Modeling a Pluse-Width Modulation(PWM) Rectifier in 3D Space

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Abstract:- Power electronics pertains to a category of devices that convert electrical power from one form to another. Semiconductor devices act as switches in power electronics circuits, serving as the central components responsible for voltage regulation. Power electronics circuits strive to convert electrical energy from one form to another, from source to load, while minimizing cost, size, and weight as much as possible. The term "rectification" refers to the power circuit which alters the ac characteristic of the line electric power in order to supply "rectified" ac power with a dc value at the load side. The rectifier is utilized to convert alternating current (AC) voltage into direct current (DC) or low-frequency AC in order to power different load configurations. The AC mains are subjected to the injection of low order current harmonics by the Conventional Phase Controlled Rectifier. These harmonics necessitate the use of filtering components of considerable size for effective attenuation. The paper explores the simulation of the Converter through various PWM techniques, including space vector pulse width modulation and sinusoidal pulse width modulation.

Key Words: SPWM, PWM Rectifiers, SVPWM.

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1. INTRDUCTION

Power electronics entered the modern era in 1958, when General Electric Company released a commercial thyristor, two years after Bell Telephone Laboratory developed the technology. The utilization of mercury-arc rectifiers and power magnetic amplifiers in the industrial sector was rapidly replaced as silicon-controlled rectifiers emerged as the prevailing standard. In under two decades since the commercialization of SCRs, significant progress in semiconductor manufacturing techniques and operational capabilities resulted in the creation of a wide range of power semiconductor devices. Power electronics circuits, which utilise semiconductor devices as switches, serve to alter or regulate an electrical current or voltage [1] [2].

Numerous control methods have been incorporated into rectifier devices in order to improve input power factor and convert input current into a sinusoidal waveform. Although the phase and amplitude control may seem like the most straightforward structure and offer an adequate switching pattern, the stability of the control system is compromised by a dc offset on the rectifier's input current during the transient stage. The synchronous frame current regulating style offers benefits such as rapid dynamic response, high precision, consistent switching frequency, and reduced sensitivity to parameter variations.

Controlling the width of the switching pulse alters the output voltage. Conventional pulse width control, Sinusoidal pulse width modulation, Multiple pulse width modulation, and space vector pulse width modulation are discussed in this work. The SVPWM modulation method is one of, if not the best, existing alternatives.

The most effective method of reducing harmonics and controlling motor speed is by means of SVPWM. In particular, it operates with minimally suppressed harmonics, even at low frequencies. Also, using SVPWM in a PWM inverter allows for a 15% increase in the output voltage's basic component. DSP advancements have made it simple to apply SVPWM.

2. CATALOGUE OF THE SYSTEM

The schematic for the three-phase voltage source rectifier is illustrated in Figure 1. The mathematical model assumes that the AC voltage is a balanced three-phase supply, and that the filter reactor, IGBT, and lossless ideal switch are linear. In the context provided, a, b, and c represent the phase voltages and currents of a three-phase balanced voltage source, while vdc denotes the DC output voltage. R1 and L stand for the mean resistance and inductance of the filter reactor, respectively. C represents the smoothing capacitor connected across the DC bus, and RL signifies the load on the DC side. Additionally, ra, rb, and rc are the input voltages of the rectifier, and iL represents the load current.

The dynamic behavior of a boost type rectifier can be described by the following equations, which can be written in Park coordinates or in d-q notation:

$$\begin{cases} L\dfrac{di_d}{dt} = u_d - i_d R_1 + \omega L i_q - u_{rd} \\ L\dfrac{di_q}{dt} = u_q - i_q R_1 - \omega L i_d - u_{rq} \\ C\dfrac{dV_{dc}}{dt} = -\dfrac{V_{dc}}{R_L} + \dfrac{3}{2}(S_d i_d + S_q i_q) \end{cases} \quad (1)$$

If we define the input voltage of the rectifier as $S_d\ V_{dc}$ and the output voltage of the switch as Sq Vdc, then $u_{rd} = S_d\ V_{dc}$ and $\mu_{rq}=S_q\ V_{dc}$. Voltage and current sources in synchronous rotation along the d-q axis are denoted by μd and μq, respectively. Where ω is the angular frequency.

