Dynamic Performance Analysis of AC Voltage Regulator Feeding RLC load

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Abstract: In this research work,the performance of AC voltage regulator feeding series RLC load is analyzed using MATLAB/SIMULINK. Various parameters are calculated and analysis of harmonics at different firing angles is achieved. The total Harmonic distortion (THD) at different firing angles are investigated using Fast Fourier Transform (FFT) technique. The SCR based regulator is being controlled by Phase angle control (PAC) method, in which by varying the firing angle the rms output voltage varies inverse proportionally. Such type of controllers is used as AC drives for various AC loads using voltage control method. Semiconductor based power devices provide higher efficiency, less maintenance and capability to withstand large amount of power. Hence, due to their numerous benefits and compact sizes AC voltage regulators finds several applications in industries. The results obtained from the investigation suggest the quality performance and effects to RLC load.

Keywords: *RLC Load, FFT, MATLAB, PAC, AC Drives, SCR, THD*

1. Introduction

An AC voltage controller is a circuit which takes fixed ac voltage at its input and delivers variable ac voltage at the output, without affecting the frequency (frequency remain same). This conversion is made very efficient and flexible with the advent of power control devices such as SCR, IGBT, MOSFET, TRIAC etcetera [1-3]. The general model of conversion is shown in figure 1.

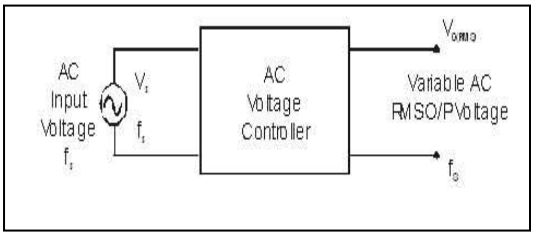

Figure 1. AC Voltage Controller

AC voltage controllers are the thyristor devices that convert a fixed alternating voltage directly into variable alternating voltage without change in frequency. The voltage control is accomplished either by phase control under the natural commutation using pair of silicon controlled rectifiers (SCRs) or by on/off control under force commutation using fully controlled GTOs, power transistors, IGBTs etc. The SCR based AC voltage controller model is shown in figure 2.

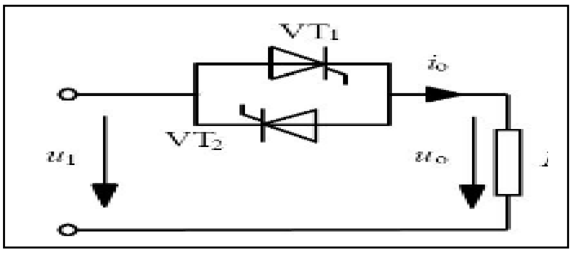

Figure 2. Thyristor based AC Voltage Controller

The presence of harmonics in the supply and load currents is harmful for the source if the load happens to be ac motors such as single-phase induction motor [1-3]. The harmonics merely increase the heating of the winding without producing useful torque for heating and lighting loads [5]. However, both fundamentals and harmonics are useful in producing ac controlled power [3][6][7][8]. In such applications, knowledge of RMS value of output voltage, *Vor* is necessary to calculate the ac power delivered to the load.
The expression for RMS value of the load voltage, is obtained as follows.

$$V_{or} = V_s\left[\frac{1}{\pi}\left\{(\pi-\alpha)+\frac{1}{2}\sin 2\alpha\right\}\right]^{1/2} \quad (1)$$

The performance analysis of ac voltage converters is mainly done to achieve the speed regulation in induction motor (IM) with in specified range at lower losses [14], the speed regulation varies in specification depending upon its power rating and internal physical structure hence its fault localization remains important factor [9] as well besides speed control. The adjustable speed drives possess various advantages based on different techniques such as using Pulse width modulation (PWM) of voltage based control [15-16]. One of the important advantage of SCR based ac-ac convertor is a control range of thyristor using phase angle control method (PAC). Digital controllers play a vital role for the speed controlling [17], such control employing PWM and PAC can also be efficiently achieved through intelligent controllers as well [18]. The performance of such converters also provide effects on soft starting of IM [10] [13], hence automatic voltage regulation and stabilization is needed [11]. The circuit configuration of ac voltage regulator is not only limited to inverse parallel of SCR type, the high performance can also be achieved through various other ac drives [12] with low THD. But

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thyristor based kind is simple and easy to develop and implement.

