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Comparative design of harmonic current reduction in variable speed drive using space vector pulse width modulation and hybrid pulse width modulation

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ABSTRACT

In industry and commerce, three-phase induction motors are frequently utilized as the primary power source for machinery. However, to increase motor performance efficiency, induction motors also need a tool for speed control. The variable speed drive (VSD) is one tool used to control the rotation speed of three-phase induction motors. Since VSD is a non-linear load, harmonic distortion will result from it. The space vector pulse width modulation (SVPWM) injection method and the hybrid pulse width modulation method were the two techniques employed by the author in this study to lower the current in the VSD. With the SVPWM injection approach, the variable speed drive's current total harmonic distortion (THD) values in the R, S, and T phases dropped to 3.77%, 3.53%, and 2.19% from 7.14%, 7.17%, and 7.58%.

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1. INTRODUCTION

Induction motors with three phases are widely used as machine prime movers in commercial and industrial domains. The reason is that induction motors have several advantages, such as simple design, high efficiency, relatively affordable costs, and easy maintenance [1]–[3]. Even though induction motors have the advantages mentioned previously, several disadvantages need to be considered, including speed control. In industries, a regulation is needed so that the speed of the induction motor can be adjusted to achieve better work efficiency. A variable speed drive (VSD) is one tool used to control the rotation speed of a three-phase induction motor. VSD is a device that has components that form a nonlinear load. A nonlinear load is a load that produces a nonlinear output waveform where the current flow is not proportional to the impedance and voltage changes. VSD consists of several components, including a rectifier, inverter, and direct current (DC) link, which connects the rectifier to the inverter and functions as a DC voltage filter. The problem with using a VSD is the emergence of harmonics that can cause losses, such as a decrease in the quality of the electric power system due to heating of the equipment, a decrease in power factor, relay failure, and reduced efficiency [4]–[6]. One way to reduce harmonics is to use the pulse width modulation (PWM) technique. With the help of frequency and amplitude parameters, the pulse width is modulated using the PWM approach. There are various PWM methods, including space vector PWM, hybrid PWM, modified sinusoidal PWM, and sinusoidal PWM [7]–[10].

Previous research regarding the comparative study of voltage source inverter (VSI) fed induction motor harmonic reduction using space vector pulse width modulation (SVPWM) and sinusoidal PWM [11] concluded that when using SVPWM, the total harmonic distortion of the voltage (THDv) value was reduced to 14.15% and harmonic distortion of the current (THDi) to 16.65%. However, when using the sinusoidal PWM method, the THDV value is reduced to 33.08% and THDi to 19.25%. Furthermore, the previous research about the hybrid trapezoidal modulation method based on distributed static compensator (D-STATCOM) for conditioning power quality and harmonic distortion [12] concluded that the trapezoidal hybrid was the most effective in reducing harmonics where the THDi value was 20.81% and THDv 2.26%.

The author is interested in comparing the harmonic current reduction in variable speed drives using the space vector pulse width modulation and trapezoidal pulse width modulation methods. This research hopes to reduce the harmonic values that occur. Meanwhile, research comparing the two methods above on variable speed drives has never been done before.

2. METHOD

The harmonic injection method is a method that provides harmonics in the opposite direction to counter the harmonic effects of a nonlinear load component. This method can reduce total harmonic current distortion ($THDi$) by 2% and total harmonic voltage distortion ($THDv$) by 60% [13]–[16]. This injection method uses the PWM technique, where another waveform regulates the ratio of the pulse waveform. PWM is a modulation technique that changes the pulse width with fixed frequency and amplitude values. Several PWM techniques exist, namely sinusoidal PWM (SPWM) [17], [18], modified sinusoidal PWM [19]–[21], space vector PWM [22]–[24], trapezoidal SPWM [25], [26], staircase SPWM [27], [28], and many more.

2.1. Variable speed drive

An electric motor's speed can be adjusted by varying the voltage and frequency supplied to it through a variable frequency drive (VFD). The goal of setting the frequency and voltage is to achieve the required motor torque and rotation speed. Current inverters with technology already use comment feedback. The inverter can change the Volt/Hertz value in real time to maintain the motor rotor rotation according to the desired conditions with different loads. The fundamental idea behind an inverter is that it converts AC voltage to DC voltage and then back to AC voltage with the appropriate frequency, allowing it to adjust frequency to a lower or higher level. For a clearer circuit, it can see in Figure 1 [6], [29].

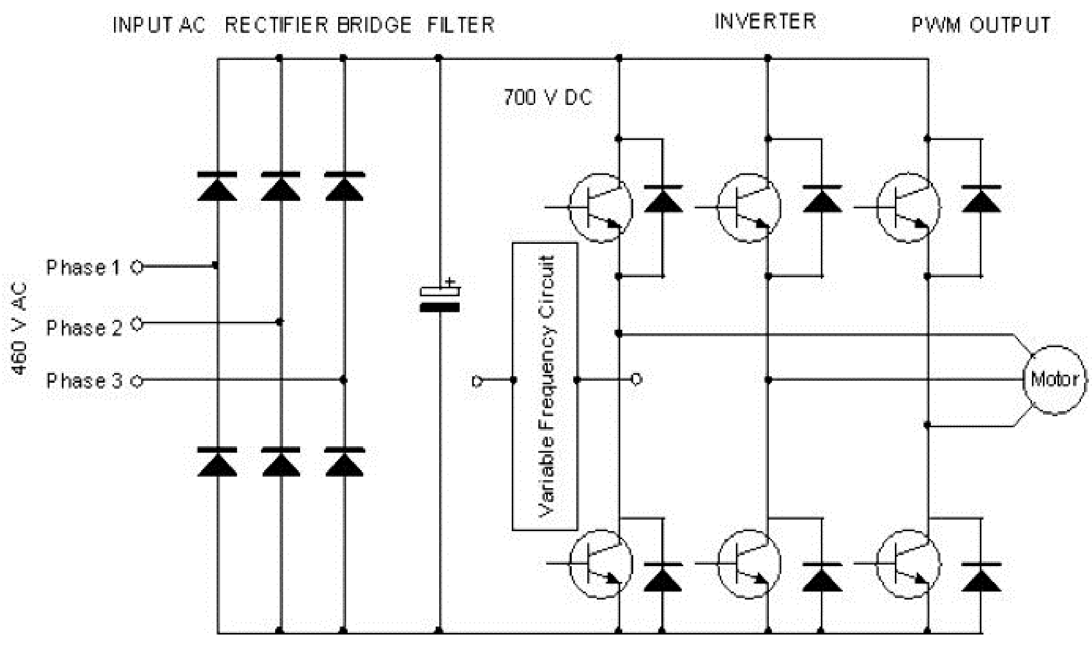


Figure 1. Circuit on variable speed drive

The working principle of the variable speed drive circuit above is:

- The incoming voltage from the grid will flow to the bridge rectifier/DC rectifier and be accommodated in the capacitor. Capacitors filter voltage to produce DC waves with less ripple.

