

COMPARISON ON SIMULATION STUDIES OF SINGLE-PHASE BRIDGE RECTIFIERS

Abhishek Mandal^{1*}, Sumanta Das²

¹Department of Electrical Engineering, Dr. B C Roy Polytechnic, Durgapur- 713206, West Bengal, India, Email ID: abhishek.mandal@bcrec.ac.in

²Department of Electronics and Tele-Communication Engineering, Dr. B C Roy Polytechnic, Durgapur- 713212, West Bengal, India, Email ID: sumanta.das@bcrec.ac.in

Abstract: *Electric energy is the key driving force for the mankind. Electricity produced in the power plant is alternating in nature i.e. bipolar signal. DC current or voltage is another variant of the electrical energy that is preferred to be used from small toys to large separately excited motors. DC signal is produced from AC signal by using bridge rectifiers. In this paper the simulation of bridge rectifiers has been analyzed and improvement of some of the key parameters have been investigated.*

Key words: *bridge rectifier, controlled rectifier, simulation, uncontrolled rectifier*

1. INTRODUCTION

Electricity is the key driving force for machines not only in the modern industry but in everyday life. Electricity is obtained either in the form of direct current (DC) or alternating current (AC). Direct current is unipolar in nature and bears an uninterrupted fixed voltage, whereas the alternating current running in the domestic or industrial premises is bipolar in nature. But AC current is easier to generate. Unlike AC current or voltage, DC current is produced from AC current. The process of converting AC current into DC current is called rectification and the circuit which does this, is called, rectifier. Among all the different types of rectifier circuits used for converting AC power into DC power, bridge rectifier is the most widely used. It is because it can be directly used with the single-phase line voltage without using bulky transformer to stepdown the line voltage to the desired AC voltage. That is why most of the transformer less power supplies include bridge rectifiers. Due to its advantages, many research works have been done on the circuits with different kinds of simulation software before fabricate the device physically. In this paper the authors have reviewed the simulation of some uncontrolled and controlled bridge rectifier circuit that runs under different loading conditions. The authors of this paper have investigated the improvements of different parameters like efficiency, ripple factor and total harmonic distortion of the different proposed bridge rectifiers through comparative analysis.

2. SIMULATION STUDIES

Rectification is a process of converting AC bipolar signal into unipolar signal by the help of bridge rectifier. A bridge rectifier is constructed by semiconductor devices among which diodes and silicon-controlled rectifier (SCR) are mostly used. Rectifiers can be classified as uncontrolled and controlled rectifiers. Uncontrolled bridge rectifier circuit is produced by help of 4 silicon diodes connected as shown by Figure 1. It results lowering the peak inverse voltage across each diode. Bridge configuration provides better control on peak inverse voltage than other configurations of full wave rectifier. The output of the circuit is pulsating unipolar signal shown in Figure 2. This output is passed through a shunt capacitor filter to reduce the AC ripple present in the DC signal. There are various different parameters based on which the performance of a rectifier is measured. One of them is ripple factor. It is the ratio of AC components RMS value and DC components value at the output of the rectifier. The ripple factor is given by the following equation:

$$\gamma = \sqrt{\left(\frac{V_{RMS}}{V_{DC}}\right)^2 - 1} \quad (1)$$

Ripple factor is reduced by applying low pass filter across the load. Usually a capacitor is used across the load to filter out the AC ripple voltages at the output and maintain a smooth output across the load.

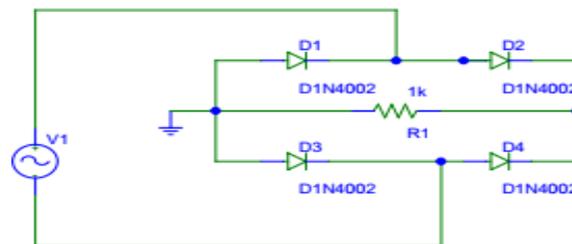


Figure 1: bridge full wave rectifier

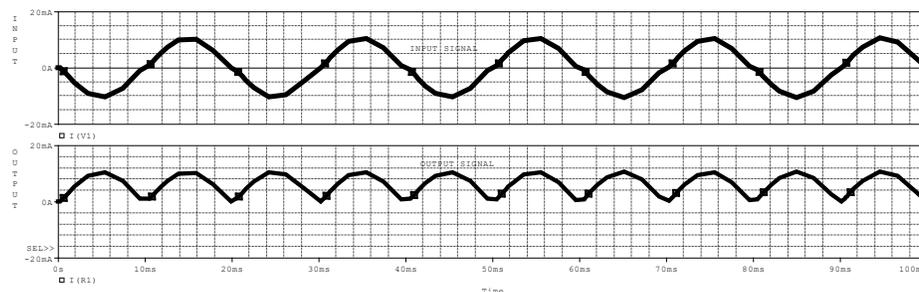


Figure 2: Input and output waveform of full wave rectifier

IntanShafinazAbd.Razaket.al.[1]studied the design of single-phase full wave bridge rectifier and discussed about the technique of reducing ripple factor below 1%. The output voltage has been varied from 5V to 24V DC with a fixed load of 220Ω. The system has been designed and simulated in Multisim software version 14 (A product of National Instruments, USA).