In phase control the on time of SCR during each cycle is controlled with firing angle. In this method, each of the two-thyristor controlled one half of wave, in phase control thyristor switches connect the load to the ac source for a portion of each of cycle of input voltage. The advantage of this method is continuous output voltage control is possible by varying the firing angle and no commutation circuit is required, the table 1 shows the relationship of phase angle (α) w.r.t. time of 20ms (50Hz)

Table 1. Relationship of Phase Angle (α) with Time

Phase Angle (α)	Time	Phase Angle (α)	Time
30°	1.667 ms	210°	11.66 ms
60°	3.33 ms	240°	13.33 ms
90°	5 ms	270°	15 ms
120°	6.667 ms	300°	16.667 ms
150°	8.33 ms	330°	18.33 ms
180°	10 ms	360°	20 ms

The model of thyristor based AC voltage controller has been made in MATLAB 2016 Simulink. The Harmonics of AC voltage controller feeding various loads are analyzed using Fast Fourier Transform Technique. The waveforms of several loads are analyzed using the Fast Fourier Transform technique. The fast Fourier transform (FFT) is a discrete Fourier transform algorithm which reduces the number of computations needed for N points from $2N^2$ to $2N \log (n)$.

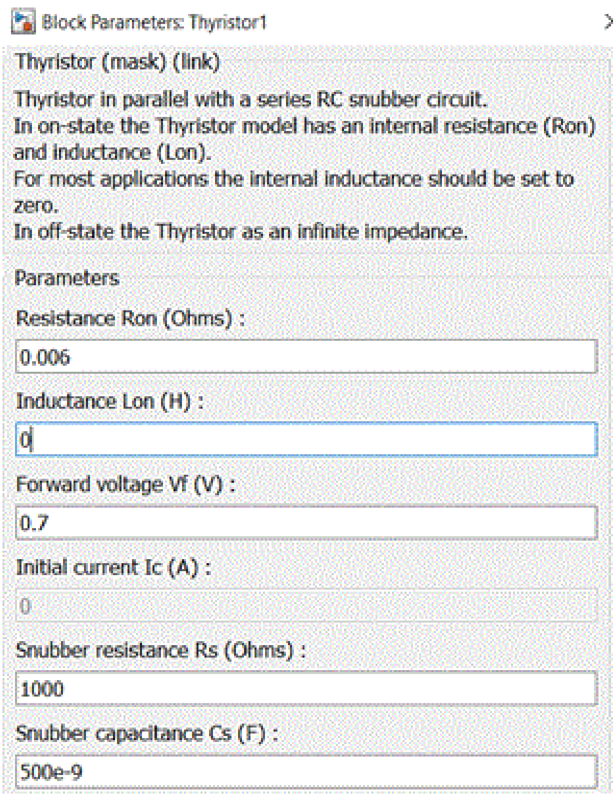

Figure 3. Thyristor specification

The performance characteristics such as output voltage, output current and power factor are evaluated with respect to the variation in firing angle α. Implementation of any converter circuit needs to be tested before going for hardware this seem beneficial in many aspects i.e. it reduces cost, man power, time. This is achieved by using simulation software's were the same model or topology can be tested with the real-time hardware ratings and device specifications. One such software for testing power electronic converter circuit is MATLAB. The application of these software's really prove their worth through their real time applications. Hence in this research ac voltage controller circuit working in firing angle control is simulated using MATLAB software. The thyristor specifications are shown in figure 3.

2. MATLAB Simulation of AC Voltage Controller feeding series RLC Load

The Simulink model of ac voltage controller feeding series RLC load R=1kΩ, L=0.06H, C=6.8μF is shown in figure 4.
The inductive & capacitive reactive reactance are given by

$$X_L = 2\pi f L = 2\pi \times 50 \times 0.06 = 18.85\Omega \tag{2}$$

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi \times 50 \times 6.8\mu} = 468\Omega \tag{3}$$

Circuit impedance is given by

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = 1096\Omega \tag{4}$$

2.1 Analysis at firing angle α=0⁰

At firing angle $\alpha=0^0$, supply input current is calculated as

$$I = \frac{V}{Z} = \frac{230}{1096} = 0.21\ A \tag{5}$$

$$\varphi = \tan^{-1}\frac{(X_L - X_C)}{R} = -24.18° = 24.18°\ \boldsymbol{lead} \tag{6}$$

The negative sign shows that the current is leading the voltage. The power factor is calculated as

$$\cos\varphi = 0.9122\ lead \tag{7}$$

2.2 Analysis at firing angle α=60⁰

At firing angle $\alpha=60^0$, supply input current is calculated as

$$I = \frac{V_L}{Z} = \frac{194.9}{1096} = 0.1717\ A \tag{8}$$

The power factor is calculated as

$$\cos\varphi = \frac{I_L^2 R}{V_l I_L} = 0.88\ lead$$

(9)The phase angle has been calculated as leading since the load current leads the load voltage.