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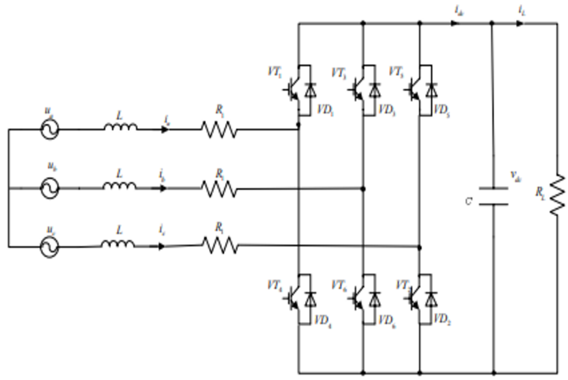


Fig.1: The diagram shows a boost-type rectifier circuit with three phases and two voltage levels.

Multiplying the main voltages (d and q) by the coupling voltages (ωL_{iq} and ωL_{id}) yields the d-q current. Eq(1) demonstrates this relationship. Eq(1) μ_{rd} and μ_{rq} can be controlled to guarantee mathematical Eq(2).

$$\begin{cases} u_{rd} = -u'_{rd} + \omega L i_q + u_d \\ u_{rq} = -u'_{rq} + \omega L i_d + u_q \end{cases} \quad (2)$$

Equation (1) is Equation (2) substituted (3).

$$\begin{cases} L\dfrac{di_d}{dt} = -i_d R_1 + u'_{rd} \\ L\dfrac{di_q}{dt} = -i_q R_1 + u'_{rq} \end{cases} \quad (3)$$

It is abundantly evident, on the basis of the equation, that the currents that run along the two axes are totally independent of one another. It is correct to say that the only link that µ'rd and µ'rq have is to id and iq. Both voltage and current can be regulated with the assistance of standard PI controllers. In Figure 2, we see the double closed-loop control technique that makes it possible to decouple the current flowing through the PWM rectifier.

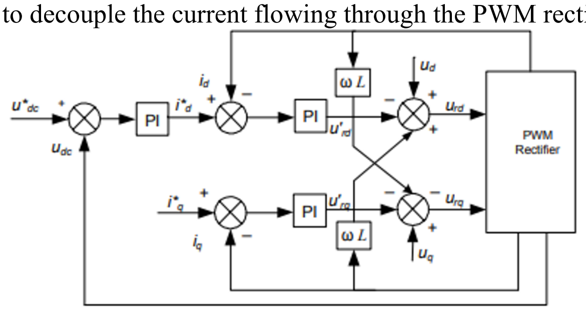


Fig.2: The rectifier's d-q dual-close-loop controller

Control block diagram

As illustrated in Fig. 2, decoupling occurs when axis current components are injected with PI regulation results. SVPWM is implemented via d-q to a-ß transformation after acquiring the µrd and µrq to precisely trace the AC current command and regulate the DC bus voltage..

3. SPACE VECTOR PLUSE WIDTH MODULATION

Space vectors are a product of mechanically rotating MMF. After applying this to a three-phase system, a revolving MMF with constant magnitude and direction is produced. The mathematical idea of a space vector can be used to examine the spatial impact of three-phase variables. There are eight possible values for the voltage at each leg of the bridge rectifier, denoted by the co-ordinate voltage vectors (V_0–V_7), depending on the state of the switching device depicted in the circuit diagram. In the fig. 3, we can see all the vectors: There are seven 0_s (V_0 and V_7) and six non-zeroes (V_1 through V_6) in the vector space. All non-zero vectors possess an equal magnitude to that of the dc bus voltage Vdc. The three-phase circuit's voltage can be symbolized by a voltage vector denoted as Vs. With the wide variety of permutations possible with the eight vectors, Vs can be synthesised using a wide variety of modulation techniques.

