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Utilizing MATLAB –SIMULINK Based Technique for Teaching the Operation of Adjustable Speed Drives and Induction Motors under Utility Unbalance Voltage

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ABSTRACT

This paper endeavors to present a comprehensive summary of the causes and effects of voltage unbalance and to discuss related standards, definitions. Several causes of voltage unbalance on the power system and in industrial facilities are presented as well as the resulting adverse effects on the system and on equipment such as induction motors and power electronic converters and drives. Power electronic converters serve as the interface for many large electronic loads ranging from three-phase uninterruptible power supplies (UPSs) to motors operating at variable speeds through the use of adjustable speed drives (ASDs). Most of these converters contain diode rectifier front-end. Under the conditions of utility voltage unbalance, the input current harmonics are not restricted to the converter characteristic harmonics, and uncharacteristic triple harmonics can appear such as the 3rd and 9th harmonics. The more details of effects of unbalanced voltages on ASD are investigated follows.

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INTRODUCTION

Power quality problems and survey results have been reported in many publications [1-3]. The affected industry and businesses include automobile manufacturing plants, medical centers, and semiconductor manufacturing plants, broadcasting facilities, and industrial and commercial buildings. It is estimated that industrial and digital economy companies collectively lose much billion a year to outages and to power quality phenomena. The unbalanced voltage gives a bad influence for the power quality. If the unbalanced power is applied to the electric apparatuses, it gives a difficult problem to them, especially the electric motors [4].

1. *Unbalance Voltage Module:*

This module consists of 5 weeks theoretical course was held in *Marvdasht Branch of Islamic Azad University*. The most important contents of this module include of unbalanced voltage principle and its effects on power system equipment. The definition of unbalance voltage is introduced, analyzed and finally the effects of unbalance voltage on operation of adjustable speed drives (ASDs) and induction motors are introduces and simulated. Also as an effective method for mitigating the intensity of unbalanced voltage on ASD, the idea of replacing the diode rectifier with an active PWM rectifier in investigated. Since the aim of this module is to introduce a helpful method to instructor for teaching the examples of unbalance voltage effects, its effects on power system and its mitigation and compensation with their results are analyzed. Therefore, the author of this article has been using MATLAB-SIMULINK as an instructional tool to teach this subject. This method of instruction has enabled students to understand the unbalance voltage concept and the necessity of its compensation subject. The success rate of students in understanding the subject shows the ability of this method. An essential feature of using MATLAB-SIMULINK is to incorporate the visualization and control of results in a graphical form on a computer screen. This is particularly important in the analysis or simulation of power networks because of their large size and wide geographical distribution.

In order to better describe of unbalance voltage concepts, at first four questions as follows are presented:

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Advances in Environmental Biology, 8(12) July 2014, Pages: 691-698

- What is unbalance voltage definition?
- What are the effects of unbalance voltage on power system?
- What is method of harmonics unbalance voltage?
- What is the operation of induction motors under unbalance voltage?
- What is the operation of adjustable speed drives under unbalance voltage?
- What is proposed technique to mitigate the non-desired effects of unbalanced voltage on ASDs?

The unbalance voltage is caused by unsymmetrical transformer windings or transmission impedances, unbalanced loads, or large single phase loads. Voltage unbalance exists in almost all three-phase power system networks. The level of unbalance is considerably large in weak power systems and also those supplying large single phase loads. Based on the ANSI report, the voltage unbalance of 66% of the electrical distribution systems in USA, is less than 1%, and that of 98% of the distribution systems is less than 3%, whilst in the remaining 2% it is larger than 3% [5]. In Figure 1 the instantaneous three phase balanced voltage are shown.

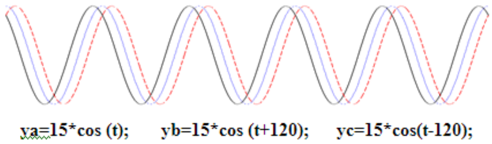

Fig. 1: The three phase balanced voltages

The unbalance voltages are two kinds. One is unbalanced due to difference in magnitude as shown in Figure 2 and another is unbalanced due to difference in phase angles (not 120 degree between phases) as shown in Figure 3. Surely, unbalanced could be occurred due to both difference in phase and magnitude.

