Rectifier controller rectifier half wave rectifier engineering essay

Rectifiers are devices that convert an alternating current to a direct current, and as such, find wide applications in electronic power sources [11].

Rectifiers converting AC from main or other AC source to DC power by using power diodes or by controlling the firing angle of thyristor or controllable switches.

An AC to DC converter circuit can convert AC voltage into a DC voltage.

The DC output voltage can be controlled by varying the firing angle of the thyristors.

The AC input voltage could be a single phase or three phase.

Semiconductor device like thyristor or IGBT are used in control rectifier, whereas power diodes are used in uncontrollable rectifier.

Rectifiers have many uses including as components of power supplies and as detectors of radio signals.

2. 2 CONTROL RECTIFIER

Definition:

Rectifier can be defined as an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which is in only one direction, a process known as rectification [1].

For the control rectifier, it can be easily defined as the rectification process that can be control, usually by another terminal called gate.

Control rectifier (thyristor) is a solid-state semiconductor device, which have four (4) layers on it, consisting with alternating N and P-type material. When thyristor receives a current pulse through its gate, it acts as a bistable switch. They continue to conduct for as long as they are forward biased and not reversely biased.

Thyristors are switched ON by a gate signal, but even after the gate signal is de-asserted (removed), the thyristor remains in the ON-state until any turn-off condition occurs (which can be the application of a reverse voltage to the terminals, or when the current flowing through (forward current) falls below a certain threshold value known as the “ holding current”). Thus, a thyristor behaves like a normal semiconductor diode after it is turned on or “ fired” [3]. There are many types of thyristor used such as:

Silicon Controlled Rectifier (SCR)

Gate Turn-off Thyristor (GTO)

Triode AC Switch (TRIAC)

Static Induction Transistor/Thyristor (SIT/SITh)

MOS Controlled Thyristor (MCT)

Distributed Buffer – Gate Turn-off Thyristor (DB-GTO)

Integrated Gate Commutated Thyristor (IGCT)

MOS Composite Static Induction Thyristor (CSMT)

Reverse Conducting Thyristor

Types of Controlled Rectifier:

Silicon Controlled Rectifier:

Figure 1: Symbol for SCR.

Silicon controlled rectifier (or semiconductor controlled rectifier) also known as SCR, is a four-layer solid state device that controls current [2].

In the normal “ off” state, the device restricts current to the leakage current. When the gate-to-cathode voltage exceeds a certain threshold, the device turns “ on” and conducts current.

The device will remain in the “ on” state even after gate current is removed so long as current through the device remains above the holding current.

Once current falls below the holding current for an appropriate period of time, the device will switch “ off”. If the gate is pulsed and the current through the device is below the holding current, the device will remain in the “ off” state [2].

SCRs are used in devices where it controls high power, possibly coupled with high voltage.

It is also suitable in medium to high-voltage AC power control application such as lamp dimming, regulators and motor control [2].

Gate Turn-Off Thyristor:

Figure 2: Symbol for GTO.

A gate turn-off thyristor (GTO) is a special type of thyristor, which are a high-power semiconductor device.

They are fully controllable switches which can be turned on and off by their third lead, the gate lead [3].

A gate signal can turned-on the GTO and the device will be turned off when it is in the reverse polarity.

When a positive current pulse is in between the gate and the cathode terminal, the device will be turn on while a negative current pulse between the gate and cathode terminal will turn it off.

The main applications are in variable speed motor drives, high power, inverters and traction [3].

Triode For Alternating Current:

Figure 3: Symbol for TRIAC.

Triode for Alternating Current (TRIAC) is a generalized tradename for an electronic component which can conduct current in either direction when it is triggered (turned on), and is formally called a bidirectional triode thyristor or bilateral triode thyristor.

TRIAC is approximately equivalent to two complementary unilateral thyristors (one is anode triggered and another is cathode triggered (SCR) joined in inverse parallel (paralleled but with the polarity reversed) and with their gates connected together.

It can be triggered by either a positive or a negative voltage being applied to its gate electrode (with respect to A1, otherwise known as MT1).

Once triggered, the device continues to conduct until the current through it drops below a certain threshold value, the holding current, such as at the end of a half-cycle of alternating current (AC) mains power.

