POWER QUALITY IMPROVEMENT USING UNIFED POWER QUALITY CONDITIONER (UPQC)

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DEDICATION

This project report is dedicated to my parents and my fellow family.

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In preparing this project report, I was in contact with many post graduate student and academicians. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my project supervisor, Dr. Mohd. Hafiz Bin Habibuddin, for encouragement and guidance. Without his continued support and interest, report would not have been the same as presented here.

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ABSTRACT

The purpose of this project is to evaluate the effectiveness of control strategy of Unified Power Quality Conditioner (UPQC) in order to improve power quality problem in distribution system specifically harmonics distortion. The performance of UPQC system controlled by Fuzzy Logic Controller (FLC) is compared by Proportional Integral (PI) controller. The control strategy depends on d-q transformation both shunt active filter and series active filter, phase-locked loop synchronization and constant dc-link voltage. The capability and performance of FLC and PI controller under non-linear load is demonstrated using test models built in Matlab / Simulink software. Simulation result is depicts the reliability of Fuzzy Logic Controller in reducing harmonics distortion in comparison with PI controller. The equipment is designed to have potential in reducing total harmonic distortion to values within the prescribed criteria set by IEEE standards.

ABSTRAK

Projek ini dilaksanakan bertujuan untuk menilai tahap kecekapan kaedah kawalan yang digunapakai oleh Penyesuai Kualiti Kuasa Disatukan (UPQC) dalam menangani masalah Kualiti Kuasa pada sistem agihan terutamanya gangguan daripada harmonik. Keupayaan UPQC yang dikawal oleh Pengawal jenis Logik Kabur (FLC) dibandingkan dengan Pengawal jenis Pengamiran Kadaran (PI). Strategi kawalan adalah bergantung kepada kaedah transformasi d-q yang diaplikasikan untuk kedua-dua jenis penapis iaitu Penapis Aktif secara Sesiri dan Penapis Aktif Selari, kesinambungan Gelung Terkunci Fasa, dan voltan pautan de yang tetap serta malar. Kebolehupayaan serta prestasi pengawal FLC dan PI apabila disambungkan dengan beban tidak linear adalah dinilai dan diukur dengan menggunakan model litar ujian yang direkabentuk melalui perisian Matlab / Simulink. Keputusan simulasi menunjukkan kebolehupayaan Pengawal jenis Logik Kabur yang lebih berpotensi mengurangkan gangguan harmonik jika dibandingkan dengan jenis PI. Peranti yang dicadangkan berkeupayaan untuk mengurangkan pengawal keseluruhan gangguan harmonik kepada sistem kuasa berdasarkan nilai bacaan yang dibenarkan oleh ketetapan piawaian IEEE.

TABLE OF CONTENTS

TITLE	PAGE
DECLARATION	ii
DEDICATION	iii
ACKNOWLEDGEMENT	iv
ABSTRACT	V
ABSTRAK	vi
TABLE OF CONTENT	vii
LIST OF TABLES	ix
LIST OF FIGURES	Х
LIST OF ABBREVIATIONS	xiii
LIST OF SYMBOLS	XV
LIST OF APPENDICES	xvi

CHAPTER 1 INTRODUCTION

1.1	Background of Study	1
1.2	Problem Statement	2
1.3	Objectives of the Project	3
1.4	Scope of the Project	4

	CHA	PTER	2
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LITERATURE REVIEW

2.1	Power Quality (PQ)	5
	2.1.1 Important of Power Quality	5
	2.1.2 Type and Sources of PQ Problem	6
	2.1.3 PQ Compensating Devices	7
2.2	Unified Power Quality Conditioner	0
	(UPQC)	8
	2.2.1 Basic Configuration of UPQC	8

	2.2.2 Function of UPQC	10
2.3	Control Strategy of UPQC	10
	2.3.1 Overview of Different type of	10
	UPQC	12

CHAPTER 3 METHODOLOGY

3.1	Introduction	15
3.2	Test Circuit Configuration	16
3.3	Proposed UPQC Model	17
3.4	Proposed Control Method	19
	3.4.1 Reference Current and Voltage	19
	using PI Controller	19
	3.4.2 Reference Current and Voltage	23
	using Fuzzy Logic Controller	23

