IMPROVEMENT IN DEEP REINFORCEMENT LEARNING CONTROLLER FOR BUCK-BOOST CONVERTER WITH CONSTANT POWER LOAD

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DEDICATION

This thesis is dedicated to my parents, spouse, and friends, who have provided me support, guidance, and wisdom to always be kind and help others.

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ABSTRACT

DC-DC converter has been used in the commercial and industrial sectors to step up and down the DC voltage. The increasing development of renewable energy technology, battery storage, and DC microgrids has stressed the importance of the usage of the DC-DC converter. However, DC-DC converters with constant power load (CPL) have experience instability issues such as voltage and frequency fluctuation. This negative effect is prominent to such an extent that it will cause negative input impedance characteristics that cause destabilize effects in the DC system and sensitive electronic components to be damaged. Many techniques are proposed to mitigate the issue, such as using passive and active damping, but they are limited to cost and physical constraints. Therefore, using an intelligent controller to manage the output of the DC-DC converter is a more attractive solution to the issues. The methods have been implemented in the controller using proportional integral derivative (PID), model predictive control (MPC), machine learning, and deep learning. As the system becomes more complex, methods that used PID and MPC controller have become infeasible to be implemented. Therefore, using machine learning and deep learning is an attractive alternative to solve the control issue. Reinforcement learning (RL) and deep reinforcement learning (DRL) have been used to solve complex control problems such as Proximal Policy Optimization (PPO). This project's purpose is to improve the DRL performance via improving reward function and compare both PPO and AC DRL controllers to analyse the performance during induced CPL by using MATLAB for the simulation. The project has shown that by improving the PPO DRL based long short-term memory (LSTM) network for actor and critic agents with an improved reward system will provide overall all improved performance when compared to the benchmark PID controller. By setting an environment in which the DRL controller is able to train properly, the performance of the buck-boost converter controller by AC and PPO DRL algorithm is compared. PPO DRL showing greater performance in converging to the reference point and a faster training period. Moreover, PPO DRL can demonstrate more robustness and improved voltage stability and settling time of the buck-boost converter without the need to further tune its training parameters.

ABSTRAK

Penukar AT-AT telah digunakan dalam sektor komersial dan perindustrian untuk menaikkan dan menurunkan kadar voltan AT. Perkembangan teknologi dalam bidang tenaga boleh diperbaharui, storan bateri dan mikro grid AT telah memberi fokus terhadap kepentingan penggunaan komponen penukar AT-AT. Walau bagaimanapun, penukar AT-AT dengan nilai Beban Berkuasa Malar (CPL) akan mengalami masalah ketidakstabilan terhadap nilai voltan dan frekuensi yang sentiasa berubah-ubah. Kesan negatif ini amat ketara sehingga ianya akan menghasilkan ciri galangan masukan negatif yang boleh menyebabkan kesan ketidakstabilan dalam sistem AT dan mengakibatkan komponen elektronik yang sensitif akan menjadi rosak. Pelbagai teknik telah dicadangkan bagi mengurangkan masalah yang berkait dengan isu ini seperti menggunakan kaedah penapis pasif dan aktif, tetapi ianya mempunyai nilai kos yang terhad dan kekangan terhadap bentuk fizikal. Oleh yang demikian, salah satu cara penyelesaian yang lebih sesuai terhadap isu dan masalah ini adalah dengan menggunakan peralatan pengawal pintar untuk mengawal nilai output bagi penukar AT-AT ini. Kaedah pengawalan yang telah digunakan adalah dengan melalui cara Berkadar-Kamiran-Terbitan (PID), Model Kawalan Ramalan (MPC), Pembelajaran Mesin dan Pembelajaran Mendalam. Apabila sistem menjadi lebih kompleks, cara yang menggunakan pengawal PID dan MPC akan menjadi lebih sukar untuk dijalankan. Oleh itu, kaedah menggunakan Pembelajaran Mesin dan Pembelajaran Mendalam ini telah menjadi salah satu kaedah alternatif yang menarik dalam menyelesaikan masalah isu pengawalan tersebut. Reinforcement Learning (RL) dan Deep Reinforcement Learning (DRL) telah digunakan bagi menyelesaikan masalah pengawalan yang kompleks seperti penggunaan kaedah Proximal Policy Optimization (PPO). Tujuan projek ini adalah untuk meningkatkan prestasi DRL melalui penambahbaikan fungsi dan membandingkan antara kedua jenis pengawal PPO dan AC DRL dalam menganalisis prestasi dengan memasukkan CPL dalam perisian MATLAB bagi tujuan simulasi. Projek ini telah membuktikan bahawa dengan penambahbaikan terhadap PPO DRL berasaskan panjang rangkaian ingatan jangka pendek atau dikenali sebagai Long Short-Term Memory (LSTM) akan memberikan peningkatan prestasi keseluruhan apabila dibandingkan dengan kawalan PID. Dengan penetapan yang sesuai terhadap pengawalan DRL, pembandingan bagi tahap prestasi pengawal penukar AT-AT di antara algoritma AC dan PPO DRL telah dilakukan. PPO DRL telah menunjukkan prestasi yang lebih baik berbanding nilai rujukan dan mempunyai tempoh yang lebih pantas. Tambahan lagi, PPO DRL adalah lebih kukuh dan stabil serta telah meningkatkan tahap kestabilan voltan dan tempoh penyelesaian masa bagi penukar AT-AT tanpa perlu membuat sebarang penetapan tambahan bagi parameter latihannya.

