Study and Performance Analysis of Three-Phase AC Voltage Controller

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Abstract:

The control of power from few watts to megawatt range is very much indeed for commercial applications.This paper presents the simulation and hardware design of three-phase ac voltage controller with star connected balanced and unbalanced loads.The unbalanced operation of the converter either may be due to loss of synchronization of pulses or load or both. The phase locked loop is used to track the frequency of the supply and generate switching pulses for thyristors so that chances of misfiring devices are less.

*Keywords:*balanced load, three-phase, phase locked loop, synchronization, switching pulses.

1. Introduction:

In general, the utility sources provide constant amplitude and constant frequency supply either in single – or three – phase system. The basic principle of power electronic ac – ac converters, convert from constant amplitude ac supply to variable amplitude, frequency and phase system.The single – phase systems are normally preferable for low power rating maximum to 1kW and large power ratings three-phase power supply system is preferred. The converters which are varying rms value of ac supply but at constant frequency is called as *ac voltage controllers or ac regulators* [1]. These converters are used for light control, heat control, speed control of induction motor and synchronous motor drives using stator voltage control method. The cycloconverters employed for variable voltage and variable frequency used for *V/f* control method of induction motor. These converters can convert from three – phase to either single – or three – phase system [2]. The load frequency can be achieved by cycloconverters from supply frequency range to 3 Hz. The three-pulse, three – to single – phase conversion, cycloconverters are used for low power rating i.e. more than 1kW, to drive single phase loads at variable rms voltage, at different power factors. Similarly, six-pulse converters are used for three- to three – phase system for large power ratings [3]. The variable firing angle scheme normally preferred to control fundamental component of the load.

This paper mostly concerns for design and analysis of three – phase ac voltage controller for lower circuit either in three or four wire system and these converters are many different configurations either converter or load or both in star or delta configurations [4]. In star connected loads, the THD of line current is more than delta connected loads because triplen harmonics are having zero phase difference and provides the path in the loop [5-6]. The later sections of this paper, shows the analysis, simulation and hardware testing for balanced R and RL loads.

2. Simulation Study

The three – phase ac voltage controller is shown in Fig.1. The neutral connection between source and load will comprise as three single-phase ac voltage controllers. The load voltages in each phase having phase difference of 120 degrees to each and very simple analysis. The sequences of switches for each thyristor is as follows: phase ‘a’ thyristors T1 and T4 are fired with reference to 0° and 180°, similarly for phase ‘b’ thyristors T3 and T6 are fired with reference to 120° and 300° and phase ‘c’ thyristors T 5 and T 6 are fired with reference to 240° and 60°. In four-wire configuration, the analysis is a bit different and complicated. The converter operation is explained in four modes along with simulation for pure resistive load of 10Ω and RL load of 10Ω and 10mH:

Mode1: This mode operation, either three thyristors in each phase or two thyristors are any two phases for a duration of $0 \le \alpha \le 60^\circ$. This mode is also called as 2/3 mode.The phase ‘b’ and ‘c’ are conducting before phase ‘a’ is fired. For a firing angle of 30°, all thyristors are conducting i.e. T1, T6 and T5, the load voltages are same and equal to phase supply voltages. At 60°, the phase ‘c’ is get turned off, from $60 \le \omega t \le 90^\circ$ two thyristors are on i.e. T1 and T6. The phase ‘c’ voltage is zero for 30° and phase ‘a’ and ‘b’ voltage magnitudes are $v_{ab}/2$. The phase ‘a’ load voltage and current waveforms for balanced R and RL loads are shown in Fig.2, for a firing angle of 30° respectively. Each phase and line rms output voltage is expressed as

$$V_{Prms} = V_s \left[1 - \frac{3\alpha}{2\pi} + \frac{3}{4\pi} \sin 2\alpha \right]^{1/2} \quad (1)$$

$$V_{Lrms} = \sqrt{3} V_{Prms} \quad (2)$$

Mode2: This mode of operation only two thyristors will conduct for a duration of $60 \le \alpha \le 90^\circ$ and also called as 2/2 mode.The phase ‘a’ load voltage and current waveforms for balanced R and RL loads are shown in Fig.3, for a firing angle of 75° respectively.Each phase and line rms output voltage is expressed as

