International Journal of Advance Research in Engineering, Science & Technology(IJAREST),
ISSN(O):2393-9877, ISSN(P): 2394-2444,
Volume 2,Issue 4, April- 2015

Simulation of AC voltage Regulator and its Control schemes, Comparison

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Abstract

At starting of induction motor it draws high inrush current and jerk on motor shaft. This paper present simulation results comparison about thyristor based three phase ac voltage regulator which is use full as a soft starting of induction motor. Simulation strategies based on delay of firing(alpha firing).firstly with R and RL load .In this paper the strategies comparison with other starting methods, also analysis without neutral point. MATLAB/SIMULINK is used to get desired analysis.

Keywords*- AC voltage regulator, Matlab, thyristor, firing angle,Gate pulse*

I. INTRODUCTION

All manuscripts must be in English. Induction motor starting has many adverse effects on the entire power system. Two of the prominent issues are the effects caused by high inrush currents on the mechanical system of the load, and the response of the generation source to the load step, of which voltage dip is of most concern. To address these issues, different starting methodologies have been developed to mitigate damaging effects. It is not economically practical to test each of these methods on a physical system because of possible equipment damage, electrical system vulnerability, and other problems. Through simulation of these systems it possible to compare the various starting methods in an economical, secure and yet effective manner. Electrical motors are the back bone of industrial plants.

A converter that changes an ac supply with alternative voltage, frequency, phase, or shape is called an AC/AC converter. The simplest one is voltage regulator, which changes ac voltage without frequency variation. They are low-effective devices and thus no use in precision system. The most usual application are the soft starter for induction motor where the voltage control provides smooth jolt-free acceleration.AC voltage regulators have a constant voltage ac supply input and incorporate semiconductor switches which vary the rms voltage impressed across the ac load. These regulators converters sin c e their thyristor switches are naturally commutated by the alternating supply. This converter turn-off necessary, particularly at low output voltage levels (relative to the input ac voltage magnitude).

A feature of direction conversion of ac to ac is the absence of any intermediate energy stage, such as a capacitive dc link or energy storage inductor. There for ac to ac converters are potentially more efficient but usually involve a larger number of switching devices and output is lost if the input supply is temporarily lost.

There are three basic ac regulator categories, depending on the relationship between the input supply frequency fs, which is usually assumed single frequency sinusoidal, possibly multi-phased , and the output frequency fo. Without the use of transformers the output voltage rms magnitude Vorms is less than or equal to the input voltage rms magnitude Vs, Vorms ≤ Vs.

• Output frequency increased, fo > fs , for example, the matrix converter
• Output frequency decreased, fo < fs, for example, the cycloconverters.
• Output frequency fundamental = supply frequency, fo = fs, for example, a phase controller.

Although this technique are characterized by low cost, simple and rugged design, it is suffering from many difficulties as high harmonics in the supply currents, narrow speed control range, and different performance depending on the shape of supply currents. The harmonic contents in line currents can be reduced using modern harmonic reduction techniques as active filters or third harmonic injection technique [4]. The problem of the different performance depending on the shape of supply currents can be removed using control system that can detect the mode of operation of the system as explained and implemented in this paper. The ac voltage controller has three mode of operation depends on the shape of supply current namely 0/2, 0/2/3, and 2/3. The best mode of operation is 2/3 because of law THD in line currents, high efficiency and low.

pulsating torque. To force the motor to work in 2/3 mode of operation, it is required to follow the limits of mode 2/3. The motor speed is directly proportional to the firing angle in modes 0/2 and 0/2/3 and inversely proportional in mode 2/3. So, the control system has to detect the mode of operation to produce the correct firing angle [1].