This makes the TRIAC a very convenient switch for AC circuits, allowing the control of very large power flows with milliampere-scale control currents.

Applying a trigger pulse at a controllable point in an AC cycle allows one to control the percentage of current that flows through the TRIAC to the load (phase control) [4].

For low TRIACs, they are used in many applications such as light dimmers, speed controls for electronic fans and other electric motors, and in modern computerized control circuits of many household small and major appliances [4].

Static Induction Thyristor:

The static induction thyristor (SIT, SITh) is a type of thyristor which have a buried gate structure in which the gate electrodes are placed in n-base region.

Since they are normally on-state, gate electrodes must be negatively biased to hold off-state.

SIT is a high power, high frequency device. It is a vertical structure device with short multichannel.

Being a vertical device, the SIT structure device, the SIT structure offers advantages in obtaining higher breakdown voltages than a Field-effect transistor (FET).

For the SIT, it is not limited by the surface breakdown between gate and drain [5].

MOS Controlled Thyristor:

MOS Controlled Thyristor (or MCT) is voltage controlled fully controllable thyristor.

MCT is similar in operation with GTO thyristor, but it has voltage controlled insulated gate.

It has two MOSFETs in its equivalent circuit.

One is responsible for turn-on and the other is responsible for turn-off.

A thyristor with only one MOSFET in its equivalent circuit, which can only be turned on (like normal SCRs), is called a MOS Gated Thyristor.

Positive voltage on the gate terminal with respect to the cathode turns the thyristor to the on state.

Negative voltage on the gate terminal with respect to the anode, which is close to cathode voltage during the on state, turns the thyristor to the off state [6].

Distributed Buffer Gate Turn-Off Thyristor:

A distributed buffer gate turn-off thyristor (DB-GTO) is a thyristor with additional PN layers in the drift region to reshape the field profile and increase the voltage blocked in the off state. Compared to a typical PNPN structure of a conventional thyristor, this thyristor would be a PN-PN-PN type structure in here [3].

Integrated Gate-Commutated Thyristor:

Figure 4: Symbol for IGCT.

The Integrated Gate-Commutated Thyristor (IGCT) is a power semiconductor electronic device, used for switching electric current in industrial equipment.

It is related to the gate turn-off (GTO) thyristor. Like the GTO thyristor, the IGCT is a fully-controllable power switch, meaning that it can be turned both on and off by its control terminal (the gate).

Gate drive electronics are integrated with the thyristor device [8].

An IGCT is a special type of thyristor similar to a GTO.

They can be turned on and off by a gate signal, have lower conduction loss as compared to GTOs, and withstand higher rates of voltage rise (dv/dt), such that no snubber is required for most applications [7].

Usually it is applied in the variable frequency inverters, drivers and traction.

MOS Composite Static Induction Thyristor:

MOS composite static induction thyristor (CSMT or MCS) is a combination of a MOS transistor connected in cascode relation to the SI-thyristor [9].

The SI thyristor (SITh) unit has a gate to which a source of MOS transistor is connected through a voltage regulation element.

The low conduction loss and rugged structure MCS make it more favorable than conversional IGBT transistors [10].

Controlled, three-phase

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Figure 5: Output voltage of controlled three phase rectifier.

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2. 3 HALF WAVE RECTIFIER

The single phase half wave rectifier is the basic building block, which uses only one diode. As shown in figure X1, this rectifies half of the input cycle. The half cycle produce at output maybe the positive or negative of the ac input depends on the connection of the diode. The transformer is used to step down or step up the voltage as per requirement of the output voltage.

P

Q

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Figure 6: Half wave rectifier with resistive load and voltage waveforms

For the positive input half cycle, of an ac input when terminal ‘ p’ is positive, the diode goes into forward bias. Considering the diode to be ideal, the voltage across it is zero, and the current is positive. The direction of current is from P to Q thus the output voltage appearing across the load. At occurrence of negative half cycle, the terminal Q is positive and diode goes to reverse bias. No current flow through diode, hence the diode acts as open circuit. From KVL equation, voltage across diode is equal to source voltage in negative value. Since no current flow through load, 0 voltages developed across the load.