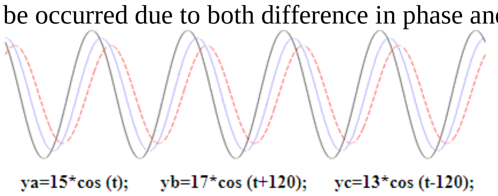

Fig. 2: The three phase unbalanced voltage due to difference in magnitude

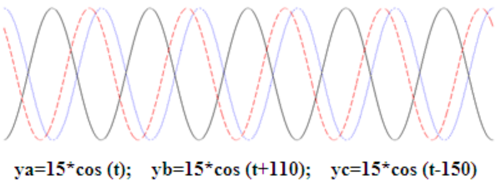

Fig. 3: The three phase unbalanced voltage due to difference in phases

2. *Definition of Voltage Unbalance:*

There are two general definitions for measuring the voltage unbalance, given by international standards NEMA [6] and IEC [7]. NEMA defined the unbalance voltage by means of the "percent voltage unbalance" (PVU):

$$PVU = 100\,\% \frac{MVD}{V_{Avg}} \tag{1}$$

Where MVD is the maximum voltage deviation from the average line voltage magnitude and VAvg is the average line voltage magnitude. The IEC standard [7] adopts the "voltage unbalance factor" (VUF) as defined by the method of symmetrical components:

$$PVU = 100\,\% \frac{V_2}{V_1} \tag{2}$$

Where, V1 and V2 are the amplitudes of positive and negative sequence voltages, respectively.

Reasons for unbalance are

- Incomplete transposition of transmission lines
- Open delta transformer connections
- Single phase loads
- Blown fuses on capacitor banks
- Railway traction loads

Advances in Environmental Biology, 8(12) July 2014, Pages: 691-698

3. Unbalanced voltage and induction machine:

In order to prevent the motor overheating due to unbalanced voltages the motor has to be operated below its rated output power which is called derating of the induction motor. As per NEMA guidelines, operating a motor for any length of time at voltage unbalance above 5% is not recommended. Any amount of unbalance makes a motor run hotter. The NEMA standard says that once unbalance reaches 5%, the temperature begins to rise so fast that protection from damage becomes impractical. The simplest protection as proposed by the NEMA standard, is to derate the motor-to reduce its output horsepower load so it can tolerate the extra heating imposed by the unbalanced supply.

When voltages are unbalanced, the percent increase in temperature rise equals about twice the square of the percent voltage unbalance. This can be defined by the following relation:

$$1+\frac{2[\mathrm{PVU}]^2}{100}=\left[\frac{Percent\ \ Load}{100}\right]^{-1.7} \tag{3}$$

The above relation can be used to find the percent load for operating under various unbalanced conditions (percent unbalance).the derating necessary to hold the temperature rise to the machine specifications can be determined. This derating curve for unbalance is given in Figure 4. At 5% unbalance for example the motor should not operate at more than 75% of its rated output.

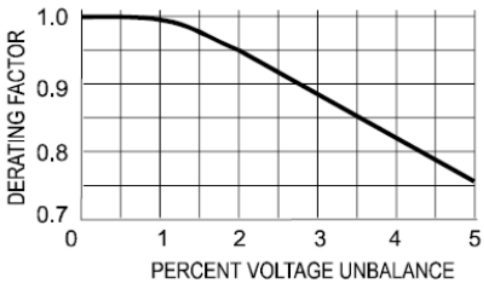

Fig. 4: Voltage divider model for computing voltage sag in a radial distribution system

4. Effects of Voltage Unbalance on Power Electronic Converters and Drives"

Power electronic converters serve as the interface for many large electronic loads ranging from three phase uninterruptible power supplies (UPSs) to motors operating at variable speeds through the use of ASDs. Most of these converters contain a diode rectifier front-end, as shown in Figure6, and dc-link capacitor to convert the incoming ac voltage to a low-ripple dc voltage. In Figure 5, the pulse-width modulated (PWM) inverter converts the dc voltage back to variable three-phase ac. The magnitude and frequency of the PWM inverter output control the motor speed.

Three-phase converters with diode rectifier front-ends draw non sinusoidal currents rich in odd harmonics. For rectifier systems supplied by balanced utility voltages, the input current characteristic harmonics are determined by [8]:

$$h = kq \pm 1 \tag{4}$$

Where, h is order of the harmonics, q is number of pulses of the rectifier system and k=1,2,3,….