$$V_{Prms} = V_s \left[\frac{1}{2} + \frac{3}{4\pi} \sin 2\alpha + \sin\left(2\alpha + \frac{\pi}{3} \right) \right]^{1/2} \quad (3)$$

$$V_{Lrms} = \sqrt{3} V_{Prms} \quad (4)$$

Mode3: This mode operation either only two thyristors or no thyristors will conduct for a duration of $90 \le \alpha \le 150^\circ$ and also called as 2/0 mode.The phase ‘a’ load voltage and current waveforms for balanced R and RL loads are shown in Fig.4, for a firing angle of 120° respectively. Each phase and line rms output voltage is expressed as

$$V_{Prms} = V_s \left[\frac{5}{4} - \frac{3\alpha}{2\pi} + \frac{3}{4\pi} \sin\left(2\alpha + \frac{\pi}{3} \right) \right]^{1/2} \quad (5)$$

$$V_{Lrms} = \sqrt{3} V_{Prms} \quad (6)$$

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Mode4: This mode of operation no thyristor will conduct for a duration of $150 \le \alpha \le 180^{\circ}$. The phase ‘a’ load voltage and current waveforms for balanced R and RL loads are shown in Fig.5, for a firing angle of 165° respectively. The phase and line rms output voltages are zero.The control range of firing angle is 0° to 150°.The THDs of the line current for different firing angles are shown in Fig.6. As the firing angle increases the THD is increasing.