- After being filtered, the DC voltage is then fed to the inverter circuit. Here, it undergoes a significant transformation, being converted back into AC voltage with a frequency as needed. This conversion process is made possible by the use of active semiconductors such as insulated gate bipolar transistors (IGBTs) and metal-oxide-semiconductor field-effect transistors (MOSFETs). The IGBT, in particular, performs gate switching to regulate the DC voltage that will be supplied. PWM is the switching technique, which produces an AC voltage with a carrier frequency of up to 20 kHz, resulting in a sinusoidal voltage.
- IGBT gate control can be done via a local keypad, an external potentiometer with input 0-10 VDC, 4-20 mA, or memory presets. All this can be done by filling in the appropriate program parameters.

2.2. Space vector PWM

The space vector PWM (SVPWM) technique has become a very sophisticated PWM technique because it produces high voltage with small harmonics, which is very good for industrial equipment. Elimination of a number of small-order harmonics provides excellent output. The SVPWM technique initially emerged as a vector approach to 3-phase inverter PWM. The SVPWM control method is a signal modulation that compares a reference signal in the form of a low-frequency wave obtained using special computing with a carrier signal in the form of a triangle wave at a high frequency in an amplitude comparison called the modulation index. Modulation of these two waves produces a pulse controlling the inverter power switch. The SVPWM method produces a wider duty cycle in the middle of the output signal, thereby reducing the number of commutations and switching losses to a lower waveform for sinusoidal PWM.

The block diagram of the injection method using SPWM is shown in Figure 2, just like the block diagram of the SPWM injection method, the SVPWM injection method contains an SVPWM generator, active filter, and inverter, which will provide harmonics in the opposite direction to counter the harmonic effects of nonlinear load components. The inverter used in this research is an active semiconductor such as IGBT. The output from inverter 2 will be injected into the VSD output with a semicircular phase shift to reduce current harmonics from the VSD output. Fast Fourier transform computation is used to find the spectral components of SVPWM [11], [22], [24].

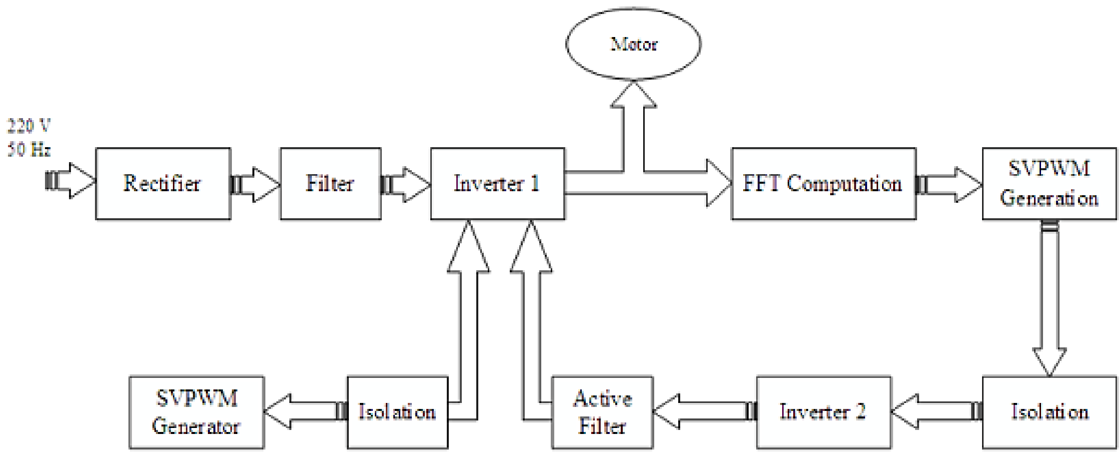


Figure 2. Block diagram of SVPWM injection method

2.3. Unipolar PWM

The SVPWM technique has become a very sophisticated PWM technique because it produces high voltage with small harmonics, which is very good for industrial equipment. Elimination of a number of small-order harmonics provides excellent output. The SVPWM technique initially emerged as a vector approach to 3-phase inverter PWM. Unipolar PWM works by controlling the on-time of the PWM pulse, which determines how long the motor phase will be activated in each cycle [30], [31]. This on-time is regulated by the duty cycle, which is usually expressed as a percentage of the PWM period. When the duty cycle is 50%, the motor phase will be active for half of the PWM period. During the on-time, the PWM signal provides a positive voltage level to one of the motor phases, and the other phases remain disconnected or do not receive pulses. After the on-time expires, the phase turns off, and the next phase is pulsed at the appropriate time in the PWM cycle.

The result is a trapezoidal wave formed by the motor phases being activated sequentially. Unipolar PWM creates rotation in the motor by controlling the time the motor phases are activated. The advantages of unipolar PWM are its ease of implementation and fairly good efficiency at low speeds. In addition, unipolar PWM reduces the complexity of the control circuit compared to other techniques, such as Sinusoidal PWM or space vector PWM. However, unipolar PWM has several disadvantages. The torque can become unstable at high speeds and is lower than other PWM techniques. In addition, the harmonic distortion in the output waveform is higher compared to the sinusoidal PWM technique, which can cause greater vibration and noise in the motor.

2.4. Bipolar PWM

Bipolar pulse width modulation (Bipolar PWM) is a control technique used in power systems or motor control to produce an output signal with a trapezoidal waveform or rectangular pulse with two opposing voltage levels. Bipolar PWM waveform. The advantage of bipolar PWM is its ability to produce higher torque at medium and high speeds compared to the unipolar PWM technique. Using two phases with opposite polarity helps achieve more substantial torque and stable rotation at high speeds. Apart from that, bipolar PWM can also reduce vibration and sound on the motor. However, bipolar PWM has a higher implementation complexity than unipolar PWM because it requires more complicated connections and control devices. In addition, bipolar PWM can also cause harmonic distortion in the output waveform, which needs to be considered in some applications. The bipolar PWM must be carefully considered based on the specific motor characteristics, load, and application requirements. If high performance and torque are required at medium and high speeds, the bipolar PWM technique may be more suitable than unipolar PWM [32], [33].

2.5. Hybrid PWM

Hybrid PWM can be used to reduce harmonic distortion in power systems. Harmonic distortion is a common problem in power electronic applications and can affect system performance and cause electromagnetic interference. This technique combines bipolar and unipolar PWM to reduce harmonic currents by exploiting the advantages of each approach. First, a load characteristics analysis is performed to understand the dynamic demands and power factor. Based on this analysis, an appropriate modulation is selected, such as using unipolar PWM at low voltage levels for simplicity of implementation. At high voltage levels, where harmonic distortion may be a problem, switch to bipolar PWM. Implementing adaptive control is the key to running this system optimally. Adaptive control can automatically switch between bipolar and unipolar PWM based on monitoring operational conditions and load. Hybrid PWM allows very precise pulse width control. High control can achieve high efficiency in precise power regulation and signal switching according to application needs. By combining unipolar and bipolar characteristics, hybrid PWM can help reduce harmonic distortion in the output signal. This can improve power quality and reduce electromagnetic interference in the system. Hybrid PWM can be designed to compensate for distortion caused by certain loads. This provides flexibility in overcoming distortion challenges that may arise in specific applications [34]–[36].

