Performance Analysis of Phase Controlled Unidirectional and Bidirectional AC Voltage Controllers

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ABSTRACT

AC voltage controllers are used to vary the output ac voltage from a fixed ac input source. They are also commonly called ac voltage regulators or ac choppers. The output voltage is either controlled by PAC (Phase Angle Control) method or on-off control method. Due to various advantages of ac voltage controllers, such as high efficiency, simplicity, low cost and ability to control large amount of power they efficiently control the speed of ac motors, light dimming and industrial heating, etc.

These converters are variable structure systems and generate harmonics during the operation which will affect the power quality when connected to system network. During the last couple of years, a number of new semiconductor devices and various power electronic converters has been introduced. Accordingly the subject of harmonics and its problems are of great concern to power industry and customers. In this research work, initially the simulation models of single phase unidirectional and bidirectional ac voltage controllers were developed by using MATLAB software. The harmonics of these models are investigated by simulation. In the end, the harmonics were also analyzed experimentally. The simulated as well as experimental results are presented.

Key Words: **AC Voltage Controllers, Phase Control, Unidirectional Converter, Bidirectional Converter, Harmonics.**

1. INTRODUCTION

The ac-ac conversion technology has been developing very rapidly because of its high efficiency and compactness. It is achieved by cycloconverters, dc link converters and ac voltage controllers [1-4]. The last one is simplest topology, control only output voltage, while its output frequency remains constant. This topology has many attractive features such as: simple controller designing as compared to other converter topologies, low volume and weight, and low cost due to less number of active and passive devices [4-10]. Because of its smart features, AC voltage controller has recently drawn attention of many researchers. It is a well known fact that ac voltage controllers are periodic variable structure systems due to their switched operation.

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The major problem concerned with these converters when operated, they generate harmonics. These harmonics create disturbances and degrade the performance of converter. Furthermore, such type of converters when connected with system network, generation of harmonics lead to deleterious effects such as presentation of low power factor to power supply distribution companies, low efficiency, electromagnetic interference in communication equipment and over heating of distribution systems [5-14].

As far as the previous research is concerned the non-linear behavior of BJT (Bipolar Junction Transistor) based ac voltage controllers have been analyzed [9]. These topologies have low current gain, need high base current to obtain reasonable collector current, expensive and complex base driven circuits. Nowadays, BJTs are not popular in new products. Phase angle of ac voltage controllers also regulated by using TRIACs [11]. Due to integrated construction of triac, it has some disadvantages such as poor gate current sensitivity, longer trun-off time, lower rate of change of voltage rating. AC voltage controllers were also used as IGBTs, GTOs, SCRs to regulate the output voltage [12-15].

This research work focuses on the single phase unidirectional and bidirectional ac voltage controllers. Harmonics of both ac voltage controllers were analyzed.

2. DESCRIPTION OF UNIDIRECTIONAL AND BIDIRECTIONAL AC VOLTAGE CONTROLLERS

AC voltage controllers are classified as unidirectional or half wave and bidirectional or full wave ac voltage controllers [4]. These converters are further categorized according to their input supply and the way the semiconductor devices are connected. The basic circuit diagram of unidirectional ac voltage controllers is illustrated in Fig. 1, which is composed of ac source Vs, thyristor TH, an anti parallel diode D connected with TH, and load.

Similarly, the ac-ac bidirectional voltage converter consists of ac supply voltage Vs, and anti-parallel Thyristors TH_1 and TH_2 which are connected back to back with load. The schematic diagram of bidirectional ac voltage controller is shown in Fig. 2. Such combination gives a bidirectional full-wave symmetrical voltage control.

The output voltage of both ac voltage controllers are controlled with PAC and on-off control method [4,6]. In this paper, output voltage is regulated by PAC method which generates significant harmonics due to discontinuity caused by delayed firing angles.

The harmonics are determined by the method of Fourier analysis [16-18]. General expression for Fourier series, periodic function f (t) of any complex wave over the period of 2? can be written as follows:

$$f(t) = a_o + \sum_{n=1,2,...}^{\infty} (a_n \, Cos \, n\omega t + b_n \, Sin \, n\omega t) \quad (1)$$

Where α_o is DC component of the original wave, (α_n Cos nωt + b_n Sin nωt) is n^{th} harmonic of the function.

