

بسم الله الرحمن الرحيم

قال الله تعالى:

وعلم آدم الأسماء كلها ثم عرضهم على الملائكة فقال

أنبئوني بأسماء هؤلاء إن كنتم صادقين (31) قالوا سبحانك

لا علم لنا إلا ما علمتنا إنك أنت العليم الحكيم (32)

،،، صدق الله العظيم،،،

سورة البقرة (مدنية) الآيات (31، 32)

# Dedication

*I DEDICATE THIS DISSERTATION*

*TO MY FAMILY*

*TO MY TEACHERS*

*TO MY COLLEAGUES*

*TO MY FRIENDS*

# Acknowledgement

First and foremost thanks to Allah. Without his help and blessing I would not have been able to finish this work.

I would like to thank my supervisor Amir Ahmed Dawood for his encouragement and support.

Thanks also to Sudan University of Science and Technology staff, especially Salah eldeen Gasim for his suggestions, help and unlimited support.

My gratitude to the National Electricity Corporation (NEC) staff represented in generation and training departments.

Then, I am very grateful and thankful to Engineer / Salih (generation staff of NEC) for his help.

Then, I am grateful and thankful to management in Giad Industrial City staff for their support and help. Also I am grateful to my friend Engineer / Khalid Yousif Elgurashi for his unlimited support.

# Abstract:

Electrical power system has many changes such as; disturbances, perturbations and oscillations caused by many factors such as electrical faults and transients in voltages and currents. Also the network has a lot of losses, which results increasing heat lead to equipment damage.

Harmonics generate that is produced in circuit elements circuits like diodes, thyristors, rectifiers, inverters, converters, power generation equipment, Variable Speed Drives of induction motors, transformers and magnetic-ballast fluorescent lamps.

Electrical arc furnace also is a major source of harmonics because it draws very high currents estimated in kilo amperes, which result in increasing heat of steel and generate harmonic currents.

These harmonic currents create heat after a period of time will raise the temperature of the neutral conductor causing nuisance and tripping of circuit breakers, over voltage problems, blinking of incandescent lights and computer malfunctions.

Among the electrical devices that seem to cause harmonics are personal computer, Dimmers, Laser printers, Electronic Ballast, Stereos, Television, Radio, Fax machines and any other equipment powered by switched-mode power supply equipment.

These problems can be reduced by using a dedicated circuit for electronic equipments. The more expensive way to reduce these problems filters the mains effectively removing all low frequency harmonics.

This thesis, studied and analyzed the harmonics, it found that the harmonics in Jebel Aulia power station is not related to induction generators, but it due to compensation grid.

According to study and analysis taken measurements and found that amount of harmonics 20.7 % to 37.1 % before filter installation, when it operates amount of harmonics reduce to 2.6 %.

By using MATLAB/SIMULINK, active filter was designed to reduce harmonics to 0.84 % instead of 2.6 %. This filter has high efficiency and sensitivity for all system variations.

## مستخلص البحث:

نظام القدرة الكهربائية له تغيرات كثيرة مثل التشويشات والتذبذبات التي تحدث بعدة عوامل مثل الأعطال الكهربائية والعبور للفولتيات والتيارات. أيضا الشبكة لها كمية من الفواقد التي تنتج ارتفاع في الحرارة والتي تؤدي الي تلف بالمعدات.

التوافقيات تولد في عناصر الدائرة مثل الثنائيات، الثايرستور، المقومات، عواكس المحولات، معدات توليد القدرة، ناقلات التيار المتردد للمحركات الحثية، ومحولات القدرة في حالة تيار الاثارة الزائد واللمبات الوهاجة (حمولات غير خطية).

القوس الكهربائي للفرن يعتبر مصدر أساسي للتوافقيات لأنه يرسم تيارات عالية جدا تقدر بالكيلو أمبير، وهذه التيارات تنتج ارتفاع في درجة الحرارة، وبعده فترة من الزمن تصل هذه الحرارة الي الموصل المحايد فيحدث ازعاج وفصل لقواطع الدائرة.

