

IMPROVING THE OUTPUT OF DC-DC CONVERTER BY PHASE SHIFT FULL BRIDGE APPLIED TO RENEWABLE ENERGY

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Key words: Dc-dc converter, Phase shift full bridge converter (PSFB), Proportional–integral controller (PI).

The dc-dc converter is crucial for boosting the output voltage of renewable energy sources, particularly wind energy. In this paper, the dc-dc converters: boost converter, flyback converter, push-pull converter, and phase shift full bridge converter (PSFB) will be compared in terms of output voltage, current and power to determine which one is the best. The phase shift full bridge converter was chosen to improve the dc-dc converter's output. Performance of each converter is simulated using MATLAB/SIMULINK.

1. INTRODUCTION

Renewable energy it is a type of energy that is derived from the natural environment or from sources that can be regenerated naturally and that do not harm the environment when is being used. Renewable energy electricity, on the other hand, is mostly a one-way and unstable energy source that cannot be directly connected to the grid [1].

Currently, the issue is how to regulate the power quality of electricity and integrate renewable energy into the national system to meet the necessary demand. To address this issue, parallel to the power system, the development of converters is needed. The dc-dc converters are commonly utilized in regulated switch mode dc power supplies.

The input of these converters is an unregulated dc voltage output generated by renewable energy systems, which will fluctuate owing to changes in natural factors. Although the input voltage varies, the average dc output voltage in these converters must be managed to be equivalent to the required value.

The dc-dc converters analyzed include boost converter, flyback converter, push-pull converter, and phase shift full bridge converter. The boost converter is analyzed in [2]. The flyback converter is discussed in [3]. The push-pull converter is presented in [4]. The phase shift full bridge converter is discussed in [5–9].

In this paper, are evaluated the converters by comparing the output voltage through simulation using MATLAB/SIMULINK software. Within the paper are compared the steady-state time, mean steady-state value, and range values of each converter. Based on the results obtained is evaluated and chosen the PSFB method to improve the output voltage of the best dc-dc converter.

This article is organized as follows: from an application point of view, the need for a dc-dc converter is discussed in Section 2, the control method of phase shift full bridge converter is discussed in Section 3 and simulation results are discussed in Section 4.

2. DC-DC CONVERTERS UTILITY

2.1. GENERALITIES

Dc-dc converters are widely used in industrial applications and the performance of these applications can be improved by using a variable dc supply. It may also be increased the controllability of the equipment by utilizing a

variable dc supply.

Dc converters can also be used to increase or decrease the voltage by using a semiconductor switch. Dc converters may be used whenever it is needed to efficiently convert dc electrical power from one voltage level to another.

These converters are required because unlike ac power they can simply step up or step down dc power.

2.2. TYPES OF DC-DC CONVERTER

In this study, four different dc-dc converter topologies are considered. These are boost converter, flyback converter, push-pull converter, and full bridge converter [6].

2.2.1. BOOST CONVERTER

As shown in Fig.1, a boost converter is a non-isolated DC-DC converter whose output voltage is always higher than the input voltage ($V_{out} > V_{in}$) [7].

As seen in Fig.1, this topology has a simple structure and a few components. It consists of a dc input voltage source V_S , a boost inductor L , a controlled switch S , a diode D , a filter capacitor C , and a load resistance R .

The duty cycle of the boost converter is generally controlled via pulse width modulation (PWM). When the switch S is ON, the current in the boost inductor increases linearly and the diode D is OFF at that time. When the switch S is OFF, the energy stored in the inductor is released through the diode D to the output RC circuit.

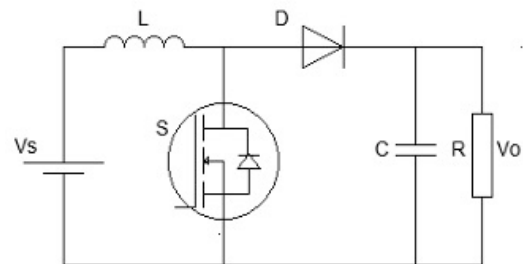


Fig. 1 – Boost converter.

