{V}(k+1)$ is applied during $T_2$ interval. In the 3-phase symmetrically modulation method, $\vec{V}(0)$ and $\vec{V}(7)$ is distributed symmetrically in one sampling period $T_S$ (Fig.2). Thus, the switching sequence is given by 0-1-2-7-7-2-1-0(sector-k=1,3,5)or 0-2-1-7-7-1-2-0(sector-k=2,4,6) with two sampling periods.

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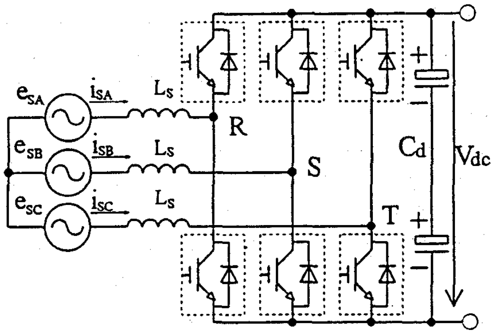

Fig.1 The main circuit of the 3-phase PWM VSR

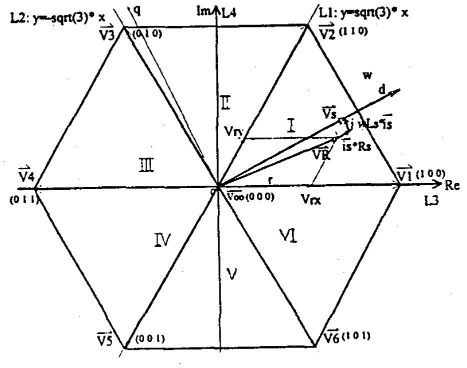

Fig.2 The relationship of the $\vec{e}_S, \vec{I}_S$ and $\vec{V}_R$

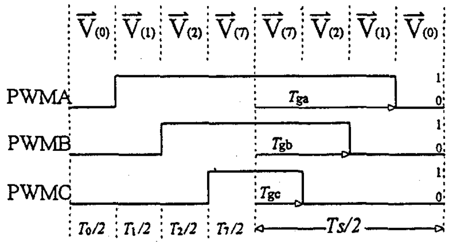

Fig.3 The geometry topology of switching pulses

$$\begin{cases} T_1 = \dfrac{\sqrt{3}}{V_{DC}} \cdot T_S \cdot \left|V_R\right| \cdot \sin\left(\dfrac{\pi}{3} \cdot k - \gamma\right) \\ T_1 = \dfrac{\sqrt{3}}{V_{DC}} \cdot T_S \cdot \left|V_R\right| \cdot \sin\left(\gamma - (k-1) \cdot \dfrac{\pi}{3}\right) \\ T_0 = \left[T_S - \left(T_1 + T_2\right)\right] / 2 \end{cases} \quad (1)$$

In order to calculate the actual switching time of each leg, the first step is to calculate $\left|V_R\right|$ and $\gamma$ of the terminal fundamental voltage space vector $\vec{V}_R$, then identify the two nearest active voltage vectors where is $\vec{V}_R$ located. $\vec{V}_R$ is partitioned to two active voltage vectors and zero voltage vector. Using the $dq$ components of reference vector with a sine lookup table, the effective times $T_1$、$T_2$ are calculated, and the actual switching time( $T_0$、$T_1$、$T_2$、$T_7$ ) is recombined (in Fig.3). Therefore, the overall process of this method is so complex that the real digital implementation is formidable.

## III. NOVEL VOLTAGE SPACE VECTOR METHOD

In the steady operation state of three phase PWM VSR, if the switching frequency $f_s$ is enough high, so high order harmonics of switching function can be ignored. Therefore, when the power factor is unity, the AC fundamental space vector $\vec{I}_S$ and the terminal fundamental voltage space vector $\vec{V}_R$ rotate at the angular speed ω($\theta$=ωt) on the plane, synchronizing with the power supply voltage vector $\vec{e}_S$ as shown in Fig.2. The switching voltage space vector is defined as follows:

$$\vec{V}(k) = \begin{cases} \dfrac{2}{3} \cdot V_{dc} \cdot e^{j(k-1)\cdot\frac{\pi}{3}}, k = 1 \sim 6 \\ 0, k = 0,7 \end{cases} \quad (2)$$

In the rotating $dq$ frame:

$$\begin{cases} V_{Rd} = V_{SM} - I_{SM} \cdot R_S \\ V_{Rq} = -w \cdot L_S \cdot I_{SM} \end{cases} \quad (3)$$

Because the voltage space vector method is established on the steady state and the instantaneous AC currents are not monitored, the system is somewhat less stable. In order to improve the robustness of the control system , it should take account of the rate of AC current transient variation.

$$\begin{cases} V_{Rd} = V_{SM} - I_{SM} \cdot R_S - L_S * dI_{SM}/dt \\ V_{Rq} = -w \cdot L_S \cdot I_{SM} \end{cases} \quad (4)$$

