UNIVERSITI MALAYSIA PERLIS

DECLARATION OF THESIS

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Date of birth : 16 of MARCH 1986

Title : Implementation of Adaptive Pole Assignment PID Controller on Dc-Dc Converters for Renewable Energy Sources

Academic Session : 2011-2013

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ACKNOWLEDGEMENT

Foremost, I would like to express my gratitude to my supervisor, Mr. Tunku Muhammad Nizar Bin Tunku Mansur for the useful comments, remarks and engagement through the learning process of this master thesis. I could not have imagined having a better supervisor for my MSc. study.

Apart from the efforts of me, the success of this research depends largely on the encouragement and guidelines of many others. I take this opportunity to express my gratitude to the people who have been instrumental in the successful completion of this research. I would like to show my greatest appreciation to my ex-supervisor, Dr. Siti Fatimah Binti Siraj as well as her husband Prof. Dr. Mohd. Zaki Bin Abdul Muin, for enlightening me the first glance of research besides their encouragement, insightful comment, and financial support by hired me as a research officer for a year funded by his research grant.

Most importantly, none of this would have been possible without the love and patience of my family. My words will fail to express my heartfelt thanks especially to my beloved husband, Mohd. Hafizuddin Bin Mat, who has supported me throughout entire process, both by keeping me harmonious and helping me putting pieces together. I will be grateful forever for your love. As for my parent, Mr. Abd Wahab Bin Ismail and Mrs. Noormah Binti Ismail, receive my deepest gratitude and love for their endless love and support through these years. And for my adorable son, love you so much.

Last but not least, I would like to thank my friends at School of Electrical System Engineering for their guidance and support. I am grateful for their constant support and help.

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LIST OF ABBREVIATIONS

DC-DC	Direct Current to Direct Current
PID	Proportional-Integral-Derivative
PIC	Programmable Intelligent Controller
K_p	Proportional constant
K_i	Integral constant
K_d	Derivative constant
AD-PID	Adaptive Digital Proportional-Integral-Derivative
FPGA	Field Programmable Gate Array
LMS	Least-Mean-Square
AVP	Adaptive Voltage Positioning
RHP	Right-Half Plane
AC	Alternate Current
PEF	Prediction Error Filter
AR	Auto-Regressive
MA	Moving Average
PD	Proportional-Derivative
PD+I	Proportional-Derivative + Integral
HLR	Hebbian Learning Rule
PWM	Pulse Width Modulated
MDAC	Multiplying Digital-to-Analog Converter
LQR	Linear Quadratic Regulator
CCM	Continuous Conduction Mode
OFA	Orthogonal-Function Approach
HTGA	Hybrid Taguchi Genetic Algorithm
PI	Proportional-Integral
HSBC	H-bridge Soft-switching Boost Converter
DSP	Digital Signal Processor
FT	Fast Transient
APM	Adaptive Phase Margin
PCMC	Peak Current Mode Control
VCMC	Valley Current Mode Control

CPL	Control Power Load
UPS	Uninterruptible Power Supplies
EMI	Electromagnetic Interference
MOSFET	Metal-Oxide Field-Effect Transistor
PO	Percentage Overshoot
PDM	Pulse-Duration Modulatio
SMPS	Switched Mode Power Supply
PV	Solar Photovoltaic
HAWT	Horizontal Axis Wind Turbine
VAWT	Vertical Axis Wind Turbine
CERE	Centre of Excellent for Renewable Energy
KCL	Kirchoff's Current Law
KVL	Kirchoff's Voltage Law
V_{ref}	Reference Voltage
DIP	Dual Inline Package
LED	Light Emitter Diode
GTO	Gate Turn Off Thyristor
SCR	Silicon Control Rectifier
PCB	Printed Circuit Board
LSB	Least Significant Bit
MSB	Most Significant Bit
MPPT	Maximum Power Point Tracking
O/L	Open-Loop
C/L	Closed-Loop

