

Performance Comparison of Single & 3- ϕ Controlled and Uncontrolled Rectifier Using Matlab-Simulink

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Abstract-This paper presents simulations & performance result of single and 3- ϕ rectifier circuits (controlled and uncontrolled) using MATLAB-SIMULINK which is one of the most used power electronics circuit. This paper also describes method & concepts used to simulate power electronic circuits using the SIMULINK toolbox within MATLAB software. The use of tool like MATLAB-SIMULINK has always been a useful for researcher and the designer for analyzing and designing different circuits. The paper demonstrate the performance comparison of single and 3- ϕ rectifier circuits in term of its output voltage , current and possible maximum and minimum firing angle.

Index Terms: Power Electronics, SimPowerSystems, Rectifier, Firing angle, powergui, Average and RMS DC voltage etc...

1. INTRODUCTION

Power Electronics includes the use of different electronics components & its structure, characteristic and application circuit, which can withstand large voltage and current. Due to the withstand capability at high voltage and current, this devices are used in industry for control application. The single and 3- ϕ uncontrolled and controlled rectifiers with R, RL load (with and without freewheeling diode); choppers; inverters; AC voltage regulator are one of them.[1]

The Rectifier is the power electronic circuit which is highly used in all power supply units. All the modern power controlled circuits like simple fan regulator to DC motor drive use the concept of phase control through which power to the output is controlled. This type of rectifier is called controlled rectifier. [2] In uncontrolled rectifier due to the use of simple power diode we can't control the voltage & current. For controlled rectifier modern devices like SCR and TRIAC are used, which can control the output voltage and current by providing the necessary pulse at appropriate angle which is called firing angle. [3]

In the section 1.1 will looks at how the modeling and simulation of a power electronic converter can be carried out using MATLAB/SIMULINK software and in section 1.2 will define important parameters to understand the performance of single and 3- ϕ rectifiers.

1.1 Matlab-Simulink for Power Electronics

In this section will study about the modeling and simulation method for the power electronics circuits. SimPowerSystems provides component libraries and analysis tools for modeling and simulating electrical power systems. The libraries offer models of electrical power components, including three-phase machines, electric drives, and components for applications such as flexible AC transmission systems (FACTS) and renewable energy systems. Harmonic analysis, calculation of total harmonic distortion (THD), load flow, and other key electrical power system analyses are automated. SimPowerSystems models can be used to develop control systems and test system-level performance. You can parameterize your models using MATLAB variables and expressions, and design control systems for your electrical power system in Simulink. You can add mechanical, hydraulic, pneumatic, and other components to the model using Simscape and test them together in a single simulation environment. To deploy models to other simulation environments, including hardware-in-the-loop (HIL) systems, SimPowerSystems supports C-code generation. [4] SimPowerSystems contains application libraries, Electrical Sources (Contains blocks that generate electric signals), Elements (Contains linear and nonlinear circuit elements.), Extra Library (Contains three-phase blocks and specialized measurement and control blocks. You can also open this library by entering `powerlib_extras` at the command line.) , Machines (Contains power machinery models.), Measurements (Contains blocks for the current and voltage measurements.), Power Electronics (Contains power electronics devices.) and powergui (used to decide supply; i.e. continues or discrete) libraries to design and stimulate different power electronics circuits. THYRISTOR, MOSFET, GTO, AC/DC VOLTAGE supply are one of the examples of various libraries blocks. Figure 1 contains some of the blocks of the SimPowerSystem.