2.6. Methodology

The motor nameplate used is a 3-phase induction motor made by TECO ELEC. and MACH. PTE LTD Δ 220 V L-L, 1,500 Watt, as seen in Table 1. This research uses a MATLAB simulation program to investigate the effect of installing SVPWM and hybrid PWM injection to reduce harmonic currents. Next, this research requires three series, namely as follows:

Table 1. Induction motor

Parameter	Value
Motor power	1,500 Watt
Motor voltage	Δ=220 Volt, Y=380 Volt
Motor current	Δ=6.32 Ampere, Y=3.66 Ampere
Motor frequency	50 Hz
Motor speed	1,405 RPM
Number of poles	4

2.6.1. Variable speed drive circuit before filtering

The variable speed drive circuit model before filtering is shown in Figure 3. The inverter, which has a DC voltage input, produces an AC voltage output. The output of the AC voltage practically contains harmonic ripples. Because of the AC ripple, the DC voltage will also experience distortion, so it also experiences ripples.

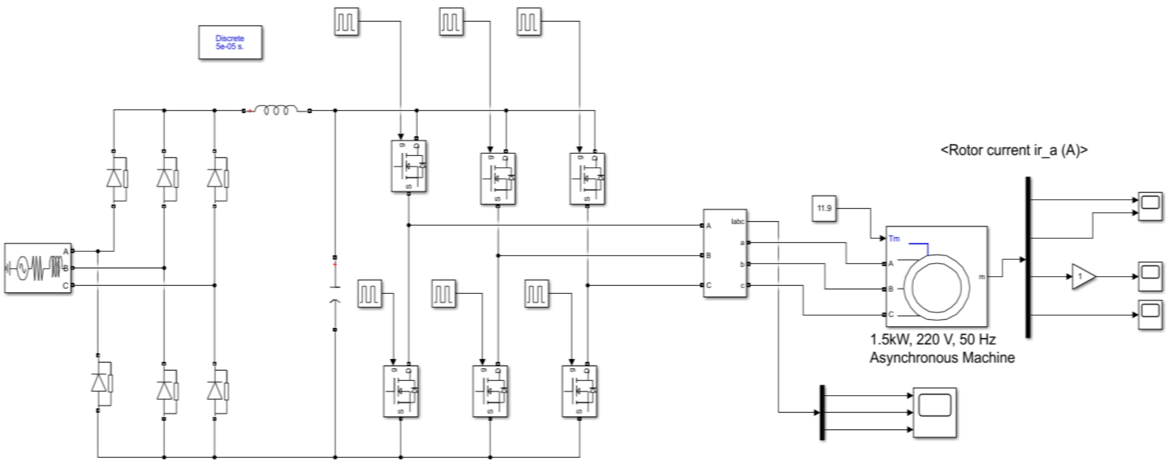


Figure 3. Variable speed drive circuit model before filtering

2.6.2. Variable speed drive series with space vector PWM injection method

The following is a model of a variable speed drive circuit with the space vector PWM injection method, as shown in Figure 4 [19], [21]. The difference here is that the PWM vector space method is added with several variables, such as the speed setpoint, inverter, and constant RPM. The space vector PWM injection method consists of a space vector PWM generator, active filter, and inverter that give harmonics in the opposite direction to counteract the harmonic impacts of nonlinear load components.

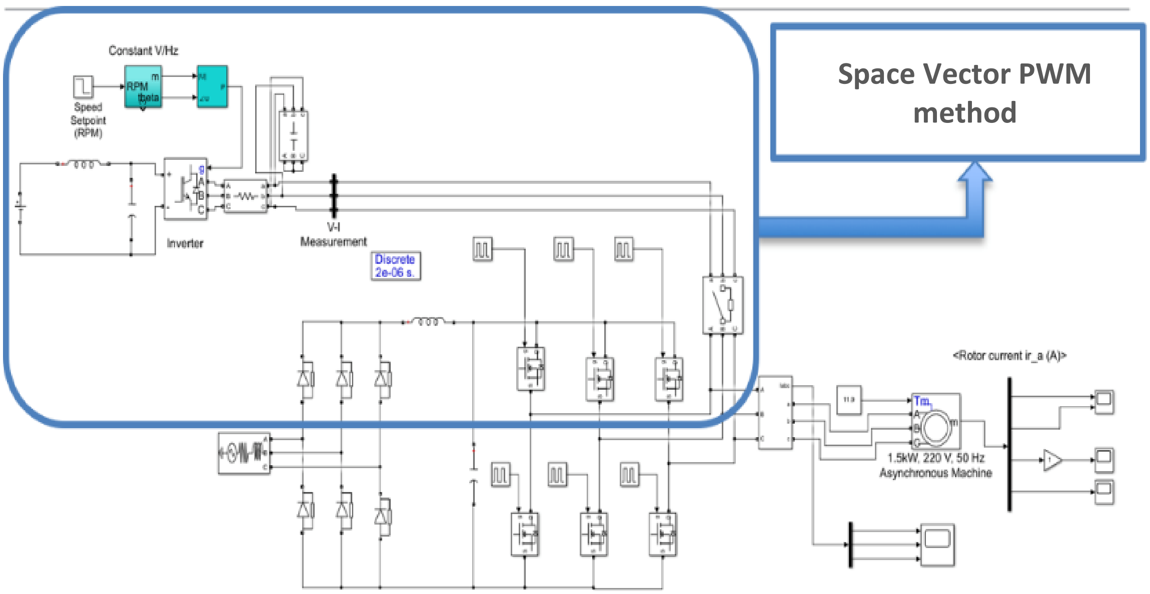


Figure 4. Variable speed drive circuit model with space vector PWM injection method

2.6.3. Variable speed drive circuit with hybrid PWM method

Variable speed drive circuit model using the hybrid PWM method as shown in Figure 5 [35], [36]. This technique reduces harmonic currents by combining bipolar and unipolar PWM and exploiting the advantages of each approach. Bipolar and unipolar PWM can be automatically switched by adaptive control depending on the load and operational parameters that are being monitored.