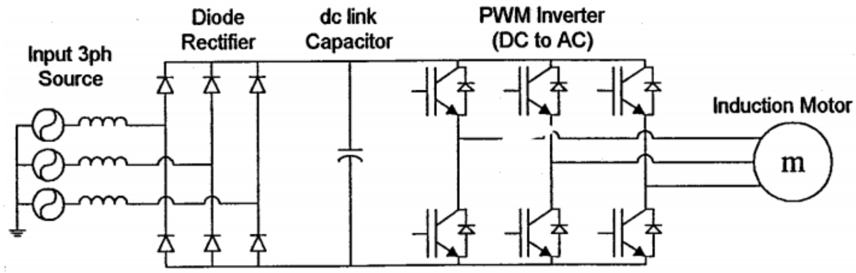

Fig. 5: Typical adjustable speed drive (ASD) system

Under the conditions of utility voltage unbalance, the input current harmonics are not restricted to the converter characteristic harmonics, and uncharacteristic triple harmonics can appear such as the 3^{rd} and 9^{th} harmonics.

The more details of effects of unbalanced voltages on ASD are investigated follows.

Notice that as the ASD input voltage unbalance increases, the input current becomes significantly more unbalanced and changes from a double-pulse wave form to a single-pulse wave form due to the asymmetric conduction of the diodes. The voltage unbalance may cause excessive current in one or two phases, which can trip overload protection circuits [9]. The increased current can also cause excess heating of the diodes and decrease the life of the capacitor or require the use of a larger capacitor. Note the increase in the percent of the 3^{rd} harmonic much increases as the voltage unbalance increases. The significant 3^{rd} harmonic can increase harmonic and resonance problems on the system as well as require larger filter ratings.

As shown in Figure 6 with replacing the diode rectifier with an active PWM rectifier has the following advantages [8-9]:

- Regulated dc-bus which offers immunity to voltage sags and transients
- Unity power factor with low input current harmonics (near sinusoidal)
- Power flow in both directions which enables regenerative braking.

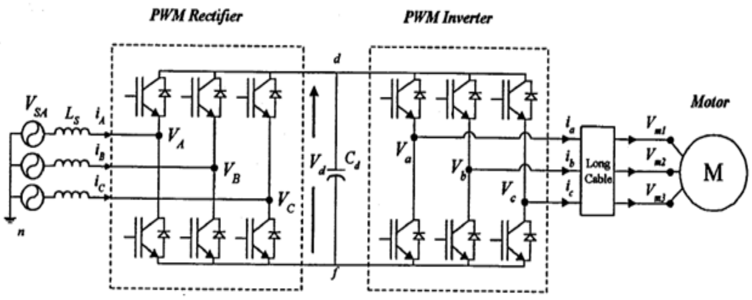

Fig. 6: ASD with PWM rectifier

5. Simulations and Results:

In this section the influence of unbalanced voltages on adjustable speed drive is analyzed. As shown in Figure 7 the MATLAB-SIMULINK simulation tool was used to develop a model that allowed the simulation and testing the theory calculations.