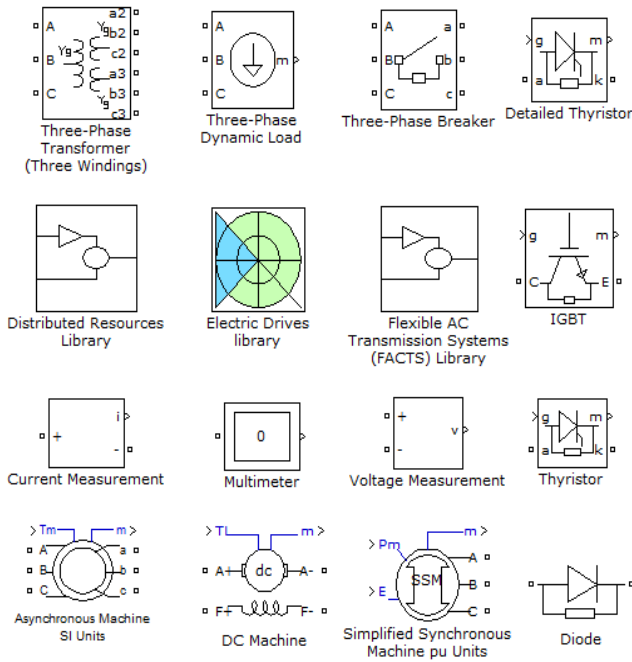


Fig 1: Simulation Blocks

1.2 Performance parameters for Rectifiers

Before starting to examine various single-phase or multi-phase rectifiers’ circuits, we should define some parameters. These parameters are needed to compare the performances among the various structures. For the performance comparison we will assume ideal switches (diodes or thyristors) with zero commutation time (instantaneous turn on and off) and zero on-resistance (when conducting they present neither voltage drop nor losses).The DC voltage on the load is the average output voltage over the period T . [5]

$$V_{DC} = \frac{1}{T} \int_0^T V_L(t).d(t) \tag{1}$$

Similarly, it is possible to define the R.M.S. voltage on the load is given by:

$$V_L = \sqrt{\frac{1}{T} \int_0^T v^2_L(t).d(t)} \tag{2}$$

The ratio of the two voltages is the Form Factor (FF).

$$FF = \frac{V_{dc}}{V_L} \tag{3}$$

This parameter is very important because it is an index of the efficiency of the rectification process.

If the load to be purely resistive, the currents can be define as

$$i_L(t) = \frac{v_L(t)}{R_L} \tag{4}$$

$$\eta = \frac{V_{DC} \cdot I_{DC}}{V_L \cdot I_L + R_D \cdot I_L} \tag{5}$$

$$I_L = \frac{V_L}{R_L} \tag{6}$$

The rectification ratio (η), also known as rectification efficiency, is expressed by

$$\eta = \frac{P_{DC}}{P_L + P_D} \tag{7}$$

$$P_{DC} = V_{DC} \cdot I_{DC} \tag{8}$$

$$P_L = V_L \cdot I_L \tag{9}$$

$$P_D = R_D \cdot I_L^2 \tag{10}$$

Where,

P_D =the losses in the rectifier

R_D =the equivalent resistance of the rectifier

By developing Equation (7), using Equations (5), (8), (9) and (10), we get:

$$\eta = \frac{V_{DC} \cdot I_{DC}}{V_L \cdot I_L + R_D \cdot I_L^2} = \frac{V_{DC}^2}{V_L} \cdot \frac{1}{1 + (\frac{R_D}{R_L})} \tag{11}$$

The ripple factor is an important parameter for the rectifier which used to describe the quality of the rectification. The RF is defined as the ratio of the effective AC component of the load voltage versus the DC voltage.

$$RF = \frac{\sqrt{V_L^2 - V_{DC}^2}}{V_{DC}} = \sqrt{FF^2 - 1} \tag{12}$$

One of the parameters used to define the characteristics of the transformer is the Transformer Utilization Factor (TUF).

$$TUF = \frac{P_{DC}}{(\frac{V \cdot A_p + V \cdot A_s}{2})} \tag{13}$$

Where,

VA_p and VA_s are the power ratings at the primary and secondary of the transformer

For the comparison of the different topologies, it is also useful to take into consideration the Peak Inverse Voltage(PIV) during the blocking state of the device or the maximum current in the load. [10][11]

2. SINGLE AND 3-Ø PHASE UNCONTROLLED RECTIFIER

The particle physics point of view, the ideal rectifier is the one that provides the best direct current to the load. This means the ideal rectifier have very low ripple, very high Stability. As we shall see later, this goal is achieved by using three-phase systems and full-wave rectifiers. Single-phase rectifiers are still in low-power stand-alone converters and as output stage in Switched Mode Power Supplies. Still Single Phase rectifier is in use for low power stand alone converter and in SMPS (Switched Mode Power Supply). Table 1 represent all the performance parameter of the single phase topology.