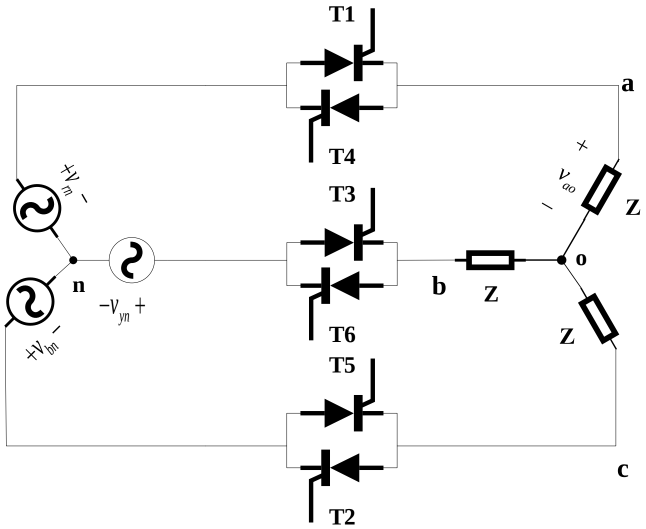

Fig. 1 Three-phase, three-wire AC voltage controller

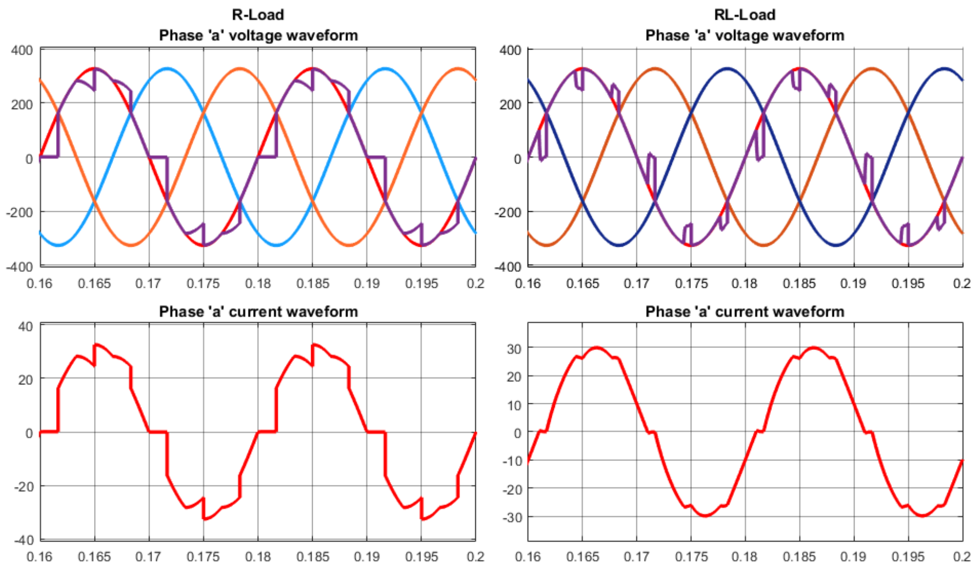

Fig. 2 Phase 'a' load voltage waveform for $\alpha = 30^{\circ}$

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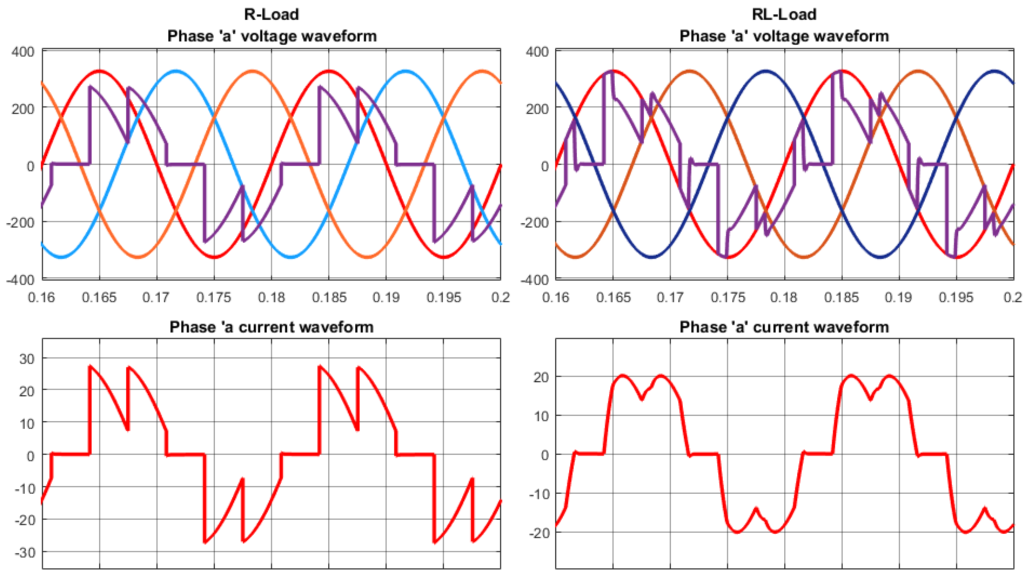