Using Faraday's law for the boost inductor:

$$V_S DT = (V_0 - V_S)(1 - D)T, \quad (1)$$

from which the dc voltage transfer function turns out to be:

$$\frac{V_0}{V_S} = \frac{1}{1 - D}. \quad (2)$$

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2.2.2. FLYBACK CONVERTER

A PWM flyback converter is a very practical isolated version of the buck-boost converter. The buck-boost converter's inductor has been replaced by a flyback transformer. The circuit of the flyback converter is illustrated in Fig. 2.

The flyback converter design is very simple and contains electrical components like a flyback transformer, switch, rectifier, filter, and resistance. The primary transformer is linked in series with the input dc source V_S and switch S. The secondary of the flyback transformer is connected in series with diode D and the RC output circuit.

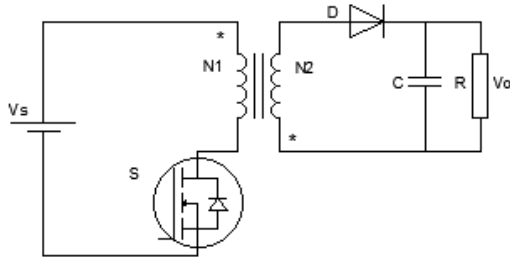


Fig. 2 – Flyback converter.

The primary of the flyback transformer is connected to the supply when the MOSFET is turned on. The current and magnetic flux in the primary side are increased and the energy is stored in it. As the diode in the secondary side is reverse biased, the negative voltage is induced in it. The load receives energy from the output filter capacitor. Current and magnetic flux in the main side are reduced when MOSFETs are turned off. As a result of the positive voltage produced in the secondary side, the diode is forward biased. Energy stored in the transformer is transferred to the output capacitor and the load [8]. The dc voltage transfer function of the flyback converter is:

$$\frac{V_0}{V_S} = \frac{D}{n(1-D)} \quad (3)$$

2.2.3. PUSH-PULL CONVERTER

The PWM dc-dc push-pull converter is shown in Fig. 3.

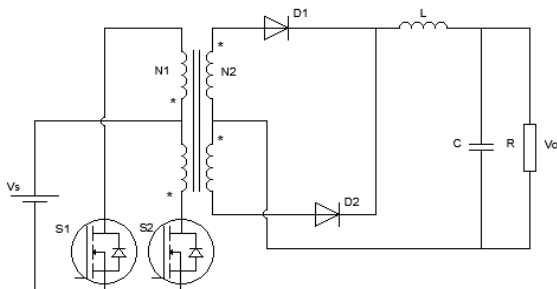


Fig. 3 – Push-Pull converter.

With the same duty ratio D , the switches S_1 and S_2 operate in phase by $T/2$, but the duty ratio must be less than 0.5. When switch S_1 is turned on, diode D_1 conducts and diode D_2 is turned off; when switch S_2 is turned on, the diode states are reversed. The diodes are on while both adjustable switches are off, and they split the filter inductor current evenly. The dc voltage transfer function of the push-pull converter is:

$$\frac{V_0}{V_S} = \frac{2D}{n} \quad (4)$$

where:

$$n = N_1/N_2.$$

2.2.4. PHASE SHIFT FULL BRIDGE CONVERTER

In Fig. 4 is illustrated the V_S , which is the input voltage. Four power valves S_1, S_2, S_3 and S_4 are commanded to open and close to create pulse voltage applied to the transformer primary winding. Pulse transformer provides voltage isolation and step-up between the input and output voltages of the system. On the secondary side of the pulse transformer, pulse diodes D_1, D_2, D_3, D_4 are used to rectify the voltage. The inductor L and the capacitor C are the filter to filter the high-frequency components. The voltage after the filter will be the dc voltage.