Table 1: Performance Parameter of the Single Phase topologies

	Half wave	Center-Tap	Bridge
Peak repetitive reverse voltage V_{RRM}	πV_{dc}	πV_{dc}	$\pi/2 V_{dc}$
r.m.s. input voltage per transformer leg V_{Srms}	$2.22V_{DC}$	$1.11V_{DC}$	$1.11V_{DC}$
Diode average current $I_{F(AV)}$	I_{DC}	$0.5I_{DC}$	$0.5I_{DC}$
Diode peak repetitive forward current I_{FRM}	$\pi I_{F(AV)}$	$\pi/2 I_{F(AV)}$	$\pi/2 I_{F(AV)}$
Diode r.m.s. current $I_{F(rms)}$	$\pi/2 I_{DC}$	$\pi/4 I_{DC}$	$\pi/4 I_{DC}$
Form factor of diode current	$\pi/2$	$\pi/2$	$\pi/2$
Form factor – FF	1.57	1.11	1.11
Rectification ratio – η	0.405	0.81	0.81
Ripple factor – RF	1.21	0.482	0.482
Transformer rating primary VA	$2.69P_{DC}$	$1.23P_{DC}$	$1.23P_{DC}$
Transformer rating secondary VA	$3.49 P_{DC}$	$1.75 P_{DC}$	$1.23 P_{DC}$
Transformer utilization factor	0.324	0.671	0.813
Output ripple frequency f_R	f_{mains}	$2f_{mains}$	$2f_{mains}$

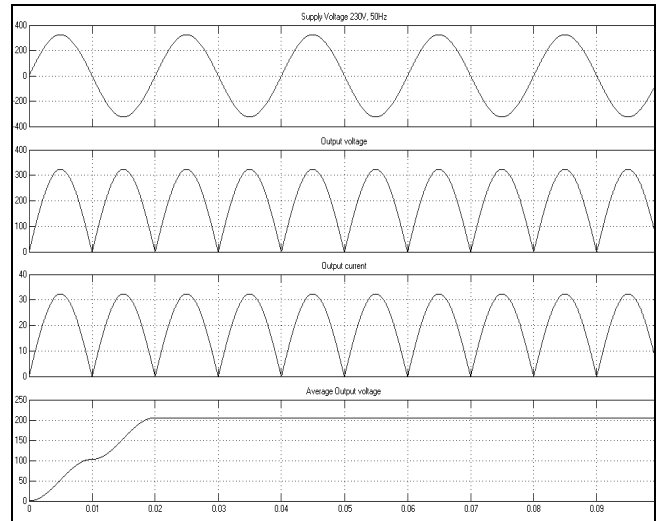


Chart -2: Matlab Simulation result for the Single phase Full wave uncontrolled rectifier

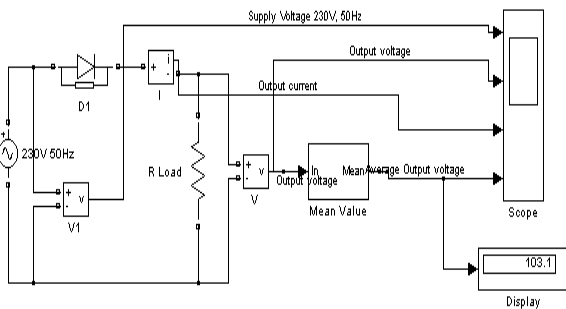


Fig -2: Matlab Simulation Model for Single phase half wave uncontrolled rectifier

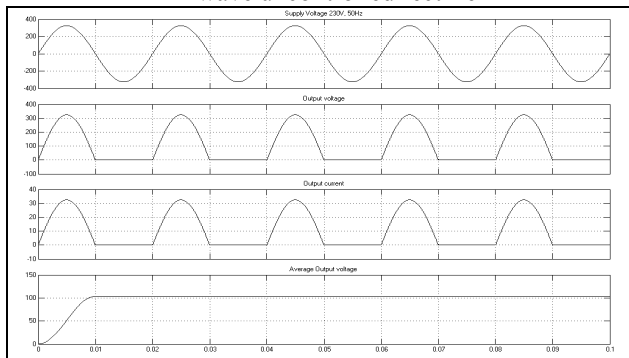


Chart -1: Matlab Simulation result for the Single phase half wave uncontrolled rectifier

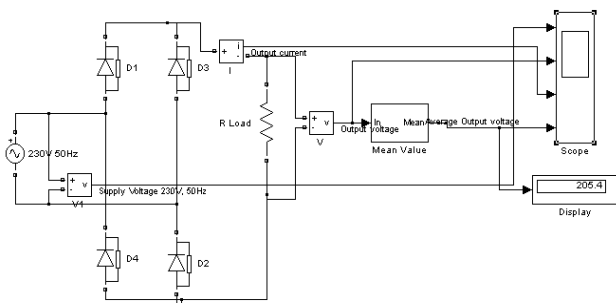


Fig -3: Matlab Simulation Model for Single phase Full wave uncontrolled rectifier