Fig. 3Phase 'a' load voltage waveform for $\alpha = 75^{\circ}$

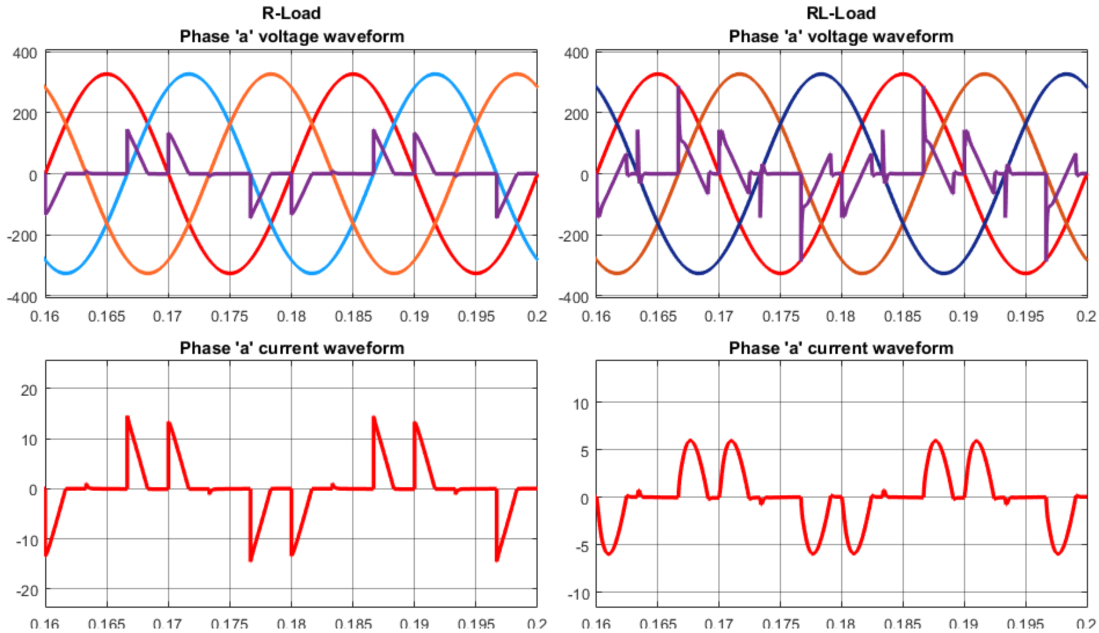

Fig. 4Phase 'a' load voltage waveform for $\alpha = 120^{\circ}$

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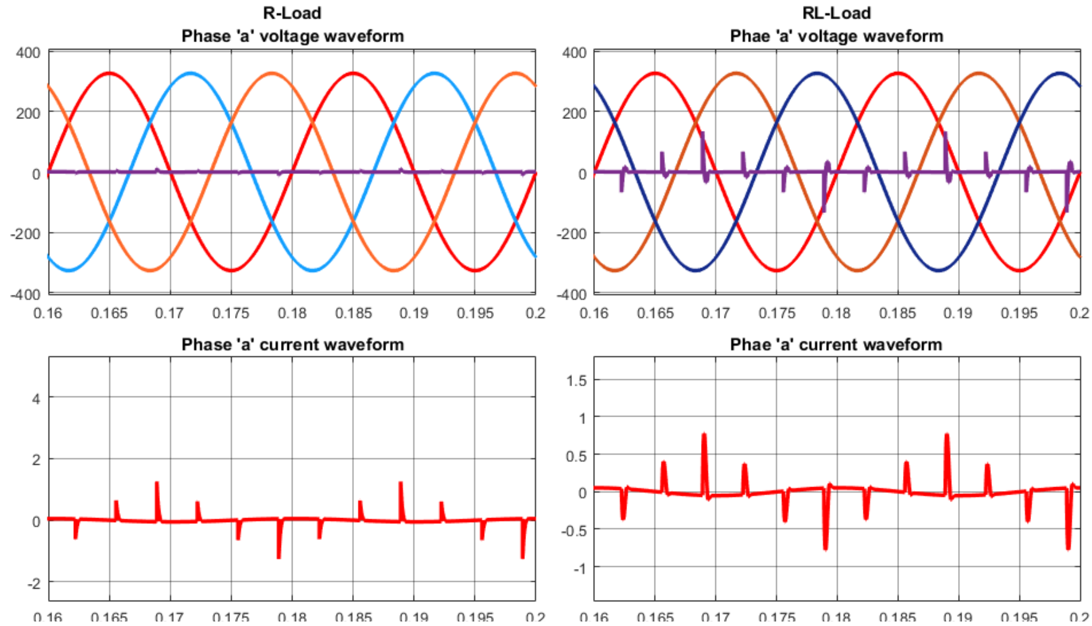
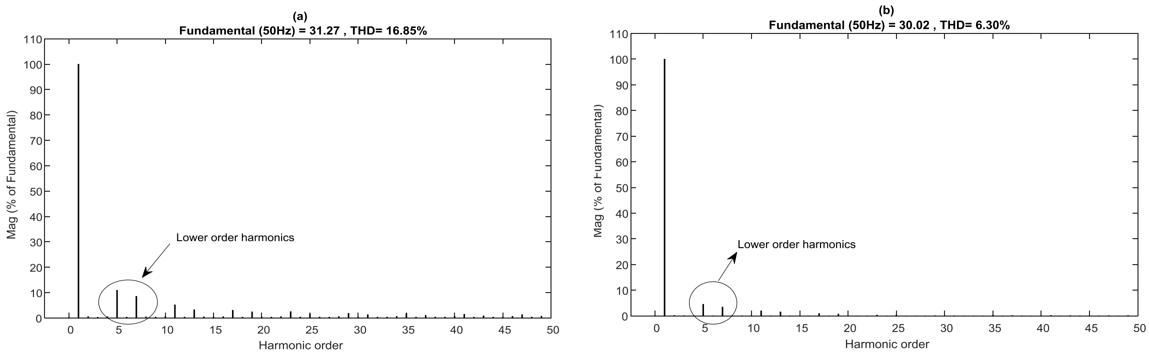