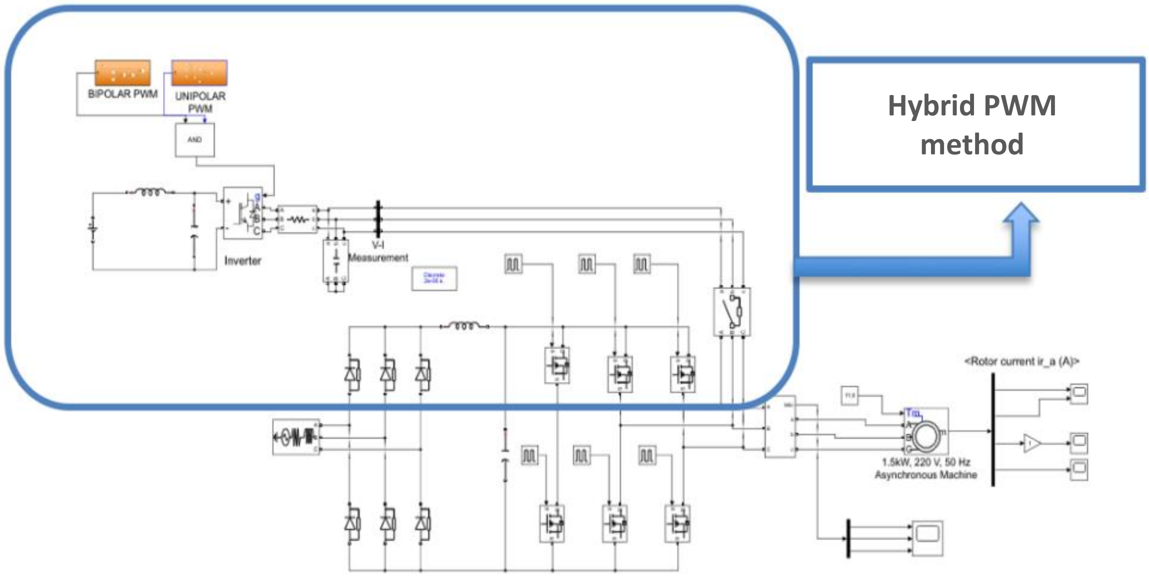


Figure 5. Variable speed drive circuit model with hybrid PWM method

3. RESULTS AND DISCUSSION

3.1. Simulation of harmonics on variable speed drive in initial conditions

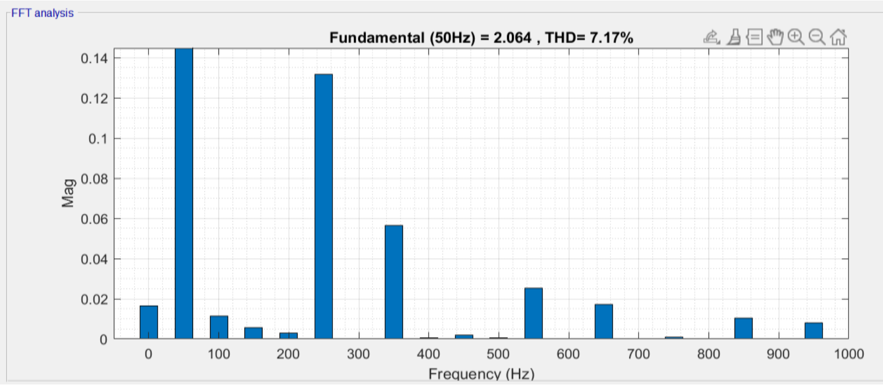
Table 2 shows that each order's individual harmonic distortion (IHD) harmonic current in the variable speed drive decreases. This is by the IEEE 519-2014 standard, where the greater the harmonic order, the smaller the permitted IHD standard. The THD value of harmonic currents in the R, S, and T phases is 7.14%, 7.17%, and 7.58%, where this value exceeds the IEEE 519-2014 standard limit, so it needs to be reduced.

Table 2. Measurement of harmonic currents on the variable speed drive in initial conditions

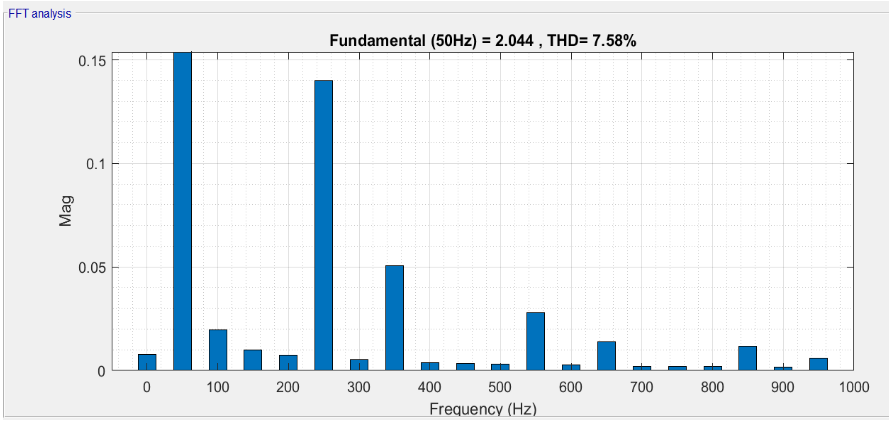
Frequency	Harmonics	Phase R		Phase S		Phase T	
		Magnitude	Phase Angle	Magnitude	Phase Angle	Magnitude	Phase Angle
0 hz	Dc	0.41%	270.0	0.79%	90.0	0.38%	270
50 Hz	1st HD	100%	-459	100%	193.2	100.00%	74.0
100 Hz	2nd HD	0.94%	17.9	0.54%	-874	0.96%	164.7
150 Hz	3rd HD	0.72%	12.4	0.28%	214.9	0.48%	179.6
200 Hz	4th HD	0.33%	12.6	0.14%	-803	0.36%	169.1
250 Hz	5th HD	6.30%	268.3	6.38%	23.9	6.84%	146.4
300 Hz	6th HD	0.26%	8.4	0.01%	258.0	0.26%	186.6
350 Hz	7th HD	2.66%	262.3	2.73%	136.0	2.47%	18.1
400 Hz	8th HD	0.20	6.8	0.03%	248.6	0.19%	178.5
450 Hz	9th HD	0.24%	0.2	0.08%	171.7	0.17%	184.2
500 Hz	10th HD	0.15%	9.4	0.02%	262.1	0.14%	180.8
550 Hz	11th HD	1.16%	252.7	1.22%	3.2	1.37%	130.1
600 Hz	12th HD	0.13%	7.9	0.00%	-796	0.13%	186.7
650 Hz	13th HD	0.76%	248.4	0.83%	117.8	0.67%	-15
700 Hz	14th HD	0.11%	7.3	0.01%	236.4	0.11%	183.2
750 Hz	15th HD	0.14%	-50	0.05%	150.2	0.10%	186.8
800 Hz	16th HD	0.09%	10.3	0.01%	249.7	0.09%	185.3
850 Hz	17th HD	0.43%	239.3	0.50%	-143	0.57%	117.5
900 Hz	18th HD	0.08%	9.6	0.00%	-790	0.09%	188.3
950 Hz	19th HD	0.33%	234.3	0.39%	100.9	0.30%	-22.8
THDI		7.14%		7.17%		7.58%	

Figure 6(a) shows the fast Fourier transform spectrum of harmonic currents of the variable speed drive in the R phases, Figure 6(b) S phases, and Figure 6(c) T phases. This figure shows harmonic current values at 0 Hz in the R, S, and T phases, namely 0.41%, 0.79 %, and 0.38 %, respectively. This is caused by wave asymmetry due to the DC component in the variable speed drive. This figure shows that the magnitude value of the 19th-order harmonic current in the R, S, and T phases is 0.39%, 0.33%, and 0.30%, respectively.