LIST OF SYMBOLS

W	Watt
I_z	Current Generator
R_L	Load Resistance
L	inductance
C	Capacitance
D	Diode
d	Duty Ratio @ Duty Cycle
v_L	Voltage accross inductor
i_L	Inductor current
I_c	Current accross capacitor
Q	Capacitance
Δi_L	peak-to-peak inductor current
ΔV_0	peak-to-peak ripple voltage
ΔQ	the change in capacitor charge
A	Area
ζ	Damping Factor
ω_n	Natural Frequency
n	set of state variable
$T(z^{-d})$	Polynomial
A	Anode
K	Cathode
°C	Celcius degree
W/m^2	Watt per metre square
m/s	metre per second
µH	micro Henry
rad/s	radian/second
MHz	Mega Herzt
kHz	kilo Herzt
mA	mili Ampere
µs	micro second
mV	mili Volt

ms	mili second
V	Voltage
A	Ampere
f_s	switching frequency
T	Period of switching frequency
T_d	Delay Time
T_r	Rise Time
T_p	Peak Time
T_{sett}	Settling Time
RC	Time Constant
V_m	Sawtooth Waveform
V_c	Control Voltage
V_{in}	Input Voltage
V_0	Output Voltage
T_0	Sampling Time
Ω	Resistance (Ohm)
µF	micro Farad
ŋ	Efficiency

Pelaksanaan Pengawal Tugasan Kutub Adaptif PID terhadap Penukar DC-DC untuk Sumber Tenaga Boleh Diperbaharui

ABSTRAK

Thesis ini membentangkan pelaksanaan pengawal tugasan penukar DC-DC untuk sumber tenaga boleh diperbaharui. Kajian ini melibatkan pemodelan dan pembangunan penukar yang dicadangkan; penaik dan penurun voltan yang dikawal oleh Pengawal Tugasan Kutub Adaptif PID. Kajian ini juga melibatkan pengumpulan data daripada sinaran suria, suhu, dan kelajuan angin. Kedua-dua penukar digunakan untuk menukar input DC tidak dikawal kepada output DC dikawal ke tahap voltan yang dikehendaki. Sistem 24V/12V digunakan untuk penurun voltan, manakala 12V/24V serasi untuk penaik voltan. Dalam penukar DC-DC, voltan output kebiasaannya adalah tidak stabil. Menjadi keperluan dalam sistem kawalan untuk penukar adalah untuk mengekalkan voltan keluaran secara berterusan tanpa mengira perubahan dalam sumber voltan DC dan arus beban dalam sistem gelung tertutup. Dalam mengawal selia output daripada panel solar dan turbin angin yang dalam bentuk arus terus (DC), output voltan yang berterusan diperlukan untuk dibekalkan kepada peralatan elektronik. Oleh itu, satu teknik penukaran dalam bentuk DC-DC diperlukan yang dikenali sebagai penukar. Selain itu, keperluan dalam sesebuah sistem kawalan untuk satu sistem yang stabil haruslah mempunyai penetapan masa yang pantas dan kurang voltan terlajak. Walau bagaimanapun, voltan keluaran penukar kebiasaannya adalah tidak stabil dan berayun terutama sekali di awal tindakbalas. Unsur-unsur redaman yang sedia ada seperti; perintang dan peraruh dalam litar penukar, menyumbang kepada peratusan yang tinggi kepada voltan terlajak dan riak voltan keluaran. Secara praktikal, voltan terlajak yang tinggi boleh menyebabkan percikan arus dan boleh membahayakan kepada pengguna. Oleh itu penukar dengan pengawal diperlukan untuk mengatasi masalah ini. Data-data daripada sinaran suria, suhu, kelajuan angin dianalisis untuk mengetahui potensi tenaga solar dan angin di Perlis. Data-data ini diperoleh menggunakan stesen cuaca yang telah dipasang di Pusat Kecemerlangan untuk Tenaga Diperbaharui (CERE), yang terletak di Kangar, Perlis. Berdasarkan purata sinaran solar bulanan bagi tahun 2011, bacaan purata sinaran suria adalah 1229W/m^2 manakala kelajuan tertinggi angin direkodkan pada 26.56m/s. Ini menunjukkan bahawa kedua-dua tenaga ini berpotensi dalam penjanaan kuasa solar dan angin di Perlis. Sementara itu, prestasi penukar DC-DC dan pengawal yang dicadangkan telah dinilai dari segi peratus lajakan dalam voltan keluaran dan juga semasa aruhan menggunakan perisian Matlab / Simulink dengan menganalisis kesan unsur redaman; perintang. Kemudian, keputusan yang diperolehi akan dinilai dengan keputusan yang diperolehi melalui eksperimen. Kedua-dua penukar ini kemudiannya akan dilaksanakan ke dalam masa nyata dengan mengaplikasikan mikropengawal PIC. Berdasarkan daripada keputusan simulasi, prestasi penukar yang disimulasi dengan nilai perintang beban yang dikira; 40Ω, menunjukkan hasil yang lebih baik berbanding dengan nilai percubaan, 84Ω walaupun disimulasikan bersama-sama dengan pengawal yang dicadangkan. Selain itu, keputusan ujikaji menunjukkan bahawa pengawal yang dicadangkan mampu dalam mengurangkan berlakunya terlajak dalam voltan keluaran dan aruhan semasa selain memberikan prestasi yang lebih baik dengan mengurangkan ayunan dalam keadaan mantap dan pantas. Secara keseluruhannya, keputusan simulasi dan keputusan eksperimen yang dinilai telah membuktikan yang memuaskan pengawal yang dicadangkan amat memuaskan dan sesuai untuk dipraktikkan bersama-sama penukar DC-DC juga dalam sistem tenaga.