4.1	Introduction	31
4.2	Simulation Results	31
	4.2.1 Case 1 – Uncompensated System	31
	4.2.2 Case 2 – UPQC with PI Controller	37
	4.2.3 Case 3 – UPQC with Fuzzy Logic	41
	Controller	41
4.3	Comparison Performance of PI Controller	46
	and Fuzzy Logic Controller	40

CHAPTER	5	CONCLUSION	
	5.1	Conclusion	49
	5.2	Future Works Recommendation	50

REFERENCES	52
Appendices A-B	55-56

LIST OF TABLES

TABLE NO.	TITLE	PAGE
Table 2.1	Type of Variation in Power System	6
Table 3.1	Parameter of Test System Design	18
Table 3.2	25 Rules of FL Controller	27
Table 4.1	% THD Voltage for Different Controller of UPQC	46
	with SLG Fault	
Table 4.2	% THD Current for Different Controller of UPQC with	46
	SLG Fault	
Table 4.3	% THD Voltage for Different Controller of UPQC	47
	without Fault Condition	
Table 4.4	% THD Current for Different Controller of UPQC	47
	without Fault Condition	

LIST OF FIGURES

FIGURES NO.	TITLE	PAGE
Figure 2.1	Basic Topology of UPQC	9
Figure 3.1	Overview Flow of Research Activity	16
Figure 3.2	Single Line Diagram of Test Circuit (a) without UPQC	16
	(b) with UPQC	17
Figure 3.3	Design Model of Test Circuit in Matlab/Simulink	19
Figure 3.4	Process Overview of PI Controller	21
Figure 3.5	Controlling Circuit of Shunt Active Filter	21
Figure 3.6	Controlling Circuit of Series Active Filter	23
Figure 3.7	Process Overview of DC Control using Fuzzy Logic	24
Figure 3.8	Membership functions (a) for Fuzzy Logic control	25
	strategy	
	(b) Input variables : 'Change Error'	25
	(c) Input variables : 'Error'	26
	(d) Output variables	26
Figure 3.9	Rules Editor of 25 Rules in Matlab/Simulink	28-29
Figure 3.10	Surface Viewer of FLC Simulink Modelling	29
Figure 3.11	FLC Simulink subsystem for 25 rules	30
Figure 4.1	The waveform of grid source voltage (V_s)	32
Figure 4.2	The waveform of grid source current (I_s)	32
Figure 4.3	The uncompensated waveform of load voltage (V $_{o}$) for	33
	SL-G Fault	
Figure 4.4	The uncompensated waveform of load current (I_o) for	33
	SL-G Fault	
Figure 4.5	The uncompensated waveform of load voltage (V_o)	34
	without Fault Condition	
Figure 4.6	The uncompensated waveform of load current (I_o)	34
	without Fault Condition	

Figure 4.7	The	spectrum	analysis	of	THD	voltage	of	35
	uncom	pensated sy	stem for S	LG F	ault			
Figure 4.8	The	spectrum	analysis	of	THD	current	of	35
	uncom	pensated sy	stem for S	LG F	ault			
Figure 4.9	The	spectrum	analysis	of	THD	voltage	of	36
	uncom	pensated sy	stem with	out Fa	ult Con	dition		
Figure 4.10	The	spectrum	analysis	of	THD	current	of	36
	uncom	pensated sy	stem with	out Fa	ult Con	dition		
Figure 4.11	The wa	weform of	load voltag	ge (V _o) for SL	-G Fault v	vith	37
	PI Con	troller						
Figure 4.12	The wa	aveform of	load current	nt (I _o)	for SL	-G Fault v	vith	37
	PI Con	troller						
Figure 4.13	The w	vaveform	of load v	oltage	e (V _o)	for no-Fa	ault	38
	Condition with PI Controller							
Figure 4.14	The w	vaveform	of load c	urren	t (I _o)	for no-Fa	ault	38
	Condit	ion with PI	Controller					
Figure 4.15	The spe	ectrum ana	lysis of TH	D vol	tage sys	tem for SI	L-G	39
	Fault w	vith PI Con	troller					
Figure 4.16	The sp	ectrum ana	lysis of TH	D cui	rent sys	tem for SI	L-G	39
	Fault w	vith PI Con	troller					
Figure 4.17	The sp	ectrum ana	lysis of TI	HD vo	oltage s	ystem for	no-	40
	Fault C	Condition w	vith PI Cont	troller				
Figure 4.18	The sp	ectrum ana	alysis of TI	HD ci	urrent sy	ystem for	no-	41
	Fault C	Condition w	vith PI Cont	trolle	.			
Figure 4.19	The wa	veform of	load voltag	ge (V _o) for SL	-G Fault v	vith	42
	FLC							
Figure 4.20	The w	aveform o	of load cur	rrent	(I _o) for	SL-G F	ault	42
	Condit	ion with FI	LC					
Figure 4.21	The w	vaveform	of load v	oltage	(V_o)	for no-Fa	ault	43
	Condit	ion with FI	LC					
Figure 4.22	The w	vaveform	of load c	urren	t (I _o)	for no-Fa	ault	43
	Condit	ion with FI	LC					

