JTVE, Special Edition NARTC 2024, Vol 9, No 2 (2024)
eISSN: 0128-0821
http://upikpolimas.edu.my/ojs/

Hybrid Diodes & MOSETs for Three Phase Half Wave Controlled Rectifier

Effendi[1], Zakwansyah[2]
Department of Electronics Technology, Aceh Polytechnic, Indonesia

Abstract: Power electronics is an application that is used to control and convert electrical power from one form to another using electronic components, for example three-phase half-wave-controlled rectifier, generally uses SCRs, its output voltage can be controlled by adjusting the delay angles of SCRs. In this research, SCRs can be replaced with hybrid silicon diodes and MOSFETs, its control system is designed by using electronic components such as op-amps, AND gates, and several other basic electronics components, and used low voltage so that three-phase input voltage must be lowered by using transformer in a star connection and then connected to three phase half wave rectifier circuit. To compare the output of a three-phase half-wave rectifier with Vref is needed comparator 1, this circuit aims to get the starting point of the triangular wave that is produced from the triangle wave circuit exactly at the cross-over point of the three-phase voltage wave, to control the MOSFET S1 delay angle can be done by adjusting the Vangles on the comparator 2, while the Sa, Sb, and Sc are activated by the comparator 3 and the AND gate circuit. Based on the simulation results by using a computer, this hybrid circuit output voltage approximates to the SCRs circuit with a resistive load, thus this proposed circuit can be an alternative to a replacement conventional circuit that uses SCRs.

Keywords: *Three-phase controlled rectifier, SCR, Hybrid Silicon Diodes and MOSFETs, Op-Amp, delay angles*

1.0 INTRODUCTION

Power electronics is the application of solid-state electronics to control and conversion of electric power from one form to another by using electronic devices(Hart W, 2011; Mohan et al., 2003; Priyadharshini et al., 2020; Rashid, 2007; Singh & Khanchandani, 2007). Three phase supply ac–dc power converters or rectifier circuits are used widely in many applications such as variable-speed drives, UPS (uninterrupted power system), battery chargers, and many other applications(Cai et al., 2009; Grbović et al., 2011; Jadhav et al., 2015; Memon et al., 2014; Premkumar et al., 2020; Priyadharshini et al., 2020; Shneen & Aziz, 2021). Three phase converters provide higher average output voltage compared to single phase converters, these reasons make three phase converters are used extensively in high power variable speed drives application (Rashid, 2007). Thyristors or silicon controleld rectifiers (SCRs), are widely used for control of power in many areas of electronics industrial applications(Hart W, 2011; Mohan et al., 2003; Rashid, 2007; Singh & Khanchandani, 2007)(Ovais et al., 2016). These devices are even referred to as high-power electronic core components, because they are able to switch large levels of power with a variety of different applications(Chakraborty & Osman, 2015).

The aim of three phase controlled rectifier is to convert the alternating current (AC) into direct current (DC) with output value that can be varied(Asnil et al., 2019), by adjusting the firing angle of the thyristor(Wallace et al., 2002)(Zhou et al., 2014). These gating circuits that used are usually low-power electronic circuits(Rangras & Acharya, 2012). The proposed three-phase half wave controlled rectifier circuit in this research uses hybrid method (diode and MOSFET) in order to replace the SCR function where the resulting output voltage is approximate to the SCRs output voltage according to the result of exprement simulation.

2.0. Basic Consept Three Phase Half Wave Controlled Rectifier with Resistive Load

The power circuits of a three phase half wave controlled rectifier topology with resistive load as shown in Figure 1. This circuits is called as the mid-point configuration circuit because all of the phase emfs (electromagnetic fields) have a common terminal which may be considered as the neutral point or center tap point, the secondary transformer is connected in star connection and the resistive load is connected to the neutral point. The leakage inductance and drops voltage on SCR are assumed to be zero in order for simplify mathematics analysis of the circuit(Singh & Khanchandani, 2007). Three phase voltage input (phase A, B, and C) with reference to the neutral as shown in Figure 2, V_{an}, V_{bn}, and V_{cn} are the sources voltage of three phase and can be expressed mathematically by using equations (1), (2), and (3) where Vm is the peak amplitude voltage that measured from the neutral to the maximum amplitude on the secondary side of the transformer, the voltage source frequency that used in this research is 50 Hz(Rashid, 2007)(Singh & Khanchandani, 2007)(Effendi & Haikal, 2020).