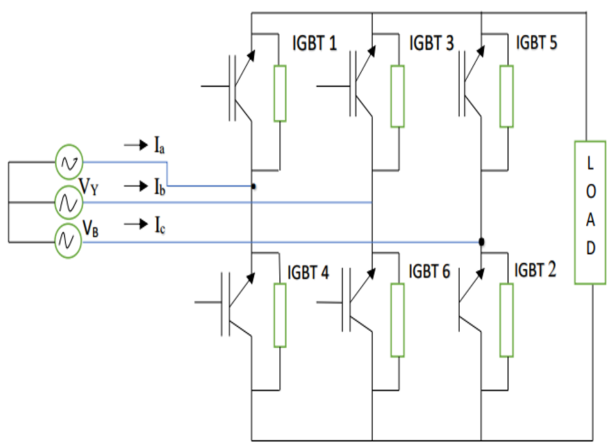
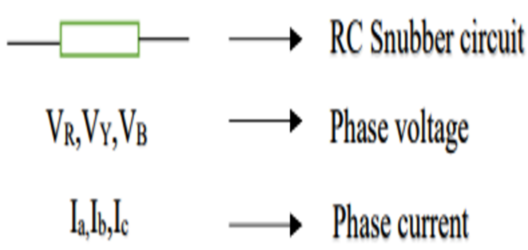


Fig.3: Circuit diagram of PWM rectifier



By keeping only one switch in its ON or OFF state during a given work cycle, switching losses can be minimised with the use of two-phase modulation. At each sub-cycle T_s, the desired reference vector can be realised by taking an average across the three nearest space vectors in the space vector plane.
The PWM algorithm is more difficult to implement because the traditional space vector approach necessitates knowledge of the angle and the sector. That's why the suggested GPWM method makes use of the notation of imaginary switching times; this simplifies the otherwise complex standard space vector approach. The voltage of the reference phase in a three-phase system is assumed to be as shown in equations (4) and (5).

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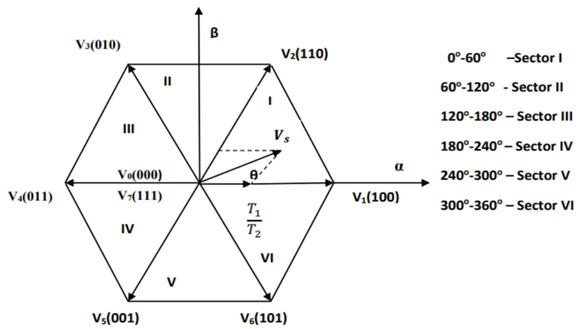

Fig.4: PWM bridge rectifier leg voltage expressed as a space-vector

$$V_{in}= V_{ref}\cos(\theta - 2(r - 1)\,\pi/3) \quad (4)$$

$$V_{ix}= V_{ref}\cos(\theta - 2(r - 1)\,\pi/6) \quad (5)$$

Assuming r=1, 2, 3, and i=a, b, and c. The instantaneous phase voltages can be used to define the values of imaginary switching times as in equations 6 and 7.

$$T_{in} = V_{in}/\, V_{dc} * T_s \;; \quad i=a,b,c \quad (6)$$

$$T_{ix}=V_{ix}\, /V_{dc} *T_s \;; \quad i=a,b,c \quad (7)$$

If the phase voltage is also negative, the accompanying switching time is considered imaginary. Each sampling interval allows for the determination of the maximum, median, and minimum imaginary switching times from

$$T_{max}= {}_{max}\,(T_{in});\ T_{min} = {}_{min}(T_{min});\ T_{mid}={}_{mid}\,(T_{in}); \quad (8)$$

$$T_{mid,x}={}_{mid}(T_{in});\ T_{max,x}={}_{max}(T_{ix});\ T_{min,x}={}_{min}(T_{min}) \quad (9)$$

If equation 10 is used, the timeframes required to transition between the active states can be determined.

$$T_k=T_{max} - T_{mid}\ ;\ T_{k+1}= T_{mid} - T_{min} \quad (10)$$

The calculation for the time of the zero voltage vector can be determined using equation 11.