I. BASIC PRINCIPLE

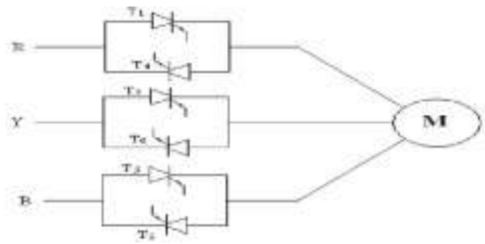

Figure 1 basic circuit

The main circuit of the intelligent Soft-Start controller for induction motor is shown in Figure.1, TI-T4, T3-T6 and T2-T5 are three pairs of thyristors in opposite direction, respectively connected in series into the motor's three phase circuits, M representing an Induction motor. To achieve smooth starting of motor, the trigger angles of the six thyristors must be adjusted in certain time sequence to control the input voltage of motor to vary from low to high according to the predetermined voltage-time curve. For this kind of circuit, the essence of the method of phase-control reduced voltage is to cut the waveform of the power supply, namely, the voltage applied to the motor is non-sine wave,

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while the positive half period and the negative half period of each phase voltage are symmetrical [4].

A. *Three Phase AC voltage Regulator without neutral*

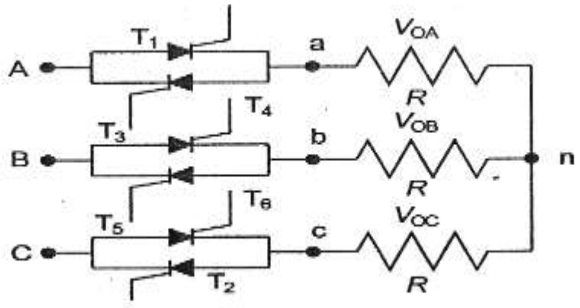

Figure 2 Basic circuits without neutral

The power to a three-phase star or delta-connected load may be controlled by the ac regulator shown in figure 2 with a star-connected load shown. If a neutral connection is made, load current can flow provided at least one thyristor is conducting. At high power levels, neutral connection is to be avoided, because of load triplen currents that may flow through the phase inputs and the neutral. With a balanced delta connected load, no triplen or even harmonic currents occur.

If the regulator devices in above figure, without the neutral connected, were Thyristor, each would conduct for ½π in the order T1 to T6 at ⅓π radians apart. In the fully controlled ac regulator of figure 2 without a neutral connection, at least two devices must conduct for power to be delivered to the load.

The thyristor trigger sequence is as follows. If thyristor T1 is triggered at α, then for a symmetrical three phase load voltage, the other trigger angles are T3 at α+⅔π and T5 at α+4π/3. For the anti-parallel devices, T4 (which is in anti parallel with T1) is triggered at α+π, T6 at α+5π/3, and finally T2 at α+7π/3.[4].

B. *Gate Pulse period*

- $\alpha < \frac{1}{2}\pi$

i. short gate pulse period

With a purely inductive load, the average output voltage is zero. If uni-directional current flow s (due to the uses of a narrow gate pulse), the average load current, hence average thyristor current, for the conducting thyristor, is

$$Io = It = \frac{\sqrt{2}V}{\pi\omega L}[(\pi - \alpha)\cos\alpha + \sin\alpha] \qquad (1)$$

Which with unipolar pulses has a maximum of √ 2V/ ω L at a=0.

ii. Extended gate pulse period

When the gate pulses are extended to π , continuous current flows, , given by Ithrms=V/ωL , lagging V by $½\pi$. Each thyristor conducts an average current and rms current of

$$h = \frac{\sqrt{2}V}{\pi\omega L}. \qquad (2)$$

- $\pi \geq \alpha \geq \frac{1}{2}\pi$(symmetrical gate pulse)

The maximum rms voltage and current are Vrms=V, Irms=V/X at α=½π .

$$Irms = \frac{V}{X}\left[\frac{2}{\pi}(\pi - \alpha)(2 + \cos 2\alpha) + \frac{3}{2}\sin 2\alpha\right] \qquad (3)$$