The cross over points angle of the voltage waveform can be found by using equations (1), (2), and (3), the delay angle α is measured from the cross over points, as shown in Figure 2 SCR T1 will start conducting from $\alpha = 30^o$ to $\alpha = 150^o$, SCR T2 will conduct from $\alpha = 150^o$ to $\alpha = 270^o$, and SCR T3 will conduct from $\alpha = 270^o$ to $\alpha = 390^o$(Singh & Khanchandani, 2007). When T1 is conducted at $\omega t = \pi/6 + \alpha$, the phase voltage Van appears across the resistif load until T2 is fired at $\omega t = 5\pi/6 + \alpha$. When T2 is conducted, thyristor T1 is reverse biased position, because the line to line voltage is negative and T1 is back to turned off again. The Vbn phase voltage appears across the load until T3 is conducted at $\omega t = 3\pi/2 + \alpha$. When T3 is conducted,T2 is back to truned off and Vcn appears across the load until T1 is fired again at the beginning of next cycle in this systems(Rashid, 2007). The voltage across the load has the positive supply voltage and has the waveforms as shown in Figure 3, by using resistive load, there are two modes of conduction, (a) continuous conduction mode for $\alpha < 30^o$, the output voltage can be calculate by equation (4), (b) discontinuous conduction mode for $\alpha > 30^o$ and the output voltage can be found by equation (5)(Rashid, 2007)(Singh & Khanchandani, 2007).

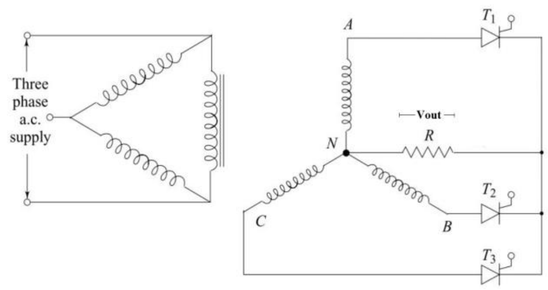

Figure 1. Three phase half wave-controlled rectifier

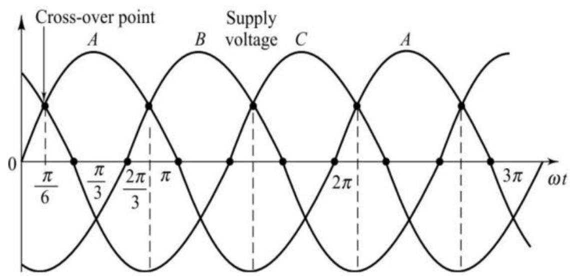

Figure 2. Three phase supply voltage

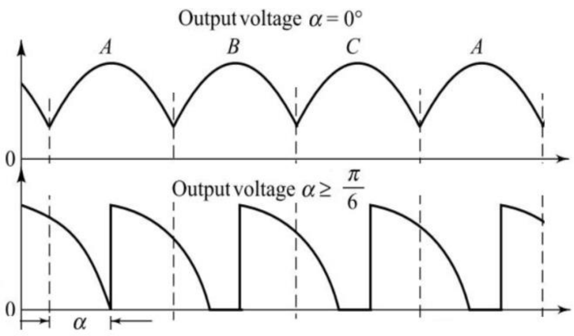

Figure 3. Waveforms for three phase with resistive load

$$V_{an} = V_m \sin(\omega t) \tag{1}$$

$$V_{bn} = V_m \sin\left(\omega t - \frac{2\pi}{3}\right) \tag{2}$$

$$V_{cn} = V_m \sin\left(\omega t + \frac{2\pi}{3}\right) \tag{3}$$

Output for countinous :

$$V_o = \frac{3}{2\pi} \int_{\frac{\pi}{6}}^{\frac{5\pi}{6}+\alpha} V_m \sin \omega t \, d(\omega t) \tag{4}$$

Output for noncountinous :

$$V_o = \frac{3}{2\pi} \int_{\frac{\pi}{6}+\alpha}^{\pi} V_m \sin \omega t \, d(\omega t) \tag{5}$$

3.0 METHODOLOGY

Three phase half wave-controlled rectifier components in generally still use SCR for rectifired, but in this research, the SCR components can be replaced by using a hybrid method that combine silicon diodes and MOSFETs. The diagram block of the circuit proposed in this research can be seen in Figure 4, where this system can be divided into two parts, namely the power circuits and the control circuit. In the power circuit, there are four units MOSFET and seven silicon diodes that are used while the control circuit is constructed by using basic electronics components such as op-amp, AND gate, capacitor, and etc.