The author has established that the calculative result and result obtained from simulations are comparatively equal except the ripple factors. The ripple factor is estimated from the equation proposed by Pyakuryal&Matin, 2013a [2].

$$\%ripple\ factor\ (\%\gamma) = \frac{V_{rms}}{V_{avg}} \times 100\% \quad (2)$$

The author shows a significant improvement in the ripple factor under the presence of the shunt capacitor filter across the load with a negligible difference of between the calculative value and simulation value for the ripple factor.

A discussion on the variation of DC output voltage with the turns ratio of the transformer reveals that increase in turns ratio increases in the DC output voltage results due to increase in output AC voltage of the transformer. In the next paper, Maleeha Parvez [3] (2019) worked with PWM rectifier and compared the output with conventional controlled and uncontrolled rectifiers. The author has attempted to solve the problem of drawing of non-sinusoidal current from source by the bridge rectifiers, buck-boost converter and SCR driven phase-controlled rectifier. The author has established that the proposed method using the pulse width modulation has the ability to control both input AC source current and output load voltage. The simulation result depicts that the PWM Rectifier with Hysteresis Current Control is suitable converter for converting AC supply into controlled DC as it follows the total harmonic distortion (THD) within specified IEEE limitation. The problem of drawing non-sinusoidal current from source is eliminated. This converter provides more output voltage than input supply, which is an additional advantage for wide range of application. But the output cannot go below the input supplied. This converter does not have any significant disadvantage except the cost is more in comparison to other AC to DC converter because it uses closed loop feedback control which requires sensors and complex controllers. Experimental results confirm the improvement in the efficiency. The table shows the total harmonic distortion of various ac to dc converter systems and the output waveform. It is found from the table that a PWM rectifier bears 3.23% total harmonic distortion which is least among the other listed rectifiers and current waveform of the source is sinusoidal and in phase with input voltage.

On the other hand, Mohamed M. Saied [4] have provided a glimpse on the steady-state and transient analysis of uncontrolled bridge rectifiers using Mathematica. The author has presented a mathematical model of PN junction diode and derived the governing system of classical uncontrolled bridge rectifier with algebraic differential equation. He has discussed the simulation along with the load resistance in presence of a smoothing shunt-capacitor filter. The mathematical model introduced the concept of the “effective resistance” of diode under the unit step input as function of current magnitude and polarity that is given by the following equation:

$$v = i(R_f \cdot u[i] + R_r \cdot u[-i]) = iR_{eq}[i] \quad (3)$$

Where R_f = forward resistance of each diode and v = voltage across the diode

R_r = resistance in reverse direction

The author has mathematically reproduced the circuit in the example 5-2 of the reference [5] to validate his simulation. In the simulation, a sinusoidal signal of 60-Hz has been applied to the full-wave bridge rectifier with peak voltage $e_{max} = 120\sqrt{2}V$. The source inductance is taken as 1mH, source resistance of $1m\Omega$, value of smoothing capacitor has been taken as $1000\mu F$ and load resistance of 20Ω . The steady state response of the simulation indicates that diode draws current from source during the respective half cycles when it is conducting whose peak current in this case is 35Amps. The voltage drop is zero across the diode. During non-conducting state, the peak inverse voltage comes out to be 180 Volt across each diode. The capacitor current is oscillating in nature and in the uncontrolled bridge rectifier the capacitor current goes to -27Amps negative peak current under steady state condition. The simulations performed are based on the mathematical equations derived from the reference examples which satisfies the basic operations of practical diode in a bridge rectifier.

Łukasz Ciepliński et.al[6] introduces the current modulator in the input side of a single-phase full wave bridge rectifier. Current modulator is a closed loop controlled current source that works on the principle of voltage inverter consists of a low pass filter. A current modulator is connected with the circuit through a wideband transformer. The current modulator is able to improve the aftereffects of suddenly drawing the current from the source by the network. It also controls the power flow in the circuit as per the requirement. The model presented by the author consumes sinusoidal current from a power grid which is compatible in phase with the fundamental harmonic of voltage. Power circuit, as well as controlling parts of the constructed simulation model created using Simulink have been shown in this paper. The author has established the fact

