

AUTOTUNED FUZZY-PROPORTIONAL-INTEGRAL-DERIVATIVE
CONTROLLER FOR CASCADE LOAD-SHARING COMPRESSOR

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DEDICATION

Specially dedicated to my beloved wife, Sharmini Marilyn and beautiful children, Marissa Anne Nicholas and Mirabelle Tresa Nicholas for being my joy and strength throughout this journey. The journey would not have started without amma and daddy for their love and care.

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ABSTRACT

This thesis focuses on a control scheme of a load sharing parallel compressors commonly utilised in process industries. Typical control systems for parallel compressors in the industry, consist of a pre-set anti-surge control and loading-sharing control scheme. In this parallel compressor system, the characteristics of individual compressors are never the same, i.e. a stronger compressor will tend to take in more flow, causing the other compressor to lose its compressibility and causes it to fall into a surge region. The challenge occurs due to the proven nature of the whole system which exhibits control interactions between the components. Therefore, in this thesis, an optimised double feedback control i.e. a self-tuner fuzzy cascade PID controller and automatic self-tuning fuzzy PID anti-surge controller, is proposed. The implementation of PID controllers is due to its simplicity and robustness, and its wide applicability in the existing process industry. On the other hand, adapting fuzzy tuners on PID controllers is proven can improve the performance of the conventional PID, and since fuzzy logic control box can be embedded to an existing distributed control system (DCS) in the process industry, the implementation is imminent. For the proposed controller, the cascade PID controller can preserve the linear structure of the PID. Meanwhile, the fuzzy logic controller able to continuously tune each of the PID parameter to adapt to rapid changes of the load sharing and surge control of the parallel compressors. The performance of the proposed controller design is evaluated with respect to the conventional cascade PID controller. The performance evaluation is performed in terms of the system's transient response i.e. rise time, overshoot and settling time as well as the system's stability using Simulink. The simulation results showing that the proposed fuzzy logic cascade PID controller can respectively achieve 72%, 88.2% and 92.9% improvement in reducing rise time, settling time and percentage overshoot as compared to the conventional cascade PID. From the results obtained, it can be concluded that the proposed controller design has a better adaptation and performance on the parallel load sharing compressors compared to the conventional cascade PID control.

ABSTRAK

Tesis ini memfokuskan pada skema kawalan pemampat selari pembahagian beban yang biasa digunakan dalam industri proses. Sistem kawalan khas untuk pemampat selari dalam industri, terdiri daripada skema kawalan anti-lonjakan dan pembahagian pemuatan yang telah ditetapkan. Dalam sistem pemampat selari ini, ciri-ciri pemampat individu tidak pernah sama, iaitu pemampat yang lebih kuat cenderung mengambil lebih banyak aliran, menyebabkan pemampat yang lain kehilangan kebolehmampatannya dan menyebabkannya jatuh ke kawasan lonjakan. Cabaran itu berlaku kerana sifat keseluruhan sistem yang terbukti menunjukkan interaksi kawalan antara komponen. Oleh itu, dalam tesis ini, dicadangkan kawalan suap balik berganda yang dioptimumkan, iaitu pengawal *self-tuner fuzzy cascade* PID dan pengawal anti lonjakan *self-tuning fuzzy* PID automatik. Pelaksanaan pengendali PID disebabkan kesederhanaan dan ketahanannya, dan penerapannya yang luas dalam industri proses yang ada. Sebaliknya, menyesuaikan *fuzzy tuner* pada pengawal PID terbukti dapat meningkatkan prestasi PID konvensional, dan kerana kotak kawalan *fuzzy logic* dapat disisipkan ke *Distributed Control System* (DCS) yang ada dalam industri proses, maka pelaksanaannya akan segera dapat dilakukan. Untuk pengawal yang dicadangkan, pengawal PID lata boleh mengekalkan struktur linear PID. Sementara itu, pengawal *fuzzy logic* dapat menala secara berterusan setiap parameter PID untuk menyesuaikan diri dengan perubahan pantas pembahagian beban dan kawalan lonjakan pemampat selari. Prestasi reka bentuk pengawal yang dicadangkan dinilai dengan merujuk pengawal PID lata konvensional. Penilaian prestasi dilakukan dari segi tindak balas sementara sistem iaitu *rise time*, *overshoot* dan *settling time* serta kestabilan sistem menggunakan Simulink. Hasil simulasi menunjukkan bahawa pengawal *cascade fuzzy logic* PID yang dicadangkan dapat mencapai peningkatan 72%, 88.2% dan 92.9% masing-masing dalam mengurangkan masa kenaikan, masa penganapan dan peratusan terlajak berbanding dengan PID lata konvensional. Dari hasil yang diperoleh, dapat disimpulkan bahawa reka bentuk pengawal yang dicadangkan mempunyai penyesuaian dan prestasi yang lebih baik pada pemampat pembahagi beban selari dibandingkan dengan kawalan PID lata konvensional.