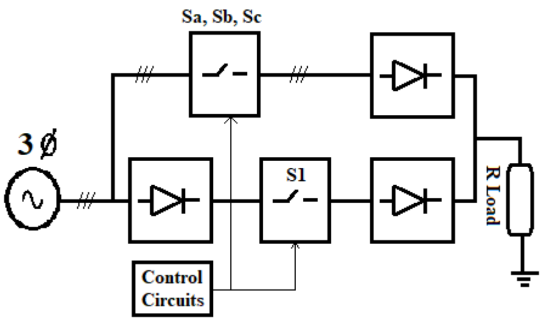

Figure 4. Diagram block proposed circuit

Control Circuit

The control circuit in this proposed research can be seen in Figure 5, where the power supply system still uses low voltage so that the three-phase source must be lowered by using a transformer that arranged in Y: Y connection, and then connected to several other supporting components, the output of this circuit is then used to trigger gate MOSFETs in power circuits.

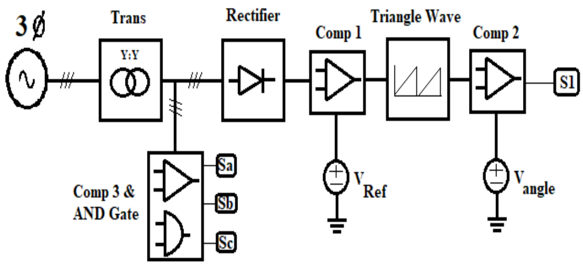

Figure 5. Diagram block circuits control

Transformer

The transformer circuit used in the control system section of this research can be shown in Figure 6, it is connected in a star (Y: Y) connection, output of this transformer circuit further connected to three phase half wave silicon diodes rectifier circuit, comparator 3 and AND gates.

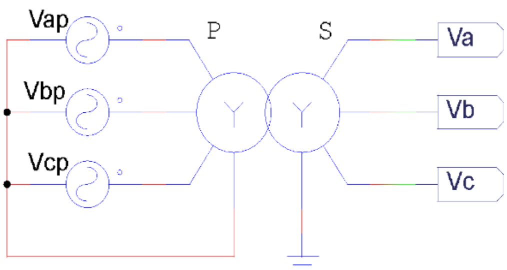

Figure 6. Transformer three phase

Rectifier

The rectifier circuit used in this proposed research was designed by using three silicon diodes as shown in Figure 7 (three phase half wave rectifier). The output of this rectifier furthermore connected to comparator 2 circuit.

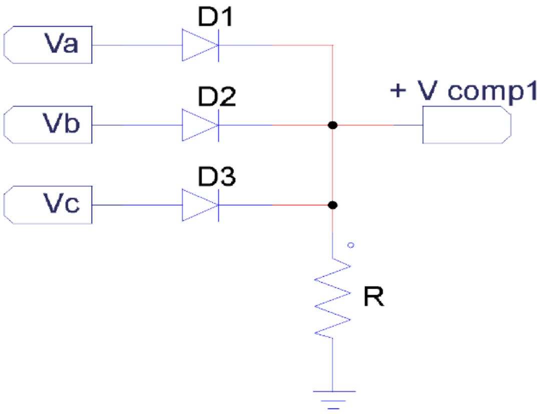

Figure 7. Three phase half wave rectifiers

Comparator 1

Circuit of comparator 1 as shown in Figure 8 designed to compare the output wave from the half wave rectifier circuit in Figure 7 with the reference DC voltage (Vref)(Effendi & Haikal, 2020). The aim this circuit is to get the starting point of the triangular wave exactly at the cross over point of the three phase voltage wave as shown in Figures 9 and 10.

