THD Reduction Using Series Transformer Connection In A STATCOM Within Mosul Ring System

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Abstract

The static synchronous compensator (STATCOM) is one of the components of Flexible AC Transmission System (FACT). STATCOM is used to compensate the reactive power with fast response. It consist of power electronic devices. The main drawback of STATCOM is harmonics injection to the system. Different techniques can be used to reduce harmonic injection, such as the use of 12-pulse STATCOM with Pulse Width Modulation (PWM) to control the operation of power electronic devices.

In this work the series connection of transformers is studied and compared with parallel connection. The study is applied to the suggested STATCOM in the ring system around Mosul city. Matlab / Simulink is used to analyze the two systems. The results are given and discussed in the paper. Also it is found that the Total Harmonic Distortion (THD) can be further reduced by using series connection of transformers secondary rather than shunt connection.

Keywords :STATCOM, Harmonic reduction, Transformer connection in STATCOM, Mosul distribution ring.

تقليل المحتوى الكلي للتشوه باستخدام ربط التوالي للمحولة في المعوض التزامني الساكن ضمن النظام الحلقي لمدينة الموصل

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الخلاصة

يعد المعوض التزامني الساكن (STATCOM) احد مكونات نظام النقل المتناوب المرن (FACT). حيث يـستخدم المعوض التزامني الساكن لتعويض القدرة المتفاعلة باستجابة سريعة. ويتكون من نبائط الكترونيات القدرة. ويمثـل توليـد مجموعة من التوافقيات في الشبكة عائقا رئيسيا عند استخدامه. وهناك تقنيات مختلفة تعمل إلى تقليل هذه التوافقيات كثيـرا منها استخدام المعوض ذو 12 نبضة وفق تقنية تضمين عرض النبضة (PWM).

تم في هذا البحث دراسة استخدام ربط التوالي للمحولة في المعوض التزامني الساكن ومقارنته مـــع ربــط التــوازي. طبق التحليل على المعوض المتزامن المقترح للنظام الحلقي لمدينة الموصل. وتم تحليل الشبكة باستخدام برنامج Matlab Simulink / مع عرض ومناقشة النتائج. ولوحظ ان استخدام ربط التوالي لثانوي تلك المحولات يقل كثيرا من المحتـوى الكلي للتشوه (THD) مقارنة مع ربط التوازي.

1: Introduction

The Iraqi North Region National Grid (INRNG) consists of 400 KV and 132 KV buses. The load of Mosul city represents an important part of the INRING load. This load is supplied by a ring consists of seven 132 KV buses as shown in Figure 1. The lines connecting the buses are mainly double circuits. There are three single circuit lines (35/36, 36/37 & 35/37). This part of the INRNG suffers from problems such as loading on these three lines can exceed the acceptable loading percent during peak load periods. This causes outage due to over load.
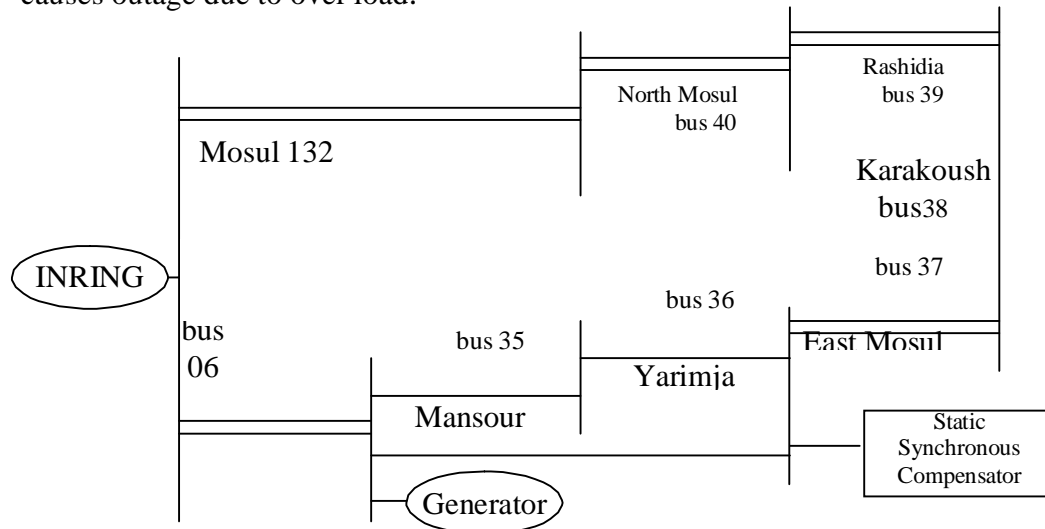