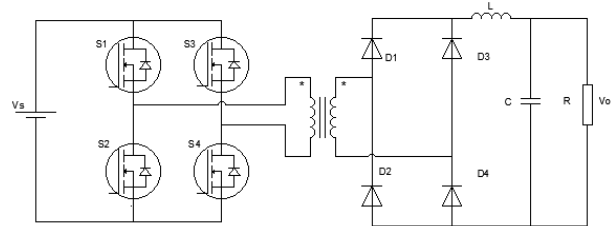


Fig. 4 – Phase shift full bridge converter.

The full bridge converter (FBC) illustrated in Fig. 4 has four MOSFET's working together, and the switch voltage is the same as the input voltage. The controllable switches are operated in pairs. The pair of controlled switches is used. Voltage V_S is supplied to the primary of the transformer when S_1 and S_4 are turned on, and the diode D_1 and D_4 will conduct. There is the voltage $-V_S$ across the primary transformer with S_2 and S_3 on, and the diode D_2 and D_3 will conduct. With all controllable switches off, both diodes conduct, similarly as in the push-pull converter. The dc voltage transfer function of the full-bridge converter is:

$$\frac{V_0}{V_S} = \frac{D}{n} \quad (5)$$

where:

$$D \leq 0.5.$$

3. CONTROL METHOD OF PHASE SHIFT FULL BRIDGE CONVERTER

Within this study is applied the phase shift control method to feedback the output voltage signal of the phase shift full bridge dc-dc converter.

The feedback voltage signal V_{out_dc} will be compared with the set voltage signal V_{ref} to obtain an error signal. This signal will be passed through PI controller to obtain the phase value. Phase value will be limited in the range $[0, 180^\circ]$ by using a limiter. The phase will be sent into the PWM generating block, which will calculate the phase shift time t_{phase} for the PWM control pulse generation algorithm. The control of phase shift full bridge converter is shown in Fig. 5.

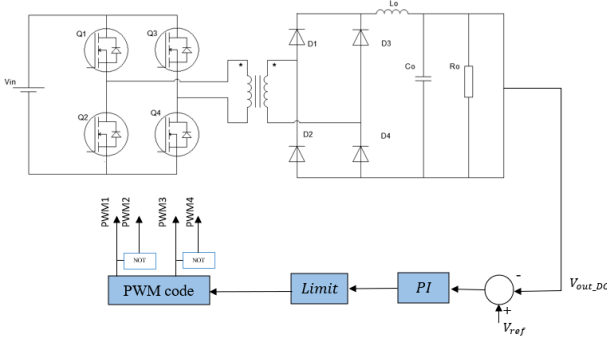


Fig. 5 – General control diagram for PSFB Converter.

The transfer function of the PI controller is given by eq. (6). This transfer function will be simulated in MATLAB/SIMULINK in the structure as shown in Fig. 6:

$$G_{PI}(s) = K_P + K_I \times \frac{1}{s}. \quad (6)$$

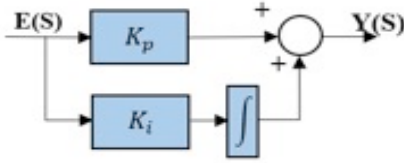


Fig. 6 – PI controller.

The flowchart of PWM generation algorithm is illustrated in Fig. 7 and consists of 8 steps:

- Step 1: When the algorithm runs: $time = 0s$, $frequency = 17 \text{ kHz}$, $t_{sample} = 0.5882 \mu s$, $phase = \text{Result-out-of-PI}$.
- Step 2: Switching cycle: $t_{switch} = 1 / frequency$. Set the pulse width modulation control pulse: $PWM_1 = 0$, $PWM_2 = 0$. Calculate MOSFET turn-on/turn-off time with Duty = 0.5 so $t_f = 0.5 \times t_{switch}$.
- Step 3: Calculate y_1 by dividing time by t_{switch} and returning the remainder. In programming, we employ the Modulo structure:

$$y_1 = \text{mod}(time, t_{switch}). \quad (7)$$

- Step 4: y_1 is verified. If y_1 is less than t_f ($y_1 < t_f$) then set $PWM_1 = 1$, otherwise set $PWM_1 = 0$. This indicates that the MOSFET will be in the ON state for the first half of the PWM_1 pulse and the OFF state for the second half of the PWM_1 .
- Step 5: Calculate the phase-shift time using the formula $t_{phase} = t_{switch} \times phase / 360$. To find y_2 , divide $(time + t_{phase})$ by t_{switch} and return the remainder. In programming, we employ the Modulo structure:

$$y_2 = \text{mod}(time + t_{phase}, t_{switch}). \quad (8)$$

- Step 6: Look at y_2 . If y_2 is less than t_f ($y_2 < t_f$) then set $PWM_2 = 1$, otherwise set $PWM_2 = 0$. This indicates that the MOSFET will be in the ON state for the first half of the PWM_2 pulse and the OFF state for

the second half of the PWM_2 .

- Step 7: Calculate the working time of the algorithm: $time = time + t_{sample}$ where t_{sample} is the sampling time.
- Step 8: If the algorithm running time exceeds the PSFB converter running time: $time > t_{matlab}$ (is used t_{matlab} because MATLAB/SIMULINK is used to simulate the model), the algorithm will cease functioning; otherwise, return to Step 3.

With the PWM control pulse generation algorithm presented above and two NOT gates, four control pulses PWM_1 , PWM_2 , PWM_3 and PWM_4 are obtained to control the power valves of the PSFB converter.

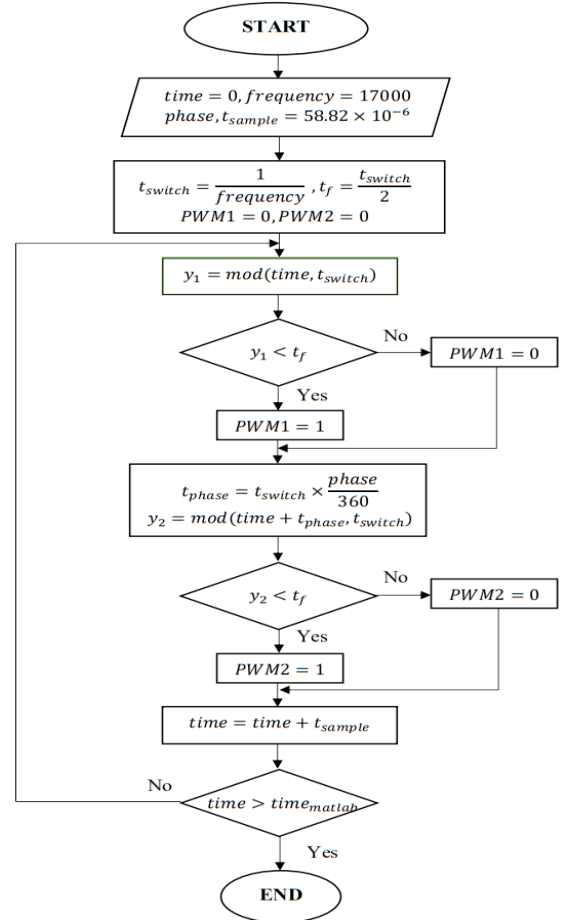


Fig. 7 – Flowchart of PWM generation algorithm.

4. SIMULATION RESULTS

The performance of above dc-dc converter is studied by using MATLAB/SIMULINK as shown in Fig. 15 and Fig. 16. We have the main converter design parameters as shown in Table 1:

Table 1.

Main converter design parameters.