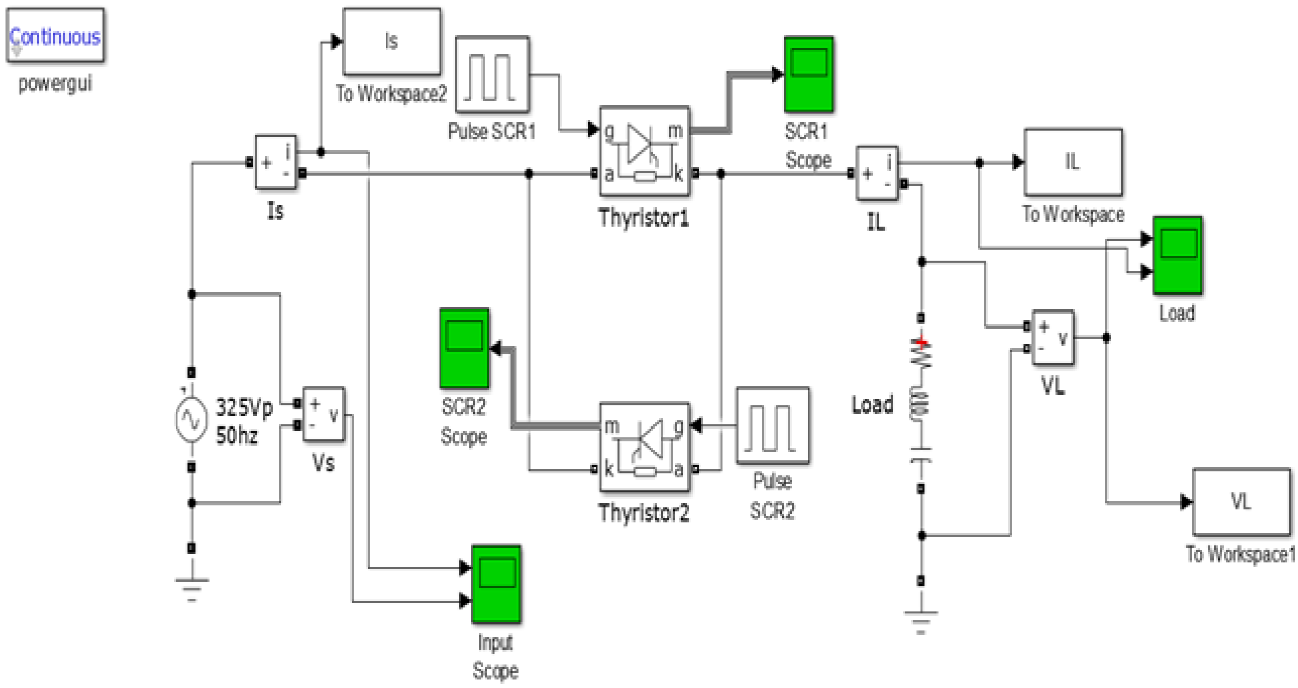

Figure 4. Simulink Model of AC Voltage Controller with series RLC load

$$\varphi = \cos^{-1} 0.88 = 28.35° \ \textbf{lead} \quad (10)$$

2.3 Analysis at firing angle α=150⁰

At firing angle $\alpha=150^0$, supply input current is calculated as

$$I = \frac{V_L}{Z} = \frac{37.76}{1096} = 0.034\ A \quad (11)$$

The power factor is calculated as

$$\cos\varphi = \frac{I_L^2 R}{V_l I_L} = 0.9\ lead \quad (12)$$

The phase angle has been calculated as leading since the load current leads the load voltage.

$$\varphi = \cos^{-1} 0.9 = 25.78\ \textbf{lead} \quad (13)$$

The figures 5-10 deliver the graphical waveforms of the simulated model at $\alpha= 0^0, 60^0, 150^0$ of input and load parameters. Whereas figures 11-16 show the FFT analysis of the load parameters.