Figure 1: Mosul city 132kV ring system

The lines over load can be reduced by supplying reactive power locally. STATCOM has many advantage like High power rating, accurate and continuous control of reactive power and fast response to improve transient stability. So a STATCOM have been suggested in the Mosul Ring[1]. In this paper, INRING is analyzed using a load flow program. The buses 36, 37, & 38 were suffering from low voltages. So these three buses were the possible location of the STATCOM. The proposed STATCOM [1] was added in one of the three week buses each time. The same load flow program was then used to analyze INRING. The added reactive power, voltage profile of the Mosul ring busses, total losses for the three cases were compared East Mosul ring bus (bus 37) was preferred for the connection of the STATCOM[1].

STATCOM injects harmonics to the system. These added harmonics can be reduced by the proper selection of its components such as leakage reactance, switching frequency, number of pulses. Also the injected harmonics can be reduced by using (PWM) techniques. The selection of appropriate component of the suggested STATCOM have been done in a previous work[2].

The 12- pulse STATCOM with PWM is recommended, due to its low THD[1,2]. The HV windings of the two 6- pulse STATCOM transformers can be connected either in parallel [1,2] or in series [3,4]. The two connections are shown in figures 2 & 3 respectively. In both cases PWM technique is used to five the switching devices of the STATCOM.

The analysis of two connection of the STATCOM transformers (series & parallel) is done for the suggested model in Mosul ring. The Matlab/Simulink software V6.5 is used in this analysis[4]. THD and wave forms of current and voltages for the two cases are presented and discussed in the following articles.
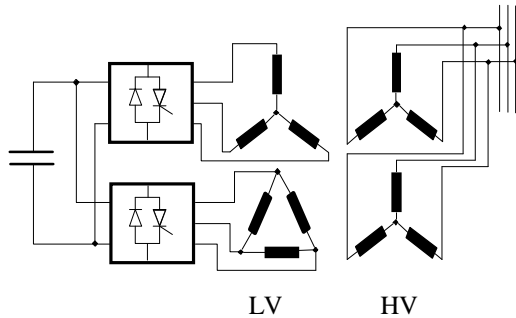
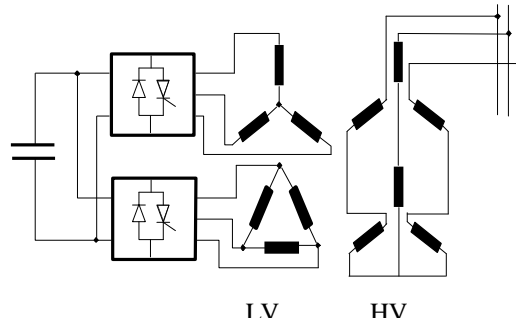16

LV   HV
Figure 2: parallel connection

LV   HV
Figure 3: series connection

2: System of Analysis:

2-1: THD Calculations:

THD is used to define the effect of harmonics on the power system voltage. It is used in low-voltage, medium-voltage and high-voltage systems. It is expressed as a percent of the fundamental and is defined as:-

$$THD = \sqrt{\frac{sum\ of\ all\ squares\ of\ amplitude\ of\ all\ harmonic\ voltages}{square\ of\ the\ amplitude\ of\ the\ fundamental\ voltage}} * 100\ \%$$

$$THD = \frac{\sqrt{\sum_{h=2}^{\infty} V_h^2}}{V_1} * 100\ \%$$

The limits lists in table 1 should be used as system design values for the "worst case" for normal operation (conditions lasting longer than one hour). For shorter period, during start–up or unusual conditions, the limits may be exceeded by 50% [5].