Input voltage	330V – 400V
Output voltage	660V
Output current	8.33A
Output power	5.5kW
Switching frequency	17kHz

4.1. VOLTAGE RESULTS

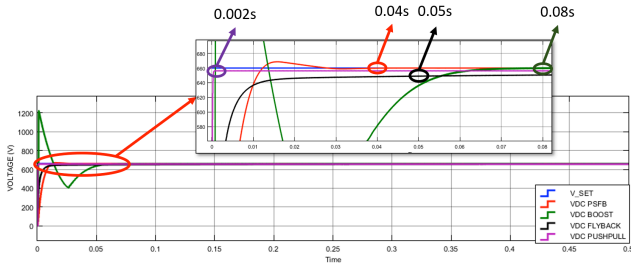


Fig. 8 – Performance of different dc-dc converter regarding the steady-state time.

Table 2

	Boost	Flyback	Push-Pull	PSFB
Color				
Steady-state time(s)	0.08	0.05	0.02	0.04
Evaluation	-	+	++	+

In Fig. 8 is illustrated the steady-state time of the output voltage of each dc-dc converter. They will be analyzed in Table 2. The output of push-pull converter in the purple line has the shortest steady-state time as 0.002 s and the steady-state time of PSFB converter in the red and flyback converter in black line are the 2nd shortest with values 0.04 and 0.05 respectively. The steady-state time of boost converter in the green line is the worst with a value of 0.08. So, we can choose push-pull converter, PSFB converter and flyback converter to get the good steady-state time.

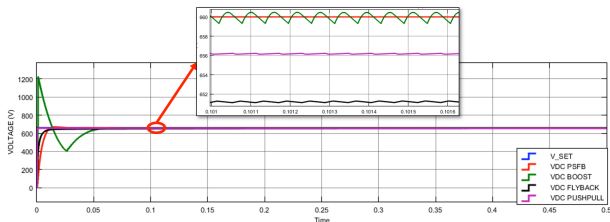


Fig. 9 – Performance of different dc-dc converter regarding the steady-state value of the output voltage.

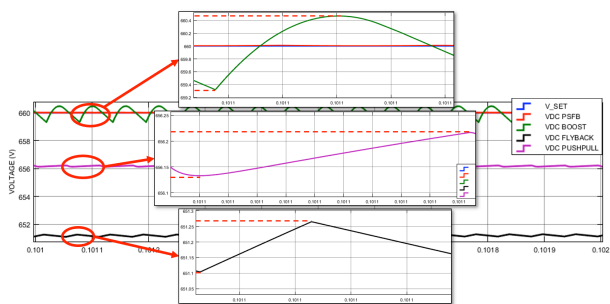


Fig. 10 – Performance the different dc-dc converter regarding the voltage-range value.

In Fig. 9 the output voltage of dc-dc converter presented in Fig. 8 is zoomed in to check the steady-state value of each converter. In Fig. 10 is zoomed in the output voltage of each converter presented in Fig. 9 to evaluate the voltage-range value of them. The results will be analyzed in Table 3.

Table 3

	Boost	Flyback	Push-Pull	PSFB
Color				

Mean steady-state value (V)	659.9	651.177	656.175	660
Evaluation (1)	++	-	+	++
Range value (V)	[659.3, 660.5]	[651.1, 651.255]	[656.125, 656.225]	~660
Evaluation (2)	-	+	+	++

In Table 3 is presented the mean steady-state value and the voltage-range value of each dc-dc converter. The mean steady-state value of phase shift full bridge (PSFB) converter and boost converter are closed to the required voltage value as 660 V. The mean steady-state value of flyback converter and push-pull converter are 651.177 V and 656.175 V, so they do not reach the required value. From the range value of each converter, it is obtained the error value of PSFB converter which is the smallest and approximately equal to 0 V.

With the steady-state time shown in Table 2, the mean steady-state value and the error value of voltage-range value shown in Table 3, it can be concluded that the PSFB converter has the best output voltage compared to the other converters.

4.2. CURRENT RESULTS

In this study, it was required an output current equal to 8.33 A. In Fig. 11 is illustrated a zoom in view for the output current of dc-dc converter, to check the steady-state value of each converter.