Implementation of Adaptive Pole Assignment PID Controller on DC-DC Converters for Renewable Energy Sources

ABSTRACT

This thesis presents the implementation of adaptive pole assignment PID controller on DC-DC converters for renewable energy sources. This study involves the modeling and development of proposed converters; buck and boost converter that controlled by an adaptive pole assignment PID controller. This study also involves the data collection of solar irradiance, temperature, and wind speed . Both converters are used to convert unregulated DC input to a controlled DC output to a desired voltage level. The system of 24V/12V is applied to a buck converter while 12V/24V is compatible to boost converter. In DC-DC converters, the output voltage on itself is usually unstable. The necessity of a control system for the converter is to maintain a constant output voltage regardless of variations in DC source voltage and the load current in closed-loop system. In regulating the output from a solar panel and wind turbine which is in direct current (DC) form, a constant output voltage is needed to supply to electronics/electronic appliances. Thus, a sophisticated conversion technique for DC-DC form is required which is known as a converter. Besides, the requirement of a control system for a stable system should be with faster settling time and less overshoot voltage. However, the output voltage of the converters on itself is usually unstable and oscillates especially at the beginning of the transient response. The existing of the damping elements; resistor and inductor in the circuit of the converters contribute to the high percentage of overshoot voltage and output voltage ripple. Practically, the high overshoot voltage may lead to spark current which it could harm to consumers. Therefore a converter with a controller is needed to overcome the problem. The data collection of solar irradiance, temperature, and wind speed were analysed to know the potential of solar and wind energy application in Perlis. These data were measured using weather station that already installed at the Centre of Excellent for Renewable Energy (CERE), located in Kangar, Perlis. Based on the average monthly solar irradiance for the year 2011, the average reading of solar irradiance is 1229W/m^2 while the highest speed of wind is recorded at 26.56m/s. This show that both energies have a potential PV and wind power generation in Perlis. Meanwhile, the performance of DC-DC converters and the proposed controller have been evaluated in terms of percentage of overshoot in the output voltage as well as inductance current using Matlab/Simulink software by analysing the effect of damping element; load resistor. Then, the results obtained will be evaluated with experimental results. These converters are then have been implemented into real-time with application of PIC microcontroller. Based on the simulation results, the performance of converters that simulated with the calculated value of the load resistor; 40Ω, show a better result compared to trial and error value, 84Ω whenever simulated with the proposed controller. Besides, the experimental results show that the proposed controller is capable in minimizing the occurrence of overshoot in output voltage and inductance current besides provide a better performance by reducing the oscillation in steady state and faster settling time. Overall, the simulation results and experimental results are evaluated and prove a satisfactory of the proposed controller to adapt with DC-DC converters as well as in these energy system.

CHAPTER 1

INTRODUCTION

1.1 Research Overview

Recently, control applications of DC-DC converters have been widely investigated particularly in renewable energy; as the primary sources. The most significant concern of research and development in this field is always to find the most suitable control method to be implemented in DC-DC converter topologies. Thus, the objective of this work is carried out in selecting a control method that capable to improve the functioning of the converters as well as reducing the effect of disturbances and load variances.