Table 1: Voltage Distortion Limits

Bus Voltage (kV)	Individual Voltage Distortion	Total Voltage Distortion THD(%)
69 and below	3.0	5.0
69 through 161	1.5	2.5
161 and above	1.0	1.5

2-2: System Data

INRNG load is 1122MW and 543.8Mvar. Mosul ring load is 316MW, 167Mvar. Mosul ring busses and lines data are given in appendix A. the loading conditions are changed continuously, so to operate the STATCOM optimally, this change must be taken in to consideration. The load range 70-150% (of the reference load) is considered. The values of the reactive power required to be supplied by the STATCOM for this load range was obtained from a previous work[1].

2-3:Analysis Model

Mosul ring with STATCOM situated at bus 37 is analyzed, using Matlab/Simulink software V6.5. Fig 4 shows the simulink model of the STATCOM, where the main idea of this research, it is the two transformers are connected, is clearly shown.

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The load range with suitable step change is used in the analysis model. The delay angle value is obtained according to active & reactive power required. Then it used in the model to obtained the THD. The Graphic User Interface (GUI) is used to get the harmonic content of voltage and current waveforms in each case. It also give THD of the analyzed waves. THD for voltages and currents (for the load range steps) are found at different buses. They are Bus 37,where the STATCOM is connected, Bus 39, a typical load bus, and bus 6 a generator bus.

Transformer ratio should be carefully chosen to match grid system in both cases. In both cases (parallel and series) the first transformer is star-star connected. While the second transformer is delta-star connected. For the parallel connection the star-star transformer is ($13.8kV/132kV$) as line to line voltages. While the delta-star transformer is of ($13.8kV/132kV$) as line to line voltages. As regard the series connection, the star-star transformer is of ($\frac{13.8}{\sqrt{3}}kV/\frac{66}{\sqrt{3}}kV$) as phase voltages. While the delta-star transformer is of ($13.8kV/\frac{66}{\sqrt{3}}kV$) as phase voltages. The sum of the two voltages of the series connection secondaries is therefore $\frac{132}{\sqrt{3}}kV$ as a phase voltage and $132\,kV$ as a line voltage. This configuration makes the two six pulse bridge share the reactive power in both the parallel & the series connections.
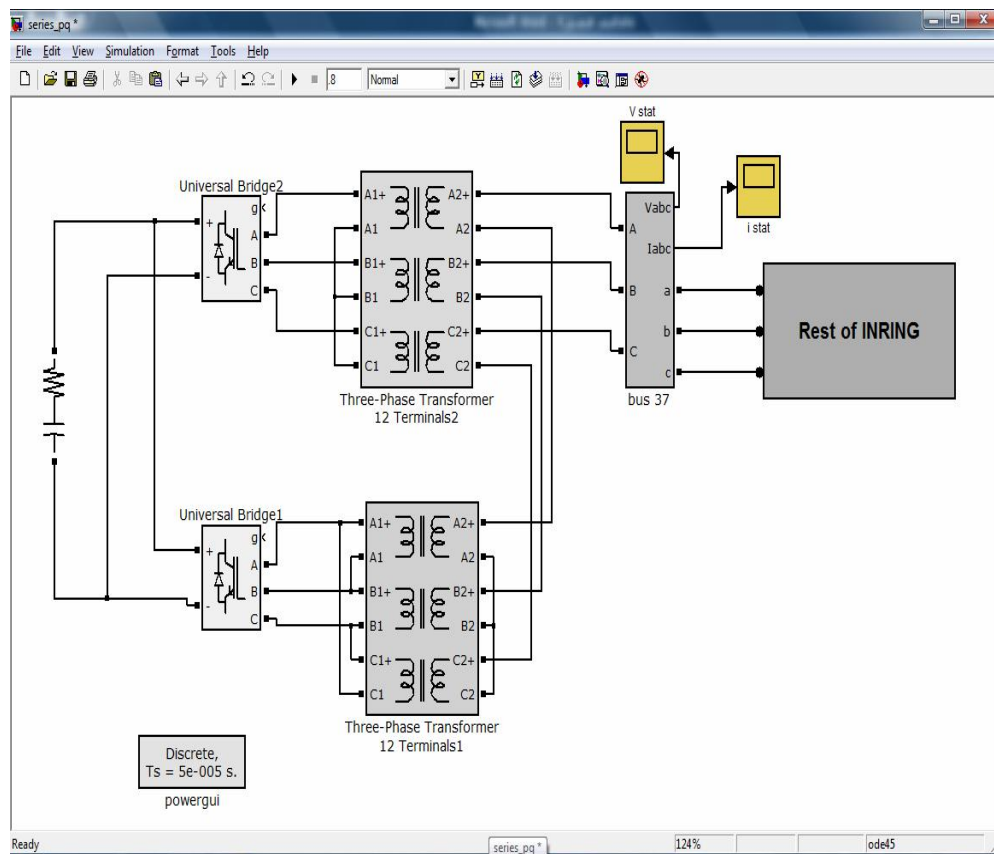