Figure 4.23	The spectrum analysis of THD voltage system for SL-G		
	Fault with FLC		
Figure 4.24	The spectrum analysis of THD current system for SL-G	44	
	Fault with FLC		
Figure 4.25	The spectrum analysis of THD voltage system for no-	45	
	Fault Condition with FLC		
Figure 4.26	The spectrum analysis of THD current system for no-	45	
	Fault Condition with FLC		

LIST OF ABREVIATIONS

APF	-	Active Power Filter
ANN	-	Artifial Neural Network
CPD	-	Custom Power Devices
CSI	-	Current Source Inverter
d	-	Direct or real
d-q-0	-	Transformation direct-quadrature-zero transformation
DC	-	Direct Current
DSTATCOM	-	Distribution Static Compensator
DVR	-	Dynamic Voltage Restorer
FFT	-	Fast Fourier Transform
FLC	-	Fuzzy Logic Controller
FOC-IM	-	Field-Oriented Control Induction Motor
IEEE	-	Institute of Electrical and Electronic
		Engineers
IEC	-	International Electrotechnical
		Commision
IGBT	-	Insulated Gate Bipolar Transistor
K	-	Gain
Ki	-	Integral
Кр	-	Proportional
LPF	-	Low Pass Filter
NB	-	Negative Big
NS	-	Negative Small
PCC	-	Point Common Coupling

PI	-	Proportional Integral
PLL	-	Phase Locked Loop
PB	-	Positive Big
PQ	-	Power Quality
PS	-	Positive Small
PV	-	Photo-Voltaic
PWM	-	Pulse Width Modulation
Ref	-	Reference
SLG	-	Single Line-to-Ground Fault
THD	-	Total Harmonic Distortion
UPQC	-	Unified Power Quality Conditioner
VSI	-	Voltage Source Inverter

LIST OF SYMBOLS

А	-	Ampere
ce	-	Change in error
e	-	error
I_L	-	Load Current
kV	-	kiloVolt
kW	-	kiloWatt
L	-	Inductor
$V_{\rm L}$	-	Load Voltage
V_S	-	Source Voltage
Х	-	Inductance
X/R	-	Ratio of total inductive reactance to its total
		resistance
Y	-	Star
Ζ	-	Impedance
Δ	-	Delta
μ	-	Micro
π	-	Pi
ω	-	Omega

LIST OF APPENDICES

APPENDIX.	TITLE	PAGE
Appendix A	IEEE 519-2014 : IEEE Recommended Practice and	55
	Requirements for Harmonic Control in Electric Power	
	Systems (Recommended harmonic voltage limits)	
Appendix B	IEEE 519-2014 : IEEE Recommended Practice and	56
	Requirements for Harmonic Control in Electric Power	
	Systems (Recommended current distortion limits for	
	systems nominally rated 120 V through 69 kV)	

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Power Quality (PQ) problem in power distribution system namely harmonics, voltage sags and swells are the major concern with increased usage of sensitive load connected to power system line as well as integration of renewable energy source such as solar energy and wind power to the grid. System experienced disturbance in grid voltage such as increased value from nominal source voltage due to intermittent nature of renewable energy (RE) source. The disturbance occurs when rising amount of RE generation and connected demands of loads is decreased. (Devassy S. and Singh. B, 2012). Interruption and disturbances in power supply affect all type of consumer including domestic, commercial and in particularly industrial customers. Impact on financial losses is main factor to control for industry player. In the recent years, people awareness towards power quality improvement have actuate the evolving of power system. Customers demands the reliability of delivered power from utility as smooth as supply power from source system.