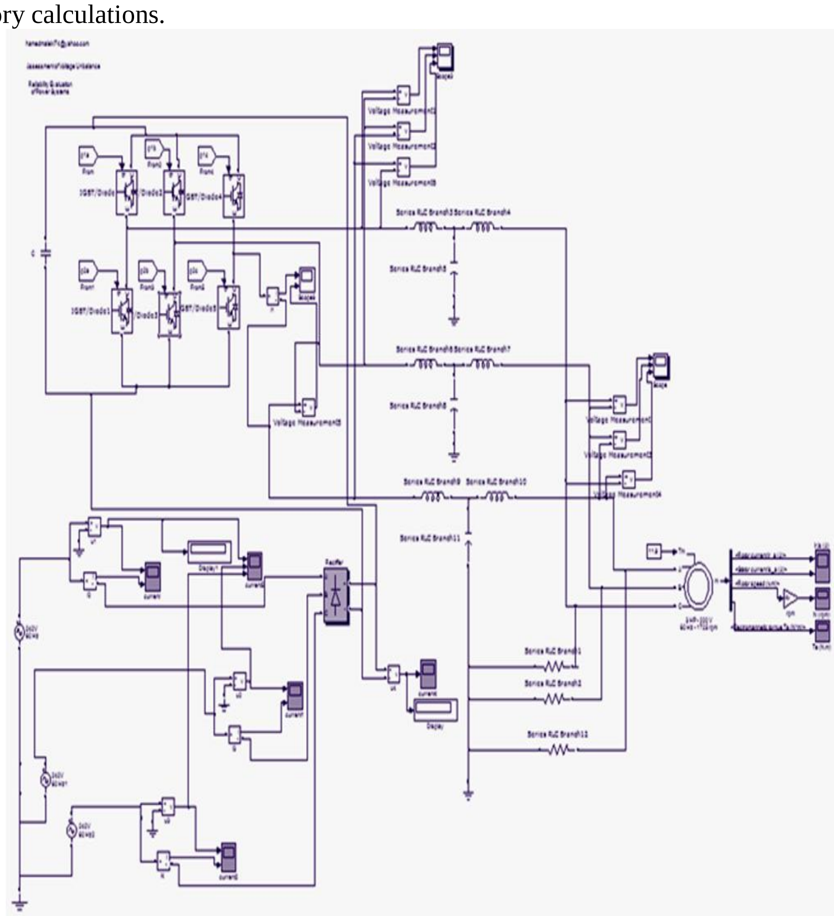

Fig. 7: The MATLAB/SIMULINK model of typical adjustable speed drive which feed with unbalanced voltages

Advances in Environmental Biology, 8(12) July 2014, Pages: 691-698

Unbalance voltage degree measurement for evaluating the percentage value of unbalance voltage is shown in Figure 8.

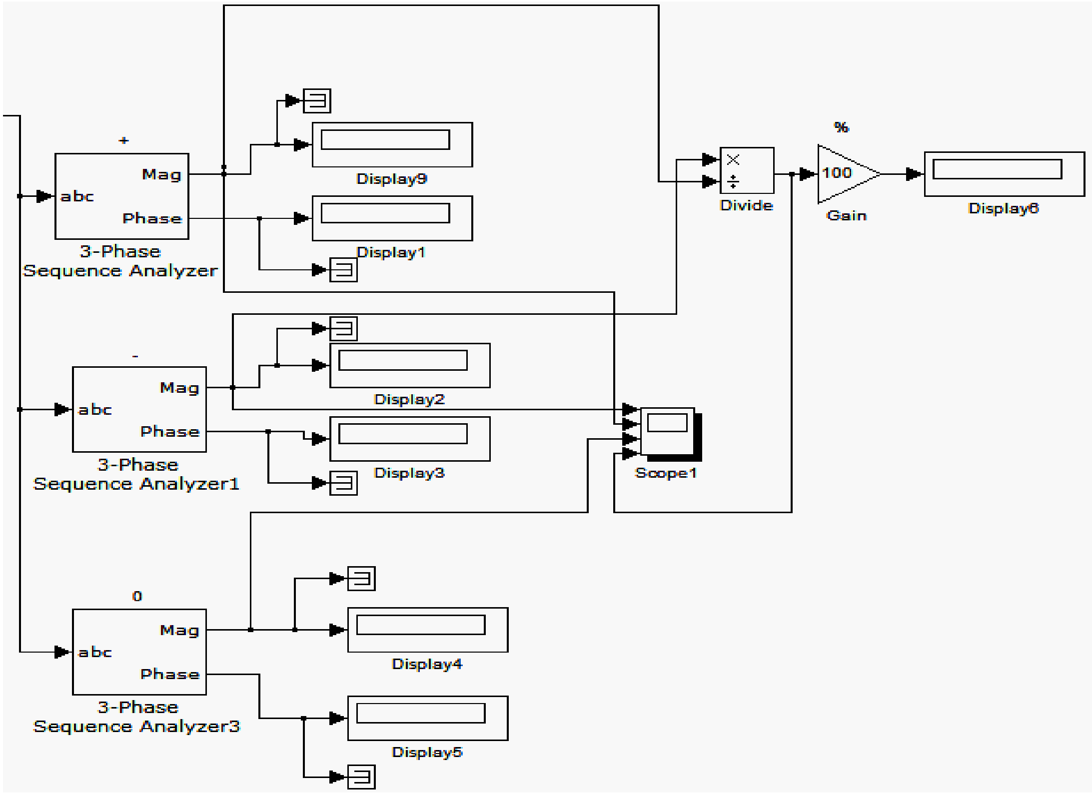

Fig. 8: Unbalance voltage degree measurement

The voltage and current of phase 'a' under balanced voltages is shown in Figure 9.