The rms equations for a greater than and less than ½ π are basically the same except the maximum period over which a given thyristor conducts changes from π to 2π (respectively), hence the rms values differ by √2. Since the output power is zero, the supply power factor is zero, for bidirectional current.[3]

C. *Gate Pulse period*

Depending on the firing angle α, there may be three operating modes,

Mode I (also known as Mode 0/2): 90° ≤ α ≤ 150°

When none or two thyristor conduct For a = 120°,Fig(3) ,earlier no thyristor were on and van=0.At α= 120, thyristor T1 is given a gate signal while T6 has a gate signal already applied .Since VAB is positive, T1and T6 are forward biased and they begin to conduct and Van=$\frac{1}{2}$VAB. Both T1 and T6 turn off, when VAB becomes negative. When a gate signal is given to T2 turns on again. When a gate signal is given to T2, it turns on and T1 turns on again.

$$Vo = Vs\left[\frac{5}{4} - \frac{3\alpha}{2\pi} + \frac{3}{4\pi}\sin(2\alpha + 60°)\right]^{\frac{1}{2}} \qquad (4)$$

For $\alpha > 150°$,there is no period when two thyristor are conducting and the output voltage is zero at $\alpha = 150°$.Thus, the range of the firing angle control is$0 \leq \alpha \leq 150°$.

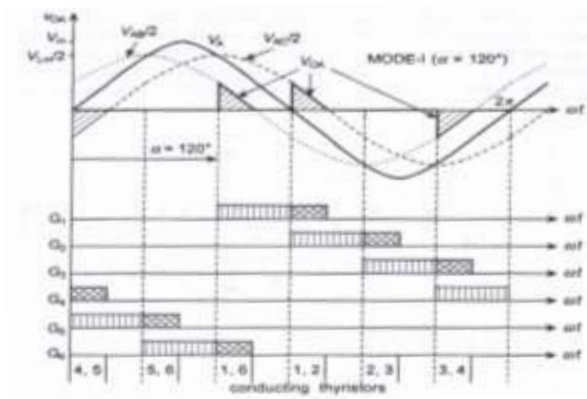

Figure 3 Mode-I (α=120°). [4]

MODE II(also known as Mode 2/2):$60 \leq \alpha \leq 90°$

Two Thyristor .one in each phase always conduct.

$$Vo = Vs\left[\frac{1}{2} + \frac{3}{4\pi}\sin 2\alpha + \sin(2\alpha + 60°)\right]^{\frac{1}{2}} \qquad (5)$$

For $\alpha = 7$ Thyristor T5 and T6 were conducting and Van=0, T1 is turned on,T6 continues to conduct while T5 turns off as Vcn is negative Van= VAB. When T2 is turned on at 135°,T6 is turned off and Van= VAc.The next thyristor to turn on is T3 which turns off T1 and Van=0.One thyristor is

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always turned off when another is turned on in this range of and the output voltage is either one-half line-to-line voltage or zero. One thyristor is always turned off when another is turned on in this range of α and the output voltage is either one-half line-to-line voltage or zero.

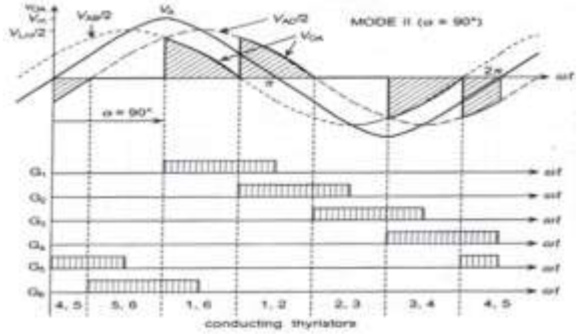


Figure 4 Mode-II (α=90°). [4]

Mode III (also known as Mode 2/3): $0 \leq \alpha \leq 60^{\circ}$

$$V_o = V_s\left[1-\frac{3\alpha}{2\pi}+\frac{3}{4\pi}\sin 2\alpha\right]^{\frac{1}{2}} \qquad (6)$$

There are periods when three Thyristor are conducting, one in each phase for both direction and periods when just two thyristors conduct as in Fig 6.