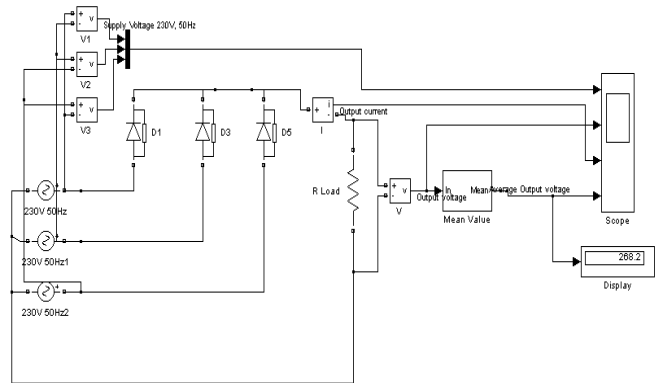


Fig -4: Matlab Simulation Model for 3-Ø Half wave uncontrolled rectifier

As shown in figure 2, figure 3 and figure 4 represent the Matlab simulation model for the single and 3-Ø Uncontrolled rectifier. Same as Chart 1, Chart 2 and Chart 3 represent output simulation result for the same.

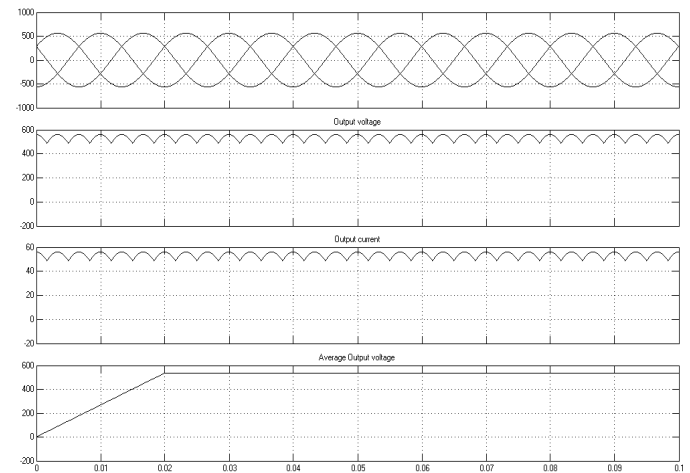


Chart -3: Matlab Simulation result for the 3-Ø Full wave uncontrolled rectifier

3. SINGLE AND 3-Ø PHASE CONTROLLED RECTIFIER

As per the above simulation we have seen that it is necessary to vary the output voltage of the rectifier. The structures as given in Figure 2, 3 and 4 provide output voltages that are in a fixed ratio with the input AC voltages. The diodes alone cannot satisfy controlling requirements. The diodes are substituted with thyristors. The thyristor is a device whose transition from the blocking to the conducting state depends not only on the polarity of the anode-cathode voltage but is also controlled via the application of an adequate current pulse. Thyristors have three terminals: the trigger pulse is applied to the gate while the anode-cathode voltage is positive. The name thyristor derives from the Greek word *thy-*, meaning ‘switch’, and the suffix *-istor*, which derives from transistor (*trans*-fer *res-istor*) to indicate that the device belongs to the semiconductor family [6][9]. Sometimes it is called Silicon Controlled Rectifier (SCR) to distinguish it from similar devices like the Gate Turn-Off thyristor (GTO) or the TRIode to control AC (Triac) or others, much less capable of handling high power, that are often used in the circuitry generating the trigger pulses for the SCR. In the rest of this paper, thyristor means SCR. In this section we still assume that we have ideal switches and purely resistive loads. Here pages we shall only consider three-phase systems and those topologies that are more commonly used to supply the load with variable voltage and, consequently, variable current. [7][8]

As shown in figure 5, figure 6 and figure 7 represent the Matlab simulation model for the single and 3-Ø controlled rectifier, where Chart 4, Chart 5 and Chart 6 represent output simulation result for the same.

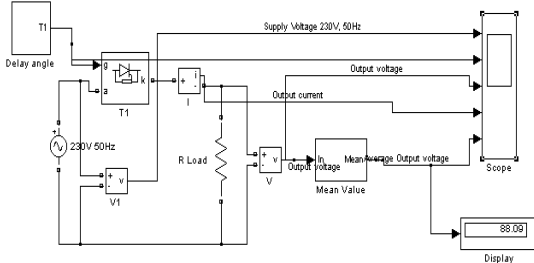


Fig-5: Matlab Simulation result for Single phase half wave phase controlled rectifier.