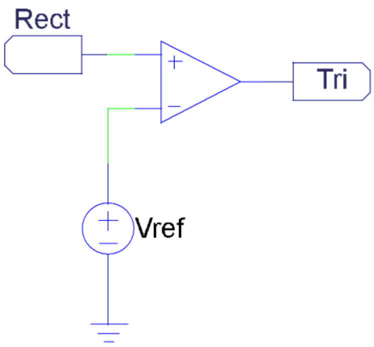

Figure 8. Comparator 1 circuit

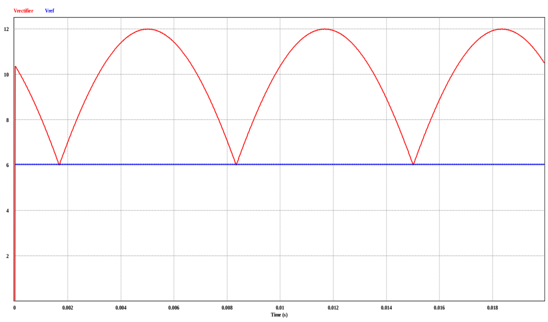

Figure 9. Output three phase half wave rectifier and Vref

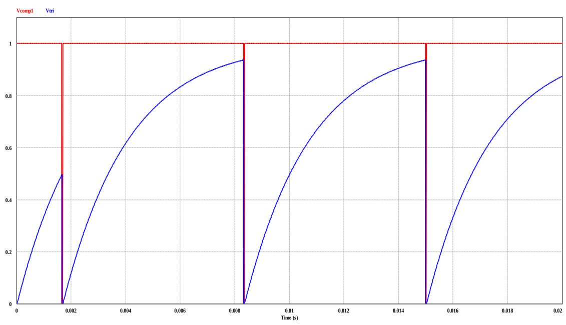

Figure 10. Output comparator 1 and triangle wave

Triangle Wave Circuit

The triangle wave generator circuit as in Figure 11 designed to convert the pulse wave that produced from comparator 1 circuit into a triangle wave as shown in Figure 10, the output of this circuit futhermore connected to comparator 2 circuit.

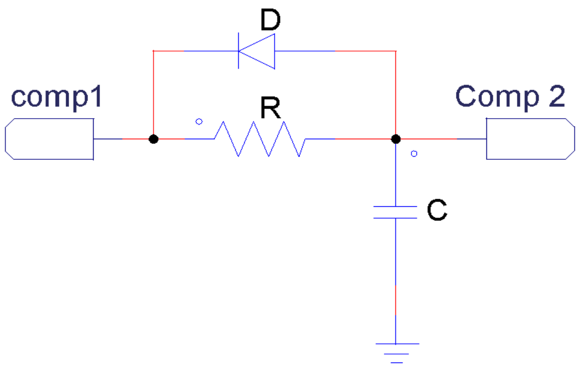

Figure 11. Triangle wave generator circuit

Comparator 2

The comparator 2 circuit as shown in Figure 12 is designed to compare the output wave of the triangle wave circuit with DC Voltage (Vangle), changes in the Vangle voltage value will affect changes in the delay angle of the output waveform on the load side, the output of this comparator 2 circuit is in the form of pulses as shown in Figure 13, futhermore this pulse is used to trigger the gate of MOSFET S1.

