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Single-phase uncontrolled full-wave rectifier on a three-phase AC generator.

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Abstract

A rectifier circuit is designed to convert alternating current (AC) generated by a generator into direct current (DC). The primary component used in this circuit is a diode. A rectifier can be either controlled or uncontrolled, with both types operating on the principle of converting an AC voltage source into a DC voltage source. One key advantage of a single-phase rectifier system is its ability to deliver high output power, as the negative voltage of the AC signal is converted into a positive voltage. In an uncontrolled rectifier circuit, the addition of a capacitor serves as an active filter, minimizing ripple and ensuring a more stable DC output. The methodology for this study includes several stages: identification, analytical calculations, system flowchart development, simulation design, and data collection related to measurements. By following these steps, we can gain a comprehensive understanding of the full-wave single-phase rectifier circuit in a three-phase AC generator, ultimately leading to a well-founded conclusion.

Keywords: Single Phase Uncontrolled Rectifier Circuit, AC Generator, AC Signal

1. Introduction

A power electronics circuit is an electrical system designed to modify a power source with a specific waveform, such as converting a sine wave into another form (Saodah et al., 2021). In these circuits, semiconductors serve various roles, including switching, conversion, and control, depending on the circuit's intended function.

A rectifier is a crucial component within power electronics, responsible for converting alternating current (AC) from a generator into direct current (DC) (Arpin, 2020) (Murtono, 2017). This process can result in either a fixed or unregulated DC output (Jatmika, Syakur, & Afrisal, 2021). Based on the power source, uncontrolled rectifiers are classified into two types: single-phase and three-phase. Fundamentally, a rectifier circuit comprises a transformer, diodes, and capacitors (Asnil, 2020). The transformer temporarily stores charge and also functions as a filter, while diodes act as rectifiers, ensuring current flow safety, regulating voltage, and blocking reverse currents (Apriliyana, 2018). The primary role of a diode in this circuit is to allow current to flow in only one direction while preventing it from flowing in the opposite direction (Atmam, Zondra, & Monice, 2020). As a result, when an AC voltage is applied, only the positive half of the waveform passes through, while the negative half is blocked.

Rectifier circuits are categorized into two types: half-wave and full-wave rectifiers (Zamroni, 2018) (Rahmad, Pradana, & Kurniawan, 2021). Full-wave rectifiers can be implemented in two ways: using either two diodes with a center-tapped (CT) transformer or four diodes without a CT transformer. The four-diode configuration, known as a full-wave bridge rectifier, is widely used in power circuits due to its superior performance (Abdullayev, 2022). This rectifier ensures that only the positive half of the waveform is utilized. When the AC input is positive, the diodes are forward biased, allowing current to flow to the load. Conversely, during the negative cycle, the diodes are reverse biased, preventing current flow (Asri et al., 2022). This results in a rectified waveform where only positive voltages are present, forming a characteristic output curve (Nugraha, Riyadi, & Adzani, 2023).

The working principle of a synchronous generator is based on electromagnetic induction. When the rotor is rotated by a prime mover, the rotor poles follow the movement. If the pole windings are energized with DC voltage, a rotating magnetic field forms on the pole surface (Nugraha et al., 2020). According to Faraday’s Law, moving a conductive material through a magnetic field induces an electric current. This principle enables an alternator to generate AC power (Nugraha et al., 2022a). Typically, an alternator consists of two terminals with positive and negative poles. The design of the circuit ensures that the winding terminals remain electrically isolated while being connected via a single slip ring.

The primary function of a generator is to convert mechanical energy into electrical energy. Given the widespread use of electronic devices, generators play a crucial role in providing electrical power. Many household appliances require direct current (DC) to operate, whereas the power supplied by the grid is typically alternating current (AC) at 220V/50Hz (Ivannuri & Nugraha, 2022). This discrepancy necessitates rectifier circuits that convert AC to DC, commonly integrated into power supplies.