3. Discussion

The load circuit behaves as a capacitive in performance making current leading the voltage by 24.18° at α=0°. The phase angle varies with change in firing angle of thyristors. At α=0°, thyristors become turned on at 0 seconds and provide full conduction of supply, hence working as diodes. The THD of supply current is 8.26%, providing sinusoidal load voltage with minimal distortion and greater leading power factor. Load voltage inversely varies with variation in triggering angle of thyristors, so by increasing α, rms output voltage decreases.

Due to the involvement of DC component in the load, the harmonics are produced. At α=60°, the load voltage reduces significantly with increased THD of 36.69%, the increment is due to the non-sinusoidal output at RLC load, with little change in phase angle between current and voltage the displacement power factor also reduces from 0.922 to 0.88 leading, this is due to the induced harmonics generated in the load which ultimately produces heating effect across the load. At α=150°, the load voltage reduces to 37.76 V_{rms}, increasing THD of 114.87 %, with minimal change in displacement factor and phase angle. The higher THD is the indication of the availability of multiples of fundamental frequencies with greater magnitudes hence the involvement of additional frequencies change the reactance of both the inductor and capacitor. The overall effect provides almost same leading displacement power factor.

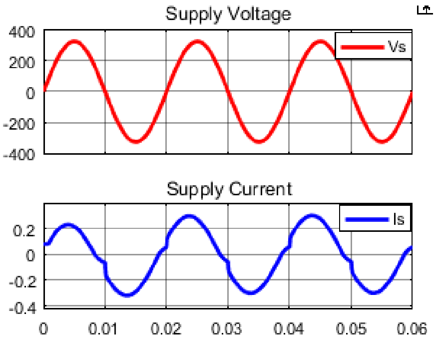

Figure 5. Input waveforms at α=0^0