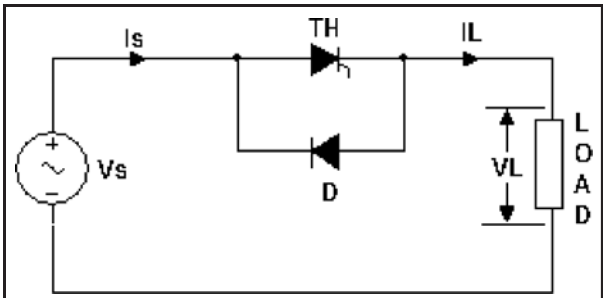

FIG.. 1. UNIDIRECTIONAL AC VOLTAGE CONTROLLER

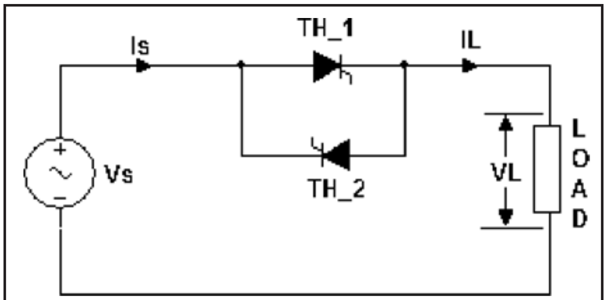

FIG.. 2. BIDIRECTIONAL AC VOLTAGE CONTROLLER

The values of α_o,α_n can be determined by the following relations.

$$a_o = \frac{1}{2\pi}\int_0^{2\pi} v_L(\omega t)d\omega t$$

$$a_n = \frac{1}{\pi}\int_0^{2\pi} v_L(\omega t)\, Cosn\, \omega t\, d\omega t$$

$$b_n = \frac{1}{\pi}\int_0^{2\pi} v_L(\omega t)\, \text{Sin}\, n\, \omega t\, d\omega t$$

Equation (1) further can be given as under:

$$f(t) = a_o + \sum_{n=1,2,...}^{\infty} (c_n\, Sin\,(n\omega t + \phi_n)) \tag{2}$$

Where Magnitude of n[th] harmonic is $C_n = \sqrt{a_n^2 + b_n^2}$ and Phase Angle is $\phi_n = \tan^{-1} a_n/b_n$.

3. DEVELOPMENT OF SIMULATION MODELS OF AC VOLTAGE CONTROLLERS

The unidirectional ac voltage controller as shown in Fig. 3 was implemented by using the SimPowerSystems and Simulink tools of MATLAB software. The output voltage is controlled by changing the phase angle of positive cycle of input voltage. This is obtained by pulse generator tool of SimPowerSystems.

The simulation model of single phase bidirectional phase controlled ac voltage regulator is given in Fig. 4. In this model, output voltage is controlled with the help of two anti-parallel thyristors.

In both circuits, the input fixed ac voltage is converted into variable ac output voltage without changing the supply frequency.

4. SIMULATION AND EXPERIMENT RESULTS

The unidirectional and bidirectional ac voltage controllers were analyses in time domain as well as frequency domain. In both converters, the waveforms and harmonics were observed by triggering the thyristors, at α=90°. The simulated waveforms of supply voltage and current of unidirectional ac voltage controller are shown in Fig. 5, similarly, the load voltage and current are shown in Fig. 6. It is clear from the supply current, load current and load voltage waveforms of Figs. 5-6,