In this work, two different topologies of DC-DC converters are modelled, where the boost converter is commonly used for solar systems while buck converter for wind energy systems. Both converters are used to convert unregulated DC input to a controlled DC output to a desired voltage level. The system of 24V/12V is applied to a buck converter while 12V/24V is compatible to boost converter.

A recent control method of adaptive pole assignment PID is selected and its effects on the output of DC-DC converters are examined. The state space average models of the converters are linearized to obtain the derivation of the small signal model using the classical linear control technique in order to design a linear control system. Modelling and simulation of the research is done using Matlab/Simulink software environment and subsequently real time implementation using a PIC microcontroller is developed.

The effect of PID controller on the steady state response of DC-DC converters in the second order system is analysed using different component variations. In this work, the studies will be focused on modelling two different converters that based on the basic theories of the converter design and topologies. Mathematically, the controller is designed by applying pole assignment method and adaptive control.

Theoretically, even in a small system damping element that caused by electronic components such as an inductor and resistor will contribute to unsatisfactory performance of the converters. Thus, the studies also will be concentrated on this matter to find the best parameters of the converters that produce a better performance. The simulation and laboratory experiment will be conducted to validate the performance of the converters. The criteria of second order system; rise time, the percentage of overshoot voltage, settling time, and steady state error, are carried out to justify the performance of the converters. The results obtained from the simulation and experiment will be analysed and compared.

1.2 Research Objective

The most important goal of this research is to study and implement a recent method of adaptive pole assignment PID to control DC-DC converters. The specific objectives of this work can be summarized as follows:

i. To model two different DC-DC converter topologies and adaptive pole assignment PID controller using an averaging technique and classical method.

ii. To enhance the performance of converters with less overshoot voltage and faster settling time.

iii. To analyse the effect of damping element in DC-DC converters.

1.3 Problem Statement

In DC-DC converters, the output voltage on itself is usually unstable. The necessity of a control system for the converter is to maintain a constant output voltage regardless of variations in DC source voltage and the load current in closed-loop system. Consequently, there are a few problems should be met in order to meet the fast transient response, hence to ensure the satisfactory functioning of this system. The specific problems are as follows:

1. In regulating the output from a solar panel and wind turbine which is in direct current (DC) form, a constant output voltage is needed to supply to electronics/electronic appliances. Thus, a sophisticated conversion technique for DC-DC form is required which is known as a converter.
2. The requirement of a control system for a stable system should be with faster settling time and less overshoot voltage. However, the output voltage of the converters on itself is usually unstable and oscillates especially at the beginning of the transient response.
3. The existing of the damping elements; resistor and inductor in the circuit of the converters contribute to the high percentage of overshoot voltage and output voltage ripple. Practically, the high overshoot voltage may lead to spark current which it could harm to consumers. Therefore a converter with a controller is needed to overcome the problem.

1.4 Scope of Work

The primary focus of this work is to develop a controller of DC-DC converters which provided a good regulation toward the system of the converters in photovoltaic system as well as wind system. The data of solar irradiance, temperature, and wind speed are collected at the beginning of this work to provide a supporting data for renewable energy. The data are taken into account to study the potential of both energies in Perlis in order to develop the converters design of both systems. Circuit design of buck and boost converter are based from the basic theories and literature studies. This work is continued by designing a PID controller by applying pole assignment and adaptive method based on the small signal control-to-output transfer function of both converters. The simulation of DC-DC converters and controller is done using Matlab/Simulink as well as Proteus. The implementation of the hardware design of the converters and the controller is done for testing and measuring the practical performance. Finally, the data from simulation and experimental will be analysed and a comparison study of the converter's performance with previous work will be carried out.

1.5 Thesis Organization

This thesis is organized into five chapters. Chapter 2 covers the basic topologies of different types DC-DC converters and their operations, including an explanation about controllers. Likewise, there are some reviews from previous works included together in this chapter with some explanations about renewable energy system, especially wind energy system and solar PV system in Malaysia.

Chapter 3 reviews the methodology and design of the converters and controllers that involved in this work. The methods including of software and real-time implementation are explained details in this chapter in order to achieve a better validation of results that will discussed in Chapter 4.