TABLE OF CONTENTS

	TITLE	PAGE
	DECLARATION	iii
	DEDICATION	iv
	ACKNOWLEDGEMENT	v
	ABSTRACT	vi
	ABSTRAK	vii
	TABLE OF CONTENTS	viii
	LIST OF TABLES	xii
	LIST OF FIGURES	xiv
	LIST OF ABBREVIATIONS	xvii
	LIST OF SYMBOLS	xviii
CHAPTER 1	INTRODUCTION	1
1.1	Background of Research	1
1.2	Problem Statement	2
1.3	Objectives of Research	3
1.4	Scopes of Research	3
1.5	Thesis Outline	4
CHAPTER 2	LITERATURE REVIEW	5
2.1	Introduction	5
2.2	Compressors Systems	5
2.2.1	Compressor in Process Industry	6
2.2.2	Compressor Load Sharing	14
2.2.3	Compressor Anti-Surge Control	17
2.2.4	Surge Control Principles	18
2.2.5	Compressor Surge Control and Protection Algorithm	20
2.2.6	Compressors System Control Schemes and Techniques	21

2.3	Heat Exchangers Systems	22
2.3.1	Heat Exchangers in Process Industry	22
2.3.2	Heat Exchanger System Control Schemes and Techniques	25
2.4	PID Control Design	28
2.4.1.1	Proportional Term	29
2.4.1.2	Integral Term	31
2.4.1.3	Derivative Term	32
2.5	Intelligent Control Design	33
2.5.1	Fuzzy Logic Control System	33
2.5.2	PID, Fuzzy Logic and Fuzzy Tuned PID Controller	41
2.5.3	PID, Fuzzy Logic and Fuzzy Tuned PID Cascade Control	43
2.6	Summary of Research Gaps	47
CHAPTER 3	RESEARCH METHODOLOGY	49
3.1	Introduction	49
3.2	Overall Research Methodology	49
3.3	Control Schemes and Techniques	52
3.3.1	Cascade Control Schemes and Techniques	52
3.3.2	Anti-Surge Control Schemes and Techniques	54
3.3.3	Integrated Load Sharing Control Schemes and Techniques	55
3.4	Modelling and Transfer Function of the System	57
3.4.1	Modelling of Centrifugal Compressors	57
3.4.2	Mathematical Model of Compressor System	59
3.4.3	Mathematical Model of Control Valve and Transmitter	63
3.4.4	Mathematical Model of Heat Exchanger	63
3.5	Intelligent Controller Designs	65
3.5.1	Self-Tuner Fuzzy PID Controller Design	65
3.5.2	Automated Self-Tuning Fuzzy PID Controller Design	69

	3.5.3 Fuzzy Rules for Self-Tuner Fuzzy PID and Automated Self-Tuning Fuzzy PID	71
CHAPTER 4	RESULT AND DISCUSSION	75
4.1	Introduction	75
4.2	Analysis of Anti-Surge Controller Performance	76
	4.2.1 Simulation of Anti-Surge PID Controller	76
	4.2.2 Performance Comparison of Conventional PID against Self-Tuner Fuzzy PID and Automated Self-Tuning Fuzzy PID	78
4.3	Analysis of Cascade Load Sharing Controller Performance	81
	4.3.1 Simulation of Cascade Load Sharing PID Controller	81
	4.3.2 Performance Comparison of Conventional Cascade PID against Self-Tuner Fuzzy Cascade PID and Automated Self-Tuning Fuzzy Cascade PID	84
4.4	Analysis of Integrated Load Sharing and Anti-Surge Controller Performance	86
	4.4.1 Load Sharing Compressor with Conventional PID Cascade Controller and Anti-Surge PID Controller	86
	4.4.2 Load Sharing Compressor with Self-tuner Fuzzy Cascade PID Controller and Anti-Surge Controller	90
	4.4.3 Load Sharing Compressor with Automated Self-tuning Fuzzy PID Cascade Controller and Anti-Surge Controller	93
	4.4.4 Load Sharing Compressor with Hybrid Self-tuning Fuzzy PID Cascade Controller and Anti-Surge Controller	97
	4.4.5 Load Sharing Compressor Controller Techniques Performance Comparison	99
4.5	Controller Technique Performance Comparison	101
CHAPTER 5	CONCLUSION AND RECOMMENDATIONS	103
5.1	Research Outcomes	103
5.2	Contributions to Knowledge	103
5.3	Future Works	104