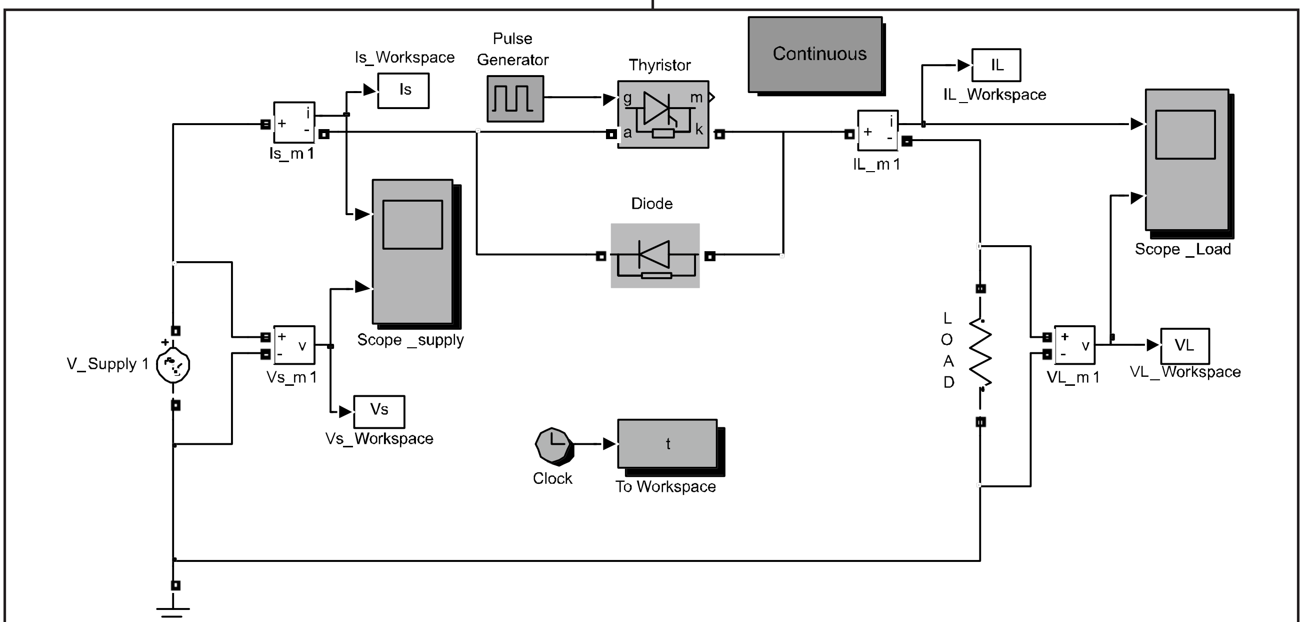

FIG. 3. SIMULATION MODEL OF UNIDIRECTIONAL AC VOLTAGE CONTROLLER.

that they do not have half wave symmetry, therefore, even as well as odd harmonics may be presented. The simulated load voltage harmonic spectrum of unidirectional controller is given in Fig. 7 which consists of dc component, odd and even harmonics. The harmonics order of load current and supply current are similar to load voltage. This is because, wave shapes of supply and load current are similar to load voltage. Fig. 8 shows the experimental results of load voltage harmonics profile of unidirectional ac voltage controller. The experimental harmonics were measured with the help of Power Quality Analyzer and necessary setup of equipments as shown in Fig. 9. Due to large number of harmonics, such type of converter has limited applications, mostly, used in low power heating load.

The model of anti-parallel based bidirectional ac voltage controller was also simulated and waveforms of supply voltage and current, load voltage and current are given in Figs. 10-11 respectively. The waveforms have half wave symmetry that is the negative half of waves is a reproduction of positive half, therefore, they consist of only odd harmonics and also such wave forms have no dc