In Chapter 4 explained details about the results obtained from the software and real-time implementation. There are also included discussions and comparison data with previous works attached together to gain a better analysis at the end of this research.

Chapter 5 is the final chapter that presents a conclusion of this research. Research findings is presented to find a better solution for the problem encountered during the experiment. Likewise, there are also concluding an improvement of work by proposing future work as well as commercialization potential beyond this study in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter reviews past work done for DC-DC converters controlled by an adaptive Proportional-Integral-Derivative (PID) controller with the application of pole assignment method which is required on demand to achieve better performance of the overall system. Its rising importance in industrial applications and green technology is due to the need to improve the system so that it can be adapted with existing technology of renewable energy and become more efficient in manufacturing. All reviews come from different sources which consist of various methods, in order to obtain a comprehensive view about the latest technique and technology of controller for DC-DC converters. Thus, a comparative study can be done amongst converters and controllers involved so that a better performance can be obtained.

2.2 Critical Review

PID controller has been designed in 1890s and since that there is a lot of improvement has been done on it thus more approaches were developed to adapt to the latest technology. From conventional method, nowadays PID was improved to the digital controllers that widely implemented with microcontroller, field-programmable gate array (FPGAs), or digital signal processor (DSP). This method has successfully developed through the design of DC-DC converters that controlled by DSP based on the implementation of a digital controller Tajuddin, M.F.N., Rahim, N.A., and Daut, I. (2009). Starting with a DC-DC buck converter and a given set of performance specifications, a digital PID controller is implemented in TMS320F2812 DSP. In this work, the effectiveness of the design is established to analyse the steady state and dynamic response performance of the controller. A digital based PID control approach for a DC–DC buck converter has been introduced along with a digital implementation of the controller using DSP. At the end of this work, the experimental performance shows that; steady-state accuracy and settling time are consistent with the simulation results.

The classic technique for tuning a PID loop has become even more popular with the beginning of controllers capable of tuning themselves. The tuning techniques namely as Ziegler-Nichols, are still used nowadays even it was published in 1942. As referred to VanDoren, V.J. (2009), stated that John "Zeke" Ziegler and Nathaniel Nichols may not have invented the proportional-integral-derivative (PID) controller, although the PID algorithm is the most popular of all feedback control strategies used in industrial applications, but the famous loop tuning techniques invented by John "Zeke" and Nathaniel Nichols helped a lot in making the PID controller as a notable controller. In fact, by tuning a PID loop the reactions of the controller to errors between the measured process variable and desired set point can be adjusted. If the controlled process happens to be relatively sluggish, the configuration of PID algorithm will take immediate and dramatic actions whenever a random disturbance changes the process variable or an operator changes the set point.

In past a decade, the application of an adaptive PID controller has been attracting other researchers (Kelly, A., & Rinne, K., 2005). A direct pole placement control strategy is introduced in this workplace as well as the execution of a discrete-time controller in the design of a DC-DC buck converter has been used. The solution involves a feedforward component in the control strategy in order to eliminate steady-state errors. The value of the feedforward gain that is completely eliminates the steady-state error is dependent upon the gain of the plant, which may not be known precisely. In their design, the feedforward gain is determined adaptively, so as to drive the steady state error to zero. This technique allows direct placement of the closed-loop poles as desired. In order for the steady-state error to be exactly zero using this feedforward technique, the feedback gain needs to be determined exactly. As this is not possible, they adapt the feedback gain using least-mean-square (LMS) techniques, so that the control error is forced back to zero. The direct pole-placement is a feasible strategy for DC-DC converter design which is allowing the selection of a simple complex conjugate pair of closed-loop poles, as well as to introduce a novel method to achieve a zero steady-state error. With this work, the performance of a prototype compared very favourably with standard design methods. An adaptation of the feedback gain using LMS techniques was proven to be effective in driving the steady-state control error to zero.

A simple auto-tuning technique for digitally controlled DC-DC synchronous buck converters was introduced by Stefanutti, W., Mattavelli, P., Saggini, S., and Ghioni, M. (2005). In this work, the proposed approach is based on the relay feedback method and the authors were introducing perturbations on the output voltage during converter soft-start. By using an iterative procedure, the tuning of PID parameters is obtained directly by including the controller in the relay feedback and by adjusting the