REFERENCES	105
APPENDICES	111
LIST OF PUBLICATION	117

LIST OF TABLES

TABLE NO.	TITLE	PAGE
Table 2.1	Components of a vapor-compression cycle	7
Table 2.2	Application of different types of heat exchanger	23
Table 2.3	Comparison of performance parameter of temperature control for heat exchanger by Soniya Kocher and Dr. A.K Kori [45]	26
Table 2.4	Comparison of controller performance of temperature control for heat exchanger by Subhransu Padhee [46].	27
Table 2.5	Comparison of controller performance of temperature control for heat exchanger by Roshdy A. AbdelRassoul et al. [47]	27
Table 2.6	Standard labels used for fuzzy sets	36
Table 2.7	Fuzzy rule matrix for PID controller loop	38
Table 2.8	PID controller fuzzy rule matrix	39
Table 2.9	Comparison of performance parameter of liquid flow control by Gaurav and Amrit Kaur [52]	42
Table 2.10	Comparison of performance parameter of cascade control techniques for furnace temperature control by Y V Pavan Kumar et al [37]	44
Table 2.11	Comparison of performance parameter of cascade control techniques for injection mould machine temperature control by Dr. I Santi Prabha et al [48]	45
Table 2.12	Comparison of performance parameter of cascade control techniques for boiler level control by Anoop Cherian Thomas et al [21]	46
Table 2.13	Comparison of performance parameter of cascade control techniques for furnace temperature control by B. Vasu Murthy et al [48]	46
Table 3.1	Cascade control block diagram details	53
Table 3.2	Anti-surge control block diagram details	55
Table 3.3	Load sharing control block diagram details	56
Table 3.4	Refrigerant compressor process parameters [3]	62

Table 3.5	Rules for five membership fuzzy inference	72
Table 3.6	Rules for seven membership fuzzy inference	73
Table 4.1	PID anti-surge time domain specification and performance criteria	78
Table 4.2	Comparison of fuzzy logic self-tuner, automated self-tuner and conventional PID anti-surge time domain specification and performance criteria	80
Table 4.3	PID cascade time domain specification and performance criteria	83
Table 4.4	Comparison of fuzzy logic self-tuner, automated self-tuner and conventional PID anti-surge time domain specification and performance criteria	86
Table 4.5	Controller performance for conventional PID cascade controller and anti-surge controller time domain specification and performance criteria	89
Table 4.6	Controller performance for self-tuner fuzzy PID cascade controller and anti-surge controller time domain specification and performance criteria	93
Table 4.7	Controller performance for self-tuner fuzzy PID cascade controller and automated self-tuning fuzzy PID anti-surge controller time domain specification and performance criteria	97
Table 4.8	Comparison of fuzzy logic self-tuner and automated self-tuner PID anti-surge time domain specification and performance criteria	99
Table 4.9	Comparison of controller type performance for the anti-surge control time domain specification and performance criteria	100
Table 4.10	Comparison of controller type performance for the cascade control time domain specification and performance criteria	100
Table 4.11	Comparison of control techniques performance for single controller	101
Table 4.12	Comparison of control techniques performance for cascade controller	102

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
Figure 2.1	Components of a vapor-compression cycle	7
Figure 2.2	Vapor-compression cycle processes	8
Figure 2.3	Types of compressors	9
Figure 2.4	Centrifugal compressor cross section view	10
Figure 2.5	Compressor characteristic curve	11
Figure 2.6	Surge cyclic diagram	12
Figure 2.7	Cascade control from master to load sharing response	15
Figure 2.8	Integration of load sharing control and anti-surge control	16
Figure 2.9	Energy processes in the condenser	24
Figure 2.10	Energy processes in the evaporator	25
Figure 2.11	Closed loop control system transfer function	28
Figure 2.12	Fuzzy controller transfer function	34
Figure 2.13	Fuzzy logic control system components	35
Figure 2.14	Fuzzy controller inference mechanism	36
Figure 2.15	Fuzzy controller membership function	37
Figure 2.16	Fuzzy rules response on a PID controller	39
Figure 2.17	Cascade control for tank level	43
Figure 3.1	Flow chart of research methodology	50
Figure 3.2	Conventional cascade control block diagram	52
Figure 3.3	Self-tuner fuzzy PID cascade control	53
Figure 3.4	Automated self-tuning fuzzy PID cascade control	54
Figure 3.5	Anti-surge conventional PID Control	54
Figure 3.6	Proposed cascade control integrated with parallel anti-surge controller	56
Figure 3.7	Structure of the self-tuner fuzzy cascade PID controller	66