Apart from that, the value of the 19th order phase angle in the R phase is 234.7º (in quadrant III), in the S phase, it is 100.9º (in quadrant II), and in the T phase, it is -22.8° (in quadrant IV). The author analyzes that the angular difference between the R-S phases is 234.7°- 100.9°=133.8º, the angular difference between S-T is 100.9°-(-22.8) =123.7°, and the angular difference between T-R is -22.8°- 234.7°=104.9°. In general, the angular difference between the three phases is 120°, so it can be concluded that the wave's distortion (deviation) causes harmonics to appear.



(a)



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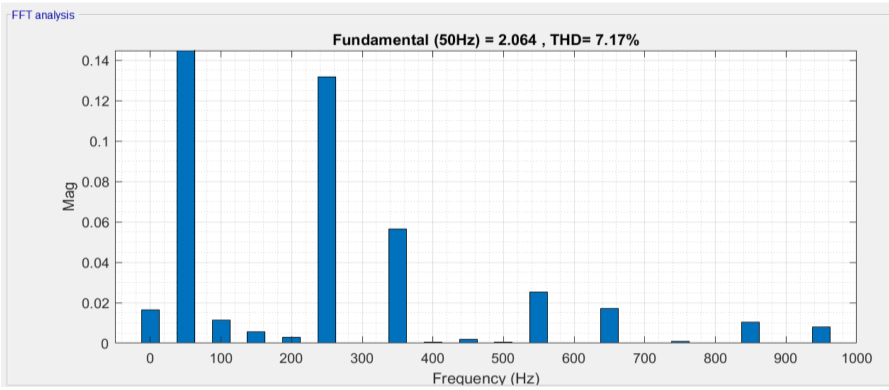


(c)

Figure 6. Fast Fourier transform spectrum of harmonic currents in variable speed drive (a) R phase, (b) S phase, and (c) T phase

From the analysis above, it can be concluded that the harmonic current waves in the variable speed drive in initial conditions experienced distortion due to deviations in the angles between the three phases. The following is the harmonic current waveform for each phase of the variable speed drive, which is shown in

Figure 7. In this figure, it can be seen that harmonic distortion causes deviations in the current waveform. This causes the waves to become deformed. The waveform resulting from harmonic distortion will cause ripples to occur, thereby destroying the waveform, which was originally sinusoidal and becomes deformed.

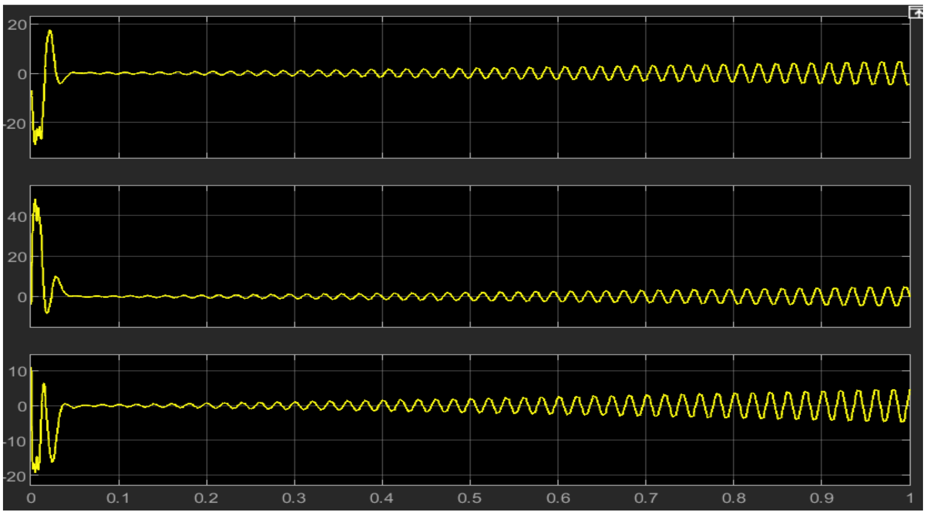


Figure 7. The harmonic current waveform in variable speed drive

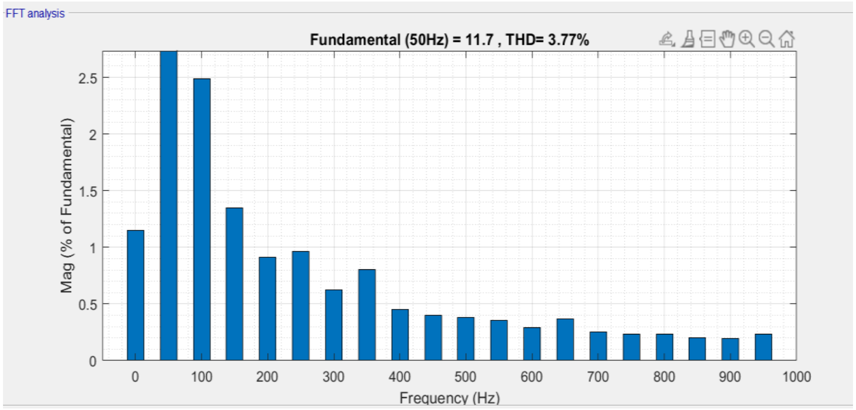
3.2. Simulation of harmonics reduction in variable speed drives using the SVPWM injection method

The simulation results of harmonic current measurements on the variable speed drive after installing the space vector PWM injection method are shown in Table 3. In this table, it can be seen that there is a decrease in the individual harmonic distortion (IHD) harmonic current in the variable speed drive after installing the SVPWM injection method, such as in several odd orders in the R phase, namely the 5^{th} order from 6.30% to 0.96% and the 7^{th} order from 2.66% to 0.80%. This causes the current THD value in the R, S, and T phase to decrease from 7.14%, 7.17%, and 7.58% to 3.77%, 3.53%, and 2.19%, and this value is by the IEEE 519-2014 standard.