$$T_z = T_s - T_k - T_{k+1} = T_s - T_{max}+T_{mid} \quad (11)$$

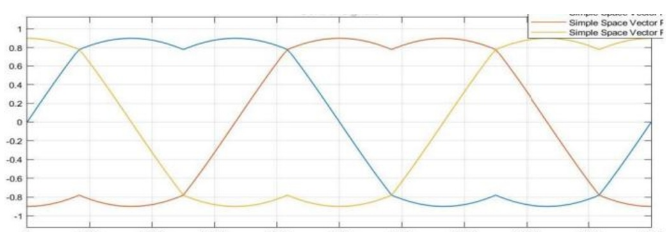

Fig.5: Modulating Waveform for SVPWM

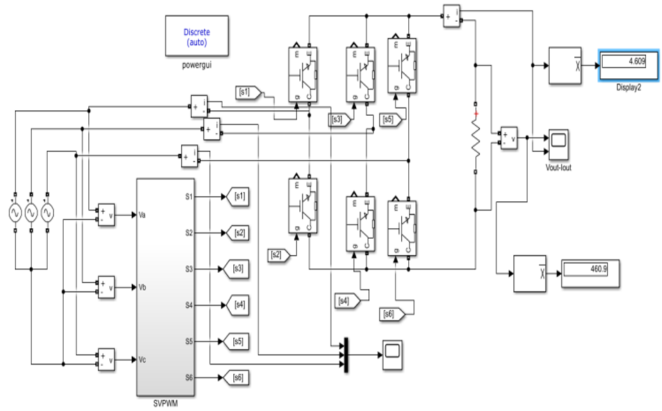

Fig.6: Power Circuit for SVPWM Rectifier

Specifically, the SVPWM method makes use of the asymmetry present in the zero-state-time distribution. Based on equation, the GPWM algorithm splits the zero-voltage state between the two possible vectors.

$$T_0 = k_o T_z \; ; \; T_7 = (1-k_o)T_z \qquad \text{where } k_o=0.5 \text{ for SVPWM}$$

The modulation index (Mi) is determined by dividing the required peak fundamental magnitude by the maximum fundamental output in six-step mode.

$$M_i = \frac{|V_{ref}|}{V_{max,sixstep}} = \frac{\pi V_{ref}}{2V_{dc}}$$

As may be seen in fig.5, the modulation waveform of SVPWM algorithms is exhibited at a modulation index of 0.9. The MATLAB Simulink power circuit for the SVPWM pulse control Rectifier is depicted in fig. 6. It is depicted in Fig. 7 how the SVPWM Pulse generator is set up; The pulses are created whenever the reference signal is stronger than the carrier signal.

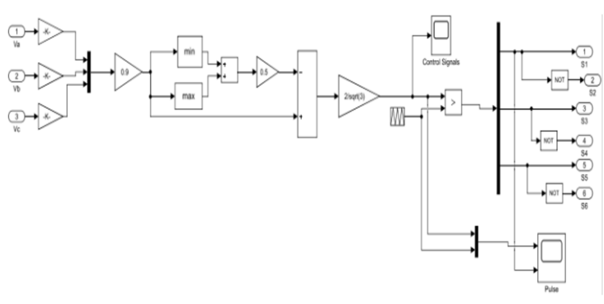

Fig.7: SVPWM pulse generator

We possess a base frequency of 50 Hz and a conversion frequency of 1 kHz. It's a double-sided triangle wave 1 in magnitude that acts as the carrier signal. There is an equation that may be used to calculate the output voltage from the circuit in Fig.3 given the input voltage.

$$V_{Rn} = 325.22\sin 314t \qquad \text{volts}$$

$$V_{Yn} = 325.22\sin\left(314t-\frac{2\pi}{3}\right) \qquad \text{volts}$$

$$V_{Bn} = 325.22\sin\left(314t-\frac{4\pi}{3}\right) \qquad \text{volts}$$

The input current depend upon the Load. As seen in Figures 9 and 10, the input current waveforms for R-Load and RL-Load under SVPWM Pulse control, respectively. Figures 11 and 12 depict the voltage and current waveforms at the output under SVPWM Pulse control with a load resistance of 100 ohms, while Figures 13 and 14 do the same for a load resistance of 350 ohms and a load inductance of 0.1 mH. Figs.15 and 16 display the FFT analysis of the R-load and RL-load, respectively. Figures 16 and 17 depict the power output waveform under R and RL loads, respectively.