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LIST OF ABBREVIATIONS

AC	-	Alternating Current
ACRL	-	Actor-Critic Reinforcement Learning
AC DRL	-	Actor-Critic Deep Reinforcement Learning
AI	-	Artificial Intelligence
ANN	-	Artificial Neural Network
AT-AT	-	Arus Terus – Arus Terus
CPL	-	Constant power load
CPU	-	Central Processing Unit
DC	-	Direct Current
DDPG	-	Deep deterministic policy gradient
DQN	-	Deep Q network
DRL	-	Deep Reinforcement Learning
FL	-	Fuzzy logic
FSMC	-	Fuzzy Sliding Model Control
GRU	-	Gated Recurrent Unit
IAE	-	Integral absolute error
LSTM	-	Long Short-Term Memory Network
LUS	-	Local Unimodal Sampling
MAE	-	Mean absolute error
MDP	-	Markov decision process
MG	-	Microgrid
MPC	-	Model predictive control
MSE	-	Mean square error
NN	-	Neural Network
PI	-	Proportional-Integral
PID	-	Proportional-Integral-Derivative
PPO	-	Proximal Policy Optimization
PWM	-	Pulse-Width Modulation
SMC	-	Sliding mode control

SISO	-	Single input/single output
SMC	-	Sliding Model Control
TLBO	-	Teaching Learning Based Optimization
ULM	-	Ultra local model
WNN	-	Wavelet Neural Network

LIST OF SYMBOLS

K_p	-	Proportional Gain
K_i	-	Integral Gain
K_d	-	Derivative Gain
T_I	-	Integral Time Constant
T_D	-	Derivative Time Constant
u_t	-	PID control variable
e_t	-	Error value
P	-	Rated power of the CPL (W)
V_{ref}	-	Reference voltage (V
V_o	-	Output voltage (V)
V_{CPL}	-	Voltage of the CPL (V)
i_L	-	Inductor current (A)
V_C	-	Capacitor voltage (V)
L	-	Inductance (H)
C	-	Capacitance (F)
σ	-	Observer design coefficient
S	-	State space
A	-	Action space
r	-	Reward function
γ	-	Discount factor
G_t	-	Accumulated discounted reward
T_s	-	Sampling Time
T_f	-	Final Time
R	-	Resistor
D	-	Duty Cycle
σ	-	Standard deviation
N	-	the size of the data
μ	-	Mean
x_i	-	Each value from the data
$\hat{A}_t$	-	Advantage function

π_θ	-	Policy parameters
s_t	-	State at time
a_t		Action at time
(s_t, a_t)	-	State-action pair
$\pi_\theta (a_t\|s_t)$	-	Policy function
$A^\pi(s,a)$	-	Advantage function
Q	-	Action-value function
$V^\pi(s)$	-	Value function
$Q^\pi(s,a)$	-	Action-value function
π	-	policy
t	-	time
L_c	-	Critic loss function
$\mu(S)$	-	Actor
$V(S)$	-	Critic
t_s	-	Starting time
D_t	-	Advantage function (AC)
$L(\theta)$	-	Surrogate objective function
$r_t(\theta)$	-	Probability Ratio
π_θ	-	Policy Parameters
$\hat{A}_t$	-	Advantage function (PPO)
D_t	-	Advantage function (AC)