Thus in the half wave rectifier, only half of the input cycle will appear across the load. The waveform of input voltage, output voltage, output current and voltage across diode are shown in figure below.

Input voltage :

Current across diode :

Voltage across diode :

Output voltge :

Output current :

Input current :

dc component

Figure 7: Graph of voltage and current against the angle

The voltage and current waveform across the source, load, and diode are shown in figure above is plotted against angle (ÏŽt). This representation is useful because the values are independent of frequency. The dc component, Vo of the output voltage is the average value of half wave rectified sinusoid:

The dc component of the current for the purely resistive load is:

Average power absorbed by the resistor can be computed as:

Resistive -inductance load

Industrial loads typically contain inductance as well as resistance. As the source voltage goes through zero, becoming positive in the circuit of Fig. 8, the diode becomes forward biased. The Kirchhoff's voltage law equation that describes the current in the circuit for the forward biased ideal diode is

——-(1)

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Figure 8: (a) Half-wave rectifier with an R-L load. (b) Waveform.

The solution can be obtained by expressing the current as the sum of the forced response and the natural response:

——–(2)

The forced response for this circuit is the current that exists after the natural response has decayed to zero. In this case, the forced response is the steady-state sinusoidal current that would exist in the circuit if the diode were not present. This steady state current can be found from phasor analysis,

Where Z= and ——(3)

The natural response is the transient that occurs when the load is energized. It is the solution to the homogeneous differential equation for the circuit without the source or diode.

——-(4)

For this first order the natural response has the form

——(5)

Where t is the time constant L/R and A is a constant which is determined from the initial condition. Adding the forced and natural responses to get the complete solution,

——–(6)

The constant A is evaluated by using the initial condition for current. The initial condition for current in the inductor is zero because it was zero before the diode started conducting and it cannot change instantly.

Using the initial condition and equation above to evaluate A,

——(7)

Substituting for A in equation above,

——(8)

—–(9)

It is often convenient to write the function in terms of the angle rather than time. This merely requires being variable instead of twitting the preceding equation in terms of angle, t in the exponential must be written as , which requires t to be multiplied by also. The result is

——-(10)

A typical graph of circuit current is shown in Fig. 2. Equation above is valid for positive currents only because of the diode in the circuit, so current is zero when the function in equation above is negative. When the source voltage again becomes positive, the diode turn on, and positive part of the waveform in Fig. 2 is repeated. This occurs at every positive half cycle of the source. The voltage waveform for each element are shown in Fig. 2. Note that the diode remains forward biased longer than radians and the source is negative for the last part of the conductive interval. This may seem unusual, but an examination of the voltages reveals that Kirchhoff’s voltage is satisfied and there is no contradiction. Also note that the inductor voltage is negative when the current is decreasing (. The point when the current reach zero in equation above is when the diode is turns off. The first positive value of in equation above that results in zero current is called the extinction angle, in equation above, the equation that must be solved is

—–(11)

This reduces to

——(12)

There is no closed form solution for Î² and some numerical method is required. To summarize the current in the half wave rectifier circuit with R-L load (Fig. 8) is expressed as

——-(13)

For

Where,

The average power absorbed by the load is i2rmsR, since the average power absorbed by the inductor is zero. The rms value of the current is determined from the current function of equation above.

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Average current is

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2. 4 FULL-WAVE RECTIFIER

Bridge full-wave rectifier:

A single diode rectifier only produces a DC current for one half of the cycle.

The negative voltages are not converted to DC.

The bridge rectifier circuit produces DC throughout the cycle.

Figure 9: First half-cycle

Look at the diagram above: in the first half-cycle, the AC current flows from terminal A of the transformer (positive voltage) through the red pathway [11].

The positive applied voltage that applied to the diode D1 forward-biases that diode, allowing the current to pass through.

Current not pass through diode D4 because the positive potential at the junction between D1 and D4 reverse-biases the diode D4, which effectively acts as an insulator.

The resistor R symbolizes some circuit that will return current.

On leaving R, the current now enters D3, as the applied potential forward-biases that diode (D4 is still reverse-biased and so does not conduct current).

On leaving D3, the current returns to the low-potential terminal B of the transformer.