For example, with α = 30 assume that at $\omega t = 0$,Thyristor T5 and T6 are conducting, and the current through the R-load in a-phase is zero making Van=0. At $\omega t = 30^{\circ}$ T1 receives a gate pulse and starts conducting; T 5 and T6 remain on and the current in T5 reaches zero at 60°, turning T5 off. With T1 and T6 staying on, Van=$\frac{1}{2}$VAB. At 90◦ T2 is turn on. The thyristor T1, T2and T6 are then conducting and Van=VAN. At 120° ,T6 turns off, living T1 and T2 on so Van=$\frac{1}{2}$VAc.Thus with the progress of firing in sequence till $\alpha = 60^{\circ}$ the number of thyristor conducting at a particular instant alternates between two and three.

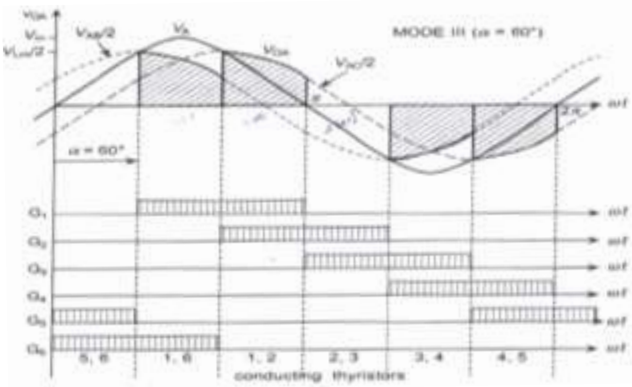
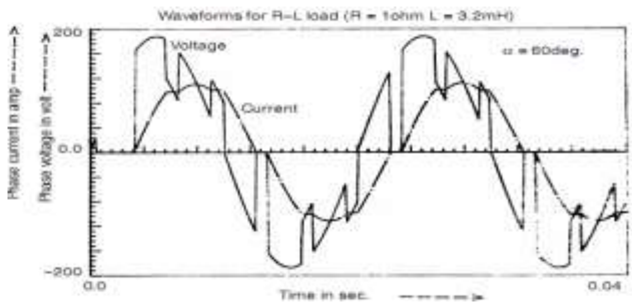
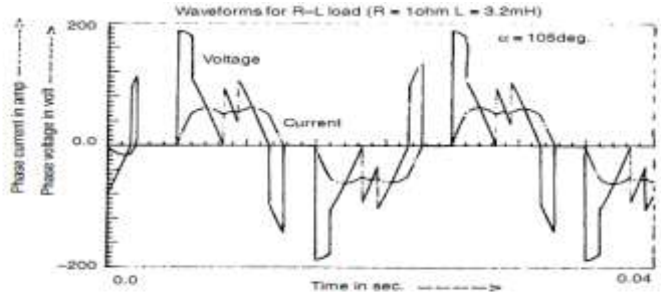


Figure 5 Mode-III (α=60°). [4]



(a)



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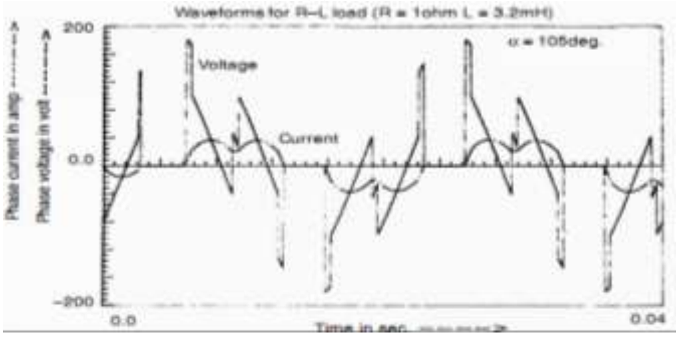