This study employs several circuit components, including resistors, voltage sources, and measuring instruments. The load and voltage source values used include 410Ω and input voltages of 30V, 45V, and 60V. After constructing the circuit, output measurements will be conducted and compared with theoretical calculations. The comparison will reveal any discrepancies and provide insights into the accuracy of the applied methodology.

2. Material and methods

2.1. Previous Study

The previous study referenced in this research includes the work of A. Jatmika, A. Syakur, and H. Afrisal, titled Designing a DC Voltage Source as a Flyback Driver Supply Using a Triac Dimmer Module and an Uncontrolled Single-Phase Full-Wave Rectifier for Wireless Application in Window Trap. This study utilizes a full-wave single-phase uncontrolled rectifier circuit along with a Triac Dimmer module to regulate voltage in its application. The rectifier circuit serves as a means to convert alternating current (AC) voltage into direct current (DC) voltage (Wibisono, Sukmadi, & Facta, 2018).

In terms of control, rectifier circuits are classified into two types: controlled and uncontrolled. A variac is commonly used as a voltage regulator for circuit input. However, with advancements in electronics, variacs can be replaced by similar electronic components that are more accessible and practical, such as Triac dimmers (Yanto et al., 2019).

To reduce ripple in the DC output voltage, filter components such as a diode bridge and a capacitor are implemented in the circuit. The primary objective is to achieve a more stable DC voltage output, as lower ripple levels result in a more consistent voltage. Therefore, the filter plays a crucial role in circuit performance (Atmam, 2017).

The fundamental components of a rectifier circuit include semiconductor elements and a transformer. The rectifier functions similarly to a switch, with its resistance varying based on the direction of current flow, allowing current to pass from the anode to the cathode. In an AC circuit, a diode conducts current when it is forward-biased, aligning with the correct polarity of the alternating voltage. Conversely, when a diode is reverse-biased, it restricts current flow, producing only a negligible current that can be disregarded. (Muhammad, n.d.).

2.2. Methods

In this circuit, several questions arise regarding the impact of running the circuit without a load compared to using an R-C load. Specifically, it is important to determine whether significant changes occur under these different conditions (Nugraha & Fathin, 2024). During simulation, each voltage setting will generate a distinct waveform, leading to variations in the recorded measurement results. These measurements will then be compared with theoretical calculations to assess accuracy. By following this approach, we can determine whether experimental results align with theoretical predictions. A deeper analysis of these comparisons helps in understanding the efficiency and performance of the rectifier circuit under various load conditions. If discrepancies arise between theoretical and experimental values, potential factors such as component tolerances, voltage fluctuations, and circuit losses can be examined (Nugraha & Ivannuri, n.d.). Furthermore, understanding these variations allows for optimization of the rectifier circuit to enhance its stability and efficiency. After completing these steps, an analysis will be conducted to interpret the observed circuit behavior during simulation and to explain the underlying reasons for these outcomes. Finally, a conclusion will be drawn based on the research findings, providing insights into circuit performance and potential improvements for future applications.

The findings from this research not only provide insights into the performance of the rectifier circuit under different load conditions but also contribute to a better understanding of how various circuit parameters influence output characteristics (Nugraha & Adi, 2024). By analyzing the differences between theoretical calculations and experimental measurements, this study helps identify key factors affecting circuit efficiency, such as diode voltage drops, transformer losses, and ripple effects. Moreover, the data obtained from simulations can serve as a reference for designing more efficient rectifier circuits in practical applications, ensuring better voltage regulation and improved power conversion (Achmad & Nugraha, 2022). Future research can explore advanced filtering techniques or modifications in circuit design to further minimize ripple and enhance output stability. The conclusions drawn from this study will serve as the foundation for further developments in power electronics, particularly in designing optimized rectifier circuits for various industrial and consumer applications.