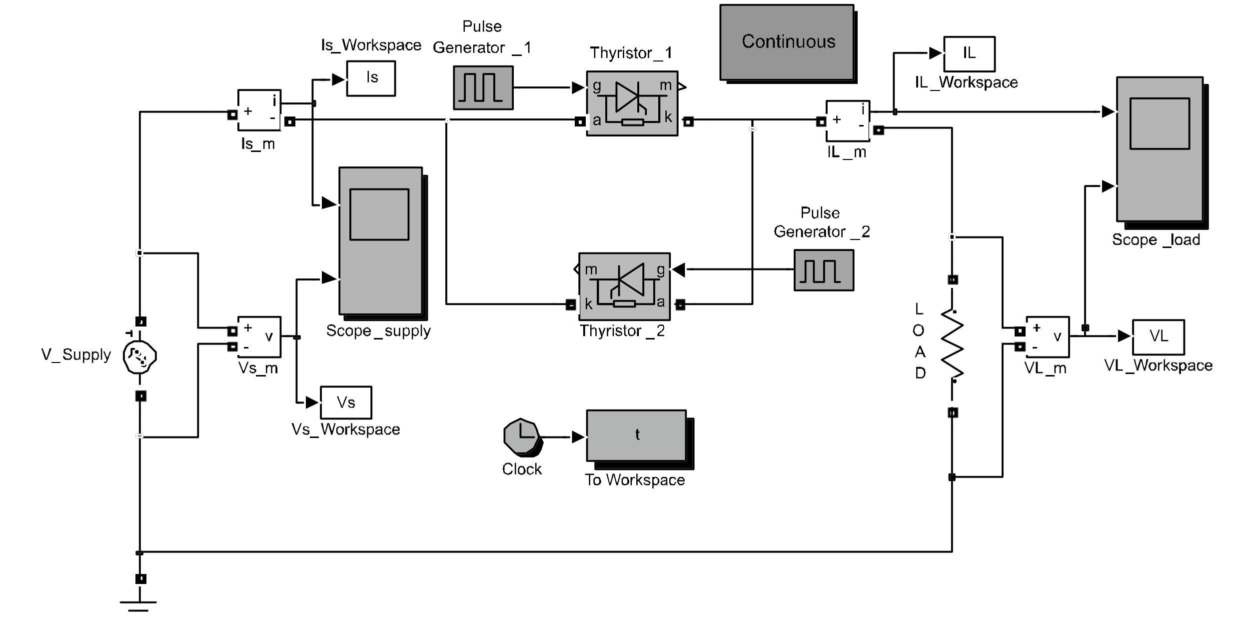

FIG. 4. SIMULATION MODEL OF SINGLE PHASE BIDIRECTIONAL AC VOLTAGE CONTROLLER

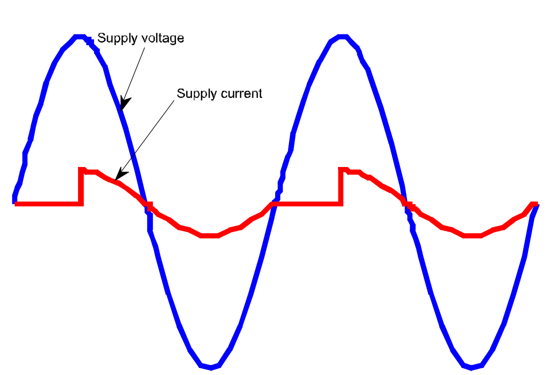

FIG. 5. WAVEFORMS OF SUPPLY VOLTAGE AND CURRENT OF UNIDIRECTIONAL AC VOLTAGE CONTROLLER

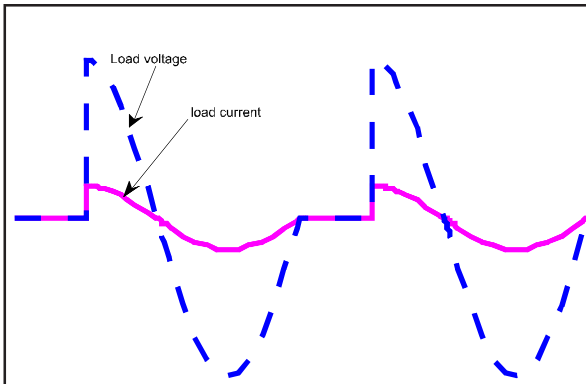

FIG. 6. WAVEFORMS OF LOAD VOLTAGE AND CURRENT OF UNIDIRECTIONAL AC VOLTAGE CONTROLLER

component. The simulated and experimental harmonic spectrum of supply current are given in Figs. 12-13 respectively. Similarly, Figs. 14-15 show the harmonics of load current. The harmonics of load voltage for a 90° firing angle of bidirectional ac voltage controller are also given in Figs. 16-17.

