AVERAGE POINT PULSEWIDTH MODULATION METHOD FOR INVERTER-BASED DG IN ELECTRIC POWER SYSTEMS GENERATION

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Abstract

The paper proposes a new pulsewidth modulation method for inverter-based DG in electric power systems, and it is the average point pulsewidth modulation method. This method was used on the Matlab/Simulink and compared the $\%THD_V$ of the pulsewidth modulation method between the space vector and the average point when the switch chopper reached a 340 wave frequency at 8,500 Hz to produce the one sine waveform. The simulation results showed that the $\%THD_V$ of the space vector pulsewidth modulation method was 0.4% and the $\%THD_V$ of the average point pulsewidth modulation method was 0.6% which showed that the $\%THD_V$ in both methods is very small.

Keywords: Pulsewidth Modulation, Distributed Generation, Grid-Connected

INTRODUCTION

Connecting the Distributed Generation (DG) to the power system has become more and more popular, especially with small DGs derived from renewable energy. The features of DG include: a secure electricity supply to customers, the liberalization of the electricity market, reduced CO_2 emission with the introduction of renewable energy sources, increased power availability and reliability, increased standby capacity, improved power quality and grid support, a combined generation of heat and power and cost savings by adding more remote generating sources. However, the advent of DG makes some problems to the stability and the power quality (such as total harmonic distortion) in the adjacent utility.

Connecting the distributed generation to the power system can be divided into two categories (Yingram et al., 2014). The first type is the synchronous-based DG, which generates electricity in Alternating Current (AC), so it does not need to be converted to alternating current before it is connected to the power system. The inverter-based DG is another, in which DG is connected via the inverters because the electricity is generated from them. Direct current (DC) requires being converted to alternating current. This is done by converting alternating current into direct current and the most popular methods are the types related to pulsewidth modulation (PWM). Based on the concept of pulsewidth modulation, the duty cycle of converter switches can be varied at a high frequency to achieve a target average low frequency output voltage or current (Satish, 2011). The group of pulsewidth modulation methods can be divided into five categories: 1) Sinusoidal PWM (SPWM) 2) Selected harmonic elimination (SHE PWM) 3) Minimum ripple current PWM 4) Hysteresis PWM and 5) Space vector PWM (SVPWM) (Chanasut, 2007). Currently, the most likely way to do this is through the Space vector PWM (SVPWM) because of its high performance and also, the Total harmonic distortion (THD) is lower than the other methods (Chanasut, 2007; Dusmez et al., 2015; Gaurav & Mohan, 2012; Keng-Yuan & Jwu-Sheng, 2012; Panda et al., 2009). The THD equation can be found as follows.

Voltage total harmonic distortion: THD_V

$$\%THD_V = \frac{\sqrt{\sum_{h=2}^{\infty} V_{h(rms)}^2}}{V_{1(rms)}} \times 100\% \tag{1}$$

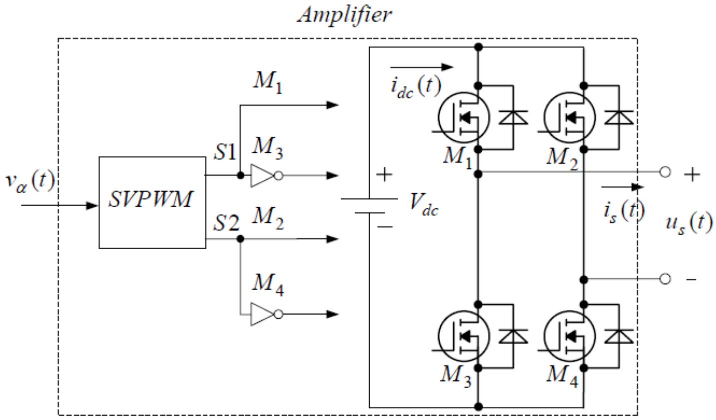
Current total harmonic distortion: THD_I

$$\%THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} I_{h(rms)}^2}}{I_{1(rms)}} \times 100\% \tag{2}$$

Due to the trend of using the inverter-based DG, the installation of the DG into the power system is becoming increasingly popular. In particular, electricity generated from renewable energy such as solar panels and wind turbines (a type of the wind turbine required through an inverter) (REN21, 2018). These are clean energy sources that can help stabilize the power system and reduce CO_2 emissions caused from burning fossil fuels to generate electricity, which causes global warming. So, minimizing the impact on power quality is the key issue for connecting distributed generation into the power system.