Figure 10: Next half-cycle

In the next half-cycle (above diagram), the terminal B of the transformer is positive with respect to A [11].

The current enters the diode D2 (D3 is reverse-biased).

Current passes through the circuit symbolized by R.

Then, the current returns via D4 (D1 is reverse-biased), to the low-potential A of the transformer.

Note that in each half-cycle, the current through R flows in the same direction.

The potential applied at A will fluctuate, but it will, in each cycle, have the same polarity.

As a result, by combining the first and the second half-cycle, we get a full wave rectification as figure 11.

Figure 11: Full wave rectification

Full – wave rectifier with R load:

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Figure 12: Full Bridge Circuit Figure 13: Center – tape Circuit

Center-tapped (CT) rectifier requires center-tap transformer. Full Bridge (FB) does not.

CT rectifier requires only two diodes, compare to four diodes for FB rectifier. Hence, CT rectifier experienced only one diode volt-drop per half-cycle. A conduction loss is half of FB rectifier.

Diodes ratings for CT rectifier are twice than FB rectifier.

For both circuit:

v0 =

DC voltage:

V0 =

Full Bridge rectifier waveforms:

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Center-tapped rectifier waveforms:

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Full – wave rectifier with R-L load:

1. Full Bridge rectifier waveforms with R-L load:

R-L load analysis:

Approximation with large L:

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R-L load approximation:

Approximate current:

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Power Factor:

Average Current in Diode:

RMS Current in Diode:

SAMPLE QUESTION

Question1: Half Wave Rectifier with Resistive (R) Load

For the half wave rectifier for figure shown below, the source is a sinusoid of 120V rms at a frequency of 60 Hz. The load resistor is 5â„¦. Determine

(a) The average load current

(b) The average power absorbed by the load

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Solution:

(a) Given, source voltage is 120 Vrms

From equation ;

The voltage across the resistor is half wave rectified sine wave with peak value

Vm= Vrms ( ) = 120 x ( )

Average current is:

== 10. 8A

(b) Average power absorbed by the load is:

= 84. 9v

Hence, = 1440w

Question 2: Half Wave Resistive-Inductive (R-L) Load

For the half wave rectifier of figure below, R= 100 Ohm, L= 0. 1H, = 377 rad/s and Vm= 100V. Determine

an expression for the current in this bias circuit

the average current

the rms current

the power absorbed by the R-L load

the power factor

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Solution:

For parameters given.

and

Equation 3-15 becomes

Sin (Î²-0. 361) + sin(0. 361)e-Î²/0. 377= 0

Using a numerical root finding program, Î² is found to be 3. 50 rads or 201°

Average current is determined from equation 3-17

= 0. 308A

The rms current is found from equation 3-16

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= 0. 474A

The power absorbed by the resistor is . The average power absorbed by the inductor is zero. So,

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= 22. 4W

The power factor is computed from the definition pf= P/S. P is power supply by the source which must be the same as that absorbed by the load.

Pf= P/S= P/Vs, rmsIrms= 0. 67

Question 3: Full Wave Rectifier with Resistive-Inductive (R-L) Load

The bridge rectifier circuit of figure below has an ac source with Vm = 100V at 60 Hz and a series R-L load with R = 10Î© and L = 10mH. Determine;

The average current in the load.

The peak-to-peak variation in load current based on the first ac term in the Fourier series.

The power absorbed by the load and the power factor of the circuit.

The average and rms currents in the diodes.

Solution:

The average output voltage is :

And the average load current is :

Amplitudes of the ac voltage terms are determined by the equation below.

For n = 2 and 4,

The amplitude of the first two ac current terms in the current Fourier series are computed from equation below:

The current I2 is much larger than I4 and higher order harmonics, so, I2 can be used to estimate the peak-to-peak variation in load current, âˆ†i0 â‰ˆ 2(3. 39) = 6. 78A. Actual variation in i0 will be larger because of the higher order terms.

The power absorbed by the load is determined from I2rms. The rms current is then determined from the equation below :

Adding more terms in the series would not be useful because they are small and have little effect on the result. The power load is:

The rms source current is the same as the rms load current. The power factor is:

Each diode conducts for one-half of the time, so,

and,