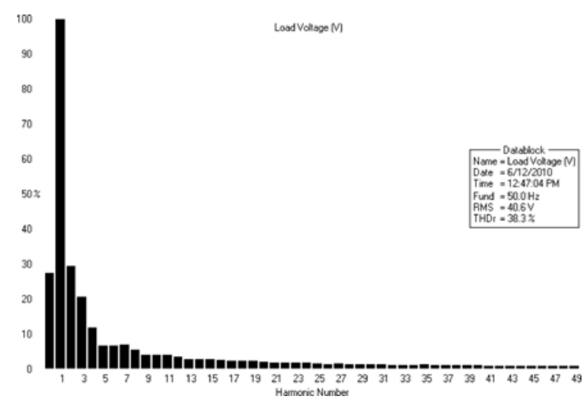

FIG. 7. SIMULATED LOAD VOLTAGE HARMONIC FOR A 90° FIRING ANGLE UNIDIRECTIONAL AC VOLTAGE CONTROLLER

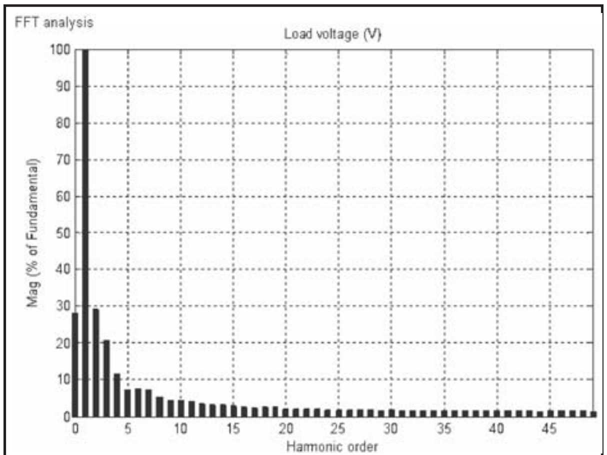

FIG. 8. EXPERIMENTAL LOAD VOLTAGE HARMONIC FOR A 90° FIRING ANGLE OF UNIDIRECTIONAL AC VOLTAGE CONTROLLER

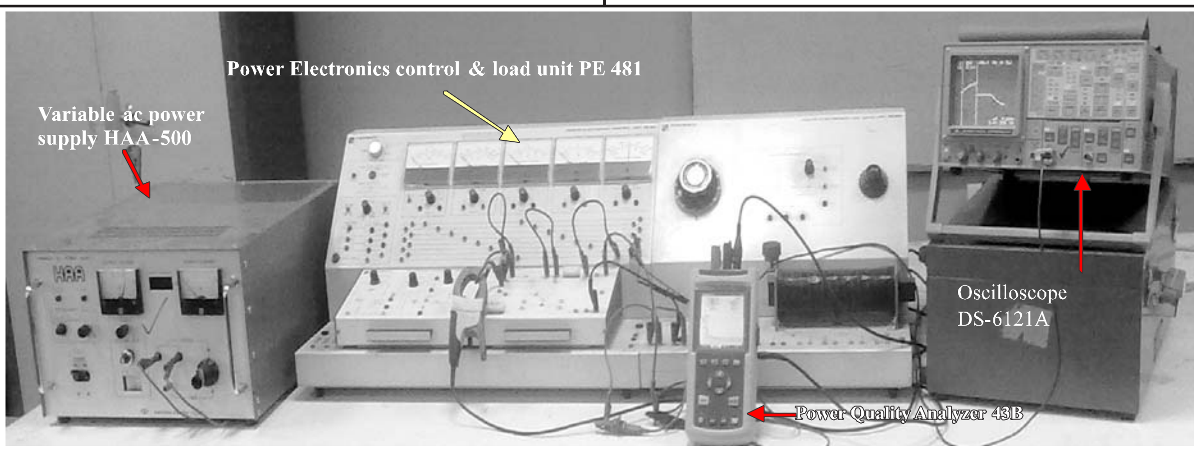

FIG. 9. EXPERIMENTAL SETUP OF AC VOLTAGE CONTROLLERS

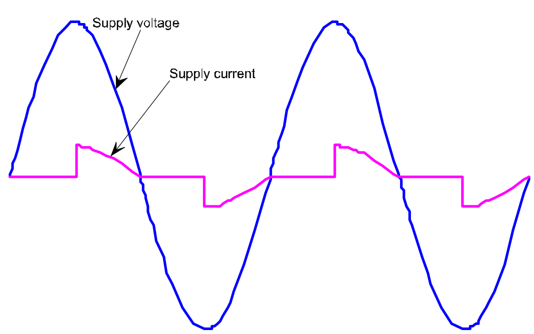

FIG. 10. WAVEFORMS OF SUPPLY VOLTAGE & CURRENT OF UNIDIRECTIONAL AC VOLTAGE CONTROLLER

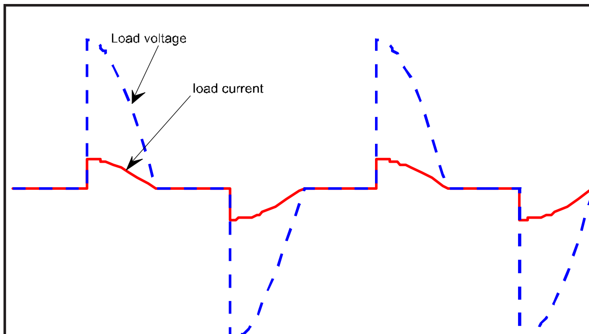

FIG. 11. WAVEFORMS OF LOAD VOLTAGE & CURRENT OF UNIDIRECTIONAL AC VOLTAGE CONTROLLER

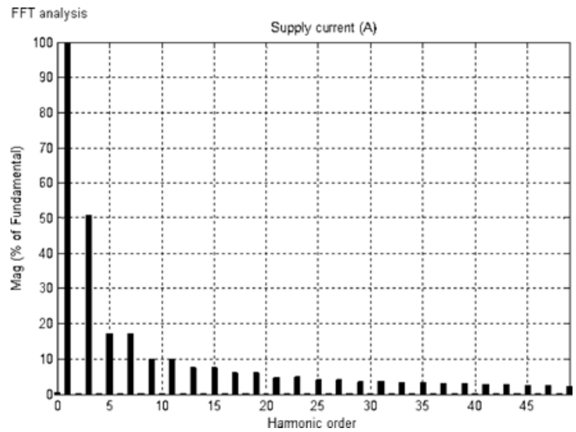

FIG. 12. SIMULATED SUPPLY CURRENT HARMONIC FOR A 90° FIRING ANGLE BIDIRECTIONAL AC VOLTAGE CONTROLLER

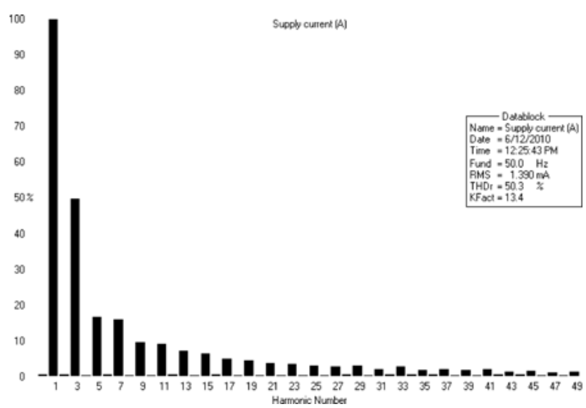