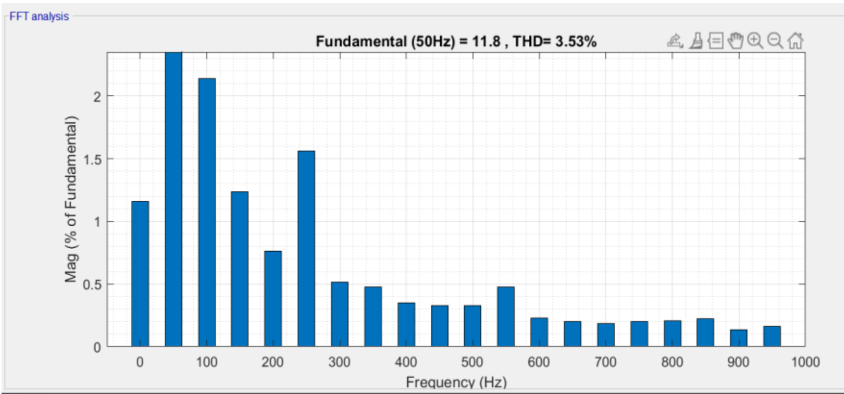
Table 3. Simulation result data for harmonic current measurements on variable speed drives using the SVPWM injection method

Frequency	Harmonics	Phase R		Phase S		Phase T	
		Magnitude	Phase Angle	Magnitude	Phase Angle	Magnitude	Phase Angle
0 hz	Dc	1.15%	270.0	1.16%	270.0	2.28%	90.0
50 Hz	1^{st} HD	100%	-21.5	100%	219.4	100.00%	98.6
100 Hz	2^{nd} HD	2.49%	168.8	2.14%	21.00	1.30%	-71.3
150 Hz	3^{rd} HD	1.35%	175.5	1.24%	14.7	0.44%	-71.7
200 Hz	4^{th} HD	0.91%	175.2	0.77%	13.3	0.29%	-58.1
250 Hz	5^{th} HD	0.96%	252.7	1.56%	38.5	0.93%	183.6
300 Hz	6^{th} HD	0.62%	172.7	0.52%	7.2	0.17%	-54.5
350 Hz	7^{th} HD	0.80%	198.2	0.48%	51.6	0.47%	-15.3
400 Hz	8^{th} HD	0.45%	177.9	0.35%	6.2	0.11%	-28.4
450 Hz	9^{th} HD	0.40%	175.3	0.33%	3.4	0.08%	-37.5
500 Hz	10^{th} HD	0.38%	180.2	0.32%	2.5	0.05%	-13.4
550 Hz	11^{th} HD	0.36%	212.0	0.48%	19.6	0.15%	169.1
600 Hz	12^{th} HD	0.29%	181.2	0.23%	3.9	0.06%	-8.7
650 Hz	13^{th} HD	0.37%	194.9	0.20%	34.1	0.18%	-6.1
700 Hz	14^{th} HD	0.25%	182.4	0.19%	7.1	0.07%	-10.5
750 Hz	15^{th} HD	0.23%	184.4	0.20%	6.4	0.03%	-8.4
800 Hz	16^{th} HD	0.23%	182.0	0.21%	2.7	0.03%	-3.4
850 Hz	17^{th} HD	0.20%	201.5	0.22%	18.6	0.02%	173.5
900 Hz	18^{th} HD	0.19%	183.9	0.13%	3.9	0.06%	4.0
950 Hz	19^{th} HD	0.23%	185.6	0.16%	19.6	0.08%	-22.2
THDI		3.77%		3.53%		2.19%	

Figure 8(a) shows the fast Fourier transform spectrum of the R phase, Figure 8(b) S phase, and Figure 8(c) T phase harmonic currents on the variable speed drive after installing the SVPWM injection. The harmonic current values at 0 Hz in the R, S, and T phases, namely 1.15%, 1.16%, and 2.28%. This is caused by wave asymmetry due to the DC component in the variable speed drive. In this picture, the magnitude values of the 19^{th} harmonic current in the R, S, and T phases are 0.23%, 0.16%, and 0.08%, respectively. Apart from that, the value of the 19th order phase angle in the R phase is 185.6° (in quadrant III), in the S phase it is 19.6° (in quadrant I), in the T phase it is -22.2° (in quadrant IV). The author takes the angular difference between the R-S phases to be 185.6°-19.6°=166°, the angular difference between the S-T phases is 19.6°-(-22.2) = 41.8°, and the angular difference between the T-R phases is 337.6°-185.6°=152°. In general, the angular difference between the three phases is 120°, so it can be concluded that wave distortion occurs, which causes harmonics to appear.



(a)



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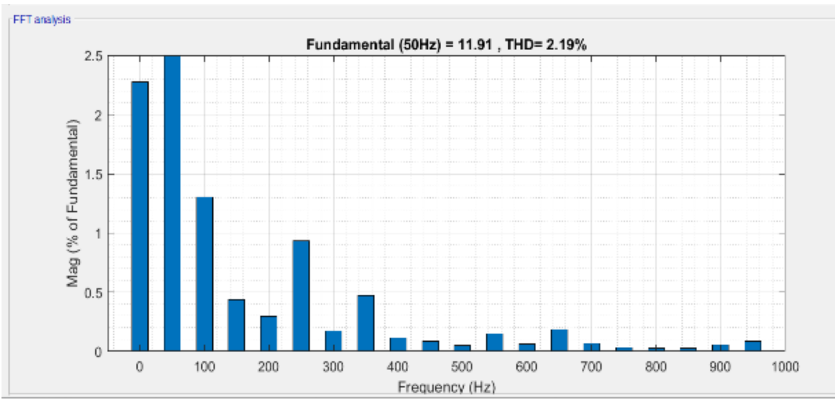


(c)

Figure 8. Fast Fourier transform spectrum of harmonic currents in variable speed drives using the SVPWM injection method (a) R phase, (b) S phase, and (c) T phase

From the analysis above, it can be concluded that the harmonic current waves in the variable speed drive, after installing the SVPWM injection method, still experience distortion due to deviations in the angles between the three phases. The harmonic current waveform for each phase of the variable speed drive is shown in Figure 9. In this figure, harmonic distortion causes deviations in the current waveform, causing the wave to become deformed. The waveform resulting from harmonic distortion will cause ripples to occur, thereby destroying the waveform, which was originally sinusoidal and becomes deformed.