In the stationary $\alpha\beta$ frame:

$$\begin{cases} V_{R\alpha} = V_{Rd} \cdot \cos\theta - V_{Rq} \cdot \sin\theta \\ V_{R\beta} = V_{Rd} \cdot \sin\theta + V_{Rq} \cdot \cos\theta \end{cases} \quad (5)$$

In the Fig.2, the equation of the switching line L1 is :

$$y - \sqrt{3} \cdot x = 0; \quad (6)$$

and the equation of the switching line L2 is :

$$y + \sqrt{3} \cdot x = 0; \quad (7)$$

By comparing the stationary $\alpha\beta$ frame components of the reference voltage vector with line L1 and line L2, the sector where the reference voltage vector $\vec{V}_R$ is located is identified. Then the switching time of each leg can be calculated simply.

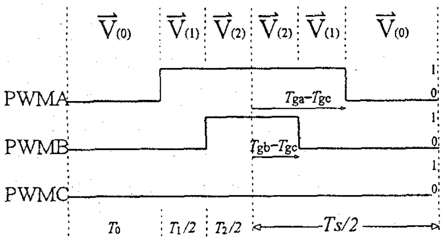

Fig.4 Equivalent PWM switching pattern

(a).If $\vec{V}_R$ is located in the sector_1or4,then:

$$\begin{cases} T_{ga}=\dfrac{T_S}{2}-\dfrac{\sqrt{3}}{4\cdot V_{DC}}\cdot T_S\cdot\left(\sqrt{3}\cdot V_{R\alpha}+V_{R\beta}\right) \\ T_{gb}=\dfrac{T_S}{2}+\dfrac{\sqrt{3}}{4\cdot V_{DC}}\cdot T_S\cdot\left(\sqrt{3}\cdot V_{R\alpha}-3V_{R\beta}\right) \\ T_{gc}=\dfrac{T_S}{2}+\dfrac{\sqrt{3}}{4\cdot V_{DC}}\cdot T_S\cdot\left(\sqrt{3}\cdot V_{R\alpha}+V_{R\beta}\right) \end{cases} \tag{8}$$

(b).If $\vec{V}_R$ is located in the sector_2or5,then:

$$\begin{cases} T_{ga}=\dfrac{T_S}{2}-\dfrac{\sqrt{3}}{2\cdot V_{DC}}\cdot T_S\cdot\left(\sqrt{3}\cdot V_{R\alpha}\right) \\ T_{gb}=\dfrac{T_S}{2}-\dfrac{\sqrt{3}}{2\cdot V_{DC}}\cdot T_S\cdot\left(V_{R\beta}\right) \\ T_{gc}=\dfrac{T_S}{2}+\dfrac{\sqrt{3}}{2\cdot V_{DC}}\cdot T_S\cdot\left(V_{R\beta}\right) \end{cases} \tag{9}$$

(c).If $\vec{V}_R$ is located in the sector_3or6,then:

$$\begin{cases} T_{ga}=\dfrac{T_S}{2}+\dfrac{\sqrt{3}}{4\cdot V_{DC}}\cdot T_S\cdot\left(-\sqrt{3}\cdot V_{R\alpha}+V_{R\beta}\right) \\ T_{gb}=\dfrac{T_S}{2}-\dfrac{\sqrt{3}}{4\cdot V_{DC}}\cdot T_S\cdot\left(-\sqrt{3}\cdot V_{R\alpha}+V_{R\beta}\right) \\ T_{gc}=\dfrac{T_S}{2}+\dfrac{\sqrt{3}}{4\cdot V_{DC}}\cdot T_S\cdot\left(\sqrt{3}\cdot V_{R\alpha}+3V_{R\beta}\right) \end{cases} \tag{10}$$

Thus, in order to calculate the actual switching time of each leg of VSR, using the signal of $V_{R\alpha}$ and $V_{R\beta}$, with the switching line of L1 and L2, it can be easily identify the sector where is located without calculating $|V_R|$ and $\gamma$. Thus the switching start point time( $T_{ga}$、$T_{gb}$、$T_{gc}$ ) is produced by (8)or(9)or(10). Therefore, the overall process of this method is so simple that the real digital execution time can be reduced and memory size will be minimized as compared with the CVSV method.

Unfortunately, the problem of power loss, especially such as the switching loss, becomes more serious as the switching frequency is increased. To solve this problem, a equivalent PWM switching pattern is proposed as shown in Fig.4 . That is : every phase of the converter can have its switching stopped for 120° in one period, so the switching loss of power device can be minimized about 33%. Its very simple for microprocessor to realize this new PWM switching pattern.

If the reference vector $\vec{V}_R$ is located in sector 1, then it is composed of voltage vector $V(1)$ and $V(2)$ with zero vector $\vec{V}(0)$ and $\vec{V}(7)$ as shown in Fig.3. Due to minimum number of switch state and equivalent reference voltage, the $\vec{V}_R$ is located in sector 1, then it is composed of voltage vector $V(1)$ and $V(2)$ with zero vector $\vec{V}(0)$ as shown in Fig.4. Thus, if $\vec{V}_R$ is located in sector 1 and 2, phase C can have its stopped for 120°, and so on.