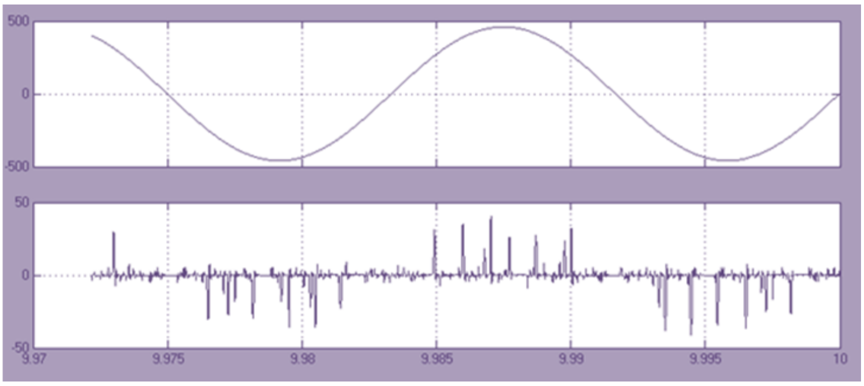

Fig. 9: The instantaneous voltage and current of phase 'a' under balanced voltage

The input current and the FFT analysis of input current harmonics under utility voltage unbalance demonstrates this matter which is shown in Figures 10-11 respectively.

Advances in Environmental Biology, 8(12) July 2014, Pages: 691-698

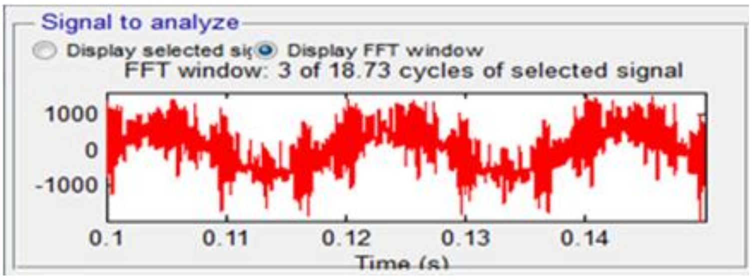

Fig. 10: Input current harmonics under balance voltage

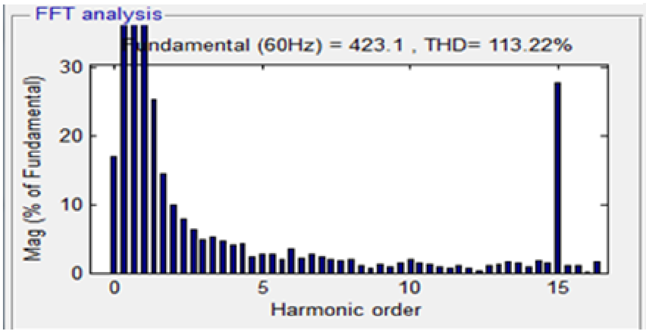

Fig. 11: FFT analysis of input current harmonics under balance voltage

At second case study, the three unbalanced voltage are applied to ASD. The voltage and current of phase 'a' under unbalanced voltages is shown in Figure 12.

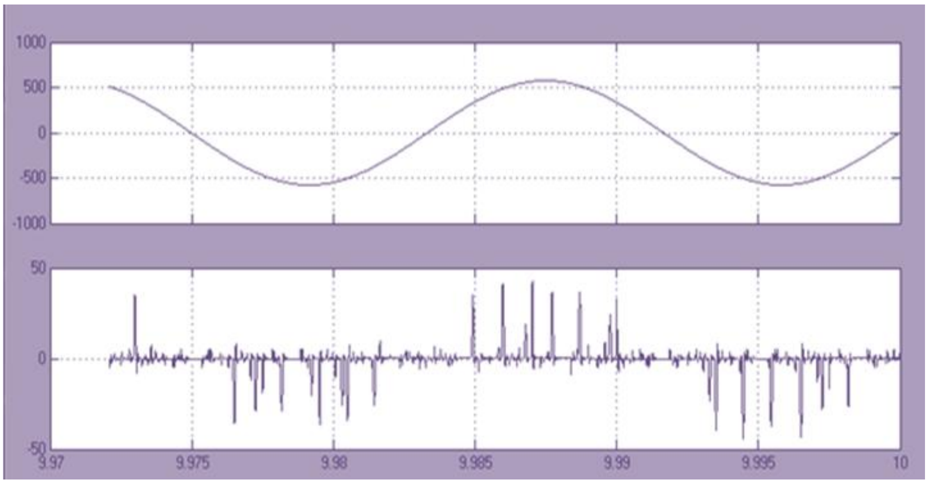

Fig. 12: The instantaneous voltage and current of phase 'a' under unbalanced voltage

Under the conditions of utility voltage unbalance, the input current harmonics are not restricted to the converter characteristic harmonics, and uncharacteristic triple harmonics can appear such as the 3rd and 9th harmonics. The input current and the FFT analysis of input current harmonics under utility voltage unbalance demonstrate this matter which is shown in Figures 13-14 respectively.