Figure 4: Simulink Model

3: Results and Discussion

The THD of the voltages and the currents at buses 37, 39 and 6 are found. Figure 5 shows the THD of the voltages at the two buses 37 & 39, for the two cases (series and parallel secondary) at 100 % loading. It is clear that the THD at bus 37 is higher, since the STATCOM is connected at this bus. It is also clear from this figure that the THD of the series connection is less than that for parallel connection by 2%. Figure 6 shows the THD of the currents at four locations: the STATCOM current, bus 37 & 39 load currents and bus 6 generator current. Clearly The THD of the STATCOM (10%) current is the highest. Again the THD in the case of series connection is lower than in the case of parallel connection.

Results for the THD of voltages and currents for different loading conditions (70 % - 150 %) are also obtained. Since THD at bus 37 is the highest the results at this bus is chosen. Figure 7 shows the THD of the voltage waves at bus 37, for the two cases (series and parallel secondary). The THD for the case of parallel connection is less than 5% which is within standard limits and the THD of the series connection (less than 3%) is even lower. Figure 8 shows the THD at the same bus 37 but for the current waves. The same conclusion applies for this case. It is clear from both figures 7 & 8 that the THD for all cases remains almost constant with loading conditions.
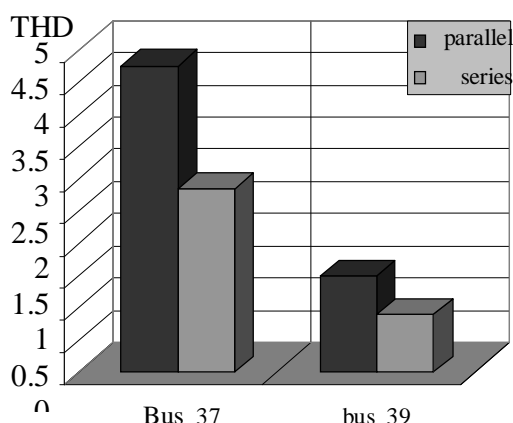
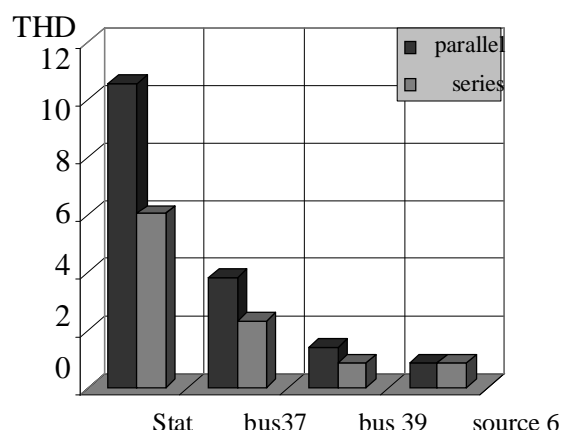Figure 5: Voltage THD in buses 37 & 39 at 100% loaded