Figure 6 (a) α=60° , (b)α=90°, (c)α=105°.[7]

D. *Comparison of starting methods*

Table 1. [2]

points	Type of starters		
	D.O.L Starter	*Star/Delta*	*Soft starter*
Slipping belts &heavy wear on bearings	yes	medium	No
High Inrush current	Yes	No	No
Heavy wear &tear on gear box	yes	yes	No
Damaged goods/products during stop	yes	yes	No
Transmission peaks	Yes	Yes	No

II. SIMULATION OF AC VOLTAGE REGULATOR IN MATLAB SIMULINK

In order to prove that the presented AC voltage regulator method is valid, the simulation using Simulink and the power system of Matlab is done. And proposed circuit topology is shown in fig 8.when continuously triggered, a pair of anti-parallel connected thyristor act as a closed switched [6]. The sequence of thyristor pair are triggered as mention in section B" Three Phase AC voltage Regulator without neutral".

The power to a three-phase star or delta-connected load may be controlled by the ac regulator shown in figure [8] with a star-connected load shown. If a neutral connection is made, load current can flow provided at least one thyristor is conducting. At high power levels, neutral connection is to be avoided, because of load triplen currents that may flow through the phase inputs and the neutral. With a balanced delta connected load, no triplen or even harmonic currents occur.

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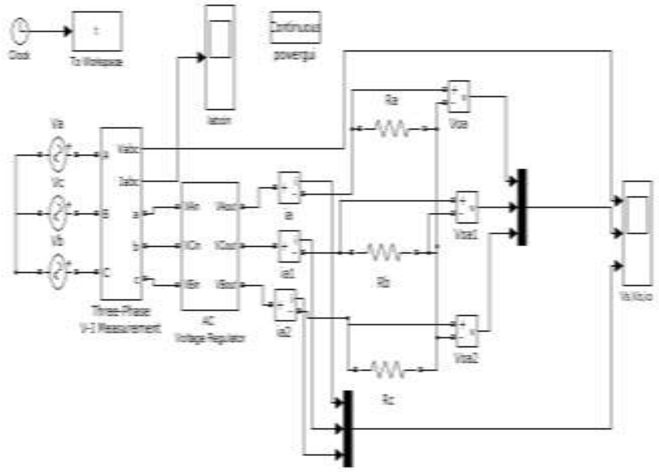


Figure 7 AC voltage regulator topology

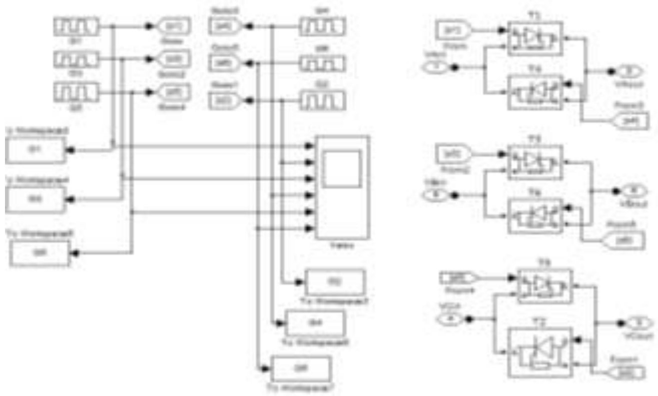
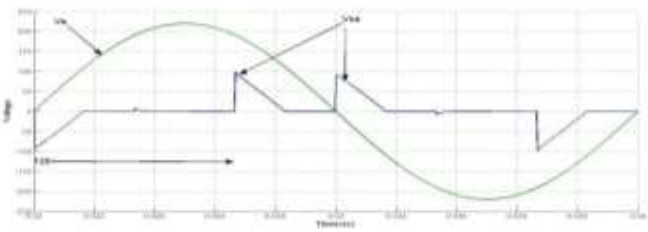