Below is the flowchart outlining the methodology and experimental process for this research:

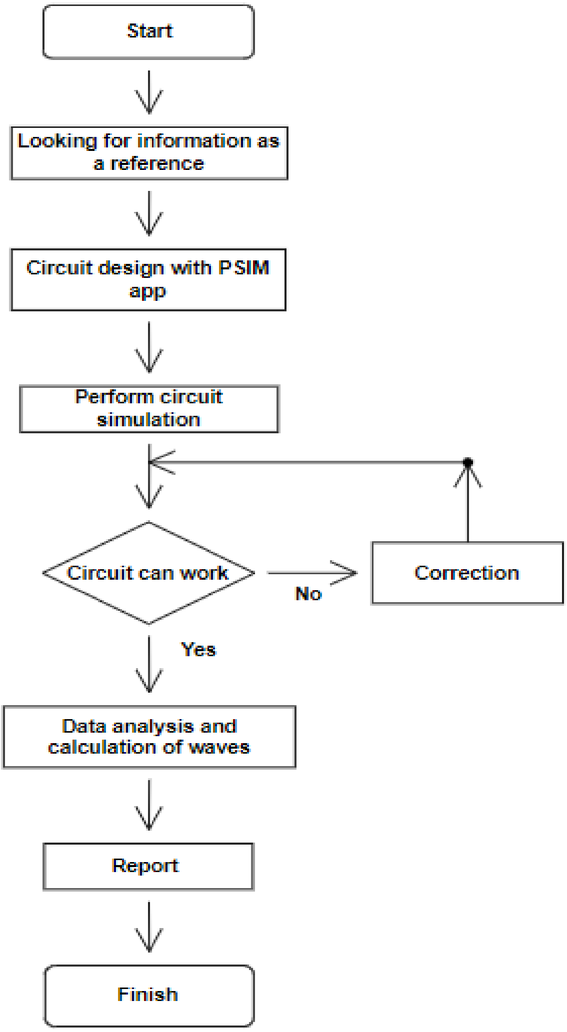

Figure 1. Flowchart

3. Results and discussion

After simulating the full-wave uncontrolled rectifier circuit in the PSIM simulation application, the results can be analyzed using various measurement tools. These tools help in understanding the circuit's behavior and performance under different conditions. By observing key electrical parameters such as voltage, current, and waveform shape, we can determine how effectively the rectifier converts AC to DC power.

One of the primary tools used in the analysis is the oscilloscope, which displays the output waveform of the rectified voltage. This visualization allows us to observe the rectified voltage characteristics, including any ripple present in the signal. The ripple factor is an important indicator of the quality of rectification, as excessive ripples can affect the stability of DC-powered devices. A smoother DC output is desirable for most applications, and analyzing the waveform helps in evaluating circuit performance.

The ammeter is another essential tool that provides current readings within the circuit. By measuring the current flow through different components, we can evaluate how the load affects the circuit's performance. This is crucial in determining the efficiency of power conversion and ensuring that the circuit operates within safe current limits. Excessive current flow could indicate component stress or inefficiencies in rectification.

In addition to the oscilloscope and ammeter, the voltmeter measures the voltage at specific circuit nodes, helping to analyze voltage drops across key components such as diodes and capacitors. These voltage measurements are important for verifying whether the rectifier is functioning correctly and if any unexpected losses are occurring due to diode forward voltage drops or capacitor inefficiencies. By comparing these measured values with theoretical predictions, we can identify discrepancies and potential circuit optimizations.

By interpreting the PSIM simulation results, we can compare the observed data with theoretical calculations to assess the overall performance of the rectifier circuit. This comparison allows us to identify deviations, analyze their causes, and determine the factors influencing efficiency. Understanding these aspects is essential in designing optimized rectifier circuits that provide stable and efficient DC power for various applications.