## IV. COMPUTER SIMULATION RESULTS

The computer simulation conditions are identical to the experimental system. Some main results of simulation are shown in Fig.5, Fig.6 and Fig.7. The simulation parameters were $V_s$=380V(RMS), $C_d$=2200μF, $L_s$=7mH, $V_{dc}$=600V. The dead-time is set to 3μS and the switching frequency is 2.4kHz. Fig.5(a).(b) show the waveform of the AC current and its spectral. Fig.6(a).(b) show the waveform of the DC voltage and its spectral. Fig.7(a).(b) show the waveform of the DC link current and its spectral.

## V. HARDWARE REALZATION AND EXPERIMENTAL RESULTS

In order to verify the feasibility of the proposed method, the experiment of a 15kW 3-phase PWM VSR laboratory prototype was built. The basic configuration of the experimental system is shown in Fig.8. The power stage is composed of intelligent power modules(IPM) IGBT whose voltage rating is 1200V and current rating is 75A. The control stage is composed of two 80c196KC microprocessor chips. The proposed NVSV method is implemented by a 80c196KC chip which operates at 16MHz clock. The other 80c196KC chip is used to achieve the A/D sample and communicate with PC computer. Two chip communicate with dual port RAM for exchanging the information.

Experiments were carried out at the sampling frequency of 2.4kHz. The system parameters were $V_s$=380V(RMS), $C_d$=2200μF, $L_s$=7mH, $V_{dc}$=600V. The dead-time is set to 3μS or so. The experimental results are shown in Fig.9 and Fig.10.

Fig.9 shows the waveform of the AC current. As it's expected to be , the AC current is nearly sinusoidal in nature with a little high order harmonic. The power factor is observed to be unity, as desired, with the current being exactly with the voltage. Fig.10 shows the waveform of the DC link current. The experimental results seem to agree fairly well with the simulation results.

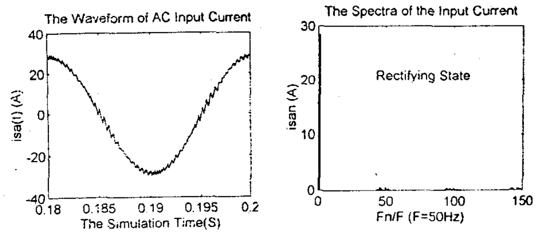

Fig.5 (a) The waveform of the AC current (b) Its spectral

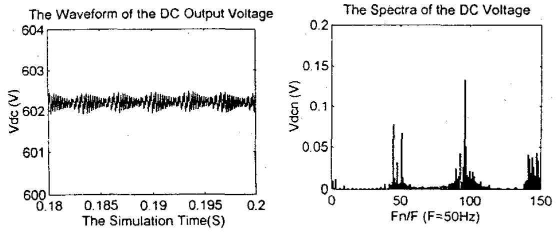

Fig.6 (a) The waveform of the DC voltage (b) Its spectral

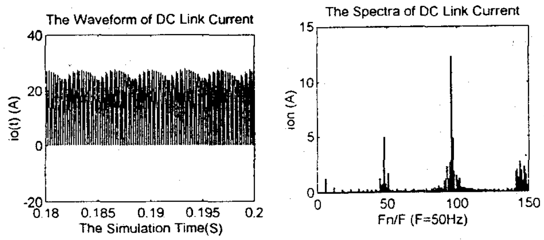

Fig.7 (a) The waveform of the DC Link current (b) Its spectral

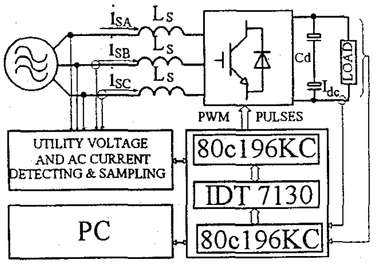

Fig.8. The basic configuration of the experimental system

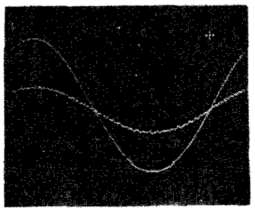

Fig.9. The waveform of the AC current

Fig.10. The waveform of the DC link current

## VI. CONCLUSION

It is shown that the NVSV method has the attractive features such as short execution time and little memory size compared with the CVSV method. Furthermore, every phase of the converter can have its switching stopped for 120° in one period, so the switching loss of power device can be minimized about 33%.

The proposed NVSV method is implemented by a 80c196KC chip and its performance has been proved by a 15kW 3-phase PWM VSR laboratory prototype. It can be seen that the experimental results are nearly coincident with the computer simulation results, thus the correctness of the proposed method is confirmed.

## VII. REFERENCES

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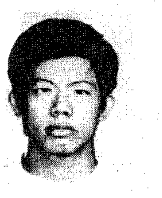
## VIII. BIOGRAPHIES



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