that the use of a current modulator in the input circuit of a single-phase full bridge rectifier not only improves the quality of the current drawn from the network by reducing the total harmonic distortion (THD) to 0.3 % but also regulates and stabilize the output voltage on the DC bus as per the desired value. K Karthik Kumar et.al (2018) [7] have analyzed the power quality of a single-phase bridge rectifier to be used for a DC motor. Total harmonic distortion (THD) and respective power factor analysis have been done by the help of Simulink model of the bridge rectifier. Since the harmonic distortion contributes to the efficiency of the converter, it becomes necessary to reduce the harmonic distortion as much as possible to attain a unity power factor. The authors have used a controlled bridge rectifier using thyristor to drive a DC motor. Four thyristors in bridge configuration produces an output current through load when a pair of thyristor conducts at each of the half cycles when a voltage is triggered at a particular firing angle. When thyristors are triggered at a firing angle, at certain moments all the thyristors go into non-conducting state from conducting state or vice versa at the time of switching. At that time no current flows through the load. But a step voltage is produced across the load which makes the output voltage a non-sinusoidal. Also due to this reason, the output current is also not a pure sinusoidal one and produces spike like output current at the armature. The authors have shown that under a constant load, the total harmonic distortion (THD) decreases at a lower firing angle of the thyristor. It has been shown that at a firing angle of 30° , the efficiency of the rectifier is 76.65% with a total harmonic distortion of 44.04% which implies that there is an improvement in efficiency also at lower firing angle. The speed of the DC motor is also improved to 2168 RPM at lower firing angle. With increase in the firing angle, the efficiency, speed of motor and power factor also decreases and the THD starts increasing. On the other hand, authors have established that with increase in torque, the total harmonic distortion is reduced while the efficiency almost remains constant.

3. SUMMARY OF EMPIRICAL STUDY OF SIMULATIONS OF BRIDGE RECTIFIERS

Empirical studies are useful to prepare a comparative analysis of the proposed new design or improvement in the existing design which has been attempted to present in this paper. Simulation studies of controlled and uncontrolled bridge rectifier has revealed many new aspects and solution to the problems currently found. Some of them are listed in the table 1 below. These are specially based on the efficiency, ripple factor, turns ratio and total harmonic distortion.

Table 1: Summary of the simulation studies on performance with various parameters

Study	Factors under consideration	Modelling Description	Performance parameters	Major Findings
IntanShafinazAbd. Razak et. al[1]	Ripple factor and turns ratio	Modelled uncontrolled bridge rectifier in multisim version 14 using ordinary diode.	Ripple factor	<ul style="list-style-type: none"> Ripple can be reduced upto 1.49% using filter capacitor Ripple is lowered with along with output voltage at less turns ratio
MaleehaParvez [3]	Efficiency, power factor	Modelled uncontrolled bridge rectifier, controlled rectifier using SCR, and PWM rectifier	Total harmonic distortion (THD), power factor	<ul style="list-style-type: none"> Total harmonic distortion reduced to 3.23% with PWM rectifier Power quality is improved since the source current and source voltage are in same phase Cost is increased due to application of closed loop feedback control mechanism
Mohamed Saied [4]	Mathematical model of diode and each element of bridge rectifier	Used Mathematica version 12 simulation software to simulate classical bridge rectifier circuit	Simulation of classical bridge rectifier with low pass shunt capacitor filter	<ul style="list-style-type: none"> The mathematical model of the diode and the entire classical system bears the expected outcome.
LukaszCiepliński et.al [6]	Total harmonic distortion, spike waveshape of current drawn from the source by the network	Modelled the closed loop current modulator system and the single-phase bridge rectifier system using Simulink.	Total harmonic distortion, filtered output ripple	<ul style="list-style-type: none"> Total harmonic distortion has been reduced to 0.3% The current drawn by the network from source is always sinusoidal. Filtered output creates less ripple using current modulator at input.
K Karthik Kumar et.al [7]	Total harmonic distortion,	Modelled the thyristor based controlled bridge rectifier using Simulink with a load equivalent to DC motor	Total harmonic distortion at the output	<ul style="list-style-type: none"> With increase in torque, the THD decreases With increase in the firing angle of thyristor the THD increases

4. CONCLUSION

From the empirical study of the controlled and uncontrolled bridge rectifier it has been found that when the output load draws current, the source current does not remain sinusoidal. It becomes some kind of spiky type of input. As a result, the source input current and input

sinusoidal source voltage produces least power factor that reduces the efficiency. It has been also seen that to improve the total harmonic distortion, PWM rectifier performs well. The distortion has been reduced to 3% almost. But, the system becomes costly due to the presence of various sensors and closed loop feedback control. ŁukaszCiepliński et.al have specified the problem and have solved the problem of harmonic distortion by help of current modulator, placed at the input side. This kind of arrangement has reduced the THD to 0.3%. But this system does not guarantee the improvement in the efficiency. In a controlled bridge rectifier, the total harmonic distortion increases with increase in firing angle of the SCR. Hence, from overall analysis of the respective techniques and simulation, it can be concluded that although the total harmonic distortion becomes less in the previously studied journal. But if the cost of the material can be beard, the system simulated by MaleehaParvez [3] is the better one among all which increase the efficiency and reduces the THD under a tolerable limit.

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