من بين المعدات الكهربائية التي يمكن أن تحدث توافقيات مثل الحاسب الشخصي، الطابعات، التلفزيونات، الراديو والمسجلات، ماكينة الفاكس وكل المعدات والتي قدرتها بواسطة معدة مغذي القدرة لانها تحتوي علي قناطر المقومات.

هذه المشاكل (التوافقيات) يمكن تقليلها أو ازلتها باستخدام الدوائر الخاصة للمعدات الالكترونية، والطريقة الأكثر تكلفة لتقليل هذه التوافقيات هي دوائر المرشحات.

هذا البحث، لدراسة وتحليل التوافقيات بمحطة جبل الأولياء، واتضح بأن التوافقيات ليس لها علاقة بالمولد الحثي، وانما قادمة للمحطة من معوضات الشبكة الردفعلية.

وتم التحقيق من ذلك بأخذ قراءات من المحطة ووجد ان كمية التوافقيات تتراوح ما بين 20.7% الي 37.1% قبل تركيب المرشح (الفلتر)، وعند تشغيل المرشح يتم تخفيضها الي 2.6%. وبناء علي ذلك تم تصميم مرشح بنظام الماتلاب استطاع تخفيضها الي 0.84% بدلا من 2.6%، وهذا المرشح ذو كفاءة و حساسية عالية لكل التغيرات التي تطرأ علي النظام.

# Contents

الايات الكريمات .....	I
Dedication .....	II
Acknowledgements .....	III
Abstract .....	IV
مستخلص البحث .....	VI
Contents .....	VII
List of tables .....	XI
List of figures .....	XII
List of Symbols and Abbreviations.....	XIV

## **Chapter One**

### **Sources of Harmonics and their Effects**

1.1 General introduction of harmonics .....	1
1.2 Background of harmonics .....	2
1.3 Nature of harmonics.....	3
1.4 Main sources of harmonics .....	3
1.5 Harmonics versus transients .....	4
1.6 The mechanism of harmonic generation .....	4
1.7 Effects of harmonics.....	6
1.7.1 The general effects of harmonics distortion .....	6
1.7.2 The major effects of harmonics distortion .....	7
1.8 Expected results of current distortion .....	9
1.9 The effects of voltage distortion .....	9

1.10 Harmonic currents create voltage distortion .....	10
1.11 Harmonic's factors .....	10
1.12 Treatment of harmonics .....	11

## **Chapter Two**

### **Resonance Circuits and Harmonic propagation**

2.1 Fourier series and Coefficients .....	13
2.2 Resonance .....	13
2.2.1 Series resonance .....	14
2.2.2 Parallel resonance .....	15
2.3 Harmonic's orders .....	19
2.4 Distributed Harmonic Sources .....	19
2.5 Propagation of harmonics in distribution systems .....	20
2.6 Observing harmonics .....	20
2.7 Propagation of harmonics in transformer.....	21
2.7.1 Short – term risk .....	22
2.7.2 Long – term risk .....	22
2.7.3 Transformer harmonic content .....	23
2.7.4 Transformer losses .....	23
2.7.5 Harmonics effects on transformer losses .....	23
2.8 Propagation of harmonics in induction generator .....	24
2.9 Problems of harmonics .....	25
2.10 Propagation of harmonics in the transmission lines.....	26
2.10.1 Nature of current in a T.L .....	26
2.10.2 Line harmonic problems .....	27
2.10.3 The SVC of a transmission line .....	27



## **Chapter Three**

### **Harmonic's Measurement, Analysis and PCC**

3.1 The measures of harmonic distortion .....	30
3.2 Power-Quality Meters and Analyzers .....	31
3.3 Harmonic analysis .....	31
3.4 Concept of Point of Common Coupling (PCC) .....	32
3.5 Harmonics agreements .....	33
3.6 Power Quality Issues .....	34
3.7 Harmonic Standards.....	34
3.8 A variable frequency drive (VFD).....	35
3.9 Classical solution for compensating the reactive power .....	37