3.1. Result

In this study, the PSIM application was utilized to conduct circuit simulations, allowing for a detailed analysis of circuit behavior under different conditions. Through this simulation, various electrical parameters such as voltage, current, and waveform characteristics could be observed and analyzed. By using PSIM, the study aimed to evaluate circuit performance, identify potential inefficiencies, and compare simulated results with theoretical expectations.

The image below represents the circuit used in this experiment. This circuit serves as the primary model for analyzing rectification, power conversion, and component interactions within the system. By simulating this circuit, the study provides valuable insights into its operational characteristics, helping to optimize design choices and improve overall efficiency.

Furthermore, the insights gained from this simulation can be applied to real-world circuit design and implementation. By understanding the effects of different components and configurations, engineers and researchers can develop more efficient and reliable power electronics systems. The ability to predict circuit behavior through simulation reduces the need for extensive physical prototyping, saving both time and resources. This study highlights the importance of simulation tools like PSIM in modern electrical engineering, enabling precise analysis and optimization of various circuit parameters for enhanced performance and stability.

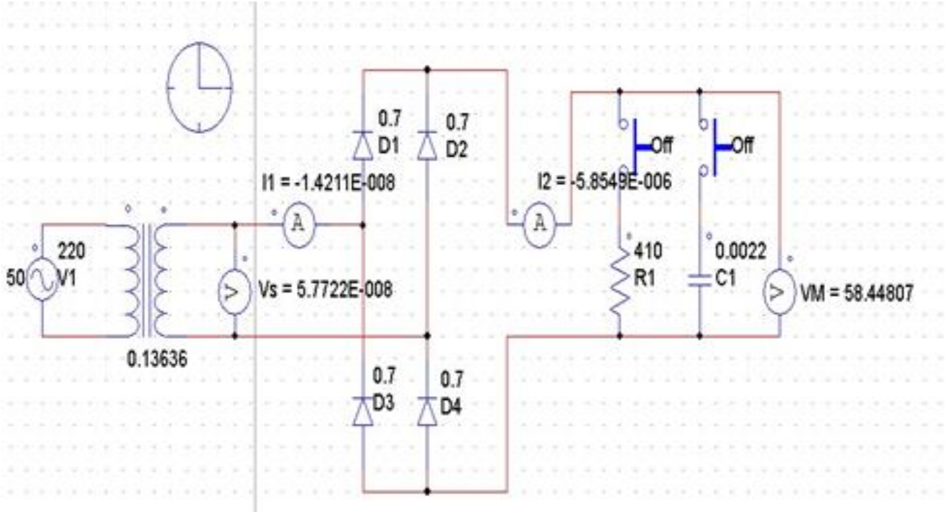

Figure 2. No load simulation

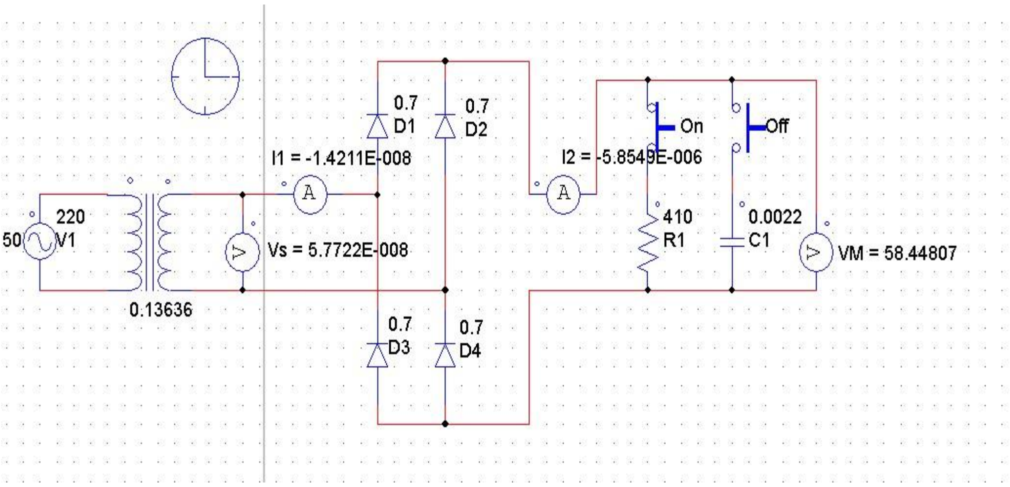

Figure 3. load simulation circuit R

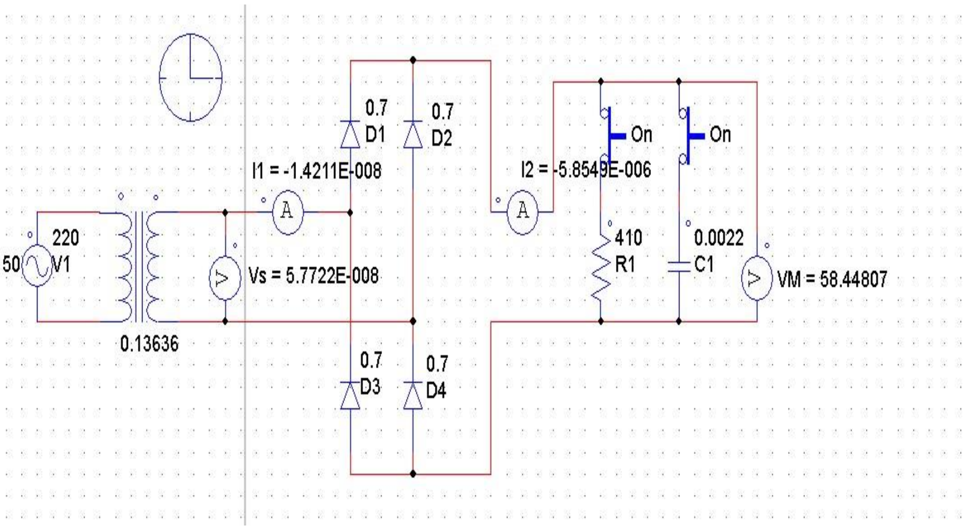

Figure 4. load simulation circuit RC

3.2. Discuccion

After simulating a full-wave uncontrolled rectifier circuit on a three-phase AC generator using the PSIM application, we can analyze the simulation results through various measurement tools. The oscilloscope displays the waveform of the rectified voltage, allowing us to observe its characteristics and any ripples present. Meanwhile, an ammeter is used to measure the current flowing through the circuit, and a voltmeter helps determine the voltage at different points in the circuit and across components. These tools provide valuable data for evaluating circuit performance.

In this study, simulations were conducted on different circuit configurations, including a no-load circuit, a circuit with a resistor load, and a circuit with an RC load. By performing these simulations, we could record measurement data and create a comparison table. This table helps in analyzing how different load conditions affect the rectifier's output, particularly in terms of voltage, current, and waveform shape. Understanding these variations is essential in determining the circuit's efficiency and identifying any possible inconsistencies.

The comparison between simulated measurements and manual calculations revealed slight differences in the results. These discrepancies, typically within a few percent, may arise due to rounding errors in calculations, inherent resistance in components, or even human errors during measurement interpretation. Such variations are common in practical circuit analysis and highlight the importance of cross-verifying results using multiple methods.

One significant observation from the analysis is that the percentage of error tends to decrease as the output voltage (Vo RMS) is set higher. This suggests that higher voltage levels lead to more stable and accurate measurements, reducing the impact of minor variations in component behavior or simulation conditions. Therefore, optimizing voltage settings in real-world applications could contribute to improved circuit efficiency.

By understanding these factors, we can refine our simulation techniques, improve accuracy in circuit design, and ensure that theoretical predictions closely match practical implementations. This study highlights the importance of simulation tools like PSIM in electrical engineering, providing a reliable way to test and optimize circuits before real-world application.