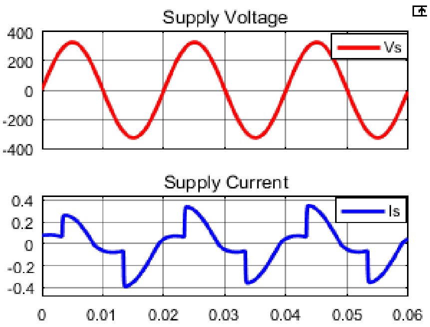

Figure 7. Input waveforms α=60^0

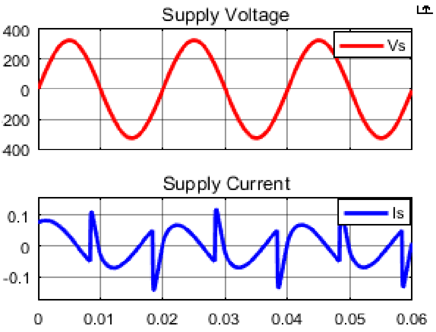

Figure 9. Input waveforms α=150^0

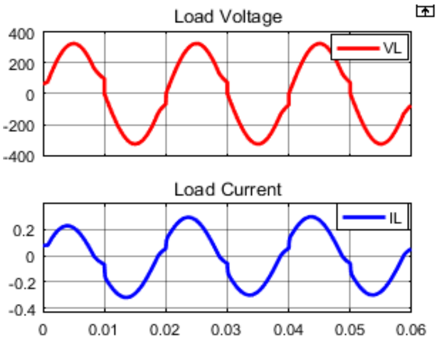

Figure 6. Output waveforms α=0^0

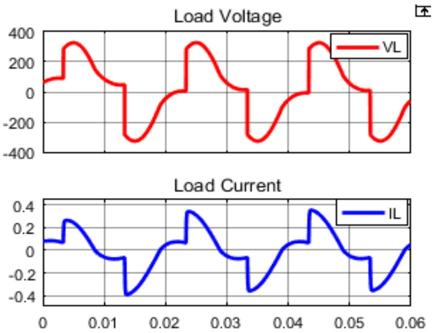

Figure 8. Output waveforms α=60^0

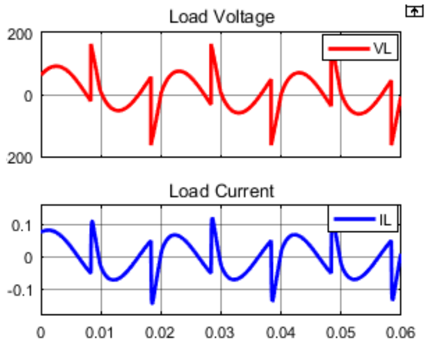

Figure 10. Output waveforms α=150^0

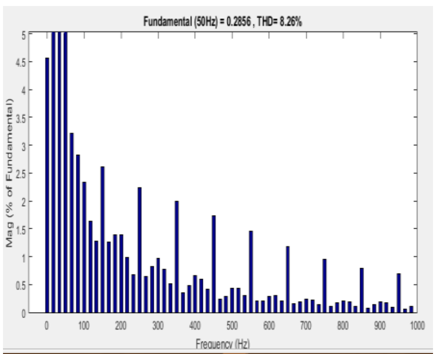

Figure 11 FFT Analysis of Load Current α=0^0

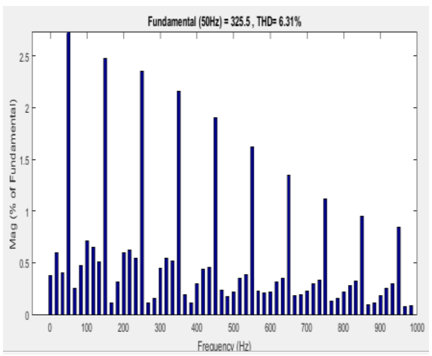

Figure 12 FFT Analysis of Load Voltage α=0^0

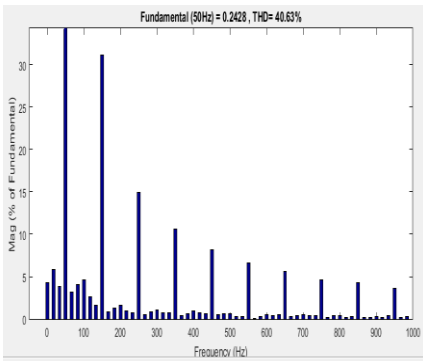

Figure 13 FFT Analysis of Load Current α=60^0

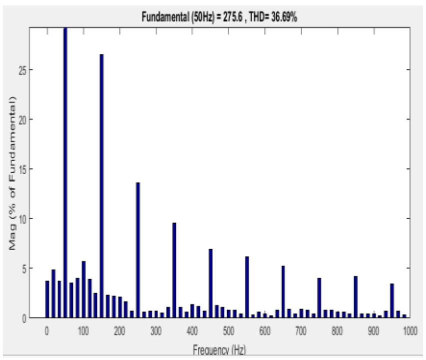

Figure 14 FFT Analysis of Load Voltage α=60^0

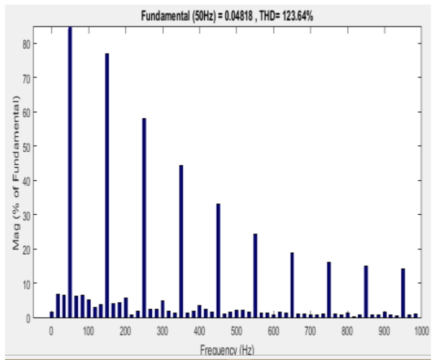

Figure 15 FFT Analysis of Load Current α=150^0

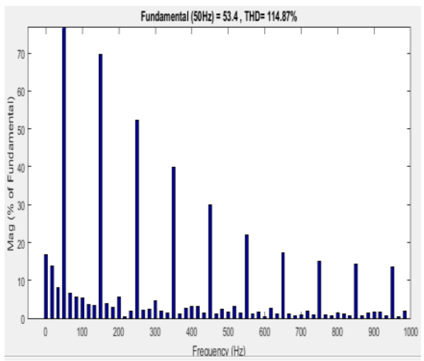

Figure 16 FFT Analysis of Load Voltage α=150^0

4. Conclusion

The above analysis and discussion present that the performance of the AC voltage converter. The FFT analysis tells that THD is almost same for both current and voltage of load, but as firing angle increases, the THD increases as well, which increases the heating effect in the system. Whereas the power factor remains constant and significant control of RMS voltage has been achieved to drive the load of RLC. The inverse parallel SCR based AC/AC converter can be utilized to be implemented in different AC systems where variable voltage control is needed, since it provides almost constant power factor.

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