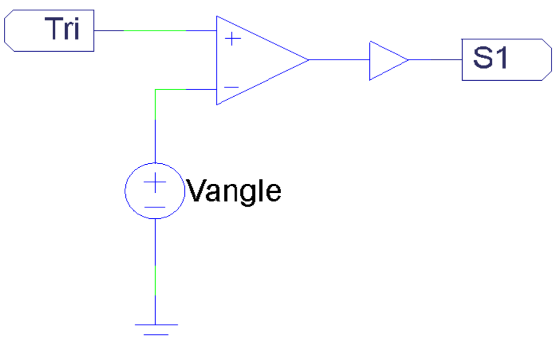

Figure 12. Comparator 2 circuit

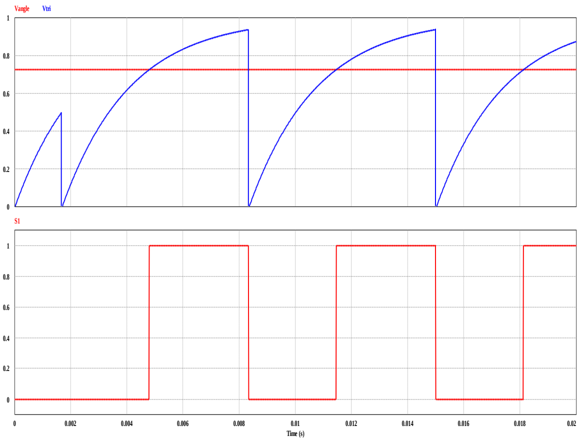

Figure 13. Triangle wave, Vangle and output comparator 2

Comparator 3 & AND Gate

The Comparator 3 & AND Gate circuit as shown in Figure 14 is designed to detect changes in phase toward neutral and changes between phase and other phase. The output of this circuit can be seen in Figure 15. This pulse wave furthermore used to drive the Sa, Sb, and Sc MOSFETs gate according to the sequence.

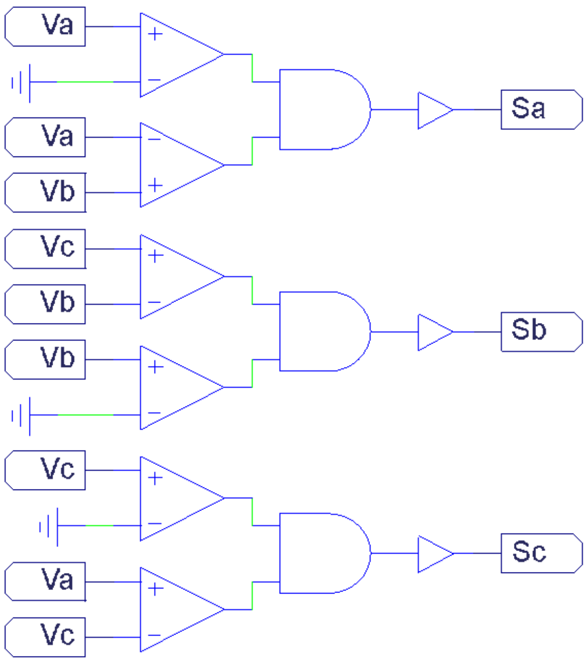

Figure 14. Comparator 3 and AND gate circuit

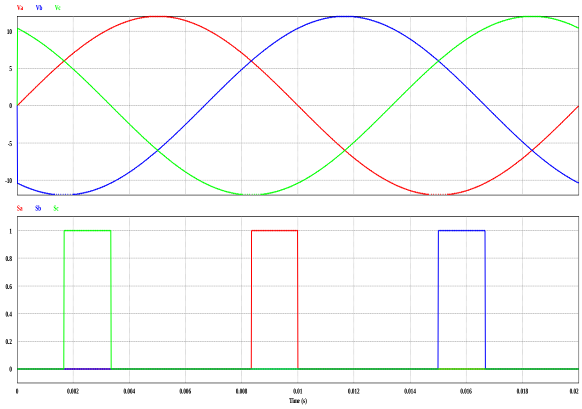

Figure 15. Pulse output Comparator 3 and AND gate circuit

Power Circuit

The power circuit that used in this research proposed uses seven silicon diodes and four MOSFETs with resistive loads as shown in Figure 16, where the input voltage source is connected in a star connection (Y) with a source frequency of 50 Hz and voltage amplitude 220 Volt.

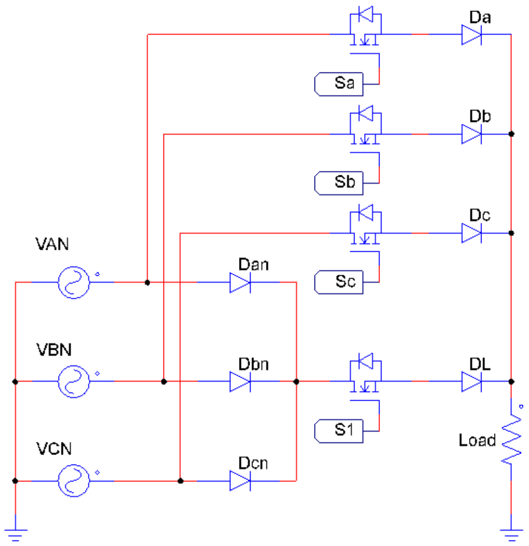

Figure 16. Power circuit

4.0 Data Analysis and Findings

The results simulation of this hybrid diode and MOSFET circuit in this research can be seen in Figure 17 where the delay angle (firing) used is 10^o, while in Figure 18 the delay angle used is 60^o. The simulation results for several other delay angles with its output voltages can be seen in Table 1.