Figure 6: Current THD in Buses 6, 37, 39 and STATCOM, at 100% loaded

Figure 9&11 show the voltage waveform at bus 37 (bus of STATCOM connection) & the current waveform at STATCOM, in series connection of transformers, respectively. The current waveform contain more harmonic components than voltage. This fact is clear from the figures 5&6.

Figures 10 & 12 show the spectrum of the voltage waveform at bus 37 & the spectrum of the current waveform of the STATCOM, respectively for the series connection. It is clear from these two figures that the dominant harmonic components of both the voltage and the current waveforms are 19th, 23rd, 41st, 43rd….. The corresponding waveforms and spectrum for parallel connection are given in reference [2] and appendix B for comparison. It is clear that the harmonic content of both voltage & current are less in series connection. The individual harmonics example the 5th, 19th, 23rd, 41st, 43rd, each of them has been reduced. The 3rd, 17th, 21st, 25th. Harmonics for the voltage and the 21st, 39th, 45th for the current are deleted.
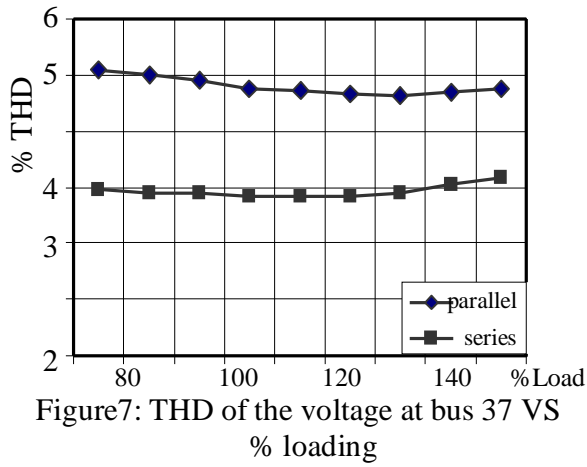
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Figure7: THD of the voltage at bus 37 VS
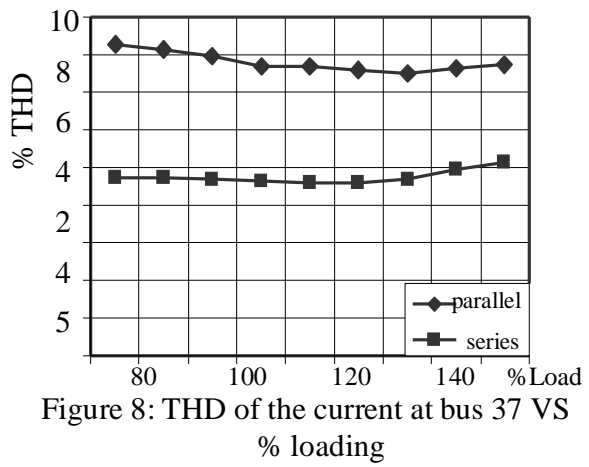% loading
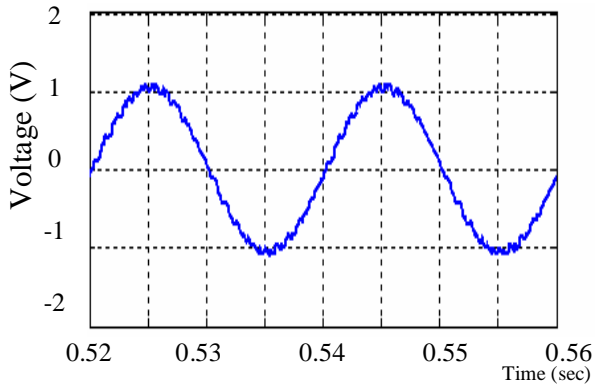
Figure 8: THD of the current at bus 37 VS
% loading