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Direct Current (DC) power systems have some advantages over Alternating Current (AC) power systems in terms of stability and being applied in DC microgrid and renewable generation system [1]–[4]. In microgrid and renewable generation system, the control schemes have to be able to extract the maximum potential by adjusting the load and regulation of controller to maintain the voltage of the source [3], [5], [6]. The interest to optimize the DC-DC converter have been studied extensively in order to produce a good quality output signal. The DC-DC converter is able to regulate the DC voltage from source and output the DC voltage with its desired setting. A buck converter reduces voltage from the source to the load, whereas a boost converter increases voltage from the source to the load. Furthermore, the output voltage of a buck-boost converter is either less than or more than the source voltage in magnitude.

The destabilizing effects on the circuit limit the potential of DC-DC converters, resulting in severe voltage and frequency oscillations [3], [7], [8]. The issue presented in DC-DC converter with constant power load (CPL) will cause the loss of power, damages to the sensitive component of the system and may cause the occurrence of fault. Therefore, optimising the control system of DC-DC converter for DC microgrid and renewable sources of energy for the production of electrical energy will bring benefit to the industry [5], [9]. To solve this issue, a model-based and model-independent strategies control scheme is presented for DC-DC converter. However, model-based is limited in effectively handling any uncertainties and complex structure. Therefore, the current trend is more toward model-independent strategies control scheme as they are able to adapt to various complex system [8].

1.2 Problem Statement

The application of using buck-boost converters is attractive as it is simple and able to increase or decrease the output voltage depending on the reference voltage. It is instrumental in applications such as battery-powered systems, renewable energy plants, or DC power systems. Still, it has a limitation that causes severe voltage and frequency oscillation when the circuit's constant power load (CPL) is applied. This will cause voltage swell or drop that will affect the power system. Therefore, a feedback control system is needed to manage the buck-boost converter to reduce the voltage in stability and settling time. The standard control techniques include proportional-integral (PI) control, proportional-integral-derivative (PID) control, and model predictive control (MPC) for the buck-boost converters. A sophisticated control technique that uses machine learning or deep learning techniques has provided more opportunities to improve the converter's performance by utilizing reinforcement learning (RL) and deep reinforcement learning (DRL) as the preferred controller. The previous study shows that the voltage stability and settling time of buck-boost converter is improved using DRL with Proximal Policy Optimization (PPO) while comparing benchmark PI controller. However, the study can further expand.

1.3 Research Objectives

The main aim of this work is to develop and validate the deep reinforcement learning algorithm in buck-boost converter controller to reduce the voltage instability and improve settling time. The objectives of the research are:

(a) To develop the DRL controller to further improve voltage instability and settling time while reaching the desired voltage through simulation by using MATLAB.

(b) To investigate the performance of the buck-boost controller by AC and PPO algorithm based DRL algorithm.

(c) To compare different reward design of DRL algorithm.

1.4 Scope of research

The scopes of this research are as follows:

(a) The DRL algorithms that will focus on this research are PPO and AC only.

(b) The benchmark to test the performance will be based on a PID controller that is tuned using the MATLAB/Simulink solver.

(c) The simulation only focuses on the ideal Buck-Boost converter only and voltage output of 30 V and 80 V only and input voltage of 48 V. Non-ideal component is neglected during the simulation of the circuit.

1.5 Outline of the Thesis

The thesis is structured into five chapters. Chapter 1 will consist of the background of the study, problem statement, research objective, and scope of research. In chapter 2, the literature reviews related to the buck-boost converter, PID and DRL are explained. In chapter 3, the designed implementation of the research project is described. In chapter 4, the results and discussion of performance comparison between DRL reward design and buck-boost controller with PID, AC DRL, and PPO DRL controller are presented. Finally, in chapter 5, the conclusion of the study is presented with recommendations for future works for the improvement of the development of DRL.

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