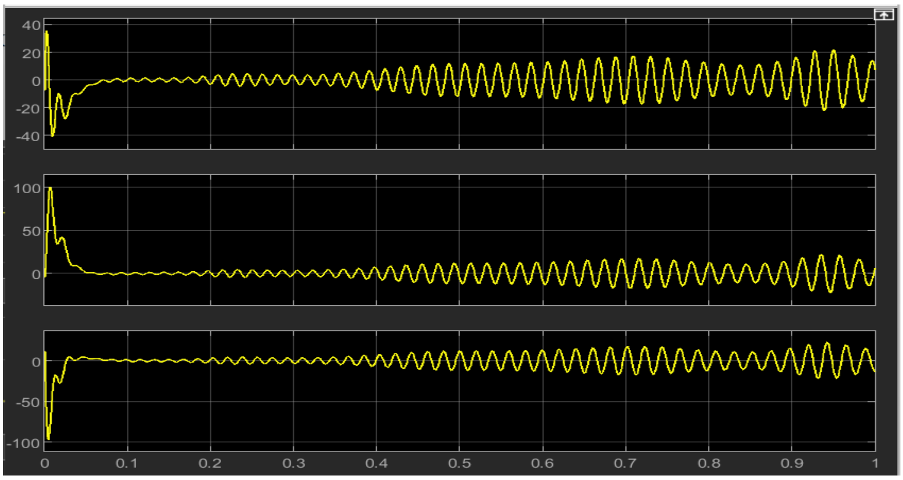


Figure 9. Harmonic current waveform on the variable speed drive after installation of the SVPWM injection method

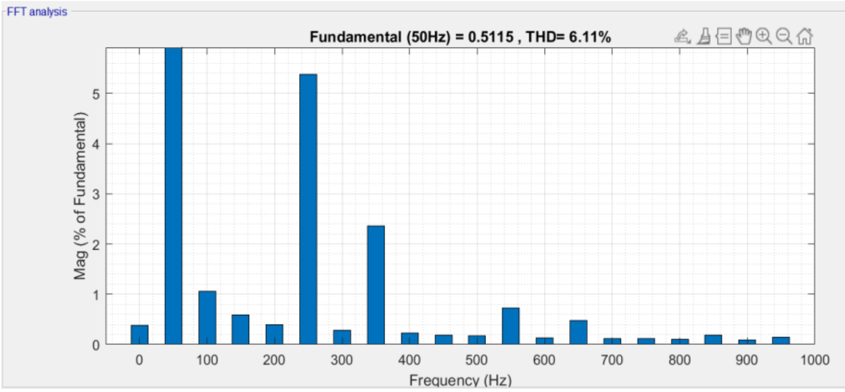
3.3. Simulation of harmonics reduction in variable speed drives using the hybrid PWM method

The simulation results of harmonic current measurements on the variable speed drive after installing the hybrid PWM method are shown in Table 4. As seen in this table, there is a decrease in individual harmonic distortion (IHD) harmonic currents in the variable speed drive after installing the hybrid PWM method, such as in several odd orders in the R phase, namely the 5th order from 6.30% to 5.37% and the 7th order from 2.66% to 2.36%. This causes the current THD value in the R, S, T phase to decrease from 7.14%, 7.17%, and 7.58% to 6.11%, 6.28%, and 6.42% and this value is by the IEEE 519-2014 standard.

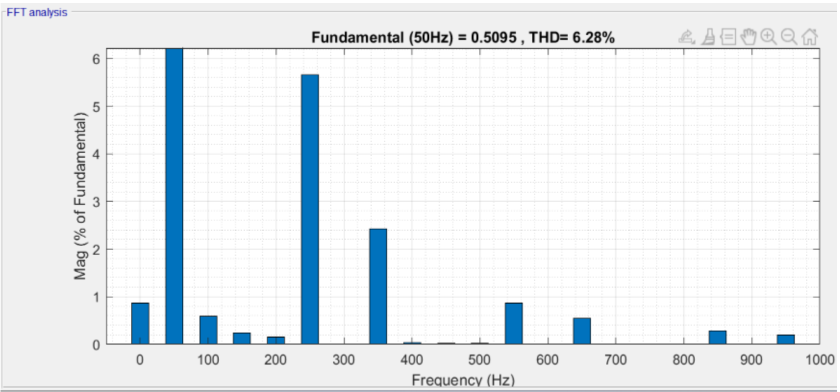
Table 4. Data from simulation results for harmonic current measurements on variable speed drives using the hybrid PWM method

Frequency	Harmonics	Phase R		Phase S		Phase T	
		Magnitude	Phase Angle	Magnitude	Phase Angle	Magnitude	Phase Angle
0 hz	Dc	0.37%	270	0.68%	90.0	0.49%	270.0
50 Hz	1st HD	100,00%	-53.3	100.00%	186.4	100.00%	66.8
100 Hz	2nd HD	1.06%	14.5	0.59 %	262.1	1.01%	161.3
150 Hz	3rd HD	0.59%	11.0	0.24%	256.9	0.55%	167.3
200 Hz	4th HD	0.40%	12.0	0.15%	255.8	0.36%	169.2
250 Hz	5th HD	5.37%	226.4	5.65%	-16.5	5.79%	107.2
300 Hz	6th HD	0.28%	1.2	0.01%	264.4	0.28%	179.6
350 Hz	7th HD	2.36%	260.5	2.42%	135.4	2.22%	16.8
400 Hz	8th HD	0.22%	1.4	0.04%	231.9	0.20%	173.0
450 Hz	9th HD	0.19%	1.7	0.03%	227.8	0.17%	175.0
500 Hz	10th HD	0.17%	3.6	0.03%	230.8	0.15%	176.4
550 Hz	11th HD	0.73%	205.3	0.87%	-39.8	0.87%	90.7
600 Hz	12th HD	0.14%	0.5	0.01%	229.7	0.13%	178.2
650 Hz	13th HD	0.48%	248.3	0.54%	116.7	0.43%	-4.7
700 Hz	14th HD	0.12%	0.2	0.01%	216.6	0.11%	175.9
750 Hz	15th HD	0.11%	0.4	0.01%	212.6	0.10%	176.8
800 Hz	16th HD	0.10%	1.8	0.01%	216.3	0.10%	177.8
850 Hz	17th HD	0.18%	188.3	0.28%	-56.1	0.26%	84.6
900 Hz	18th HD	0.09%	0.4	0.01%	216.8	0.09%	178.2
950 Hz	19th HD	0.15%	245.8	0.20%	104.4	0.13%	-27.1
THDI		6.11%		6.28%		6.42%	