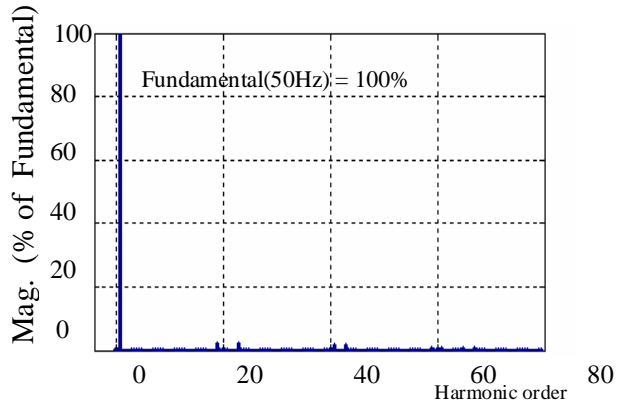Figure 9: The voltage waveform at bus 37

Figure 10: The spectrum analysis of a
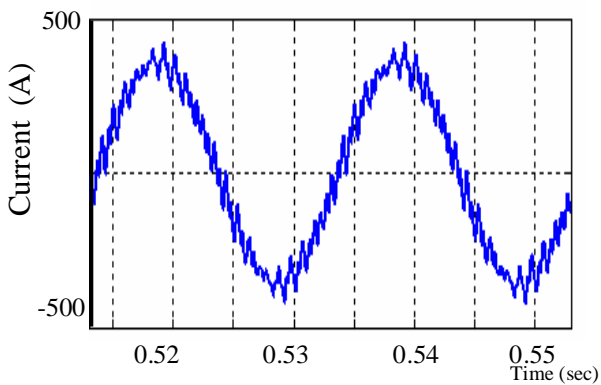voltage waveform at bus 37
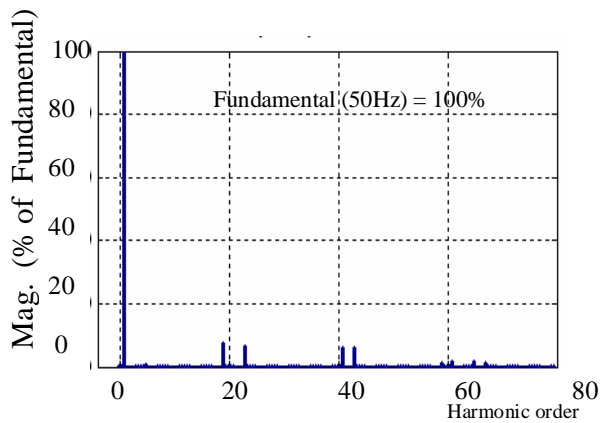
Figure 11: The current waveform at STATCOM

Figure 12: The spectrum analysis of a
current waveform at STATCOM

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4: Conclusions

The suggestion of using static synchronous compensator in the 132 kV ring system of Mosul city is a promising solution for the problems encountered in it. By implementing, PWM technique in a 12 pulse STATCOM with conventional transformer connections a total harmonic distortion of less than 5% may be obtained which is within standard limits. In this work it is found that this amount of distortion can be further reduced (by 3%) by using transformers with series connection rather than the conventional parallel connection. Furthermore some individual harmonics like 21st have been deleted.

5: References

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Appendix A

Table A-1: Mosul City Ring System Loads.