Institute of Electrical and Electronics Engineers (IEEE) defined Power Quality (PQ) as "the concept of powering and grounding sensitive electronic equipment in a manner suitable to the operation of equipment". In other words, it defines as "the ability of electrical equipment to operate in satisfactory manner, given proper care and maintenance and without adversely affecting the operation of other electrical equipment connected to the system." (T.Gonen,2014). This experiences to the possibility of disturbance in sinusoidal waveform deviation of power system supply voltage or load current quality. The

common issue related to PQ in power system are current and voltage harmonic. Impact of these issue encounter large amount of financial loss. Numerous research article discloses that sensitive loads experience stern impact of harmonic distortions is at the feeder of Point of Common Coupling (PCC).

In order to improve harmonics profile in the distribution system, Custom Power Devices (CPD) are introduce as customized solution to PQ issues. Enhancement of reliable power quality deliver to customers is achieved by application of CPD. It works due to capability of electronic power converters and fast adaptation of control adjustment for the electrical system.

UPQC is more advanced type of CPD combining two Active Power Filters (APFs). This device is the best CPD in dealing with distortion of load current as well as supply voltage. UPQC has advantages by providing the reactive power which required by load demands to ensure that voltage and current supply both operate in similar phase. Hence, installation of additional equipment to correct measurement of power factor is not required (P.Ram Kishore et.al, 2012). The device is adaptable to deliver its function on compensate the load and control the voltage system simultaneously

1.2 Problem Statement

The effectiveness and performance for UPQC when dealing with power quality problem is depends on reliability of different control strategies. The distortion can be eliminated by using proper control strategies and filters in both series and shunt inverter of UPQC The capability of different type of control strategy had presented from various number of previous literature and publication. A Proportional Integral (PI) is commonly used as control strategy for power enhancement by reducing the distortion in the output power. At the same time, application of Fuzzy Logic Control (FLC) has increased in past few years because it neither needs of complex mathematical formulae nor quick processors to react. Despite of that, this method requires minimum storage of data because the function is duly on knowledge base including Membership Functions (MF's) and rules.

An operation of FLC generally based on the required number of linguistic variables. Increased number of linguistic variables resulted to increasing computational time and large number of memory space requirement. It is happened because to ensure FLC working in most efficient, large computation time is requires by the device to process each step time in order to obtained the suitable control value to the system for implement. Thus, a reduce number of large fuzzy rule base is introduced to applied in the system.

1.3 Objectives of the Project

The objectives of this project are stated as follows:

- i. To study power quality problem especially harmonic distortion in the distribution system with presence of non-linear loads.
- ii. To develop simulation models of UPQC controller which can be use in distribution system subject to suppress harmonics

 To evaluate and analyse the performance between different types of controller of UPQC (PI and Fuzzy Logic) in compliance with IEEE 519-1159 standards.

1.4 Scope of the Project

The scopes of this project are shown below:

- i. Identify harmonics effect at grid line when non-linear load is connected to distribution network comprising 11kV feeder
- Modelling two (2) type of controller (PI and Fuzzy Logic) and evaluation of its performance is carried out using MATLAB-Simulink software. In this work, FLC with 25 rules is applied to reduce computation effort and shorten the period of processing time.
- iii. Analyzing the performance of the proposed model of UPQC by testing under SingleLine-to-Ground Fault

REFERENCES

- [1] T.Geury, S.Pinto and J.Gyselinck,"Direct Control Method for a PV System Integrated in Indirect Matrix Converter Based UPQC", in 4th IEEE International Conference on Smart Energy Grid Engineering, 2016
- [2] S.Devassy and B.Singh,"Design and Performance Analysis of Three-Phase Solar PV Integrated UPQC", IEEE Transaction on Industry Application, Vol.54, No.1, 2018
- [3] S.Devassy and B.Singh,"Modified pq-Theory-Based Control of Solar-PV-Integrated UPQC-S", IEEE Transaction on Industry Application, Vol.53, No.5, 2017
- [4] S.Devassy and B.Singh, "Enhancement of Power Quality using Solar PV Integrated UPQC", in Systems Conference (NSC), 2015 39th National,2015
- [5] C.Vengatesh and M.K.Elango,"Improvement of Power Quality Using a Hybrid UPQC in Renewable Energy", in International Conference on Renewable Energy (ICRESE'13), 2013.
- [6] S.Samal and P.K.Hota, "Power Quality Improvement by Solar Photovoltaic/Fuel cell Integrated System Using Unified Power Quality Conditioner", International Journal of Renewable Energy Research, Vol.7, No.4, 2017
- P. Kannan and V.Rajamani, "Modelling the Combination of UPQC and Photovoltaic Array", International Journal of Engineering Research & Technology (IJERT), Vol. 1 Issue 6, 2012
- [8] Design of the PV-PQC System For Long Voltage Interruption Compensation
- [9] Power Quality Improvement By Dynamic Voltage Restorer (DVR) and Power Quality Conditioner Using Fuzzy Logic [9]
- [11] W. Xu, "Component modelling issues for power quality assessment," vol. 21, no. 11, pp. 12–1, Nov. 2001.
- [12] M. R. Patel, "Wind and solar power systems," 1999.
- [13] J.H.R. Enslin, W.T.J. Hulshorst, A.M.S. Atmadji, P.J.M. Heskes, A.Kot- sopoulos, J.F G. Cobben, and P.Van der Sluijs, "Harmonic interaction between large numbers of photovoltaic inverters and the distribution network," vol. 3, pp. 1–6, June 23–26 2003.