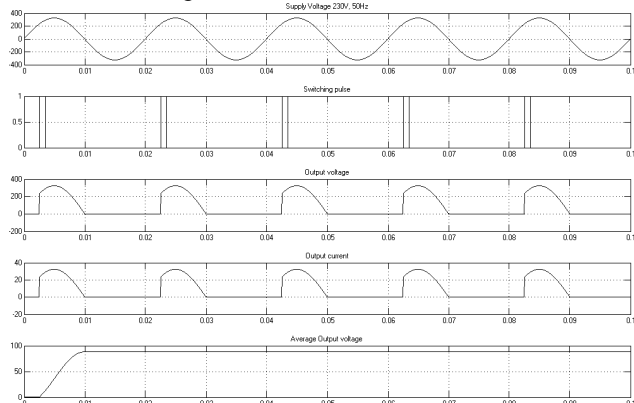


Chart -4: Matlab Simulation result for the Single phase half wave controlled rectifier

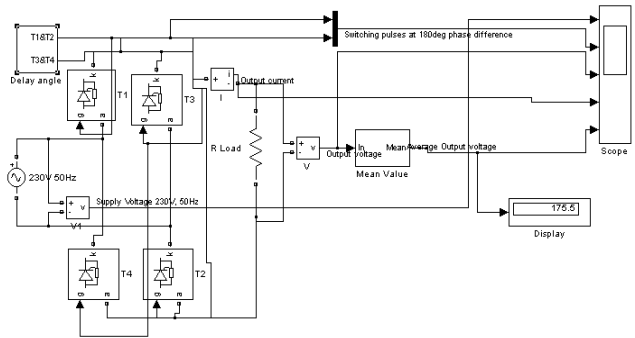


Fig-6: Matlab Simulation result for Single phase Full wave phase controlled rectifier.

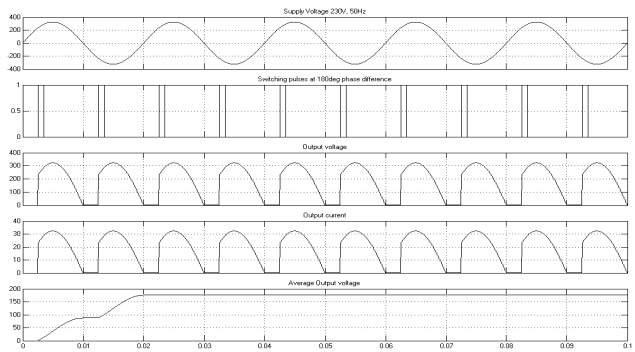


Chart -5: Matlab Simulation result for the Single phase Full wave controlled rectifier

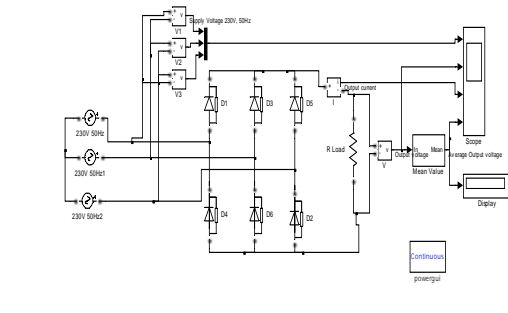


Fig-7: Matlab Simulation result for 3-Ø Full wave phase controlled rectifier.

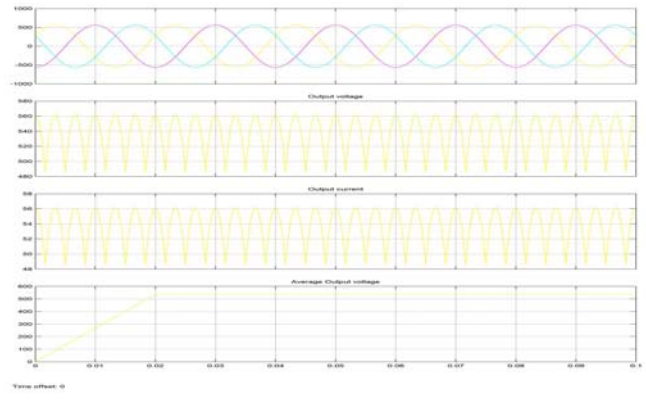


Chart -6: Matlab Simulation result for the 3-Ø Full wave phase controlled rectifier.

CONCLUSIONS

As Power Electronics is one of the important branches in recent industry revolution and power electronic systems are getting more complex today, the simulation is one of the easiest and effective sources for research and design development. The use of this Simulation toolbox must be a part of the modern syllabus for the students to enhance their knowledge. Even with the help of present model students can simulate the power electronics circuit with various load & conditions to understand and to explore in the design field. Most studies either deal with devices like diodes or thyristors — simultaneously handling high currents and high voltages (up to some kA/kV, see for example, Refs. [12], [13], [14]) or with their control, for example the use of microcontrollers in a new design for firing pulse generation (see Ref. [15])

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