Fig. 5Phase 'a' load voltage waveform for $\alpha = 160^{\circ}$



(a) **(b)**

Fig. 6 THD spectrums of line current for $\alpha = 30^{\circ}$ with balanced R and RL loads

3. Hardware testing

The prototype model of the hardware circuit is shown in Fig. 7 and 8. The firing pulse for thyristors are generated from control circuit and pulse transformers. The power circuit with overvoltage protection circuit is shown in Fig.8. The circuit is tested with 50Ω and 5mH balanced load. The load voltage waveform for phase ‘a’ is shown for R load in Fig.9 and RL load in Fig.10 and line current waveform for RL load in Fig.11 at different firing angles.

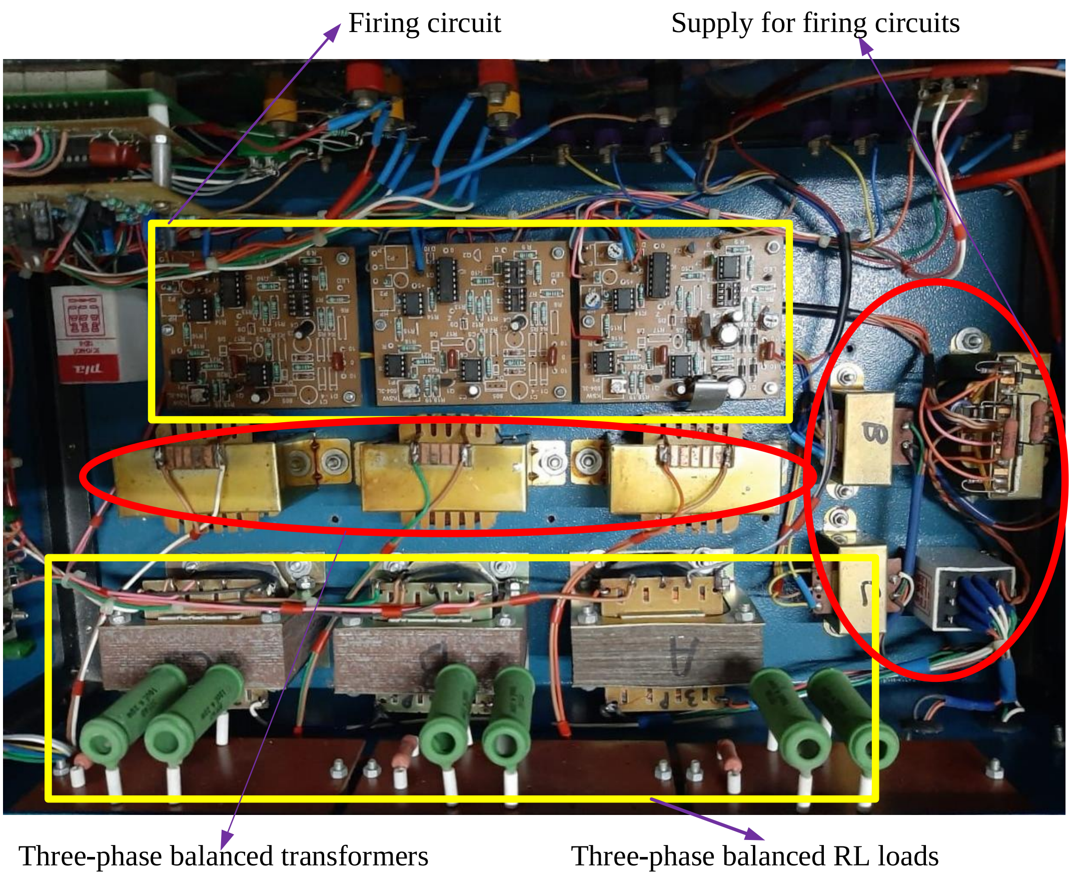


Fig. 7 Three-phase ac voltage controller circuit

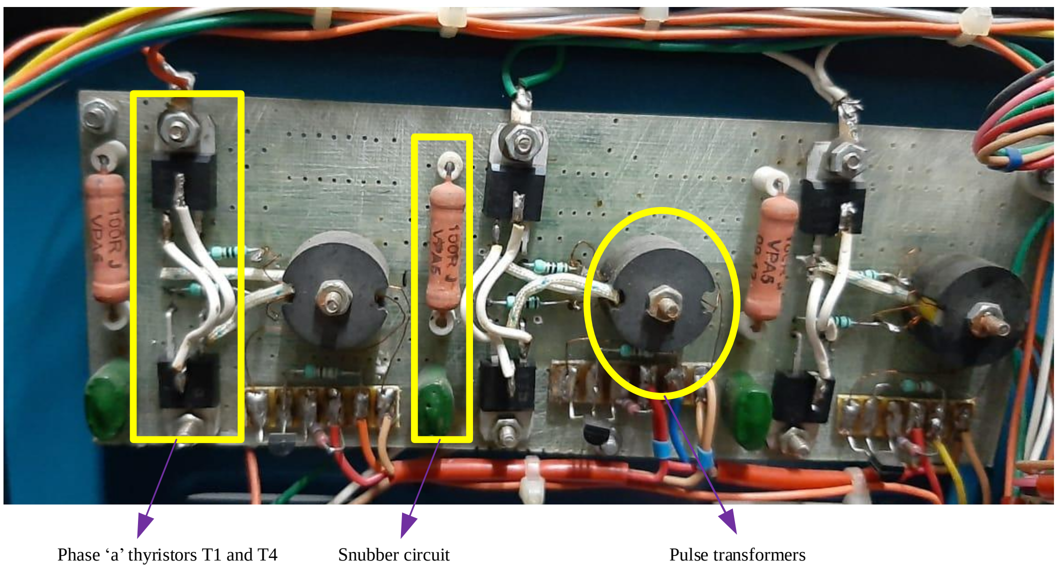


Fig. 8 Three-phase ac voltage controller power circuit

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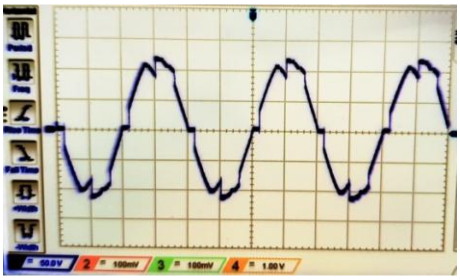
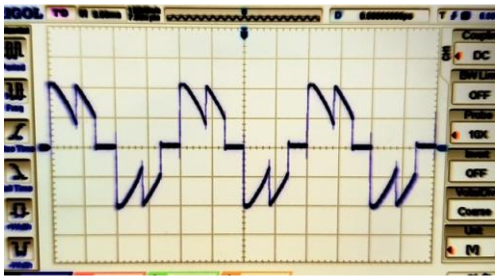
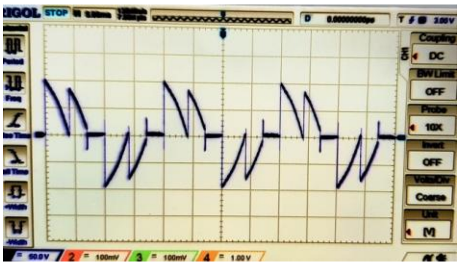