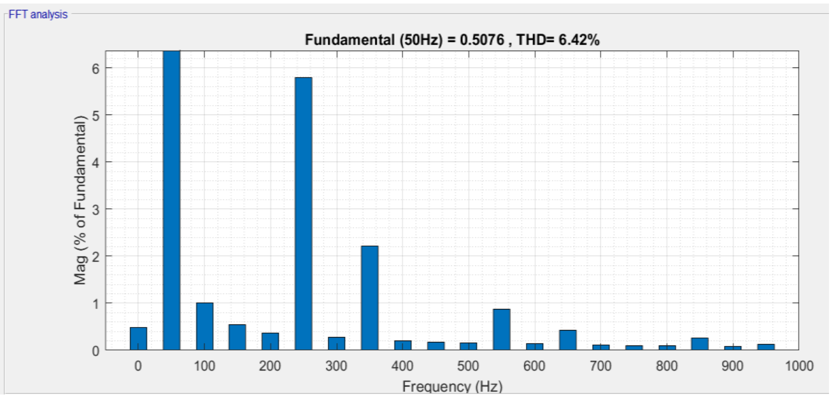
Figure 10(a) shows the fast Fourier transform spectrum of the R phase, Figure 10(b) S phase, and Figure 10(c) T phase harmonic currents on the variable speed drive after installing the hybrid PWM method. This figure shows the harmonic current values at 0 Hz in the R, S, and T phases, namely 0.37%, 0.68%, and 0.49%. This is caused by wave asymmetry due to the DC component in the variable speed drive. Furthermore, the magnitude value of the 19th harmonic current in the R, S and T phases is 0.15%, 0.20%, 0.13%. In addition, the value of the 19th order phase angle in the R phase is 245.8° (in quadrant IV), in the S phase, namely 104.4° (in quadrant I), in the T phase, namely -27.1° (in quadrant IV). The author takes the angular difference between the R-S phases to be 245.8°-104.4°=141.4°, the angular difference between the S-T phases is 104.4°-(-27.1)=131.5°, and the angular difference between the T-R phases is 332.9°-245.8°=87.1°. In general, the angular difference between the three phases is 120°, so it can be concluded that there is a deviation.



(a)



(b)



(c)

Figure 10. Fast Fourier transform spectrum of harmonic currents in variable speed drives using the hybrid PWM method (a) R phase, (b) S phase, and (c) T phase

From the analysis above, it can be concluded that the harmonic current waves in the variable speed drive after installing the hybrid PWM method still experience deviations (distortion) due to deviations in the angles between the three phases. The following is the harmonic current waveform for each phase of the variable speed drive, which is shown in Figure 11. As shown in this figure, harmonic distortion causes deviations in the current waveform, causing the wave to become deformed. The waveform resulting from harmonic distortion will cause ripples to occur, thereby destroying the waveform, which was originally sinusoidal, and causing it to become deformed. Based on the analysis above, there is a decrease in harmonic currents after using the SVPWM injection method. The SVPWM method is more effective than hybrid PWM because the SVPWM injection method utilizes another circuit harmonic source to be injected into the initial circuit so that the phasor angles of the two harmonic sources will cancel each other out, thereby reducing the overall harmonic current.

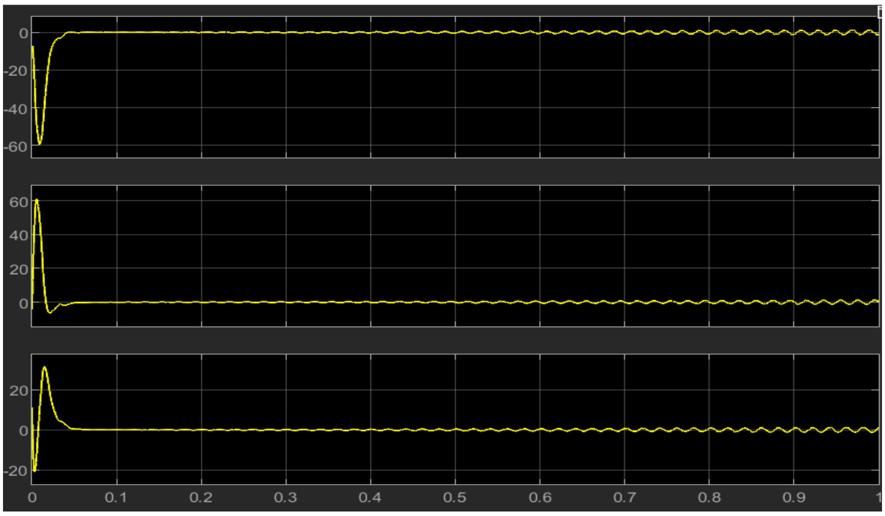


Figure 11. Harmonic current waveform on the variable speed drive after installing the hybrid PWM method

3.4. Comparison results of harmonic reduction simulations on variable speed drives

A comparison of harmonic current reduction after installation of each method is shown in Figure 12. As shown in this figure, the space vector pulse width modulation (SVPWM) method is the most effective method for reducing harmonic currents. The current THD values in the R, S, and T phases decreased from 7.14%, 7.17%, and 7.58% to 3.77%, 3.53%, and 2.19%, respectively.

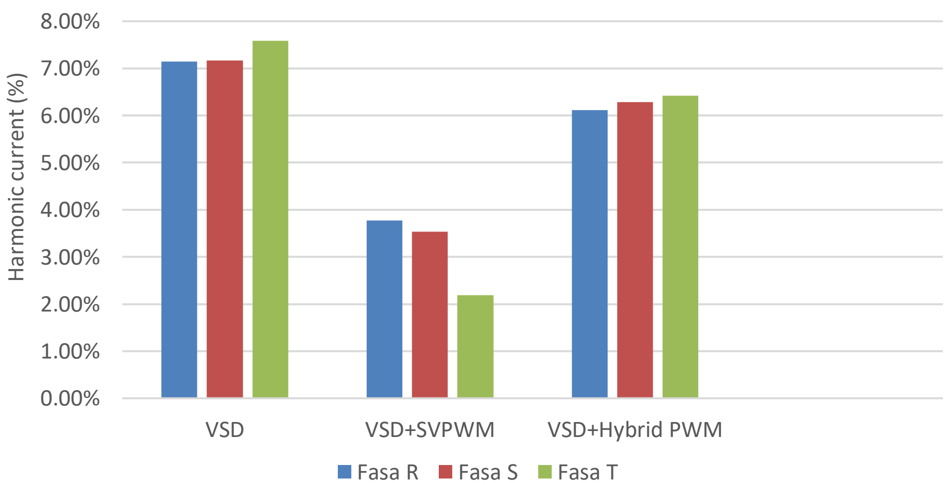


Figure 12. Comparison of harmonic current reduction after installing SVPWM and hybrid PWM

4. CONCLUSION

Based on the research results that have been explained, conclusions are obtained, such as that the current THD values in the R, S, and T phases produced by the variable speed drive are 7.14%, 7.17%, and 7.58%. Furthermore, the current THD values in the R, S, and T phases produced by the variable speed drive after using the SVPWM injection method decreased from 7.14%, 7.17%, and 7.58% to 3.77%, 3.53%, and 2.19%. Meanwhile, the current THD values in the R, S, and T phases produced by the variable speed drive after using the hybrid PWM method decreased from 7.14%, 7.17%, and 7.58% to 6.11%, 6.28%, and 6.42%. The last conclusion is that the best method for reducing harmonic currents in variable speed drives is to use the space vector pulse width modulation injection method rather than the hybrid PWM method. It is important for the research field to reduce harmonics.

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