The space vector pulsewidth modulation (SVPWM) is the most efficient switching technique and popular today. Details and simulation results of the SVPWM for inverter 1 phase are as follows (Jian-guo et al., 2011; Menon & Nehrir, 2007; Muangpongoen, 2011; Yingram, 2015; Yingram, 2017).

Figure 1 shows that the inverter circuit uses the modulation method to generate PWM signals to control the switch. The DC voltage (V_{dc}) is constant. While the switch *M1* operates, *M3* will not work. The circuit is simple to understand, as shown in Figure 2 with a truth table.



$v_\alpha(t)$ = alpha voltage signal

$u_s(t)$ = output voltage of SVPWM

$i_{dc}(t)$ = dc current

$i_s(t)$ = output current of SVPWM

Figure 1 Method of signal amplification with inverter circuit.

Output voltage of the inverter is V_0 and $V_3 = 0$ because they are zero vector, while V_1 and $V_2 \neq 0$ because they are non-zero vectors. Figure 3 shows the space vector of the voltage of the bridge inverter, and it has two stages. There are two space vectors of variable voltages and another two space vectors of unchanged voltages.

To convert DC into AC by the SVPWM on the Matlab/Simulink and the SVPWM method is illustrated in Figure 4, based on Equation (3) and Equation (4).

$$d_{s1}(t) = \frac{1}{2} + \frac{d(t)}{2} \quad (3)$$

$$d_{s2}(t) = \frac{1}{2} - \frac{d(t)}{2} \quad (4)$$

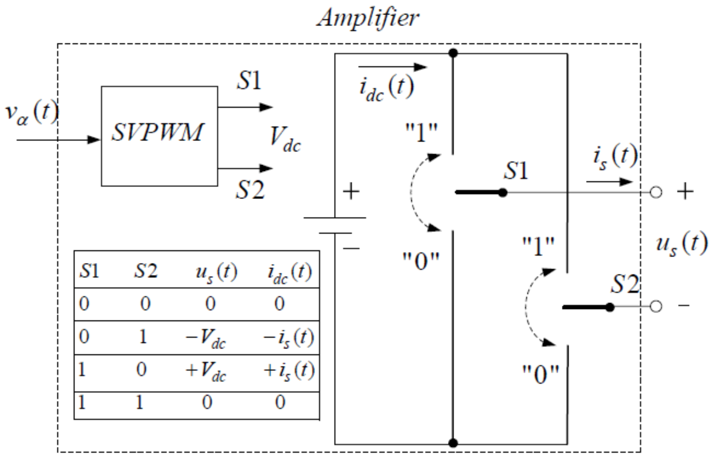


Figure 2 Method of signal amplification with simple inverter.

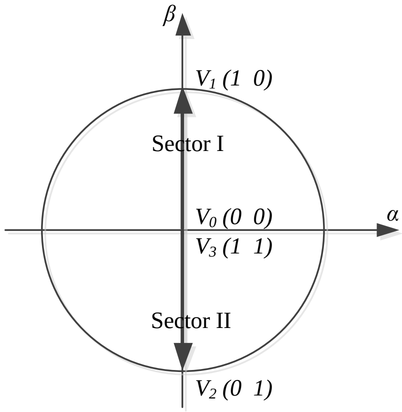


Figure 3 Space vector of voltage.

The cycle value is compared to the triangular signal using the relational operator function to generate the PWM. The data from the relational operator function is the Boolean type, which cannot perform mathematical operations. Therefore, the Boolean data types are converted to int types by the data type conversion (Muangpongoen, 2011; Yingram, 2015).