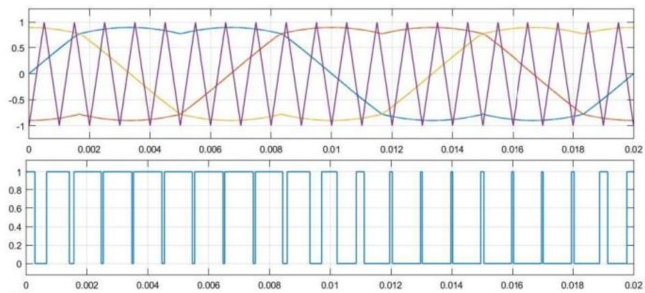

Fig.8: IGBT-1 Pulse generation of SVPWM Control Technique

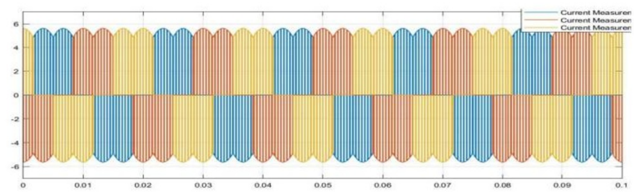

Fig.9: Input Current Waveform for R-Load with SVPWM Pulse control

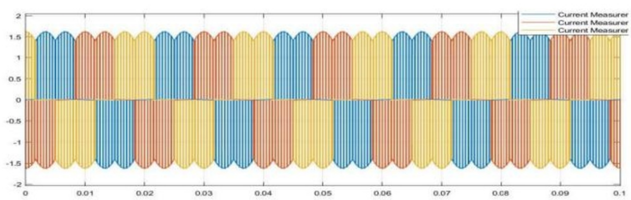

Fig.10: Input current waveform for RL-Load with SVPWM Pulse control

4. SIMULATION RESULTS

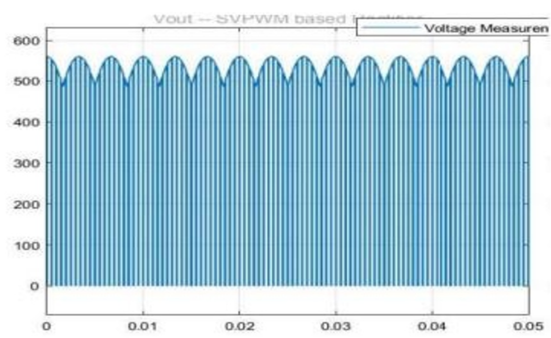

Fig.11: R-load SVPWM output voltage waveform

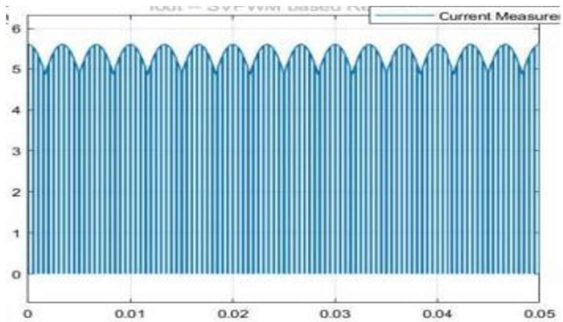

Fig.12: R-load SVPWM output voltage waveform

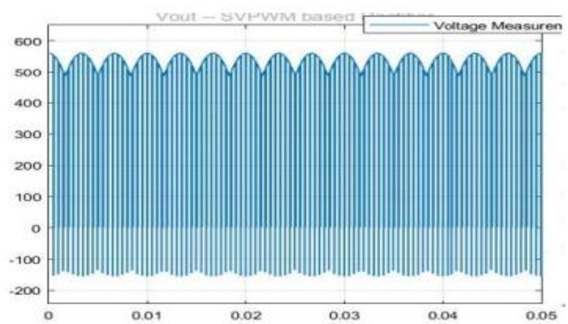

Fig.13: RL-load SVPWM output voltage waveform

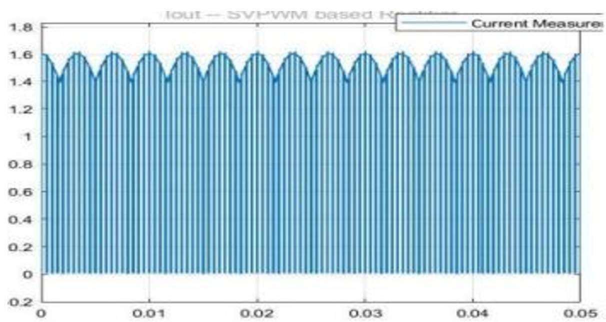

Fig.14: RL-load SVPWM output voltage waveform

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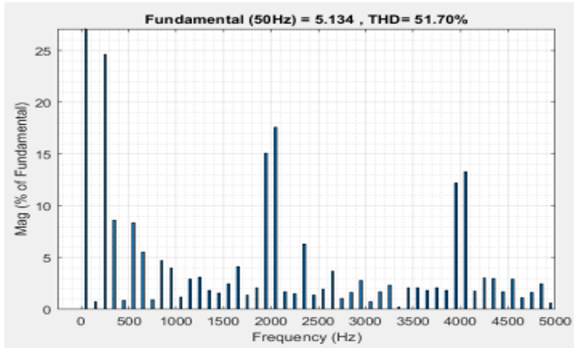

Fig.15: FFT analysis for R-Load with SVPWM Pulse control

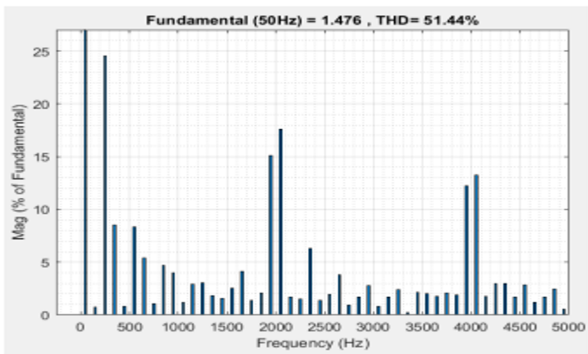

Fig.16: FFT analysis for Rl-Load with SVPWM Pulse control

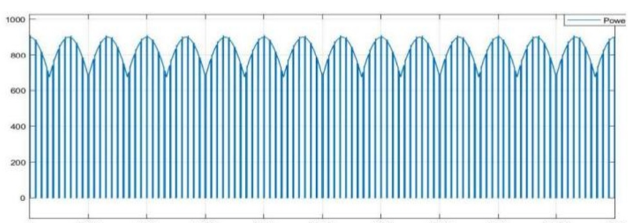