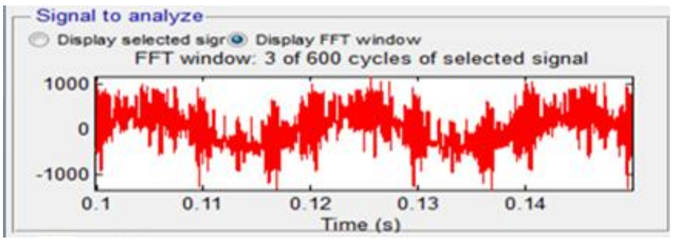

Fig. 13: The input current harmonics under utility voltage unbalance

Advances in Environmental Biology, 8(12) July 2014, Pages: 691-698

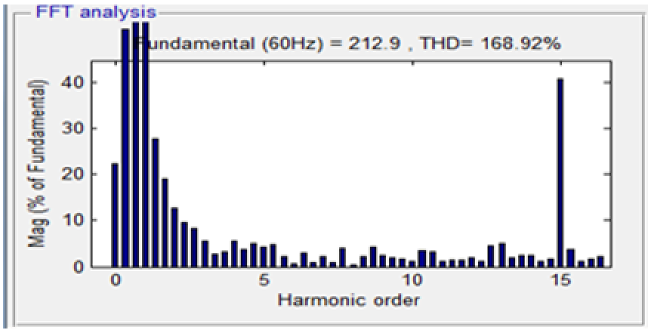

Fig. 14: FFT analysis of input current harmonics under utility voltage unbalance

6. Students Feedback:

The methodology illustrated in this paper has explained for 30 senior undergraduate students in power system, all of them have passed power quality courses. The students employ the methodology and in the presence of instructor filled a questionnaire form. The questionnaire, comprising six questions, is listed in Table 1. The students graded them as 1(poor), 2 (medium), 3 (good), and 4 (excellent). Figure 15 shows the global results obtained from the students' questionnaire.

Table 1: Questionnaire Answered by the Students and Engineers

Question	Score
1. The content of this practical is valuable for a student of engineering course	
2. Do you understand the concept of unbalance voltage and its difference with other power quality phenomena?	
3. Are you more familiar with the influence of unbalance voltage on power system operation	
4. Are you more familiar with the influence of unbalance voltage compensation?	
5. Are you more familiar with the influence of unbalance voltage on operation of ASDs and induction motors?	

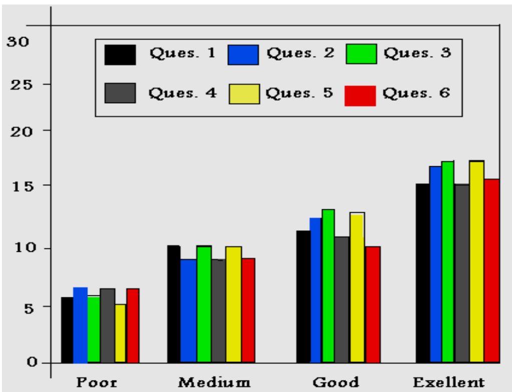

Fig. 12: Answers of students to the questionnaire.

Table 2 gives the average scores for each question out of students' feedback.

Table 2: Average Score Obtained From Students' Answers

	Average Score
Question 1	3.00
Question 2	3.50
Question 3	4.00
Question 4	3.82
Question 5	3.75
Question 6	3.53
Total	3.34

Conclusion:

This paper deals with investigation the effects of unbalanced voltage of utility grid and resulting adverse effects on induction motors and adjustable speed drives. Standards addressing voltage unbalance were discussed and clarified. In this research two case study were analyzed. At first the behavior of ASD under balanced voltage are investigated. And second case, the influence of unbalanced voltage analyzed. The FFT analysis of input current harmonics under utility voltage unbalance demonstrates this matter which the THD could be increased from 113% under balanced voltage to 165% under unbalanced voltage. Under the conditions of utility voltage unbalance, the input current harmonics are not restricted to the converter characteristic harmonics, and uncharacteristic triple harmonics can appear such as the 3^{rd} and 9^{th} harmonics.

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