Table 1. No load

Vo(RMS)	IS(RMS)	Vo(DC) Prac	Vo(DC) Theory	Io(DC) Prac	Vo(RMS) Theory	Vo(RMS) Prac	Io(RMS) Prac
30	3.68e-006	17.7189	18.2166	1.27e-009	20.2233	19.9610	2.39e-009
45	5.59e-006	27.2617	27.7707	1.28e-009	30.8299	30.5651	2.74e-009
60	7.50e-006	36.8068	37.3248	1.41e-009	41.4365	41.1695	3.00e-009

Table 2. 205Ω resistor load circuit

Vo(RMS)	IS(RMS)	Vo(DC) Prac	Vo(DC) Theory	%	Io(DC) Prac	Vo(RMS) Theory	Vo(RMS) Prac	%	Io(RMS) Prac
30	0.0973	17.7188	18.2166	2.7%	0.0864	20.2233	19.9610	1.2%	0.0973
45	0.1490	27.2616	27.7707	1.8%	0.1329	30.8299	30.5851	0.8%	0.1490
60	0.2008	36.8068	37.3248	1.3%	0.1795	41.4365	41.1695	0.6%	0.2008

Table 3. 205Ω resistor load circuit, capacitor 0.0022f

Vo(RMS)	IS(RMS)	Vo(DC) Prac	Vo(DC) Theory	%	Io(DC) Prac	Vo(RMS) Theory	Vo(RMS) Prac	%	Io(RMS) Prac
30	3.2474	27.7893	28.28	1.7%	0.7561	28.2808	27.9606	1.1%	3.2474
45	4.9254	42.3780	43.11	1.6%	1.1559	43.1113	42.6315	1.1%	4.9254
60	1.2612	56.9651	57.95	1.6%	1.5499	58.0102	57.9518	0.1%	1.2612

3.3. Calculation

The following section presents the mathematical formulation of manual calculations based on established electrical equations. These calculations are performed to analyze the behavior of a full-wave uncontrolled rectifier circuit under different load conditions. By applying the appropriate formulas, we can determine key electrical parameters such as output voltage, current, and power for each scenario. The theoretical values obtained through these calculations serve as a reference for evaluating the accuracy of simulation results.

The calculations are carried out for three distinct circuit conditions: no-load condition, resistive load (R), and resistive-capacitive load (RC). In the no-load condition, the rectifier operates without any external resistance or capacitance, allowing us to observe its fundamental behavior without external influences. When a resistive load (R) is introduced, the circuit experiences a controlled flow of current, affecting voltage levels and ripple characteristics. Similarly, when an RC load is applied, the capacitor introduces a smoothing effect on the output waveform, reducing ripple voltage and improving DC output stability.

By performing these manual calculations, we can compare the theoretical predictions with the simulation results obtained from the PSIM application. Any discrepancies between the two results can be analyzed to understand potential sources of error, such as component tolerances, measurement accuracy, and rounding approximations. This process is essential in validating the performance of the rectifier circuit and ensuring that the theoretical models align with practical implementations.