Fig.17: Output power waveform for R-Load with SVPWM Pulse control

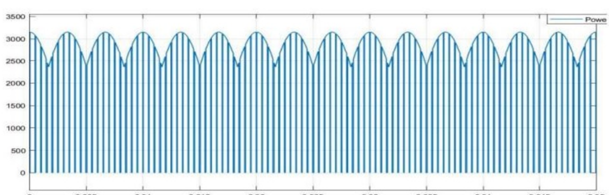

Fig.18: Output power waveform for RL-Load with SVPWM Pulse control

Table No.1: Performance comparison of PWM Rectifier with 0.9 Modulation Index

Modulation Index 0.9	**SPWM** Ref(13)		**SVPWM**	
Average output voltage(V)	400.3	397.3	464.1	458.4
Average output current(A)	1.144	1.135	1.318	1.31
THD (%)	67.09	67.09	51.36	51.74
Displacement factor	1	1	1	1
Distortion factor	0.8304	0.8304	0.8895	0.8882
Power factor	0.8304	0.8304	0.8895	0.8882

5. CONCULSION

Since the typical space vector approach requires angle and sector information to determine rectifier gating durations. In this paper, the generalised SVPWM algorithm simplifies the standard space vector technique. The most common PWM methods are SPWM and SVPWM. The simulation findings show that SVPWM pulse control outperforms SPWM pulse control in voltage, current, power factor, total harmonic distortion, and distortion factor.

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