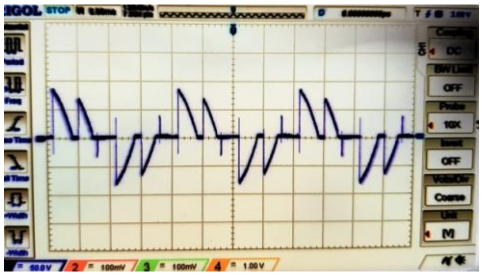
(a)



(b)

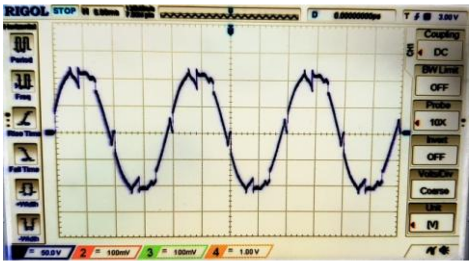


(c)

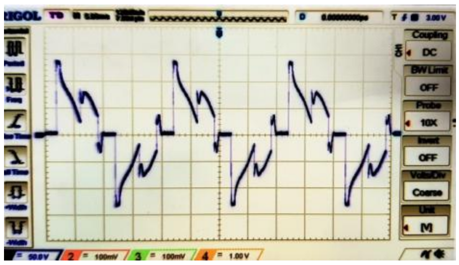


(d)

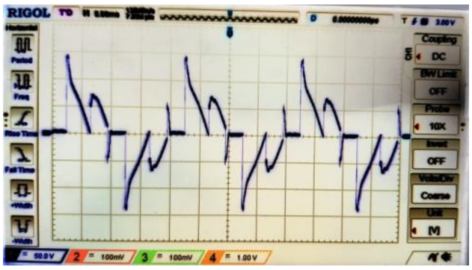
Fig. 9 Phase 'a' voltage waveform for α is (a)30°,(b)75°,(c)90° and (d)105°



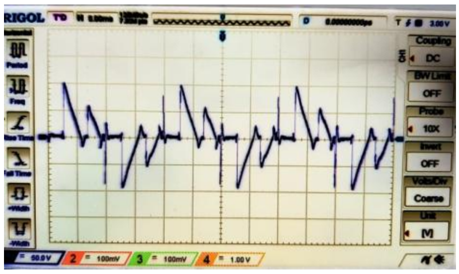
(a)



(b)

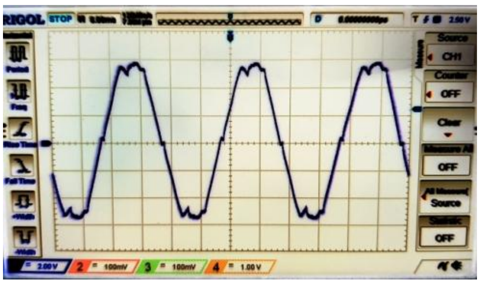


(c)

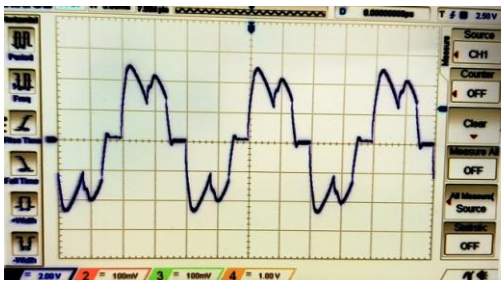


(d)

Fig. 10Phase 'a' voltage waveform for α is (a)30°,(b)75°,(c)90° and (d)105°



(a)



(b)

Fig. 11Phase 'a' current waveform for α is (a)30°and (b)75°

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4. Conclusion

The analysis, simulation and hardware testing are shown in this paper. The prototype model is designed and tested with low power loads. The line voltage of 400V is step-down to 148V. The balanced load is designed with negligible error of unbalance effect with 50Ω and 5mH. The phase rms load voltage measured for a firing angle of 38°, 68.5°, 90° are 81.8V, 61.1V, 49.2V respectively. In future, the high circuit will be designed for testing of three-phase induction motor drive.

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