## **Chapter Four**

### **Measurements of harmonics in laboratories**

4.1 Measurements of harmonics in SUST lab .....	40
4.1.1 Harmonics in dimmers ( $\alpha = 90^\circ$ ) .....	40
4.1.2 Harmonics in dimmers ( $\alpha = 180^\circ$ ) .....	41
4.1.3 Harmonics in D / Y transformer .....	43
4.1.4 Harmonics in dimmers using filter.....	45
4.1.5 Measurements of harmonics in electric ballast .....	47
4.1.6 Harmonics voltages in dimmers .....	49
4.1.7 Harmonics voltages in electric ballast .....	49
4.1.8 Investigation of harmonics (by calculations) .....	50
4.1.9 The present passive filter .....	51
4.2.1 Background about JAPS .....	52

4.2.2 Mechanism of an induction generator .....	52
4.2.3 Harmonics of induction generator .....	53
4.2.4 Test of harmonics in JAPS .....	54
4.2.5 Testing of G running without C .....	55
4.2.6 Testing of G running and sharing $C_s$ .....	57
4.2.7 Induction generator behavior (MATLAB results) .....	68

## **Chapter Five**

### **Design of filters**

5.1 Filter background .....	71
5.2 Superior filtering performance .....	71
5.3 Design of an active filter in SUST laboratory .....	71
5.4 Design of an active filter in JAPS laboratory.....	73
5.5 MATLAT results of harmonics without filter.....	74
5.6 MATLAB results of harmonics with active filter .....	75

## **Chapter Six**

### **Conclusion and Recommendations**

6.1 Conclusion.....	77
6.2 Recommendations .....	77
References.....	79
Appendices.....	81

# List of Tables

---

Table 2.1 Harmonics spectra of load equipment .....	17
Table 2.2 Harmonics orders with frequency .....	19
Table 4.1 Harmonics measurement of SUST lab ( $\alpha = 90^\circ$ ).....	40
Table 4.2 Harmonics measurement of SUST lab ( $\alpha = 180^\circ$ ).....	42
Table 4.3 Harmonics results in case of dimmer lamps .....	43
Table 4.4 Harmonics measurement in SUST lab .....	45
Table 4.5 Harmonics measurement in SUST lab .....	47
Table 4.6 Harmonics measurement in SUST lab .....	49
Table 4.7 Harmonics measurement in SUST lab .....	49
Table 4.8 Volts/ Amps with G running and without sharing capacitors ....	55
Table 4.9 Power and power factor with G running and no capacitor .....	56
Table 4.10 Power & power factor with G running and sharing C1 .....	57
Table 4.11 Power & power factor with G running and sharing C2 .....	59
Table 4.12 Power & power factor with G running and sharing C3 .....	60
Table 4.13 Power & power factor with G running and sharing C4 .....	61
Table 4.14 Volt/ Amps .....	62
Table 4.15 Power & power factor with G running and sharing C5 .....	64
Table 4-16 Volts, Amps, CF with G running and share C5 .....	64
Table 4.17 Harmonics of voltages .....	66
Table 4.18 Harmonics of currents .....	67