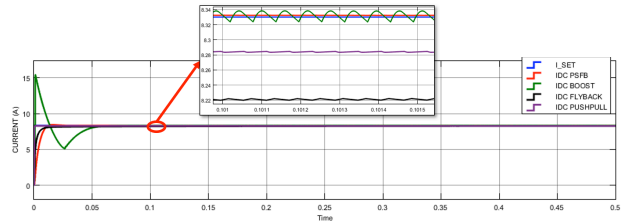


Fig. 11 – Performance the different dc-dc converter regarding the steady-state value of the output current.

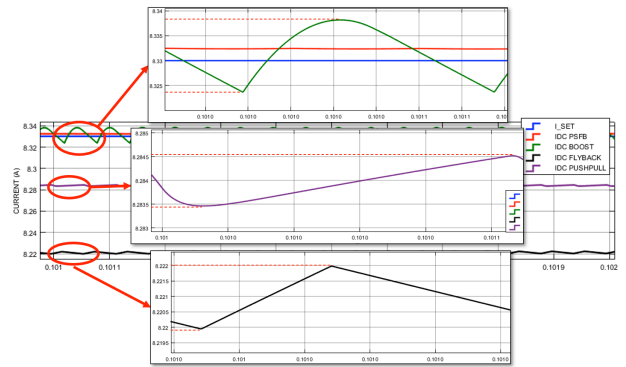


Fig. 12 – Performance the different dc-dc converter regarding the current-range value.

Figure 12 presents the zoom in view for the output current of each converter illustrated in Fig. 11 to evaluate their current-range value. The results are analyzed in Table 4.

Table 4

	Boost	Flyback	Push-Pull	PSFB
Color				
Mean steady-state value (V)	8.325	8.221	8.284	8.332
Evaluation (1)	++	-	+	++
Range value (A)	[8.315, 8.335]	[8.198, 8.222]	[8.2835, 8.2845]	~8.332
Evaluation (2)	-	+	+	++

In Table 4, are presented the mean steady-state value and the current-range value of each dc-dc converter. The mean steady-state value of phase shift full bridge (PSFB) converter and boost converter are closed to the required current value of 8.33 A. The mean steady-state value of flyback converter and push-pull converter are 8.221 A and 8.284 A, so they do not reach the required value. For the current-range value of each converter, the error value of PSFB converter is the smallest and approximately equal to 0 V.

Based on the mean steady-state value and the error value of current-range value shown in Table 4, it can be concluded that the PSFB converter has the best output current compared to the other converters.

4.3. POWER RESULTS

In this study it was required an output power equal to 5500 W. In Fig. 13 is illustrated a zoom in for the output power of dc-dc converter, to check the steady-state value of each converter. Then, as shown in Fig. 14, is illustrated a zoom in of the output power of each converter in Fig. 13 to evaluate the power-range value of them. The results will be analyzed in Table 5.

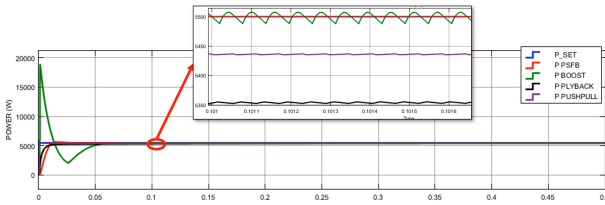


Fig. 13 – Performance the different dc-dc converter regarding the steady-state value of the output power.

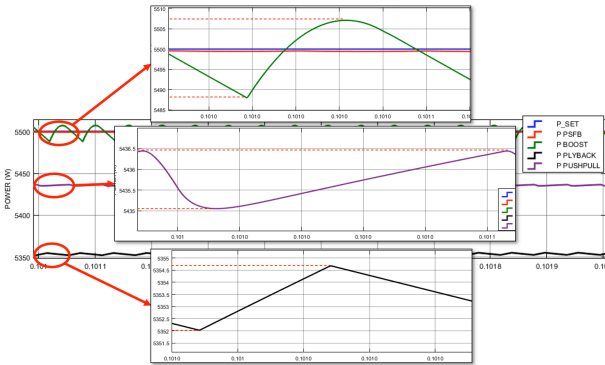


Fig. 14 – Performance the different dc-dc converter regarding the power-range value.