No	Name	Load (MW)	Load (MVAR)
6	Mosul 132	0	0
35	Mansour	23	5
36	Yarimja	53	35
37	East Mosul	64	46
38	Karakous	94	21
39	Rashidia	70	23
40	North Mosul	57	37

Table A-2: Mosul City Ring System Parameters.

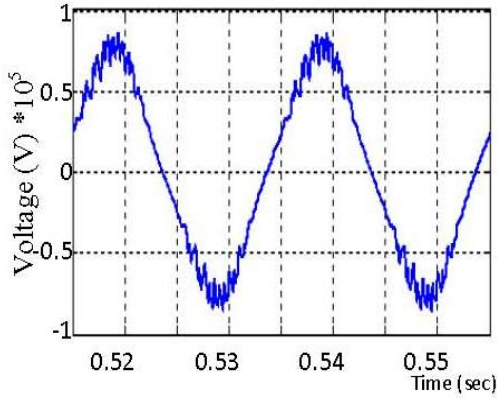| Sending Ends	Receiving Ends	R (p.u.)	X (p.u.)	Y (p.u.)	No. of Lines
6	35	0.0066	0.0140	0.00250	2
6	40	0.0044	0.0094	0.00160	2
35	36	0.0150	0.0687	0.02479	1
35	37	0.0185	0.0850	0.03128	1
36	37	0.00554	0.00251	0.00870	1
37	38	0.0125	0.0574	0.02114	2
33	39	0.2020	0.0420	0.00716	2
39	40	0.01003	0.0212	0.00379	2

Appendix B

Figure B1: The voltage waveform at bus 37 for parallel connection
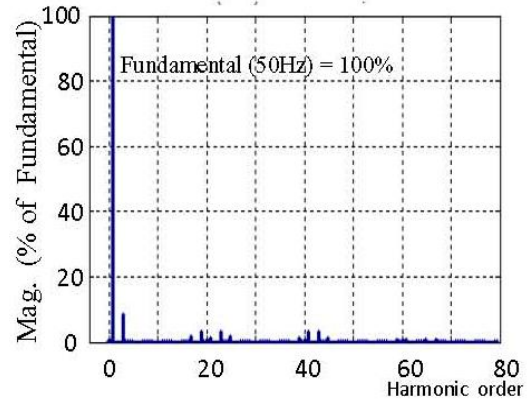

Figure B2: The spectrum analysis of a voltage waveform at bus 37 for parallel conn.
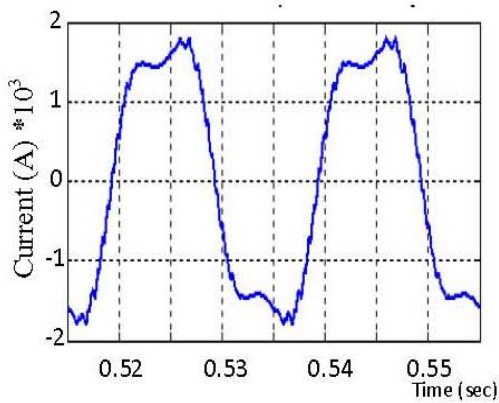

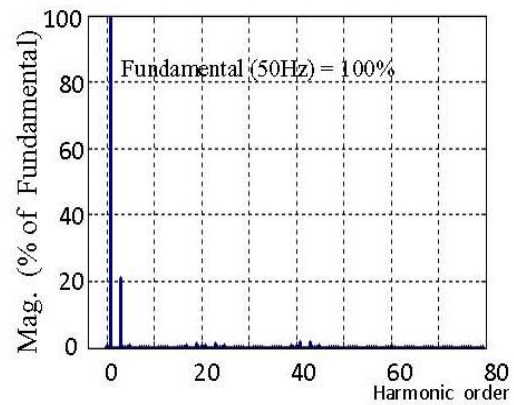Figure B3: The current waveform at STATCOM for series conn.

Figure B4: The spectrum analysis of a current waveform at STATCOM for series conn.

The work was carried out at the college of Engg. University of Mosul