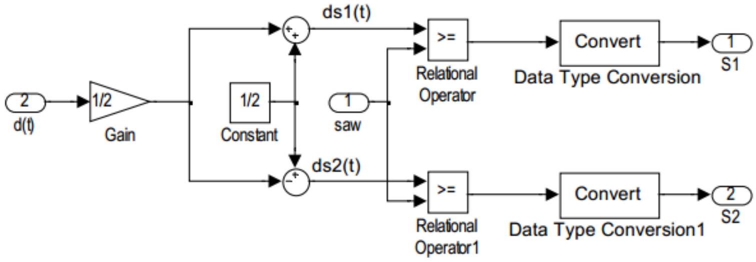


Figure 4 SVPWM method on Matlab/Simulink.

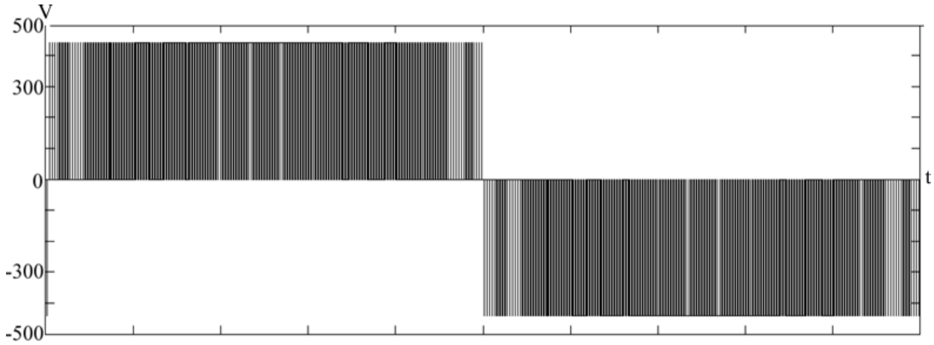


Figure 5 Simulation result of SVPWM method.

Figure 5 shows the simulation results of the SVPWM method. The set reference signal is a triangular wave at 170 waves in sine wave 1 wave at a frequency of 8,500 Hz. From the processing, it shows that the $\%THD_V = 0.4\%$, which is considered very low.

Therefore, this paper proposes a new pulsewidth modulation method for inverter-based DG in electric power systems. The details include: the SVPWM, which is the current popular method, a proposed average point pulsewidth modulation, the simulation results and analysis and a conclusion.

MATERIALS AND METHODS

This section proposed the use of an Average point pulsewidth modulation (APPWM). The concept of the APPWM method is to, "Find the average point by the number of points up to the frequency used to the switch chopper. Each point has a pulse width equal to the value obtained by calculating the average of sine wave from one point to another." When considering the switch chopper to obtain the required voltage waveform the voltage value of APPWM method is;

$$V_{api} = \frac{V_m}{t_i - t_{i-1}} \int_{t_{i-1}}^{t_i} \sin(\omega t) dt \qquad (5)$$

V_{ap} = average voltage per point

i = sequence in the switch chopper on time axis

n = number of all points require to the switch chopper

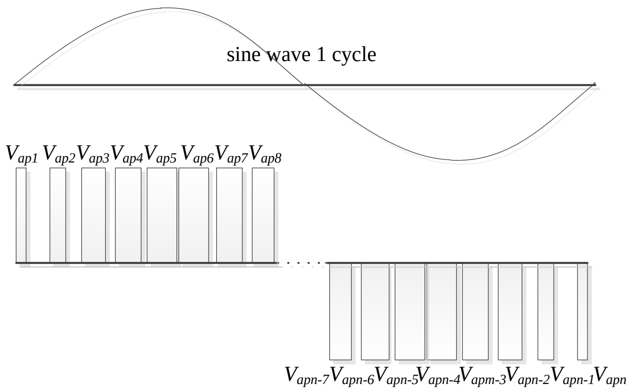


Figure 6 Characteristic of APPWM method.

Figure 6 shows the characteristics of waveform of the APPWM method compared to a sine wave. This simulation shows the results of the average point pulsewidth modulation method on the Matlab/Simulink. In comparison to the SVPWM method, the waveform that will be generated by the APPWM method is generated by shuffling the switch to create the same amount.

The SVPWM method used a reference signal, which is a triangular wave of 170 waves that makes the switch chopper 340 waves in sine wave 1 wave at a frequency of 8,500 Hz. Thus, the APPWM method will use the switch chopper 340 waves as well. The switch points are located at S1 and S2 as shown in Figure 7 in a single phase inverter block. Then, a block was created to generate the signal to the switch chopper directly at the same frequency at 8,500 Hz. Equation (5) was used to calculate the switch chopper for 340 times to create one sine wave.