FIG. 13. EXPERIMENTAL SUPPLY CURRENT HARMONIC FOR A 90° FIRING ANGLE OF BIDIRECTIONAL AC VOLTAGE CONTROLLER

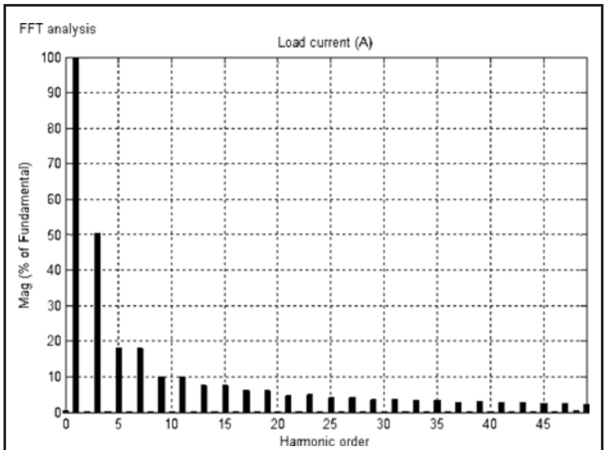

FIG..14. SIMULATED LOAD CURRENT HARMONIC FOR A 90° FIRING ANGLE BIDIRECTIONAL AC VOLTAGE CONTROLLER

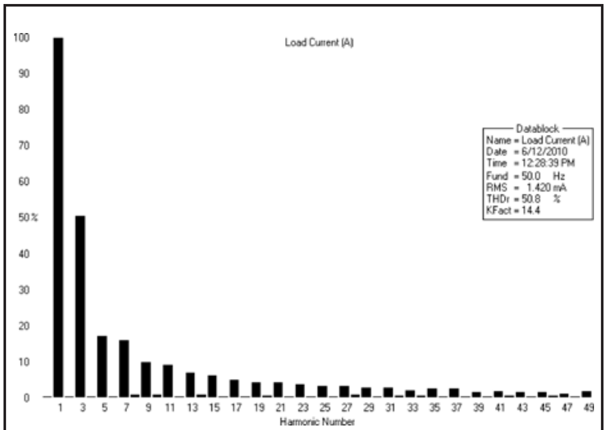

FIG. 15 EXPERIMENTAL LOAD CURRENT HARMONIC FOR A 90° FIRING ANGLE OF BIDIRECTIONAL AC VOLTAGE CONTROLLER

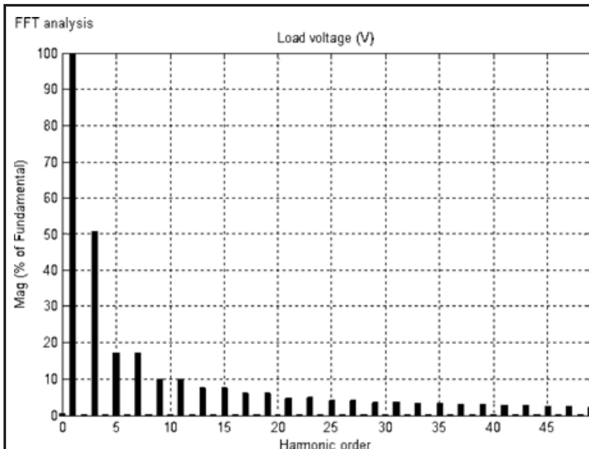

FIG..16. SIMULATED LOAD VOLTAGE HARMONIC FOR A 90° FIRING ANGLE BIDIRECTIONAL AC VOLTAGE CONTROLLER

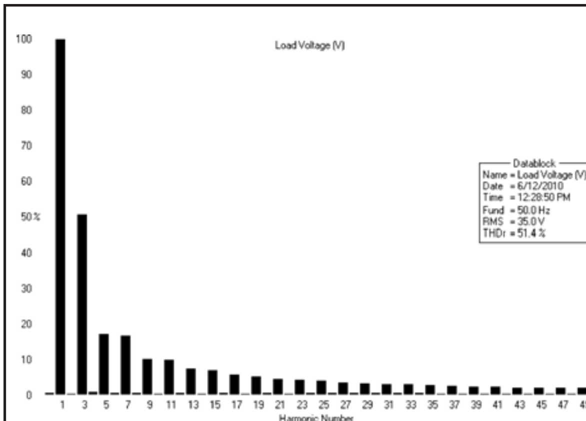

FIG. 17. EXPERIMENTAL LOAD VOLTAGE HARMONIC FOR A 90° FIRING ANGLE OF BIDIRECTIONAL AC VOLTAGE CONTROLLER

5. CONCLUSIONS

The models of unidirectional and bidirectional AC voltage controllers were successfully developed and simulated by using the simulink and SimPowerSystems tools of MATLAB software.

In this research paper, the harmonics of these converters were also investigated through MATLAB software as well as experimentally. The experiment results are in good agreement with the simulated results. As unidirectional ac voltage controllers use only one thyristor, it is economical as compared to bidirectional. But it has more harmonic content and also it introduces a dc component.

It is also clear from the results that these types of converters generate harmonics and will lead to the problems of power quality. Furthermore, when these converters are connected with system network they generate abnormal harmonics which have deleterious effects on the systems network as well as on the performance of the converters.

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