Figure 8 Gate pulse circuit

A. Simulation Result

- With R Load



(a)

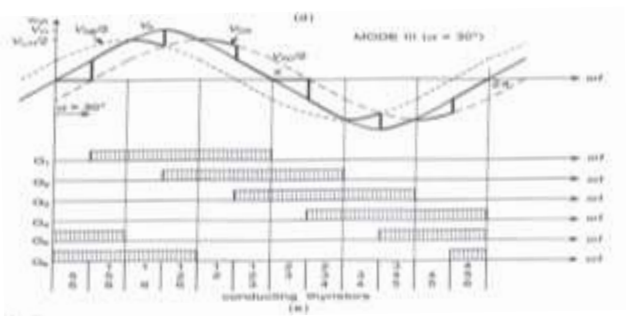


Figure 9 Mode-III (α=30°). [4]

- ***with RL load***

For star-connected pure L-load, the effective control starts at α > 90. And the expressions for two ranges of α are:

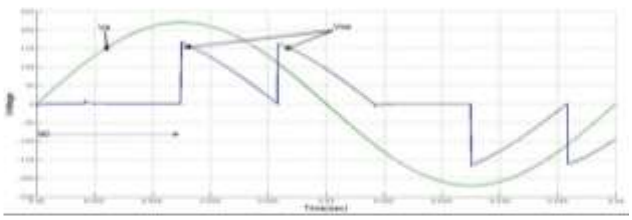
- $90° \leq \alpha \leq 120°$

$$Vo = Vs\left[\frac{5}{2} - \frac{3\alpha}{\pi} + \frac{3}{2\pi}\sin(2\alpha)\right]^{\frac{1}{2}} \tag{6}$$

- $120° \leq \alpha \leq 150°$

$$Vo = Vs\left[\frac{5}{2} - \frac{3\alpha}{\pi} + \frac{3}{2\pi}\sin(2\alpha)\right]^{\frac{1}{2}} \tag{7}$$

Figure 7 (a) (b) (c) shows typical simulation results using the later approach [7] for a three-phase voltage controller fed RL load for α = 60., 90., and 105. Which agree with the corresponding simulation result in Fig 11.



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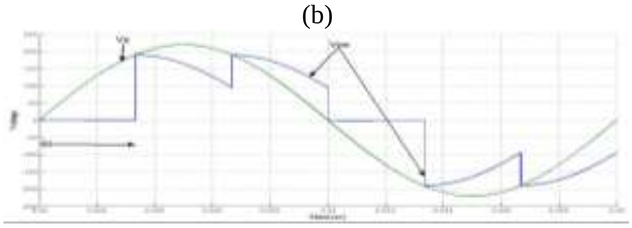
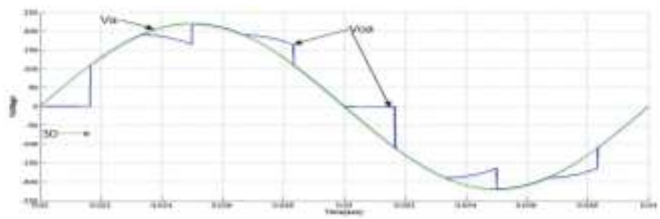


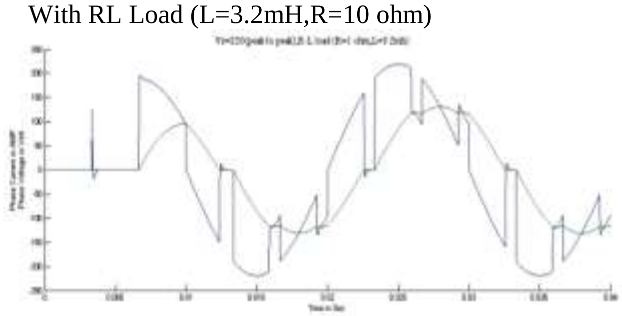
(c)



(d)

Figure 10 Simulation results With R load
(a) α =120°(b) α =900°(c) $\alpha = 60°$,(d) $\alpha = 30°$.