## List of Figures

---

Fig 1.1 Block diagram of harmonics and methods of its elimination .....	2
Fig 1.2 Mechanism of harmonics generation .....	5
Fig 2.1 Series resonance circuit .....	15
Fig 2.2 Parallel resonance at a point of common coupling .....	15
Fig 2.3 Diagram of harmonics propagation in transformer .....	21
Fig 2.4 Diagram oh harmonics propagation in distributed generation .....	24
Fig 2.5 Diagram of harmonics propagation in transmission line .....	26
Fig 2.6 SVC in normal condition .....	28
Fig 2.7 SVC in voltage sag .....	28
Fig 2.8 SVC in voltage surge .....	29
Fig 3.1 PCC .....	32
Fig 3.2 Schematic of a PWM variable frequency drive .....	36
Fig 3.3 Configuration of TSC .....	37
Fig 3.4 Configuration of TCR .....	38
Fig 3.5 Characteristics of voltage current TCR .....	38
Fig 3.6 Static Var Compensation using TSC & TCI .....	39
Fig 4.1 Harmonics currents in graphical form .....	42
Fig 4.2 Harmonics currents in graphical form .....	43
Fig 4.3 Harmonics currents in graphical form ( $\alpha = 90^\circ$ ).....	44
Fig 4.4 Harmonics currents in graphical form ( $\alpha = 180^\circ$ ).....	45
Fig 4.5 Harmonics currents in graphical form (N.C) .....	46
Fig 4.6 Harmonics currents in graphical form (filter) .....	46
Fig 4.7 Harmonics currents in graphical form without filter .....	47
Fig 4.8 Harmonics currents in graphical form with a D / Y – T .....	48
Fig 4.9 Harmonics currents in graphical form with filter .....	48

Fig 4.10 Harmonics voltages in graphical form (filter OFF) .....	50
Fig 4.11 Harmonics voltages in graphical form (filter ON) .....	50
Fig 4.12 Harmonics results of currents as graphical form.....	53
Fig 4.13 Harmonics results of voltages as graphical form .....	54
Fig 4.14 Harmonics of voltage distortion .....	56
Fig 4.15 Harmonics of current distortion .....	57
Fig 4.16 Harmonics of voltage distortion .....	58
Fig 4.17 Harmonics of current distortion .....	58
Fig 4.18 Harmonics of voltage distortion .....	59
Fig 4.19 Harmonics of voltage distortion .....	60
Fig 4.20 Harmonics of current distortion .....	61
Fig 4.21 Harmonics of voltage distortion .....	62
Fig 4.22 The voltage wave in step 4 .....	63
Fig 4.23 Harmonics of currents .....	63
Fig 4.24 Harmonics of voltages .....	65
Fig 4.25 The voltage wave .....	65
Fig 4.26 Harmonics of current distortion.....	66
Fig 4.27 The inrush currents in step 5 .....	67
Fig 4.28 Rotor current of the induction generator .....	68
Fig 4.29 Stator current of the induction generator .....	68
Fig 4.30 Rotor speed of the induction generator .....	69
Fig 4.31 Electromagnetic torque of the induction generator .....	69
Fig 4.32 Phase to phase voltage of the induction generator .....	70
Fig 5.1 Load current of induction generator .....	75
Fig 5.2 Total harmonics distortion of load current before filter .....	75
Fig 5.3 load current of induction generator (sinusoidal wave).....	76
Fig 5.4 Total harmonics distortion of load current when filter ON.....	76

# List of Symbols and Abbreviations

THD	Total Harmonic Distortion
FF	Form Factor
CF	Crest Factor
UPS	Uninterruptible Power Supply
SMPS	Switched-Mode Power Supply
ANSI	American National Standard Institute
IEEE	Institute of Electrical and Electronics Engineers
RMS	Root mean square
CSA	Canadian Standards Association
IEC	The International Electro technical Commission
$P_{OSL}$	Other stray loss in the core, clams and structural parts of transformer
SCR	Silicon Controlled Rectifiers
TV	Television
DG	Distributed Generation
PCC	Point of Common Coupling
PWM	Pulse-width modulation
TDD	Total Demand Distortion factor
NEC	National Electricity Corporation
VFD	Variable frequency drive
ASD	Adjustable Speed Drives
SUST	Sudan University of Science & Technology
EAR	Electricity Authority Requirements
SVC	Static Var Compensation
SVCS	Static Var Compensation System
PI	Proportional-Integral

APSC	Advanced Power System and Control Lab
WTIG	Wind Turbine and the Induction Generator
STATCOM	Static Synchronous Compensator
VSD	Variable Speed Drive
TCR	Thyristor controlled reactor
TSC	Thyristor Switched reactor
SC	Synchronous compensator
TL	Transmission Line
GIS	Giad Industries Steel
JAPS	Jebel Aulia Power Station
G	Generator
C	Capacitor