A. No load Circuit

Table 4. Mathematic Result (Theory) No Load

Vs: 30	Vm = Vs – 1,4 Vm = 30 – 1,4 Vm = 28,6V	$\mathrm{Vo(DC)} = \frac{2\mathrm{Vmax}}{\pi}$ $\mathrm{Vo(DC)} = \frac{2(28.6)}{3,14}$ $\mathrm{Vo(DC)} = \frac{57,2}{3,14}$ $\mathrm{Vo(DC)} = 18,2166\ \mathrm{V}$	$\mathrm{Vo(rms)} = \frac{\mathrm{Vmax}}{\sqrt{2}}$ $\mathrm{Vo(rms)} = \frac{28,6}{\sqrt{2}}$ $\mathrm{Vo(rms)} = 20,2233\mathrm{V}$
Vs: 45	Vm = Vs – 1,4 Vm = 45 – 1,4 Vm = 43,6V	$Vo(DC) = \frac{2Vmax}{\pi}$ $Vo(DC) = \frac{2(43.6)}{3,14}$ $Vo(DC) = \frac{87,2}{3,14}$ $Vo(DC) = 27,7707\ V$	$Vo(rms) = \frac{Vmax}{\sqrt{2}}$ $Vo(rms) = \frac{43,6}{\sqrt{2}}$ $Vo(rms) = 30,8299\ V$
Vs: 60	Vm = Vs – 1,4 Vm = 60 – 1,4 Vm = 58,6V	$Vo(DC) = \frac{2Vmax}{\pi}$ $Vo(DC) = \frac{2(58.6)}{3,14}$ $Vo(DC) = \frac{117,2}{3,14}$ $Vo(DC) = 37,3248\ V$	$Vo(rms) = \frac{Vmax}{\sqrt{2}}$ $Vo(rms) = \frac{58,6}{\sqrt{2}}$ $Vo(rms) = 41,4365\ V$

B. Resistor load Circuit

Table 5. Mathematic Result (Theory) Resistor Load

Vs: 30	Vm = Vs – 1,4 = 30 – 1,4 = 28,6V	$\mathrm{Vo(DC)} = \frac{2\mathrm{Vmax}}{\pi}$ $= \frac{2(28.6)}{3,14} = \frac{57,2}{3,14}$ $= 18,2166\ \mathrm{V}$	$\mathrm{Vo(rms)} = \frac{\mathrm{Vmax}}{\sqrt{2}}$ $= \frac{28,6}{\sqrt{2}}$ $= 20,2233\mathrm{V}$	$Io(DC)$ $= \frac{Vo(DC)}{R}$ $= \frac{18,2166}{410}$ $= 0,0444\ A$	$Io(rms)$ $= \frac{Vo(rms)}{R}$ $= \frac{20,2233}{410}$ $= 0,0493\ A$
Vs: 45	Vm = Vs – 1,4 = 45 – 1,4 = 43,6V	$Vo(DC) = \frac{2Vmax}{\pi}$ $= \frac{2(43.6)}{3,14} = \frac{87,2}{3,14}$ $= 27,7707\ V$	$Vo(rms) = \frac{Vmax}{\sqrt{2}}$ $= \frac{43,6}{\sqrt{2}}$ $= 30,8299\ V$	$Io(DC)$ $= \frac{Vo(DC)}{R}$ $= \frac{27,7707}{410}$ $= 0,0677\ A$	$Io(rms)$ $= \frac{Vo(rms)}{R}$ $= \frac{30,8299}{410}$ $= 0,0751\ A$
Vs: 60	Vm = Vs – 1,4 = 60 – 1,4 = 58,6V	$Vo(DC) = \frac{2Vmax}{\pi}$ $= \frac{2(58.6)}{3,14} = \frac{117,2}{3,14}$ $= 37,3248\ V$	$Vo(rms) = \frac{Vmax}{\sqrt{2}}$ $= \frac{58,6}{\sqrt{2}}$ $= 41,4365\ V$	$Io(DC)$ $= \frac{Vo(DC)}{R}$ $= \frac{37,3248}{410}$ $= 0,0910\ A$	$Io(rms)$ $= \frac{Vo(rms)}{R}$ $= \frac{41,4365}{410}$ $= 0,1010\ A$