- With RL Load (L=3.2mH,R=10 ohm)



(a)

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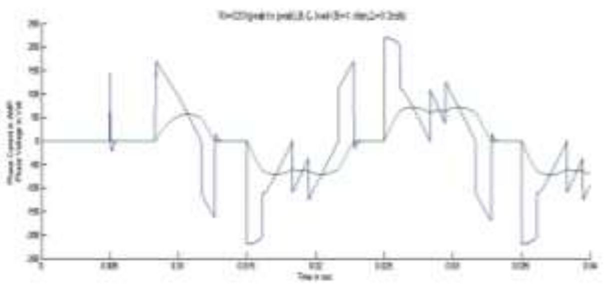

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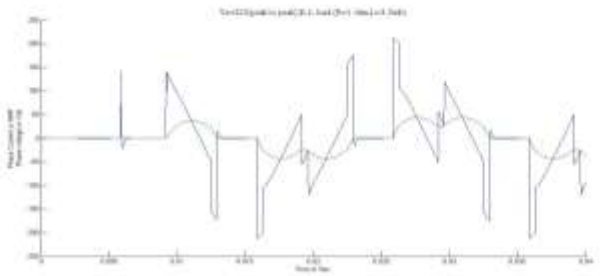

(c)

Figure 11 Simulation results With RL load(a)α =60°(b)α =90°(c)α =105°

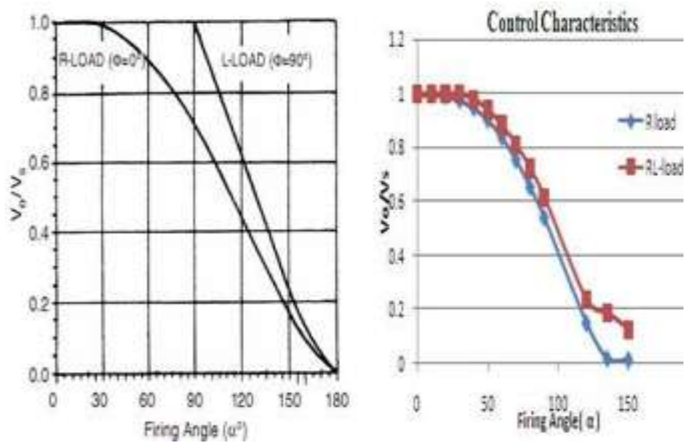

Figure 12 Control characteristics [7]

III. Application Areas

Soft starters with a pump module are nowadays used in many areas. Some of these are water supply ,purification plants , breweries / dairies ,long-distance heating plants , swimming pools ,food and drinks production, chemical and petrochemical plants, mining ,bottling plants ,paper industry ,wood processing[3].

A. Advantages of soft starters

• Increased acceleration time can be beneficial for motor and machine.
• The starting current is reduced or can be limited.
• The torque is adapted to the corresponding load.
• For pumps, surges during start and stop can be avoided.
• Jerky movements and shocks, which could hamper a process, are avoided.
• The wear and tear of belts, chains, gears and bearings is avoided.
• By means of the different controls, simplified automation is possible
• By using a soft starter, the torque impact which occurs on the mechanical parts of a machine can be prevented.
• By means of a soft starter it is possible to limit the motor starting current (limited by the amount of starting torque required)
• This reduces the strain on the network.[3]

IV. Conclusion

A simulation of thyristor based voltage regulator starter without neutral operating with R and RL load has been presented .behavior of the voltage regulator shown as in the different form of wave shape. The paper presents a AC voltage comparison with “Standard Book”, which similar to simulation results.

Acknowledgment

I would like to thank Prof. Rajesh Prasad , SCET Surat for providing me support to carry out my work with excellent computational facilities. Then I would like to dedicate this to my parents and friends who support to me.

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