Figure 3.8	Structure of the self-tuner fuzzy PID controller	67
Figure 3.9	Detailed block diagram of self-tuner fuzzy PID	69
Figure 3.10	Structure of the automated self-tuning fuzzy cascade PID controller	69
Figure 3.11	Structure of the automated self-tuning fuzzy PID controller	70
Figure 3.12	Detailed block diagram of automated self-tuning fuzzy PID	71
Figure 4.1	Simulink block diagram of PID anti-surge controller transfer function	76
Figure 4.2	Step response of PID anti-surge controller	77
Figure 4.3	Step response of self-tuner fuzzy PID anti-surge controller	79
Figure 4.4	Step response of automated self-tuning fuzzy PID anti-surge controller	80
Figure 4.5	Simulink block diagram of PID cascade controller transfer function	81
Figure 4.6	Step response of cascade PID controller	83
Figure 4.7	Step response of self-tuner fuzzy PID cascade controller	84
Figure 4.8	Step response of automated self-tuning fuzzy PID cascade controller	85
Figure 4.9	Integrated load sharing compressor with conventional PID cascade controller and anti-surge PID controller block diagram	87
Figure 4.10	Load sharing compressor cascade control transfer function block diagram	88
Figure 4.11	Step response for integrated load sharing's anti-surge PID controller	88
Figure 4.12	Step response for integrated load sharing's cascade PID controller	89
Figure 4.13	Load sharing compressor with self-tuner fuzzy cascade PID controller and anti-surge controller block diagram	90
Figure 4.14	Load sharing compressor with self-tuner fuzzy cascade PID controller transfer function block diagram	91
Figure 4.15	Detailed block diagram of self-tuner fuzzy PID controller	91

Figure 4.16	Step response for self-tuner fuzzy PID anti-surge controller	92
Figure 4.17	Step response for self-tuner fuzzy cascade PID controller	92
Figure 4.18	Load sharing compressor with automated self-tuning fuzzy PID cascade controller anti-surge controller block diagram	94
Figure 4.19	Load sharing compressor with automated self-tuning fuzzy PID cascade controller transfer function block diagram	94
Figure 4.20	Detailed block diagram of automated self-tuning fuzzy PID controller	95
Figure 4.21	Step response for automated self-tuning fuzzy logic PID anti-surge controller	95
Figure 4.22	Step response for automated self-tuning fuzzy PID cascade controller	96
Figure 4.23	Step response for hybrid self-tuning fuzzy PID anti-surge controller	98
Figure 4.24	Step response for hybrid fuzzy PID cascade controller	98

LIST OF ABBREVIATIONS

PID	-	Proportional-Integral-Derivative
DCS	-	Distributed Control System
LNG	-	Liquefied Natural Gas
LPG	-	Liquefied Petroleum Gas
SLL	-	Surge Limit Line
SCL	-	Surge Control Line
SISO	-	Single Input Single Output
MIMO	-	Multi Input Multi Output
FLC	-	Fuzzy Logic Controller
IPS	-	Instrument Protective System

LIST OF SYMBOLS

τ	-	Minimal error
Q_s	-	Flow
β	-	Beta Ratio
ρ	-	Compression Ratio
h_s	-	Differential pressure
U_{gc}	-	Universal gas constant
e	-	Error
Δu	-	Change of control signal
Δe	-	Change of error
ρ	-	Density
ΔP	-	Differential pressure across orifice
C	-	Orifice coefficient
ϵ	-	Valve coefficient
R	-	Ideal gas constant of proportionality
n	-	Number of moles
mw	-	Molecular weight
t	-	Time or instantaneous time
V	-	Volume
v	-	Velocity

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
Appendix A	Fuzzy Logic Diagrams from Simulink	111

CHAPTER 1

INTRODUCTION

1.1 Background of Research

In process engineering industry, the processes involved are designed to improve certain standards in fulfilling current customers' requirement. In the oil and gas industry, load sharing and anti-surge control schemes in compressors are common scenarios. In this research, the integration control of load sharing and anti-surge control in refrigeration compressors are explored and analysed. The control scheme proposed is based on cascade control and feedback control using conventional PID. The control scheme is then further improved using fuzzy logic for automation and self-tuning.

Having a parallel operating compressor for process refrigeration has a significant advantage of the ability to cover a larger spectrum of cooling load requirements. The challenge is as the compressor operates over a period of time, the wear and tear of the compressor deteriorates, leading to a condition where one of the compressors being 'stronger' than the other, thus having the potential in taking more flow than the 'weaker' one. The application of a load sharing philosophy will be able to address this situation. Various methods can be applied such as sequence for starting/ stopping of compressor, flow balancing or compressor surge margin control.