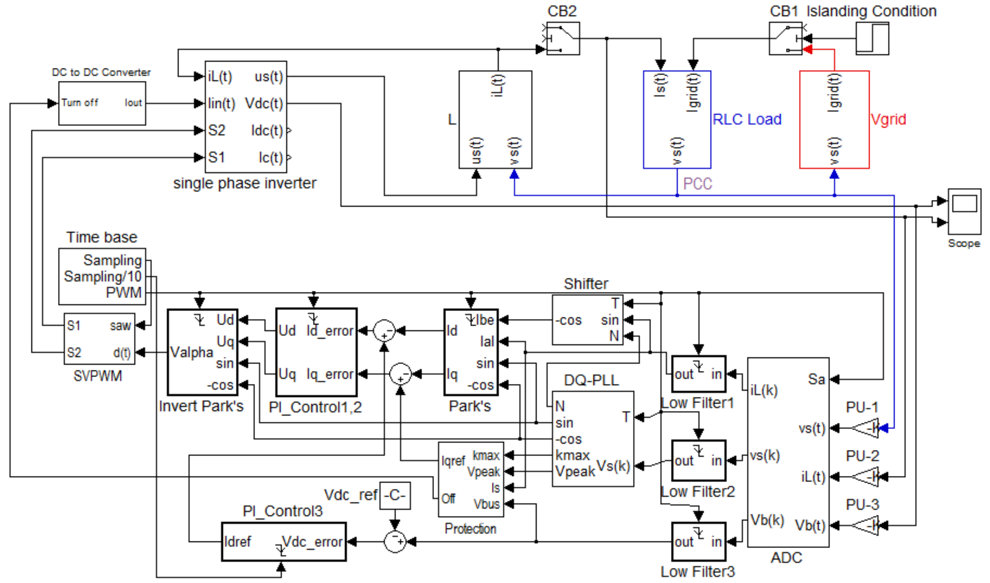


Figure 7 Model of a single phase grid-connected inverter.

RESULTS AND DISCUSSION

A simulation was performed and the simulation results are shown in Figure 8. From the processing, it is shown that the $\%THD_V$ = 0.6%, which is considered very low as well.

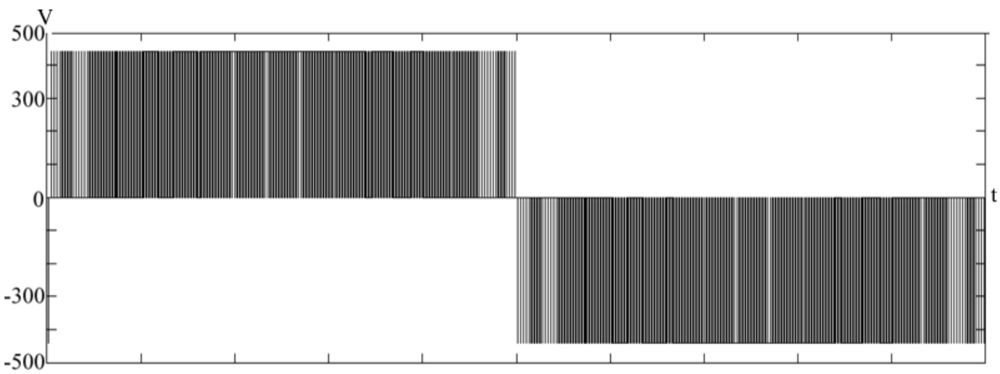
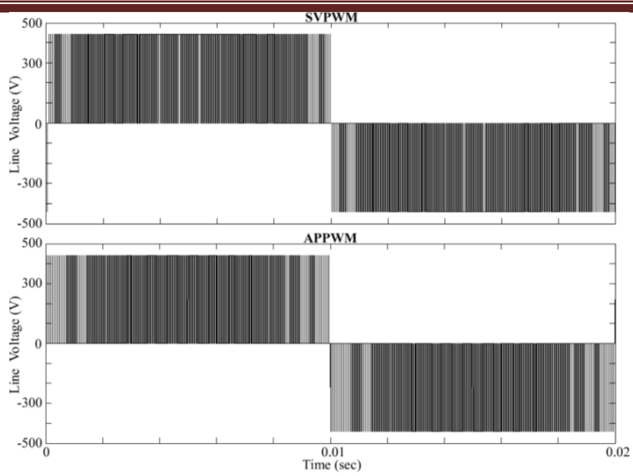
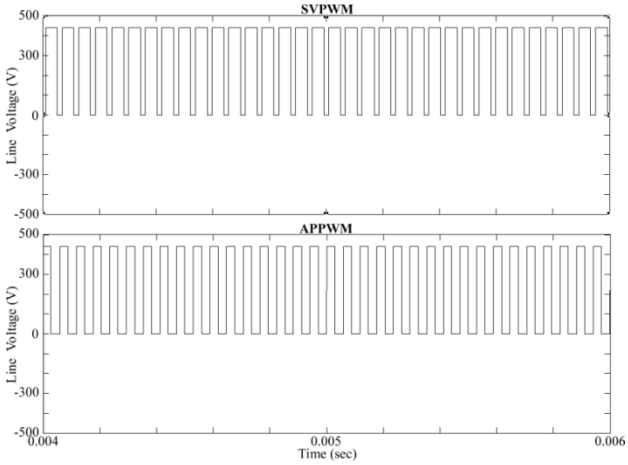