C. RC load circuit

Table 6. Mathematic Result (Theory) Resistor Capacitor Load

Vs: 30	Vm = Vs – 1,4 = 30 – 1,4 = 28,6V	$\Delta Vo = \frac{Vmax}{2fcr}$ $= \frac{28,6}{2x50x0.0022x410}$ $= \frac{28,6}{90,2} = 0,31707$ V	Vo(DC) $= Vmax - \frac{\Delta Vo}{2}$ $= 28,6 - \frac{0,31707}{2}$ $= 28,6 - 0,15853$ $= 28,44\ V$	Vac = $\frac{\Delta Vo}{2\sqrt{2}}$ $= \frac{0,31707}{2\sqrt{2}}$ $= 0,11210$ V	$Vo(Rms)$ $= \sqrt{Vo(dc)^2 + Vac^2}$ $= \sqrt{(28,28)^2 + (0,11210)^2}$ $= \sqrt{799,75 + 0,01256}$ $= \sqrt{799,77} = 29,28022\ V$
Vs: 45	Vm = Vs – 1,4 = 45 – 1,4 = 43,6V	$\Delta Vo = \frac{Vmax}{2fcr}$ $= \frac{43,6}{2x50x0.0022x410}$ $= \frac{43,6}{90,2} = 0,48337\ V$	Vo(DC) $= Vmax - \frac{\Delta Vo}{2}$ $= 43,6 - \frac{0,48337}{2}$ $= 43,6 - 0,24168$ $= 43,35\ V$	Vac = $\frac{\Delta Vo}{2\sqrt{2}}$ $= \frac{0,48337}{2\sqrt{2}}$ = 0,17089 V	$Vo(Rms)$ $= \sqrt{Vo(dc)^2 + Vac^2}$ $= \sqrt{(43,35)^2 + (0,17089)^2}$ $= \sqrt{1879,22 + 0,02920}$ $= \sqrt{1879,25}$ $= 43.35033\ V$
Vs: 60	Vm = Vs – 1,4 = 60 – 1,4 = 58,6V	$\Delta Vo = \frac{Vmax}{2fcr}$ $= \frac{58,6}{2x50x0.0022x410}$ $= \frac{58,6}{90,2} = 0,64966\ V$	Vo(DC) $= Vmax - \frac{\Delta Vo}{2}$ $= 58,6 - \frac{0,64966}{2}$ $= 58,6 - 0,32483$ $= 58,27\ V$	Vac = $\frac{\Delta Vo}{2\sqrt{2}}$ $= \frac{0,64966}{2\sqrt{2}}$ $= 0,22968$ V	$Vo(Rms)$ $= \sqrt{Vo(dc)^2 + Vac^2}$ $= \sqrt{(58,27)^2 + (0,22968)^2}$ $= \sqrt{3395,39 + 0,05275}$ $= \sqrt{3395,44}$ $= 58,27045\ V$

4. Conclusion

From the analysis, it can be concluded that the capacitor plays a crucial role in stabilizing the rectified voltage and ensuring a smooth DC output. The relationship between capacitor size, ripple voltage, and overall circuit performance can be summarized as follows:

1. Effect of Capacitor Value on Ripple Voltage
    - Increasing the capacitor value decreases ripple voltage, resulting in a smoother DC output.
    - A larger capacitor filters out fluctuations more effectively, improving voltage stability.
    - Conversely, a smaller capacitor leads to higher ripple voltage, making the output less stable.

2. Output Voltage Across the RC Load
    - The output voltage across the RC load is approximately equal to the peak votage generated by the transformer output.

3. RMS and Peak Voltage Measurements
    - The RMS value represents the effective voltage or current, which can be measured using ammeters and voltmeters.
    - The peak voltage is observed using an oscilloscope, displaying the maximum instantaneous voltage.

4. Capacitor’s Role in Voltage Filtering
    - The capacitor functions as a filter, smoothing fluctuations and ensuring the DC output resembles a steady waveform.
    - It helps maintain consistent current flow by reducing voltage variations.

5. Pump Capacitor and Voltage Regulation
    - The pump capacitor aids in voltage regulation by temporarily storing charge and supplying voltage when needed.
    - This function helps stabilize the output voltage, preventing fluctuations and ensuring a steady power supply.

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