Typically, in the industry, when one of the compressors is at the surge control line, a pre-set load sharing controller design will be executed. At this point, both the compressors will not be able to manage the throughput and will lead to possibility of both the compressors going into cyclic condition due to surge. Hence causing a change in the suction pressure which causes the other compressor to react.

Therefore, in this research, the integration of the existing control scheme with the proposed control design will be conducted, hence obtaining a balance on load sharing hence ensuring that both compressors are well protected.

1.2 Problem Statement

Existing control systems for a parallel compressor typically consist of a pre-set anti-surge control and loading-sharing control scheme. In parallel compressors system, a stronger compressor will tend to take in more flow, causing the other compressor to lose its compressibility and causes it to fall into a surge region. Various approaches for the optimisation of parallel compressors and network of compressors have been previously explored and researched. The interest in this has been challenging due to the proven nature of the control targets in a parallel compressor system which exhibits control interactions between the different control loops.

Constraints arises from operational requirements of the compressor, such as limits on the rotating speeds and safety criteria of the compressor. The state of instability in the compressors only allow a small stable operating range which is limited at low and high mass flow rates by surge, rotating stall or a combination of both. Rotating stall and surge have been a problem since the creation and usage of these rotating equipment in the process industry [1]. Active surge control is an active research field to improve the performance and efficiency of the compressors [2]. Surge phenomena are described together with the dynamics operations of the compressors using active surge control schemes only by single operation compressors [3].

PID controllers are a widely utilised algorithm in the process control industry. However, performance loss was exhibited when applied to a system with non-linear characteristics. This can be overcome by applying a properly tuned PID-controller. For systems which require fast changes and responses, PID controllers have difficulties to maintain the required controllability range. Changes in process

conditions and equipment condition may require frequent tuning of the controllers. In this research, current techniques utilising fuzzy controller and its extension on conventional PID controller is proposed. The proposed controller can preserve the linear structure of the PID and capable in improving the overall performance of the compressor system. The proposed PID features proposed is self-tuning to adapt to rapid changes of the load sharing and surge control.

1.3 Objectives of Research

The main objectives of this research are:

1. To develop a PID control scheme for a parallel load sharing refrigerant compressor.
2. To develop and optimised PID control approach using automated fuzzy self-tuning control.
3. To analyse the performance of the proposed control scheme by comparing to the conventional PID control scheme.

1.4 Scopes of Research

To achieve the objectives of this research, there are several scopes that need to be determined. Firstly, the research is conducted to develop the transfer function of the temperature-pressure load sharing cascade control and compressor anti-surge based on reference from research paper and available industrial compressor and heat exchanger datasheet. The mathematical model is derived from the reference paper using the available process data from the compressor datasheet and heat exchanger datasheet. The controller block is built for temperature-pressure cascade control scheme using conventional PID and compressor anti-surge PID control scheme using Simulink. In addition, the conventional PID controller is optimised using fuzzy control to automatically tune the controller under fluctuating process condition leading to non-linear conditions using Simulink. The limitation of the research

assumed that the simulated compressor is fixed speed single stage centrifugal compressor, pressure drop across the compressor, heat exchangers and other related components were negligible. The compressor refrigeration inflow and outflow rate are same therefore the refrigerant level is maintained constant in the heat exchanger. The boundary on the simulated control scheme was limited to 2 compressors operating in parallel for a refrigeration process.

1.5 Thesis Outline

This thesis is divided into several chapters which are introduction, literature review, research methodology, result and discussion as well as conclusion and recommendation. The first chapter, Introduction, elaborates the essential background and summary of related work in heat exchangers, compressor anti surge control and load sharing control. The chapter includes the research objectives which are the aim of this research, as well as scopes of the research conducted. Chapter 2 describes the literature review of load sharing and anti-surge compressor control, process industry heat exchangers, PID controller and fuzzy logic control. The review includes identification of research gaps that are further exploited in this research. In addition, there is also a review of fuzzy logic tuned PID controller. Chapter 3 focuses more on the research methodology of this research, the sequence of the research, mathematical modelling of the compressor system, heat exchanger and transfer function of the proposed control scheme. This chapter explains the flow of the research in detail. In chapter 4, results and discussion of the proposed work is represented. The results obtained are represented in step change response and implementation on Simulink simulation. Finally, in chapter 5, the conclusion of this research and the recommendation and future works is discussed.

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