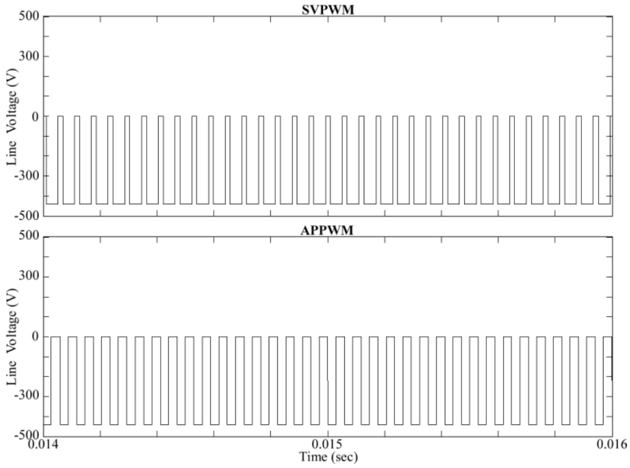
Figure 8 Simulation result of APPWM method.



(a) caracteristic of the one wave form



(b) caracteristic of the positive side



(c) caracteristic of the negative side

Figure 9 Comparison $u_s(t)$ between the SVPWM and the APPWM.

This compares the appearance of waveform incident and the $\%THD_V$ between the SVPWM method and the APPWM method. The waveforms of both can be seen from the simulation results shown in Figure 9. It can be seen that the appearance of the waveforms is similar in that in the early part of the waveform there will be a strip of narrow space. The center of the waveform is the 90 degree zone of the sine wave. The strip of space is wide. When comparing, the $\%THD_V$ between the SVPWM method = 0.4% and the APPWM method = 0.6%, thus, it can be seen that the value of both is similar. This suggests that if the APPWM method has developed, it is possible %THD of APPWM≤%THD of SVPWM method. So, the method can be optional for creating a sine wave by PWM.

Based on the simulation results, it was found that the two approaches are similar to the space bar generation and have less $\%THD_V$. Because of the creation of PWM, the two approaches into the inductors produces the sine waveform. This causes a very low $\%THD_V$.

CONCLUSION

From the presentation of the concept of the average point pulsewidth modulation method, the simulation results and analysis can be concluded. When comparing the $\%THD_V$ of the pulsewidth modulation method between the space vector, the average point at the switch chopper, at a 340 wave frequency at 8,500 Hz, produced the one sine waveform. The simulation results show that the $\%THD_V$ of the space vector pulsewidth modulation method = 0.4% and the $\%THD_V$ of the average point pulsewidth modulation method = 0.6%, which shows that the $\%THD_V$ of both methods is very small. This is due to the fact that the creation of the PWM of the two approaches into the inductors, produces the sine waveform and looks very similar to the sine wave. This causes a very low $\%THD_V$.

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