Table 5

	Boost	Flyback	Push-Pull	PSFB
Color				
Mean steady-state value (W)	5493.67	5353.33	5435.75	5499.1
Evaluation (1)	++	-	+	++
Range value (W)	[5485.5, 5506.84]	[5352.1, 5354.56]	[5435, 5436.5]	~5499.1
Evaluation (2)	-	+	+	++

In Table 5, are presented and analyzed the mean steady-state value and the power-range value of each dc-dc converter. The mean steady-state value of Phase Shift Full bridge (PSFB) converter and boost converter are closed to the required voltage value of 5500 W. The mean steady-state value of flyback converter and push-pull converter are 5353.33 W and 5435.75 W, so they do not reach the required value. From the power-range value of each

converter, it is obtained the error value of PSFB converter which is the smallest and approximately equal to 0 V.

With the mean steady-state value and the error value of power-range value shown in Table 5, it can be concluded that the PSFB converter has the best output power compared to the other converters.

After analyzing the voltage, current and power results, it resulted that the phase shift full bridge (PSFB) converter has the best performance compared to the other three converters (boost converter, flyback converter, push-pull converter).

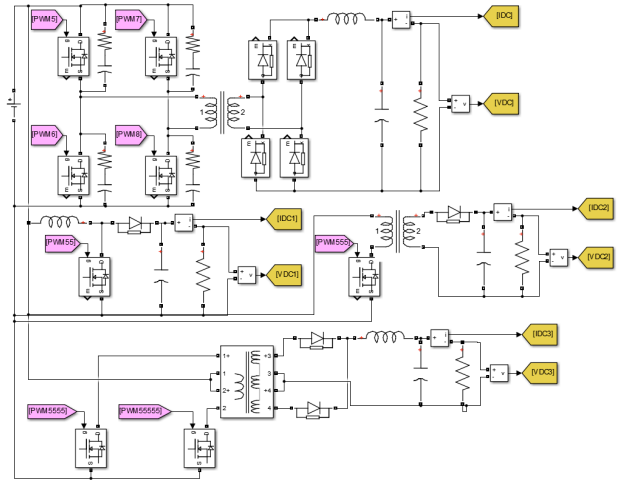


Fig. 15 – General simulation diagram.

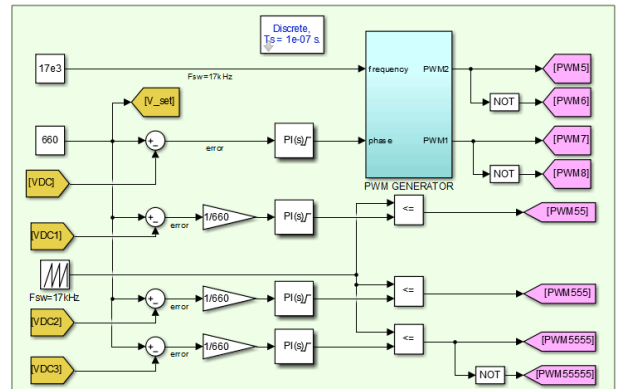


Fig. 16 – Converter control block.

5. CONCLUSIONS

This paper presented about the phase shift full bridge converter and how to control this converter by using phase shift control method. The phase shift full bridge converter is compared with the converters (boost converter, flyback converter and push-pull converter) in terms of output voltage, current and power. From there, it is proved that the phase shift full bridge converter is better than other converters. The eminent results with the help of MATLAB/SIMULINK tool are the efficient operation of the proposed converter.

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