- [14] A Naderipour, AAM Zin, MHB Habibuddin, MR Miveh, JM Guerrero, "An Improve Synchronous Reference Frame Current Control Strategy for Photovoltaic Grid-connected Inverter Under Unbalanced and Nonlinear Load Conditions", in PLoS ONE 12(2): e0164856. https://doi.org/10.1371/journal.pone.0164856, 2017
- [15] A Naderipour, AAM Zin, MH Habibuddin, JM Guerrero,"A Control Scheme to Improve the Power Quality with Absence of Dedicated Compensation Devices in Microgrid ", in Research and Development (SCOReD), 2015 IEEE Student Conference on, 239-244, 2015
- [16] K.S.Ravi Kumar, S.V.A.R Sastry,"Application of PI, Fuzzy Logic and ANN in Improvement of Power Quality using Unified Power Quality Conditioner ", in IJCSET Vol.1 Issue 2, page 214-217, June 2011
- [17] N.Ramchandra, V.SumaDeepthi,"Comparison of Different Controllers on Unified Power Quality Conditioner ", in IOSR Journal of Engineering, Vol.2 Issue 9, page 06-14, September 2012
- [18] V.Khadkikar,"Enhancing Electrical Power Quality Using UPQC : A Comprehensive Overview", in IEEE Transaction on Power Electronics, Vol.27 No.5, May 2012
- [19] AAM Zin, A Naderipour, MH Habibuddin, JM Guerrero, "Harmonic Current Compensator GCI at the Microgrid", in Electronics Letters 52 (20), 1714-1715, 2016
- [20] S.Samal and P.K.Hota, "Design and Analysis of solar PV-fuel cell and Wing Energy based Microgrid System for Power Quality Improvement", Cogent Engineering (2017), 4:1402453, 2017
- [21] P.Anil Kumar, KK Kuthadi, "Power Quality Improvement for Microgrid based UPQC System with Fuzzy Controller", in International Journal of Advance Research in Science and Engineering IJARSIE, Vol.4, Issue 2, February 2015
- [22] A.S.Shah, V. Patel, M.Patel, "Different Control Strategies for Unified Power Quality Conditioner – A Review", in International Journal of Innovation Research in Electrical, Electronics, Instrumentation and Control Engineering, Vol.2, Issue 3, March 2014.
- [23] F. Kakar, (2015). Power Quality Improvement By Dynamic Voltage Restorer and Unified Power Quality Conditioner Using Fuzzy Logic (Master's thesis). Universiti Teknologi Malaysia.
- [24] DM Said, (2017). Power Quality Teaching Module. 2nd Edition. Universiti Teknologi Malaysia

- [25] Turan Gonen, (2014). Electric Power Distribution Engineering. 3rd Edition. CRC Press Taylor & Francis Group
- [26] P.Ram Kishore Kumar, K.S.R Anjaneyulu, T.M Krishna, "New Technique for Improving the Power Quality in Power Transformer by FPGA", in International Conference Computer and Electrical Engineering, 2008
- [27] M.Kesler and E.Ozdemi, "Synchrnous Reference Frame Based Control Method for UPQC Under Unbalanced and Distorted Load Conditions ", in IEEE Transaction on Industrial Engineering Electronics, Vol.58, No.9, September 2011
- [28] R.V.D Ramarao, (2012). Improvement of Power Quality Using Custom Power Devices (PhD's thesis). Jawaharlal Nehru Technological University Hyderabad.