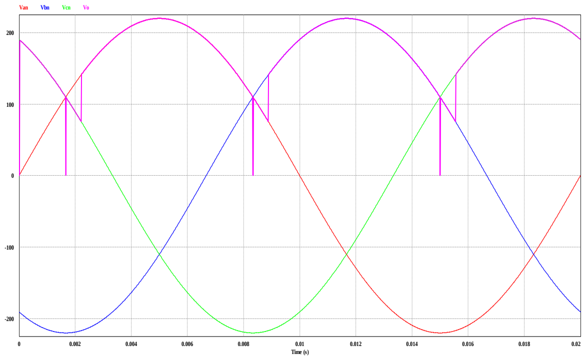

Figure 17. Output with delay angle 10^o

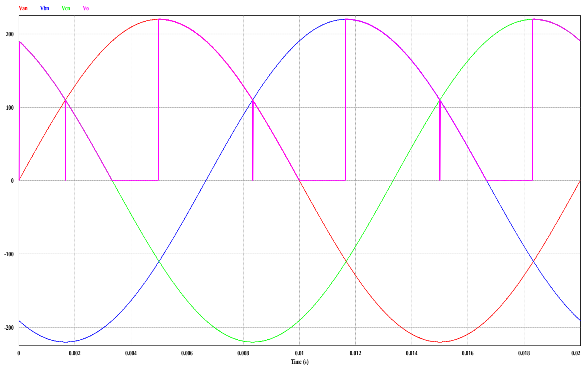

Figure 18. Output with delay angle 60^o

Based on the results of the simulation test for a three-phase half wave rectifier circuit with a resistive load by using hybrid diode silicon and MOSFET circuit method in this proposed research, the output voltage results approximatly to the three-phase half wave rectifier circuit results that uses SCR's. This can be seen in table 1 where the diffrent output voltage that produce by the two methods is relatively small. The output voltage comparison between SCR and the hybrid method according to delay angle changes can be seen graphically in Figure 19.

Table 1. Simulation results

No	**α**	**SCR (Volt)**	**Hybride (Volt)**	**Δ|V| (Volt)**
1	10^o	179,179	178,813	0,366
2	20^o	170,955	170,620	0,335
3	30^o	157,515	157,146	0,369
4	40^o	140,985	140,417	0,568
5	50^o	123,264	122,908	0,356
6	60^o	104,987	104,852	0,135
7	70^o	86,819	86,463	0,356
8	80^o	68,098	68,633	0,465
9	90^o	52,473	52,199	0,274
10	100^o	37,536	37,854	0,318
11	110^o	24,563	24,930	0,367

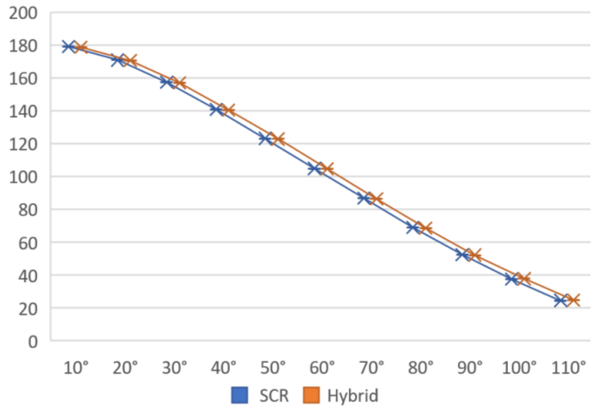

Figure 19. Output voltage SCRs and hybrid method

5.0 DISCUSSION AND CONCLUSIONS

Based on simulation results by using a computer, the hybrid silicon diode and MOSFET circuit proposed in this research produces output voltage data that is relatively the same as a conventional controlled rectifier circuit using a component in the form of an SCR, where the resulting error is no more than 1 volt for several delay (firing) angels tested, in general the proposed circuit is stated to function as a three-phase half-wave controlled rectifier with a resistive load, thus this proposed circuit can be an alternative controlled rectifier as a replacement for the conventional circuit that uses SCR's component.

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